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CONVERGENCE FROM CHAOS TO ORDER IN CAPITAL PROJECTS USING CHAOS ATTRACTORS – AN EXPLORATIVE STUDY

by

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THESIS SUMMARY

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Degree	:	PhD (Project Management)

Abstract

Successful capital projects contribute to sustain society and accelerate socio-economic development due to its inherent multiplier effect. The linear project management paradigm does not seem to stem either historical or current capital project cost overruns and failures. Accelerative societal change in terms of trends, megatrends, paradigm shifts, Black Swan events, and disruptive technologies require capital projects to be executed in a volatile, uncertain, complex and ambiguous environment that is expected to result in more chaos and failures of capital projects. This research contributes to the non-linear 'management by chaos' paradigm and develops and test chaos theories and models for employment in capital projects. The objective of this research is to explore if chaos attractors could cause local convergence (first research question) and overall convergence (second research question) from chaos to order in capital projects and thereby contribute to reduce capital project cost overruns and failures.

Using the grand chaos theory and literature references to chaos attractor metaphors as a starting point, six lower-level chaos theories and variance models were built for fixed-point attractors, fixed-point repellers, limit-cycle attractors, torus attractors, butterfly attractors and strange attractors. One lower level-theory and variance model were built for a landscape that comprised of the six chaos attractors. A randomness-chaos-complexity-order continuum model was derived from literature to represent the context within which dynamic capital project behaviour unfolds.

Assuming a constructivist research paradigm, a two-round qualitative explorative research strategy was employed with the capital project as the unit of analysis. The Nominal Group Technique was employed in the first round of interviews with 12 experienced capital project managers to obtain grounded definitions, an understanding of the randomness-chaos-complexity-order continuum model and the concept of chaos attractors. Voice recordings from interviews were transcribed and content analysis was done using the Atlas.ti software. Five capital project archetypes were identified by respondents. This was followed by a second round of deep individual interviews using semi-structured questions with 14 experienced capital project managers. Content analysis was used to confirm the archetypes and test the transferability and convergence effect from chaos to order of the six chaos metaphors and one landscape of the six chaos metaphors to the capital project domain.

Evidence was found in terms of examples, characteristics, value statements and variance model scoring to suggest that local convergence in capital projects from chaos to order could occur as a result of the six individual chaos attractors. Similarly, that overall project convergence could occur as a result of a specific constellation of these six chaos attractors located across the capital project life cycle. Nine convergence-divergence archetypes were defined by respondents that described the dynamic behaviour of different types of capital projects in the randomness-chaos-complexity-order continuum. It was also found that achieving capital project convergence from chaos towards an ordered project state, using chaos attractors, do not imply project success. However, an ordered project state could aid the minimisation of capital project cost overruns.

“Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by the following six chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange”. This exploratory research found evidence to support the existence of this grand theory and its associated mid-range and lower-level theories, but further research is required to validate the generalisation of these findings.

LIST OF PAPERS PUBLISHED BY THE CANDIDATE

The following two papers were submitted during October 2019 for publication in the Project Management Journal:

Converging and Diverging Life Cycle Archetypes in Capital Projects

Abstract

This research contributes to the study of project success and failure by characterizing repeatable converging – diverging evolutionary life cycle patterns for capital projects. It builds on previous research that associates project success with project convergence and project failure with project divergence. A randomness-chaos-complexity-order continuum model is defined to represent dynamic states in capital projects. Two different groups of capital project managers were successively interviewed, and nine capital project life-cycle architectures emerged from their descriptions using qualitative research approach. Archetypes could be employed in capital projects to solicit proactive responses from project stakeholders to facilitate project convergence towards project success.

Convergence from Chaos to Order in Capital Projects Using Fixed-Point Chaos Attractors

Abstract

This paper proposes a theory and model to address undesirable chaos in capital projects. It contributes to the non-linear 'management by chaos theory' research paradigm. The fixed-point chaos attractor metaphor is proposed as a mechanism to create convergence from chaos to order in capital projects. Based on chaos theory, lower level theories and a variance model are derived using references from other sciences. Exploratory interviews were conducted with 14 experienced project managers to reveal the characteristics and examples of fixed-point chaos attractors in capital projects. Fixed point chaos attractors could help project managers to manage chaos in capital projects.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my study leader, Dr Giel Bekker, who has guided me for nearly 8 years towards the completion of this thesis. Thank you for allowing me to read about the field of project complexity for close to 3 years before finally deciding to explore the unknown territory of chaos theory and chaos attractors for capital projects. Your patience and skilful guidance is highly appreciated.

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Sonder my vrou sou die begin, voortsetting en finalisering van ‘n PhD studie nie moontlik gewees het nie. Baie dankie my skat vir al jou opofferinge en ondersteuning deur die 8 jare. Jy het my altyd moed in gepraat en aangemoedig om nie op te gee nie – ek waardeer jou liefde opreg!

Ich möchte mich bei meinen drei Kindern, Walter, Lisabeth und Marthinus vom Herzen bedanken. Meine Kinder sind mit dem vorigen und diesem Studium im Hause aufgewachsen. Ihr wart immer begeistert, neugierig und habt viele Fragen bezüglich das Chaos gestellt. Danke für euren Mitmachen und Mitgestalten auf diesem Weg zur Vollendung der Doktorarbeit.

Schließlich bin ich davon überzeugt, dass der prominenteste Chaos Attraktor sich in 1. Mose 1:1-3 widerspiegelt:

> ***Am Anfang schuf Gott Himmel und Erde. Und die Erde war wüst und leer, und es war finster auf der Tiefe; und der Geist Gottes schwebte auf dem Wasser. Und Gott sprach: Es werde Licht! und es ward Licht...*** *(Lutherbibel 1912)*

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CHAPTER 1: INTRODUCTION

1.1 Background

Evidence suggests that cost overruns on capital projects are not improving despite a multitude of theories, models and methods that are available to the project manager to aid in the successful planning and execution of projects.

Examples of project cost overruns are provided by the Standish Group (Hastie and Wojewoda, 2015; Standish Group, 2009) on global Information Technology (IT) type projects over the past 21 years indicating that about 70% of the projects are “challenged” or “failed” relating to cost overruns. The Hertie School of Governance in Germany studied large public infrastructure projects for the past 54 years and found an average cost overrun of 73% (Kostka and Anzinger, 2015). The well-known global longitudinal study of Flyvbjerg on global transportation projects over a period of 80 years reported an average cost overrun of 50% (Flyvbjerg et al., 2002). These studies seem to indicate that cost overruns may be considered a phenomenon of projects that could thus far not be addressed efficiently.

Many Best Practices and Standards are available to the project manager. For example, the Project Management Body of Knowledge Guide® (PMBoK) originates from the Project Management Institute (PMI, 2017) in the USA and is used by many global project managers to “initiate”, “plan”, “execute”, “monitor and control” and “close-out” (PMI, 2017:23) work packages, stages, phases and complete projects. Six versions of the PMBoK Guide® have been published between 1996 (PMI, 1996) and 2017 (PMI, 2017). The content of these guides has increased by approximately 330% from 176 pages from the 1st edition to the current 756 pages of the 6th edition. Other project management best practices such as the Association of Project Management Body of Knowledge (APM BoK) is currently in its 6th edition since its first publication in 1992 (APM, 2012), while PRojects IN Controlled Environments (PRINCE2®) that was originally developed under the auspices of the United Kingdom Government, is also now in its 6th edition since 1996 (AXELOS Limited, 2017). The International Project Management Association Project Excellence Baseline (IPMA PEM) for the assessment projects is based on Total Quality Management (TQM) approach and the European Foundation for Quality Management (EFQM) model. This model was first published by the German Project Management (GPM) association in 1990 and since then has been used and refined for project assessments (IPMA, 2016). The International Standards Organisation (ISO) published their first Standard on Project management in 2012

(ISO, 2012). This data seems to indicate a rapid growth in best practices at least during the past 25 years.

Simon and Popa (2017) indicated that the annual number of publications in the field of project management has increased five-fold in the period 1999 to 2017 (18 years). They have used the Science Direct database to obtain their data for analysis. These publications included papers published in journals (88%), books (10%) and reference works (2%) (Simon and Popa, 2017:960).

However, the question remains if the increase in the quantity of research and knowledge output in the field of project management had any effect on project cost overruns. Based on the historical data on project cost overruns and the exponential growth in knowledge from project management best practices and publications, it seems that a project management dilemma exists: *Despite an increase in knowledge about project management, projects historically appear to continue to have substantial cost overruns and be considered as failed projects*. These arguments are based on historical perspectives on project cost overruns, best practices, standards, research and the creation of knowledge.

This further raiser the question if the project manager is equipped with theory, models and methods to manage projects in the current and fast changing future environment as well as the nature of influence on the project internal and external environment due to a fast changing environment. Steffen et al. (2011) display the exponential increase in the rate of change in human activity that has occurred, in many dimensions of society, since the Industrial Revolution in Figure 1-1.

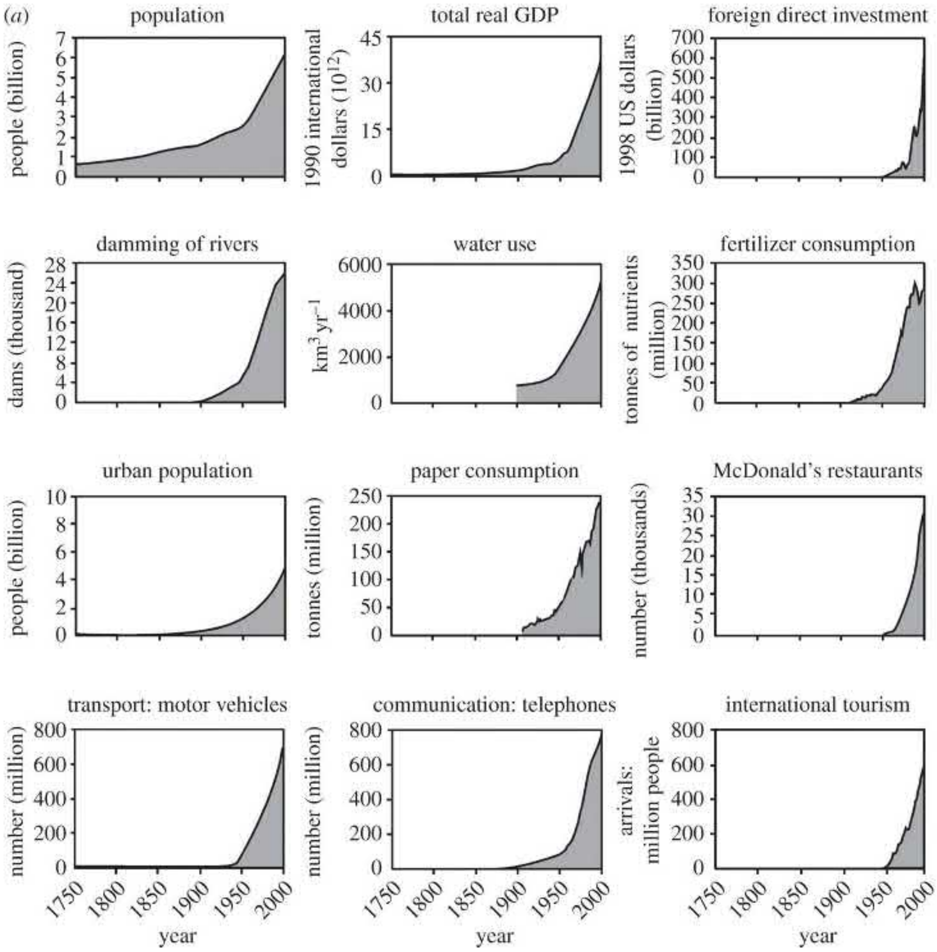

Figure 1-1: Increase in the Rate of Change in Human Activity Since the Industrial Revolution (1750) and the Great Acceleration after World War II (1950) (Steffen et al., 2011:851, Figure 1)

Exponential growth curves could be seen in all the dimensions shown in Figure 1-1. For the period of 50 years (1950 – 2000+) after World War II, the human population has increased from 3 billion to 6 billion, human economic activity increased 15-fold, motor vehicles increased from 40 million after the war to 700 million by 1996. This increase in accelerated change since 1950 became known as “The Great Acceleration” (Steffen et al., 2011:849).

The question could be asked what the effect of these rapid changes could be on projects and how do they influence the internal and external project environment? Gandhi (2017) described the current and future world in which we live as volatile, uncertain, complex and ambiguous (VUCA) to give expression to the “chaotic, turbulent, and rapidly changing business environment”. This VUCA condition in the business world prevents diagnosis with confidence, “befuddles executives” and “render useless any efforts to understand the future and to plan responses” according to Bennett and Lemoine (2014:311). The VUCA concept will be further explored in Chapter 2.

Looking forward into the future and considering the exponential growth in many dimensions of human activities and the VUCA effect, the following statement could be formulated: *If project cost overruns in general could not previously and are not currently being reduced or avoided using existing theories, models and methods, then a need exists for new and additional theories, models and methods that could be used in the future expected chaotic, complex, non-linear, fast changing project environment to reduce or avoid project cost overruns.* This statement formed the origin, interest and point of departure for this research.

Padalkar and Gopinath (2016) evaluated six decades of project management research and found that this field lacks in two areas: a) absence of convergence on explanations of project performance and b) the weak theoretical foundation of the project management discipline. In 2003 the United Kingdom Engineering and Physical Sciences Research Council (EPSRC) launched a research initiative called "re-thinking project management" (Winter et al., 2006; Svejvig and Andersen, 2015). The objective was to generate knowledge and gain a better holistic and pluralistic understanding of project management. Pluralism is described by Remington and Pollack (2007) as having the flexibility to use different methods and tools to deliver projects. This initiative spawned new concepts such as Project Management Second Order (PM-2) where a new paradigm towards the management of projects is proposed that is more suitable for a project environment with "increased complexity in society, economics, and technology" (Saynisch, 2010:21). The contribution of this research is aimed at this initiative in the field of project management.

Laszlo (2009:213) states that "the challenge is to learn how to work with change, to cope with uncertainty, to dance with evolution". Remington and Pollack (2007:1) are convinced that project management problems should be approached by recognising that a project is a complex system and that a plurality of tools will be required by the project manager to gain control over his project – the so called "systemic pluralism". Cooke-Davies et al. (2007) acknowledged the link between complexity theory and project management practice when they stated that "concepts such as nonlinearity, emergence, self-organization, and radical unpredictability have major implications for the uncodified paradigm that underpins project management practice and research". He defined complexity theory as: "the study of how order, structure, pattern, and novelty arise from extremely complicated, apparently chaotic systems" (Cooke-Davies et al., 2007:52). In 2011 Project Management Institute (PMI) published a summary of aspects related to complexity in managing projects in a complex world (Cooke-Davies et al., 2011). Interestingly this publication contained an outline of a research agenda for “Project Management 2.0” (Cooke-Davies et al., 2011:179) to incorporate complexity as part of the future project management research and practices. Kiridena and Sense (2016) summarised the acquired knowledge on complexity science in project management literature and confirmed the viewpoint that a project could be seen as a complicated system, a complex system or a complex adaptive system. It therefore seems that a gradual and growing acceptance is taking place among project management researchers and practitioners that the complexity paradigm should perhaps be considered in explaining and predicting project behaviour

Complexity theory also contains elements of chaos theory (Cooke-Davies et al., 2007). Radu et al. (2014:1546) are of the opinion that chaos theory and its principles contribute to management of “a new set of paradigms used to criticize and to complete the Newtonian models of management” and that “chaos theory undermines the concepts of tight control and fixed stable processes provided by the traditional management” paradigm.

This research aims to explore the use of chaos theory and chaos theory concepts (Lorenz, 1995) in capital projects to create order from chaos. The chaos attractor metaphor, which originates from chaos theory, is proposed as an environmental and context-independent convergence mechanism that could potentially aid the capital project manager to create convergence from chaos to order in his project. It is believed that achieving such an ordered condition in capital projects in the current and expected future environment, could lead to improved project performance and the potential minimisation of cost overruns. This research covers a literature review on chaos theory and chaos attractor metaphors. Theory and model building are then done by deriving chaos theory as well as chaos attractor variance models for capital projects. Exploratory theory and model testing are done using a sample population of experienced capital project managers. The results were analysed and indicate that the selected experienced capital project managers were generally able to transfer chaos theory concepts to capital projects, create new project archetypes (form-types of projects) and agree on the potential local and overall convergence effect from chaos to order using chaos attractors for capital projects.

The remainder of this chapter will focus on the value of capital projects to society, historical capital project cost overruns and various dimensions of the fast-changing world and its potential influence on capital projects. Chaos theory and chaos attractors will then be presented as mechanisms that could create convergence from chaos to order in capital projects. This will be followed by indicating the research gap, the relevance of this research and major and sub-research questions. This chapter is concluded with the contribution and limitations of this research, as well as the structure and chapter layout.

1.2 The Value of Capital Projects

A capital project is defined by the Business Directory (2018:1 of 1) as a "Long-term investment project requiring relatively large sums to acquire, develop, improve, and/or maintain a capital asset (such as land, buildings, dykes, roads)". A simple definition for capital projects is provided by the Market Business News (2018:1 of 2) as "a huge project that costs a lot of money, lasts a long time, and is generally extremely complex". The question could be asked why capital projects are undertaken, what is the value to society and why is it necessary that these projects are successfully completed even if they are regarded as complex.

The potential value of completing successful capital projects and the influence on the economy is demonstrated, for example, by Shumilkina et al. (2015) in their power sector economic multiplier tool. Power generation capital projects, when executed successfully, have both a backward and forward production effect on the economy. The backward production effect on the economy is created by expanding the power generation industry and this translates into the requirement for intermediate goods such as fuel and machinery as well as services such as construction and professional services. This backward production effect stimulates industry sectors that are related to power generation. The forward production linking effect on the economy of the expansion of the power generation industry is created when more power is now available to other industries as a factor of input which they can use to produce goods and services such as mines, refineries, manufacturing etc. The stronger the backward and forward linkage, the greater the economic multiplier (Shumilkina et al., 2015). Examples of various economic multiplier effects as a result of the successful completion of typical capital projects are shown in Table 1-1.

Table 1-1: The Effect of Successful Capital Projects on Economic Multipliers

No.	Type of Investment / Project	Economic Multiplier	Reference
1	Infrastructure	1% Rise in infrastructure assets increases GDP temporarily by 1-2%	Serven (2010)
2	Infrastructure	Each $1bn invested creates potentially 18,000 jobs	Embassy of the United States of America (2012)
3	Capital (utilities, energy, transport, waste management, flood defence or telecommunications)	Every $1 spent on capital projects generates an economic return of between $5 - $25	PwC (2014)
4	Transportation	8% increase in user cost-benefits relating to savings in travel time, accident reduction, road decongestion as well as externality benefits	Legaspi et al. (2015)
5	Power Generation	Employment multipliers ranging from 1.5 – 3.3 for US new build and operation of Photovoltaic, Wind and Coal power generation projects	Yergin and Gross (2012)

Shumilkina et al. (2015) argue that the successful power generation capital project has at least four effects in the specific industry and wider economy. Firstly, the hiring of labourers as well as professional staff, either temporary or permanent, for the duration of the specific capital project is known as the *direct effect*. Secondly, the engineering, construction, operation and maintenance resulting from the project and power plant (asset created) requires inputs from other industries such as cement, cables, goods and services that is known as the *indirect effects*. Thirdly, the increased spending by contractors involved in the project creates spill over effects such as guesthouses, restaurants etc. that are utilised – this effect is known as the *induced effect*. Fourthly, the *second order growth effect* comes into being when electricity or more electricity is now available to various sectors in the economy to allow them to generate goods, services, employment etc. and increase the Gross Domestic Product (GDP). Capital projects therefore have the ability to create value similar to entrepreneurial firms as they combine tangible assets (financial, physical, and technological assets) with less tangible assets (human, organisational, and social assets) towards increased value offerings (Brush et al., 2001). However, the economic multiplier effect (GDP) as well as the social multiplier effect (job creation and sustainment) are diminished by the cost overruns of capital projects.

1.3 Historical Cost Overruns in Capital Projects

Khan et al. (2013:3) conducted research on project success factors for public sector projects during a 10-year period and found that "there is no common set of project success criteria or project success factors that can be applied to all projects" and that "project success is dependent on context and perspective". Jugdev and Müller (2005) have done research on project success literature during the past 40 years and found that the concept of project success has changed from focusing on only the project implementation phase towards coverage across the system and product life cycle. In line with this research finding Shenhar and Dvir (2007) indicated that project success should be measured at various time intervals after completion of the project. Project success measurement intervals should be taking place at: a) project completion in terms of efficiency, b) first months after project completion for the impact on the customer and project team, c) 1 – 2 years after project completion for the direct business impact and d) 3 – 5 years after project completion in terms of preparing the business for the future Shenhar and Dvir (2007). It therefore seems that the formulation of a common definition of project success will be difficult to achieve due to the various basis of comparison. Perhaps better agreement exists among practitioners on the definition of project failure.

1.3.1 Definitions of Capital Project Failures and Cost Overruns

At least two private institutions have defined project failure metrics or criteria and have built databases with project data for benchmarking and comparative purposes. The Standish Group provides a project benchmarking service to industry with a specific focus on Information Technology (IT) projects since 1994. The origin of these projects is predominantly in the United States of America (USA) and Europe (Standish Group, 2009). The Standish Group provides three categories to categorise project success and failure at project completion as shown in Table 1-2.

Table 1-2: Success and Failure Criteria for Information Technology Projects (Standish Group, 2009:1)

No.	Criteria	Threshold for Failure
1	Successful Project	Project delivered on time, on budget, with required features and functions
2	Challenged Project	Project late, over budget, and/or with less than the required features and functions
3	Failed Project	Project cancelled prior to completion or delivered and never used

The Independent Project Analysis (IPA) Group provides an industrial megaproject benchmarking service to the petroleum, mining, pharmaceutical and power generation industries since 1987 predominantly in the USA and Europe. The IPA uses five criteria to define project failure as shown in Table 1-3. Cost overruns greater than 25% and a cost overrun greater than 25% compared to similar projects (cost competitiveness), together with schedule overruns constitute a megaproject failure. The final failure metric is when the project does not deliver the production capacities two-years after completion of the project. The basis for comparison is the baseline schedule and cost at the time when the projects have been fully developed, are ready for execution and received full funds authorisation.

Table 1-3: IPA Failure Criteria for Industrial Megaprojects (Merrow, 2011:38)

No.	Type of Outcome	Threshold for Failure
1	Cost overruns	> 25 percent
2	Cost competitiveness	> 25 percent
3	Slip in execution schedules	> 25 percent
4	Schedule competitiveness	> 50 percent
5	Production versus plan	Significantly reduced production in year 2

Clearly defined metrics for project failure enables the comparison of the same categories of projects using the same basis of comparison of historical capital project performance and can provide information and knowledge about the effectiveness of project practices.

1.3.2 Studies Indicating Capital Project Cost Overruns for the Past 21 Years, 54 Years and 80 Years

The Standish Group has gathered data from world-wide Information Technology (IT) projects since 1994 and produces an annual "Chaos" report on the performance of these projects. The 2015 Chaos Report covered 50,000 IT projects, from around the world ranging from small enhancements to fully fledged system re-engineering projects (Hastie and Wojewoda, 2015). By combining the historical project data for 21 years covering the period 1994 – 2015 (Hastie and Wojewoda, 2015; Standish Group, 2009), the results could be plotted as shown in Figure 1-2 using the Standish Group project success and failure metrics as indicated in Table 1-2.

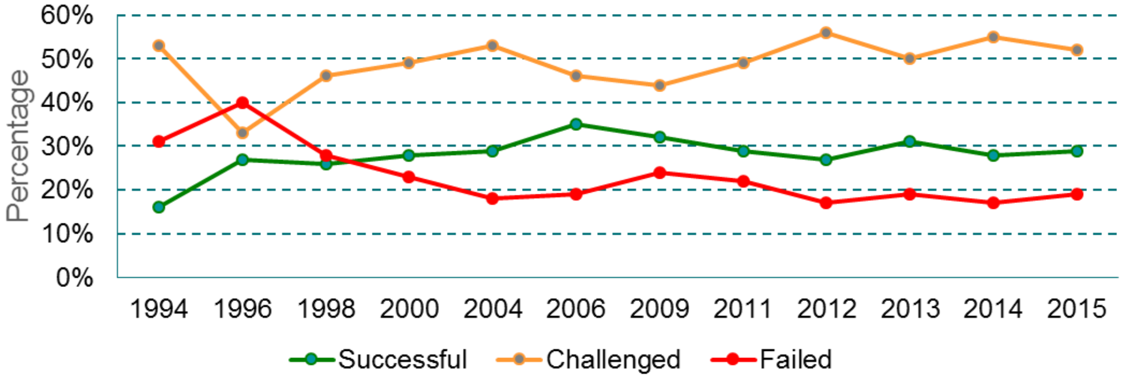

Figure 1-2: Historical Success and Failure Data for IT Projects for a Period of 21 Years (Hastie and Wojewoda, 2015; Standish Group, 2009)

The results in Figure 1-2 indicate an increase in successful projects (green line) between the period 1994 to 2006 with an accompanying decline in project failures (red line) for the same period and then a stabilisation of all metrics from 2006 onward to 2015. What is alarming is that about 70% of IT projects (successful and challenged) continued to be over cost, over schedule, did not deliver all the required functions and were either cancelled or never used according to the definition of "challenged" and "failed" projects as indicated in Table 1-2.

A cross sectional analysis was done for 170 large public infrastructure projects in Germany covering a period of 54 years (1960 – 2014) to understand project cost overrun behaviour (Kostka and Anzinger, 2015). The study included different project types in different sectors, including buildings, energy, IT, defence acquisition and transportation. Project sizes ranged from €4.4 million to €23bn. The average cost overrun of the finished projects was found to be 73% as shown in Figure 1-3. The worst performing sectors were found to be Energy and Information and Communications Technology (ICT) with average cost overruns of 136% and 394% respectively. The cost overruns for the worst performing individual infrastructure projects – the so called “Flop 10 projects” – ranged from 208% to 1,150% and this group of projects alone accounted for 36% of the total cost overruns of the sampled projects (Kostka and Anzinger, 2015:16&17). The researcher added dotted lines to the sketch to indicate the 25% cost overrun benchmark (IPA) and 73% average cost overrun for finished projects.

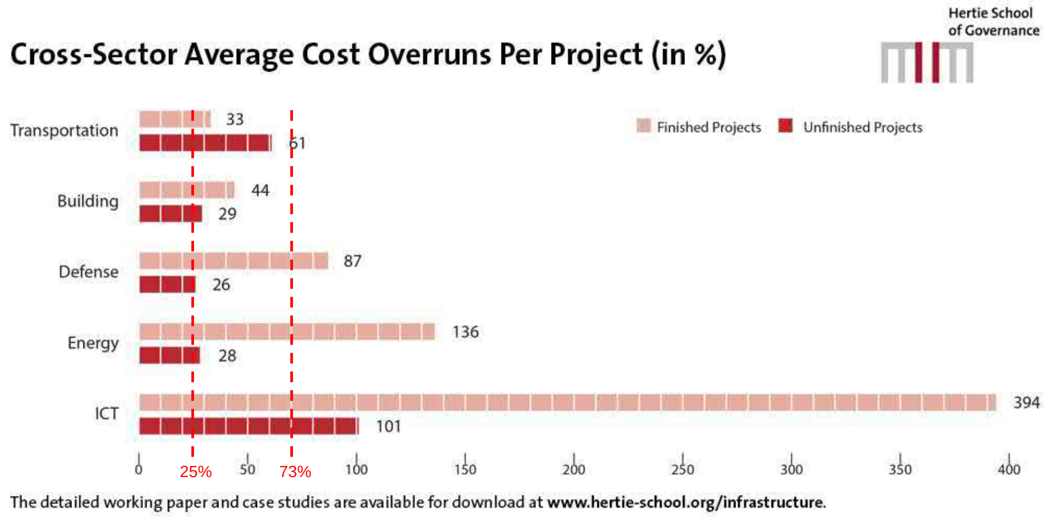

Figure 1-3: Average Cross-Sector Cost Overruns for 170 Public Infrastructure Projects in Germany over a 54 year period (1960 – 2014) (Kostka and Fiedler, 2016)

Flyvbjerg et al. (2002) have studied the world-wide project cost overrun behaviour of 258 transportation infrastructure projects over a period of 80 years (from 1910 – 1998). The results for 111 of these projects, for which cost data was available, are shown in Figure 1-4 and covers transportation projects with different project types, geographical regions and historical periods. The researcher added a dotted line to indicate 25% cost overrun benchmark (IPA). Except for project cost overruns exceeding a value of about 100%, no noticeable improvement in project cost overruns is visible. The study also shows that similar cost overruns occur for projects that include power plants, dams, water distribution, oil and gas extraction, information technology systems, aerospace systems, and weapons systems. In another study on cost overruns for industrial megaprojects Flyvbjerg (2014:9) references cost overruns for individual projects ranging from 50% to 1,900% and remarks that "nine out of ten such projects have cost overruns; overruns of up to 50% in real terms are common, over 50% are not uncommon".

In contrast to the findings as reported by Flyvbjerg (2014) that 90% of capital projects in his studies showed large cost overruns, the IPA has found a bimodal distribution in their research data (Jamima priciple) that indicate that large capital projects are either ‘good’ or ‘bad’ (Merrow, 2011). This may point to the fact that not all capital projects are plagued by severe cost overruns and considered to be failed projects. This research should therefore contribute to the explanation using theories and/or models on why capital projects could be deemed successful (converging) or failed (diverging).

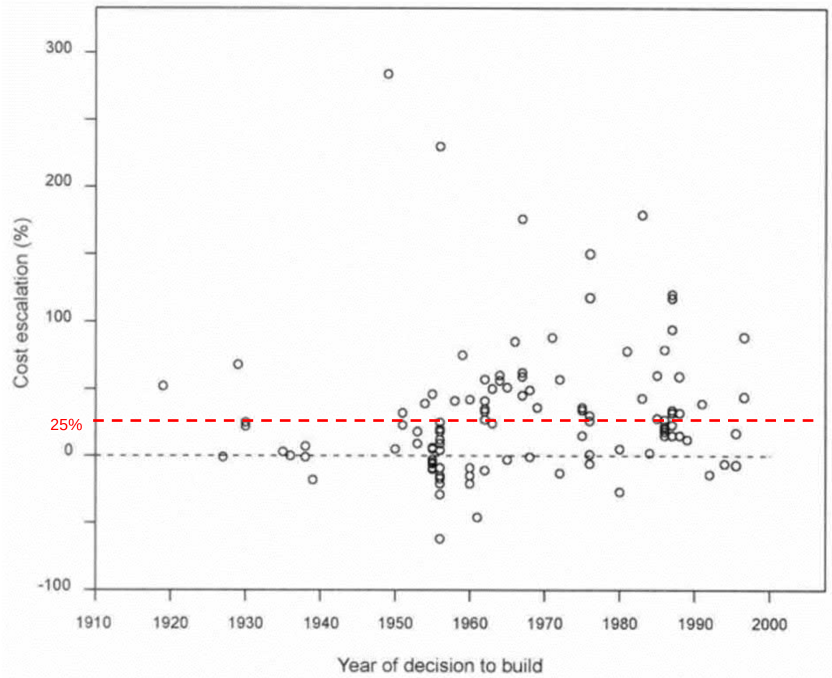

Figure 1-4: Historical Project Cost Overrun Data for 111 Global Transportation Infrastructure Projects for 80 Years (Flyvbjerg et al., 2002:287, Figure 3)

1.3.3 Potential Causes for Capital Project Cost and Schedule Overruns

The 2015 Chaos Report on IT type projects indicated the following five key contributors to project success or perhaps, by implication contributors to project failure by their absence as: a) executive sponsorship, b) emotional maturity, c) user involvement, d) optimisation and e) skilled resources (Hastie and Wojewoda, 2015). One trend that is highlighted in this report is that an increase in project size and complexity is related to project failure. According to Flyvbjerg et al. (2002), the reasons for the cost overruns in megaprojects could be attributed to deception or misrepresentation (lying). A list of potential causes for project failures and cost overruns as cited by various researchers, are given in Table 1-4.

Table 1-4: Reasons for Project Failures and Cost Overruns

No.	Cause of Cost & Schedule Overrun	Type of Megaproject	Research Finding	Reference
1	Cost Underestimation	Transportation Infrastructure Megaproject	"Cost underestimation exists across 20 nations and 5 continents; it appears to be a global phenomenon"	Flyvbjerg et al. (2002:290)
2	Strategic Misrepresentation	Transportation Infrastructure Megaproject	"Cost underestimation cannot be explained by error and seems to be	Flyvbjerg et al. (2002:290)

No.	Cause of Cost & Schedule Overrun	Type of Megaproject	Research Finding	Reference
			best explained by strategic misrepresentation i.e. lying".	
3	Cost Externalisation	Energy Megaprojects	"the project outcome is supplemented with guaranteed public finance".	Kostka and Anzinger (2015:3)
4	Negative Learning	Nuclear Power Generation Megaprojects	"perils of the assumption of robust learning effects resulting in lowered costs over time in the scale-up of large-scale, complex new energy supply technologies".	Grubler (2010:5174)
5	Psychological Bias – Planning Fallacy	Large Capital Projects	"the tendency of people to underestimate task-completion times and costs even when they know that the vast majority of similar tasks have run late or gone over budget".	Flyvbjerg et al. (2014:8)
6	Psychological Bias – Anchoring	Large Capital Projects	"the answer to a question [on project cost] is subconsciously affected by the first cost or budget numbers considered [and] …becomes an anchor for later-stage estimates, which never sufficiently adjust to the reality of the project's performance".	Flyvbjerg et al. (2014:8)
7	Misplaced Incentives	Large Capital Projects	"when the biases of project champions are strong enough or their incentive misdirected enough that they act, deliberately and strategically, to bring about financial or political outcomes different from those preferred by the people they represent or work for".	Flyvbjerg et al. (2014:8)
8	Inadequate Front End Loading (FEL)	Industrial Megaprojects	"As FEL degrades, mega project cost overruns mount quickly".	Merrow (2012:40)
9	Complexity	Information Technology Megaprojects	"The more complex and bigger [the project] the higher the risk of failure".	(Hastie and Wojewoda, 2015:5 of 6)
10	Regulatory Ratcheting	Energy Infrastructure Megaprojects	"The Nuclear Regulatory Commission (NRC) has been tightening regulations to reduce the risks of reactor accidents. This program of "regulatory ratcheting" has increased the cost of a nuclear power plant by a factor of 4-5 over and above inflation.	Cohen (1987:3 of 5)

This list in Table 1-4 shows that the potential causes for project cost overruns range from cost underestimation, strategic misrepresentation, psychological biases, and inadequate project development to environmental factors. Project cost overruns seem to have a multi-dimensional character. These causes also seem to contain both process and procedural issues (hard issues) as well as psychological and sociological issues (soft issues). Interestingly, the current project management bodies of knowledge such as PMBOK, APMBOK and PRINCE2 emphasise the procedural requirements of projects with little focus on human resource requirements (i.e. psychology and sociology).

1.3.4 Conclusion on Historical Capital Project Cost Overruns and Observation

Based on research done on the historical cost overruns for global capital projects for periods of 21 years, 54 years and 80 years as shown in Figure 1-2, Figure 1-3 and Figure 1-4, it appears that the current combined knowledge and application thereof in terms of project management theory, models and methods provided by best practices and research, seem ineffective to impact current capital project cost overruns.

If the current project management knowledge and the application thereof has not been able to have a noticeable impact on historical capital project cost overruns, what will be the impact of this knowledge if the future project internal and external environment becomes even more complex due to the influences of a fast-changing world?

1.4 The Fast-Changing World and the Unknown Effect on Capital Projects

This paragraph will explore change phenomena, increase in technology adoption rates, decrease of company life cycles, potential outcomes of accelerative change, and increase in the overall level of complexity and the simultaneous occurrence of phenomena that result in change. This paragraph concludes by anticipating the effects of these influences on current and future capital projects and the need for the reduction from chaos to order under these circumstances.

1.4.1 Trends, Megatrends, Paradigm Shifts, Black Swan Events and Disruptive Technologies

In order to gain a first order understanding of the expected influences on the future capital project internal and external project environment, five influences were summarised from available literature for their potential effect, on the capital project internal and external environment, as shown in Appendix A. These influences are: a) trends, b) megatrends, c) paradigm shifts, d) disruptive technologies, and e) Black Swan events. This list is not exhaustive but the data in Appendix A shows that capital projects cannot escape these influences as they both influence current capital projects, will influence future capital projects and by their nature, these influences create new capital projects. A model is shown in Appendix A, Figure A-2, that illustrates all the identified trends and megatrends, paradigm shifts, disruptive technologies and Black Swan events and their influence on different types of capital projects. A simplified derived construct for that model is represented in Figure 1-5.

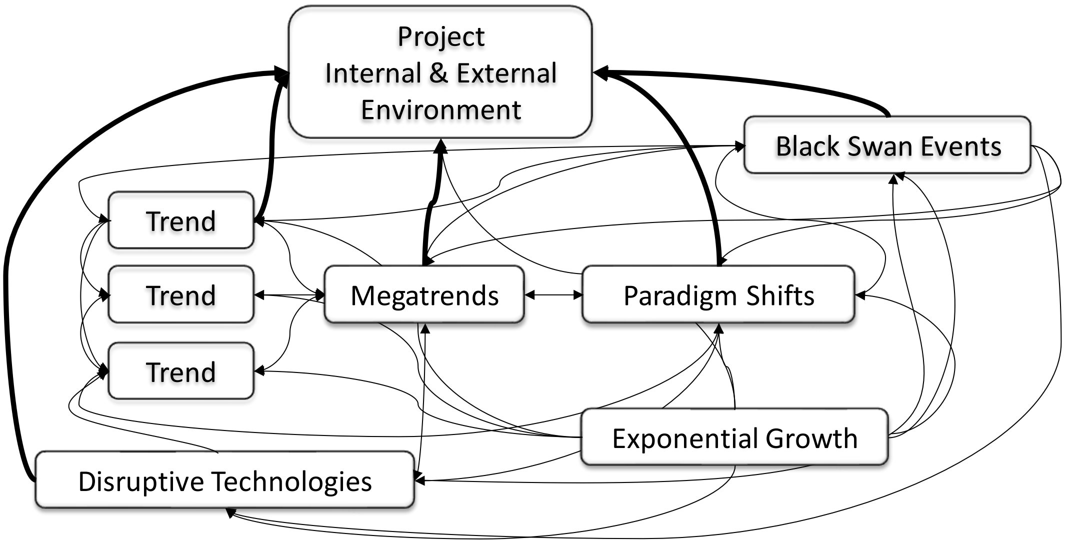

Figure 1-5: Simplified Derived Construct for Five Groups of Influences on Capital Projects Based on the Model in Appendix A, Figure A-2.

The expected influences on the capital project internal and external environment is assumed to be stationary as shown in Figure 1-5. It would be interesting to gain an understanding of the level of overall complexity of the project environment if these influences are not stationary and change at different rates.

1.4.2 Increase in Technology Adoption Rates

The rate at which communication technologies are adopted by the human population seems to have increased exponentially as shown in Figure 1-6(a). For example, it took approximately 35 years for the telephone to be adopted by 25% of the United States (US) population, approximately 15 years for the Personal Computer (PC), seven years for the Web and just four years for Smartphones. It also appears that the rate at which communication technologies have been adopted by the US since 1900 have increased significantly by looking at the increased angle of the adoption rate lines as shown in Figure 1-6(b) (steeper angle of the red lines compared to the angle of the blue lines).

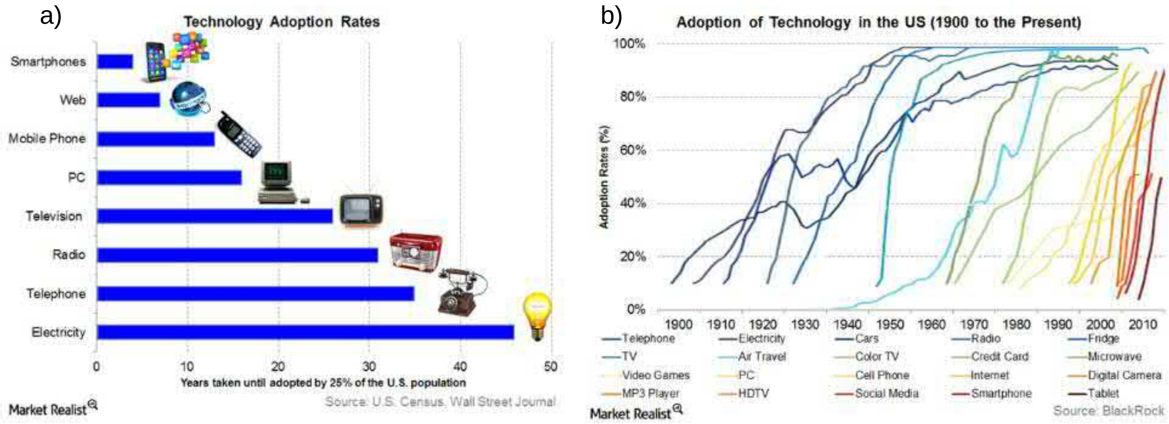

Figure 1-6: Increase in Technology Adoption Rates for (a) Selected Electronic Technologies and (b) Adoption Trends from 1900 to 2010 (Rieder, 2015:1, 2 of 3)

Bayus (1994) did research to determine if product life cycles were generally getting shorter, by analysing relevant data for industry, product category, product technology and product models. He could not find conclusive empirical evidence that product life cycles were getting shorter, but he found that: a) the time duration between an invention and its first application was decreasing b) a greater number of new products are introduced over time, and c) the time between innovations is decreasing. He concluded that more product variations are available in the market at any point in time and that firms are not removing products at the same rate as they were introducing new products. Chubay (2016) found in his research evidence to suggest shorter software product development life cycles, a higher number of software products in each product portfolio and less revenue from product portfolios. During 2016, Deloitte (Deloitte, 2016) did a global survey among nearly 900 supply chain professionals in a wide range of companies and industries, to understand when these companies were planning to introduce disruptive technologies in their supply chains. The results are shown in Figure 1-7 and indicate a strong push and uptake in global markets for all of these technologies in the next 6 years. The researcher added the percentage increase of technology adoption over a six-year period for each category of this sketch.

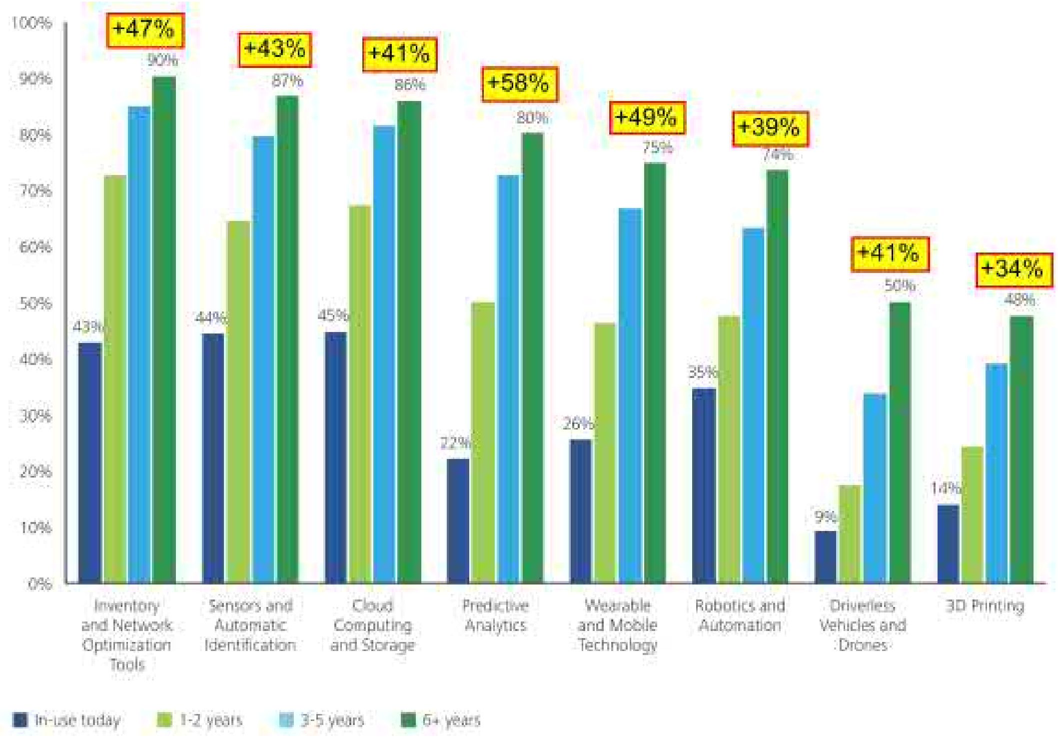

Figure 1-7: Survey Results of Expected Diffusion of Disruptive Technologies within Six Years (Deloitte, 2016:3, Figure 1)

Based on the data presented in Figure 1-7 it could be speculated that more disruptive technologies will enter the market in the near future and they may influence the relevance of current planned capital projects as well as capital projects in execution as chosen technologies may become obsolete before project completion. These disruptive technologies may not only cause obsolescence in the capital project but also cause current technology supplying companies to become irrelevant and close.

1.4.3 Decrease in Company Life Spans

The Standard & Poor's 500 Index (S&P 500) is an index of the top 500 listed American companies with a market capitalisation (outstanding shares multiplied by the current share price) of greater than 5bn USD (Investopedia, 2016). These companies cover approximately 80% of the US equity market by capitalisation. Since 1960 the composition of these 500 companies has been changing by companies leaving, merging or joining in the index. The seven-year rolling average of the average company life span for the S&P 500 index is reproduced in Figure 1-8. The researcher added a blue trend line and average values to this sketch.

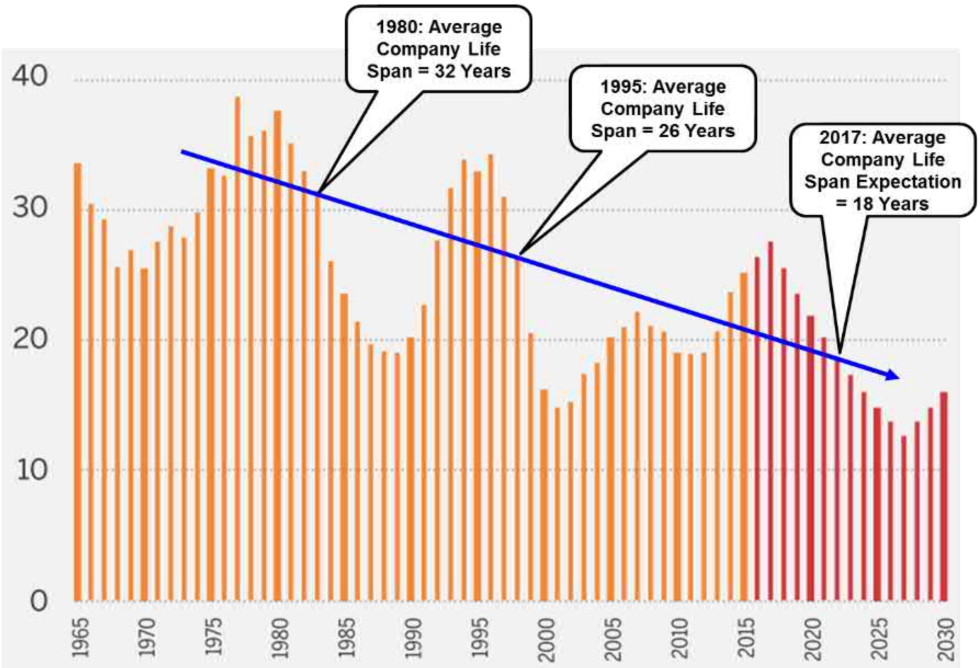

Figure 1-8: Decreasing Average Company Lifespan for S&P 500 Listed Companies. Index shown in 7-Year Rolling Averages (Anthony et al., 2016:2)

Anthony et al. (2016) expect that half of the companies currently listed on the S&P 500 will, during the next 10 years, be replaced by new companies with new products and new markets. They attribute the reason for the downward trend in company life span to economic shocks, technology shifts, economic cycles, intense mergers and acquisitions and highly valued start-ups i.e. the “Unicorn” phenomenon (Anthony et al., 2016:3).

If the trend as shown in Figure 1-8 is extrapolated to generic technology supplying companies that delivers goods and services to capital projects, it may mean that a plant with a life span of 40 years may not be able to do a mid-life upgrade due to the original equipment manufacturers (OEMs) being out of business. The question could be asked how long this downward trend in the average life span of companies could continue and what will be the effect on the stability of the capital project internal and external environment.

1.4.4 Laws of Acceleration and Singularity

Gordon Moore, one of the founders of the Intel Corporation, noticed in 1965 that the number of transistors that are added by manufacturers to a printed circuit board doubled every two years (Moore, 2006). This acceleration effect became known as Moore’s Law (Myhrvold, 2006). This acceleration has led to a continuous increase in the chip performance and computer processing power and the resulting increase in performance of related digital technologies such as sensors and cameras.

Kurzweil (1999) formulated the Law of Accelerating Returns to describe the evolutionary process that leads to an acceleration in social and technological change. He stated that "as [technological] order exponentially increases, time exponentially speeds up (i.e., the time interval between salient events grows shorter as time passes)." (Kurzweil, 1999:30). Evolution, according to Kurzweil, is not a closed process and therefore obtains new input from the chaotic surrounding environment for new options of diversity. Evolution progresses and feeds on increased technological order. In turn, technological order increases exponentially, time speeds up and therefore the returns, i.e. products of the evolution process, also speed up. Technology, he reasons, "is the continuation of evolution by other means" (Kurzweil, 1999:23) and has a positive feedback loop, i.e. it feeds onto itself with each iteration of development and that results in an *exponential growth of exponential growth*. This double exponential growth phenomenon, he states, is as a result of a specific positive feedback loop such as computation that becomes more cost effective and then more resources are deployed to make the process even more effective (Kurzweil, 2001). Technology development therefore is about tools and the ability of humans to store and capture the knowledge of one tool, apply innovation and improve the next version of the same tool i.e. evolution (Kurzweil, 1999). The continuation of this evolutionary process could lead to a situation where "ultimately, the technology itself will create new technology" (Kurzweil, 1999:22).

The accelerating rate of events for major human and technological changes since the beginning of life is mapped graphically by Kurzweil (2005) as shown in Figure 1-9.

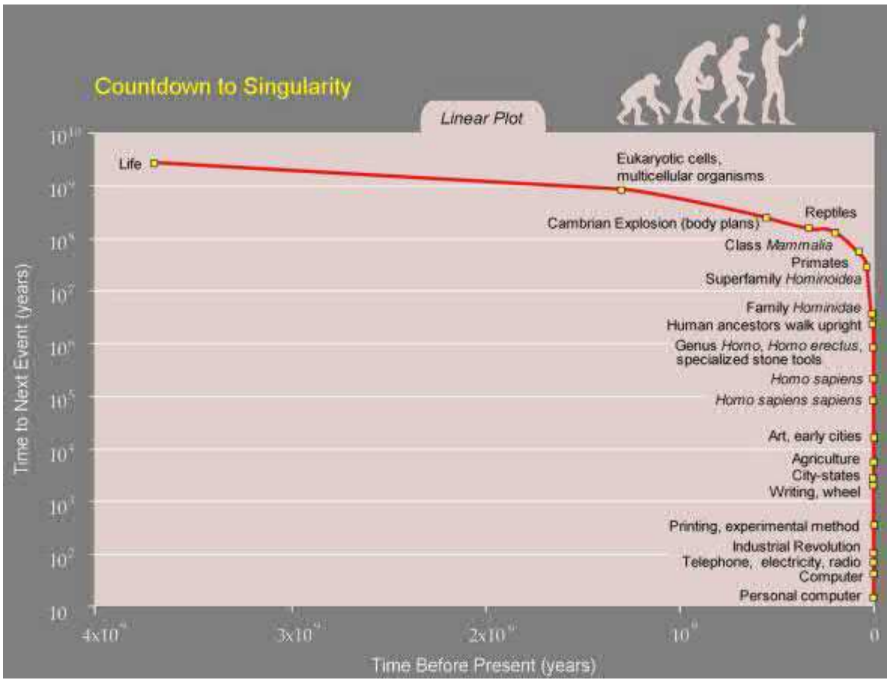

Figure 1-9: Major Events in Human and Technological Development (Kurzweil, 2005:32)

Kurzweil (2005:33) has shown that although he has subjectively chosen these major events, the general trend of the graph as shown in Figure 1-9 remains the same when compared with similar work done by Modis (2002). The graph shows on the y-axis that the “time to the next event” is becoming shorter and shorter. On the x-axis it is shown that most of the major human and technological changes have occurred during the recent past. This graph, when turned upside down, is also referred to as the “J-Curve” or “Super-Exponential Curve” (The Foresight University, 2018). Kurzweil states that a point will be reached when the technological development happens so fast that we as humans will not be able to follow or adapt to change. Humans will lose control and it will cause a “rupture in the fabric of human history” Kurzweil (2001:5 of 47). This point or condition has been defined as “Singularity” (Kurzweil, 2001:1 of 47). Vinge (1993:14) describes the point of singularity as a condition of "intellectual runaway", while Moravec (2013) is of the opinion that singularity is a point where it will become increasingly difficult for any human to *understand* and *predict* the future technological developments or advancements.

Toffler (1970) also refers to the accelerative events in human history. In his book "Future Shock" he states that if the last 50,000 years of man’s existence is divided into life spans of 62 years, there are about 800 such lifetimes that have passed. A total of 650 lifetimes were spent in caves; only in the last six lifetimes could man communicate effectively from one lifetime to another due to the invention of writing. Time could only be measured with precision during the last four lifetimes and only in the last two lifetimes has anyone used an electric motor anywhere on earth. The overwhelming majority of all the material goods that we use every day, have been developed in the current "800th lifetime" (Toffler, 1970:22). The effect of the increased rate of change in society is a superimposition of a new culture on an existing one that creates a "future shock" or an "avalanche" (Toffler, 1970:20) of change. The superimposition of an existing culture on a new one, according to Toffler, creates a condition with radically new circumstances that may lead to *disorientation, unpreparedness, fear* and an *inability to cope*. The question could now be asked if accelerated growth has a limit.

1.4.5 Three Potential Outcomes of Accelerated Growth

Vinge (2005) considered three scenarios as possible outcomes of the exponential growth in hardware and software trends, as shown in Figure 1-10.

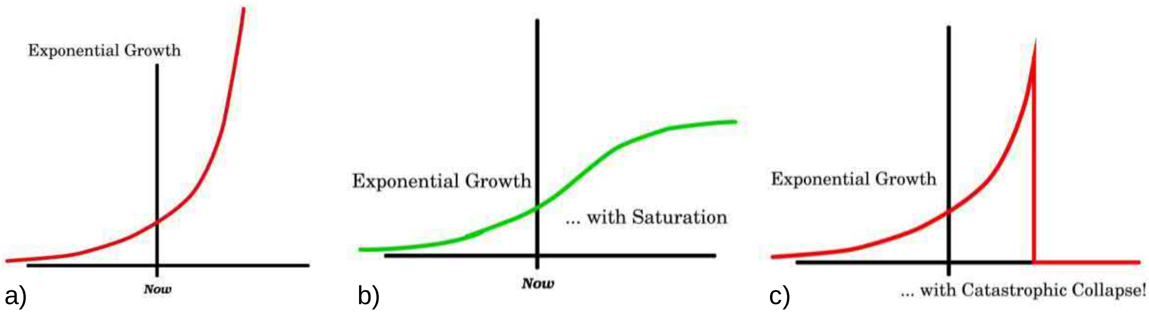

Figure 1-10: Three Possible Outcomes of Exponential Growth for Hardware & Software Development as a) Unlimited Exponential Growth, b) Exponential Growth with Saturation and c) Exponential Growth with Catastrophic Collapse (Vinge, 2005)

Unlimited exponential growth as shown in Figure 1-10(a) is similar to the mathematical concept of singularity where what comes next cannot be based on the past as explained by Vinge (2005). The output of data, knowledge and technology keeps on multiplying as it reinforces and feeds back on itself in a positive feedback loop archetype ("runaway condition") as explained by Senge (2006:79) as well as the law of accelerating returns as explained by Kurzweil (1999). Van den Hoff confirms the view on the multiplication effect of knowledge due to the availability of the Internet. He states that the Internet not only connects people with "each other 24/7, but also with each other's information and collective knowledge" (Van Den Hoff, 2014:196). Gharajedaghi (2011:75) states that "unlike energy [knowledge] is not subjected to the first law of thermodynamics – the law of conservation of energy" i.e. a finite quantity. He reasons that the dissemination or spread of knowledge helps with the multiplication and creation of new knowledge and in this manner, knowledge keeps on growing exponentially without limits.

Exponential growth with saturation as shown in Figure 1-10(b) occurs when the positive feedback or reinforcing loop is balanced by a negative feedback or balancing loop due to some physical constraints in the environment that prevent unlimited growth (Senge, 2006). The end of Moore's law in the current paradigm of computational speed, i.e. the physical limit on the placement of more transistors on an integrated circuit (IC), is an example of such a limitation that will saturate the exponential growth and cause it to slow down (Courtland, 2015).

The third potential outcome of exponential growth as indicated in Figure 1-10(c) is sudden collapse. Sudden collapse occurs when the carrying capacity or architecture framework of the system is insufficient, overloaded and stressed beyond a tipping point (Mrotzek and Ossimitz, 2008; Zeeman, 1976).

Given that a project environment is subjected to exponential growth impulses caused by trends, megatrends, paradigm shifts, disruptive technologies and Black Swan events, the question could be asked what would be the effect of these phenomena on capital project stability and convergence.

1.4.6 Increase in Overall Level of Complexity in Society

Gharajedaghi (2011:57) states that "self-organisation, or the movement toward a predefined order, is one of the critical conceptions that describe the essence of sociocultural systems". This movement towards a pre-defined order implies that there is a movement in a sociocultural system from less order to more order and Gharajedaghi denotes this as Integration i.e. the *movement from chaos towards order*. He also notes that differentiation (variety) is a process that happens when a sociocultural system moves from a simple state to a complex state. The concepts of integration and differentiation are shown schematically in Figure 1-11(a). His theory of purposeful systems states that these sociocultural systems have plurality of functions, structures and processes and can transform itself by learning and serving itself, its members and its environment. Purposeful systems therefore develop and transform themselves by moving towards higher levels of differentiattion and integration at the same time (p. 73) as schematially shown in Figure 1-11(b). These systems cycle between differentiation (new varieties and new structures) and integration (maintaining and converging structure), develops and moves towards higher levels of integration and diferentiation at the same time.

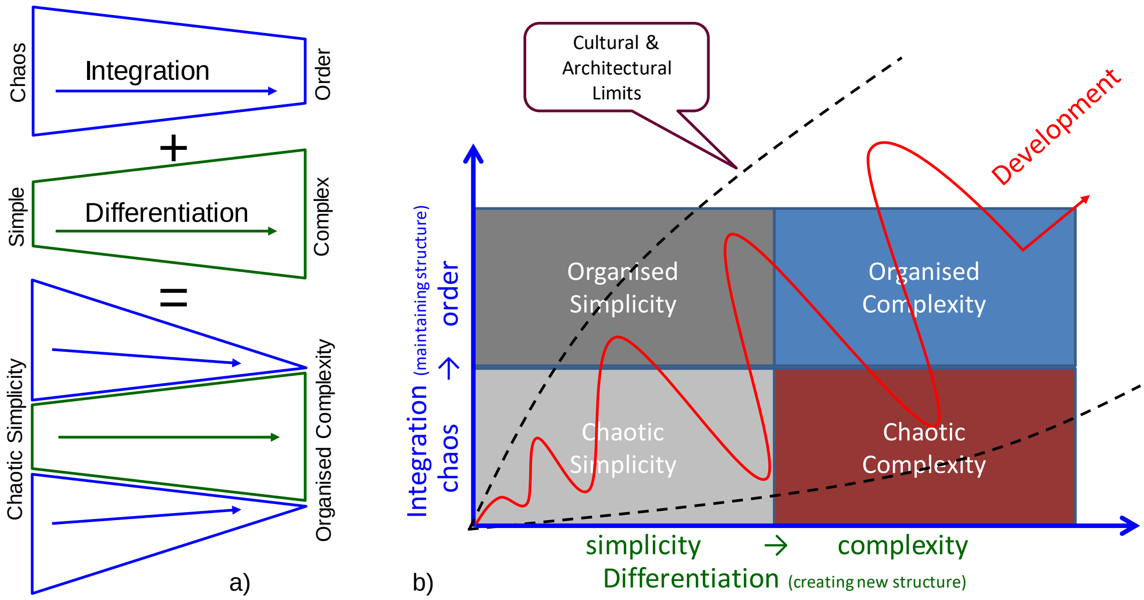

Figure 1-11: Model for the Development of Purposeful Sociocultural Systems (a) Simultaneous Integration and Differentiation, (b) Cycling between Integration and Differentiation at the same time Based on Information from Gharajedaghi (2011:73-74)

Gharajedaghi therefore maintains that sociocultural systems keep on developing and self-organising themselves to higher levels of complexity through a developmental process. He also indicates that when a sociocultural system touches the cultural or architectural limits during its development, it will be subjected to violent reaction and in the worst case collapse (p. 74).

Perhaps some of the principles of purposeful system are also manifested in capital projects as a variety of ideas, technologies and configurations (differentiation) needs to be facilitated during the project life cycle from a state of chaos towards a state of order (integration) to meet stated project objectives. Such capital project frameworks will be required in the VUCA world when various change phenomena are occurring in an unsynchronised manner in real-time.

1.4.7 Concurrent, Simultaneous and Cumulative Occurrence of Phenomena

In the previous paragraphs the changes (trends, megatrends, paradigm shifts, disruptive technologies and Black Swan events) and the rate of change (exponential growth) were identified as individual concepts. These concepts were also portrayed to develop and follow each other in a life cycle and sequential format. Reality does not behave in this manner. For example, by 2020 multiple generational types such as: Traditionalists, Baby Boomers, Gen X, Gen Y and Gen Z will be working together side-by side at the work place, each with fundamentally different backgrounds, ideals, behaviours and values (EY, 2015; CGK, 2015). People with different world views will simultaneously share the same space and time. The same principle applies to the various phenomena that are treated in this chapter. The elements of megatrends, demographics, paradigm shifts, disruptive technologies and exponential growth, as shown in Table 1-5, are all occurring simultaneously and concurrently in time while new concepts are added to current and previous concepts.

Table 1-5: Concurrent and Simultaneous Occurrence of Phenomena Now and in Future

No.	Dimension	Type of Variable	References
1	Megatrends	Digital Globalisation + Global Marketplace + Individualism and Activism + Resources and Environment + Demographics + Urbanisation + Health + Technology and Entrepreneurship + Sustainability	Appendix A, Paragraph A.2
2	Demographics	Traditionalists + Baby Boomers + Gen X + Gen Y + Gen Z	Appendix A, Paragraph A.2.5, EY (2015), CGK (2015)
3	Paradigm Shifts	Web 1.0 + Web 2.0 + Web 3.0 + Web 4.0 Industry 1.0 + Industry 2.0 + Industry 3.0 + Industry 4.0 Society 1.0 + Society 2.0 + Society 3.0 + Society 4.0	Appendix A, Paragraph A.3
4	Disruptive Technologies	Inventory and network optimisation tools + sensors and automatic identification + cloud computing and storage + big data and predictive analysis + wearable and mobile technology + advanced robotics and intelligent automation + driverless vehicles and drones + 3D printing + automation of knowledge work + advanced materials and miniaturisation + bio technologies and genome sequencing + renewable technologies	Appendix A, Paragraph A.4, Deloitte (2016), Manyika et al. (2013)
5	Exponential Growth	Singularity + saturation + catastrophic collapse	Paragraph 1.4.5, Figure 1-10

It could be reasoned that if the phenomena as indicated in Table 1-5 occurs simultaneously, then the overall level of complexity in society is continuously, cumulatively and exponentially growing and increasing towards ultra-complexity. The capital project internal and external environment will be immersed in this ultra-complex environment and relevant theories, models and methods are required for guiding the project practitioner in the planning and execution of his capital project.

1.4.8 Conclusions on the Overall Influences of a Fast-Changing World on Capital Projects

The change phenomena as described in this paragraph 1.4 as well as their possible influence on the current and future capital project environment have been summarised in Table 1-6.

Table 1-6: Possible Influences of Change Phenomena on Current and Future Capital Project Environments

No.	Change Phenomena	Reference	Possible Influence on Capital Project Environment
1	Trends, megatrends, paradigm shifts, Black Swan events and disruptive technologies	Paragraph 1.4.1	New industries, new products and services, geographical changes, new ways of competing and new projects
2	Increase in technology adoption rates	Paragraph 1.4.2	More projects, shorter project life cycles, more new product development type of projects
3	Introduction of disruptive technology in supply chains	Paragraph 1.4.2	Increase in project cost and schedule overruns due to first-time technology introductions
4	Decrease in company life spans	Paragraph 1.4.3	Project instability and change of project sponsors
5	Laws of acceleration	Paragraph 1.4.4	Exponential growth of exponential growth, humans not able to follow or adapt to change, difficulty to understand and predict, disorientation, unpreparedness, fear and an inability to cope
6	Three potential outcomes of accelerated growth	Paragraph 1.4.5	Runaway increase in data, knowledge and technology, saturation, catastrophic failures and collapse
7	Increase in the overall level of complexity in society	Paragraph 1.4.6	Self-organisation, integration as the *movement from chaos to order*, differentiation as the movement from simplicity to complexity
8	Concurrent, simultaneous and cumulative occurrence of phenomena	Paragraph 1.4.7	Increase in the total span between “old” and “new”, increased elements, increased complexity

It seems from Table 1-6 that capital project environment may be affected in multiple ways as a result of these simultaneously occurring change phenomena. It could be argued that the capital project external environment will be affected by new, industries, new products and services and the capital project internal environment by new products and shorter product life cycles in an environment of super exponential growth. This condition in turn, may lead to project tension, instability and undesirable self-organisation of project stakeholders. The overall complexity in the internal and external capital project environment is expected to increase and perhaps these projects are prone to become chaotic at any point in time. There will then be a need to gain control of the capital project environment using appropriate theories, models and methods.

Alderman and Ivory (2011:17) argue that project "success and failure can be characterized in terms of a continuum between project convergence and divergence". This research will depart with the assumption that the concept of integration as explained by Gharajedaghi (2011) (i.e. the movement from chaos to order) is similar to the concept of convergence as explained by Alderman and Ivory (2011) (i.e. achieving project success) and the focus will be to establish in which manner *convergence from chaos to order* could be achieved in capital projects with the possibility to contribute to successful current and future capital projects, with the resulting reduction or avoidance of capital project cost overruns.

1.5 Chaos Theory and Chaos Attractors Applied to the Capital Project Environment for the Creation of Project Convergence

Chaos theory is explained in this paragraph and definitions are provided for chaos, order and convergence that will be used for the remainder of this research.

1.5.1 Chaos Theory

A summary of some of the references in the literature on chaos theory, the production of order from chaos and the chaos attractors, that are responsible for the creation of order, are shown in Table 1-7.

Table 1-7: Different Versions of Chaos Theory and Chaos Attractors

No.	Different Versions of Chaos Theory	Reference
1	"Despite its name, chaos theory considers the tendency toward order a *natural phenomenon* produced by the action of four types of attractors: point attractors, cycle attractors, torus attractors and strange attractors".	Gharajedaghi (2011:57)
2	"Although known as the four 'chaos attractors', they are really the opposite - they are cosmos attractors that balance chaos. The four 'attractors' bring order out of chaos… these attractors balance entropy, providing order from out of chaos."	School of Wisdom (No Date:1 of 4)
3	"Attractors configure the evolution of complex adaptive systems… since attractors are the most stable and robust elements in these systems... they do not end up in chaos or randomness, but organise themselves around various attractors."	Kuhmonen (2017:214, 218) (Gerrits, 2012, 157)

Based on the quotations in Table 1-7 it appears that chaos theory states that it is possible to create order from chaos. Furthermore, this order is brought about by four chaos attractors namely: a) point attractors, b) cycle attractors, c) torus attractors and d) strange attractors.

The function of the fixed-point chaos attractor is described as attraction to a fixed point of any nearby elements (Vallacher and Nowak, 2007). The limit cycle causes attraction of nearby elements when a cycle of an activity is completed (Butner et al., 2015). The torus chaos attractor is formed by multiple inner cycles contained in a single outer cycle and attracting nearby elements when these cycles are executed (Young and Kiel, 1994). Finally, the strange chaos attractor is believed to attract nearby elements in strange ways (Bums, 2002). These descriptions of the chaos attractor are explained at a metaphorical level and it is the objective of this research to gain an understanding of the manner in which these metaphors could be applied in capital projects to cause chaos attraction.

Interestingly, the “tendency toward order” is considered to be a “natural phenomenon” by Gharajedaghi (2011:57). If it is assumed that the “production of order” (Gharajedaghi, 2011:57), the “bringing of order” (School of Wisdom, No Date:1 of 4), the “self-organisation towards order” (Kuhmonen, 2017:214, 218) and the “integration from chaos to order” (Gharajedaghi, 2011:73) is similar to “project convergence” (Alderman and Ivory, 2011:22) in capital projects, a construct for the application of chaos theory to capital projects could perhaps be configured as shown in Figure 1-12.

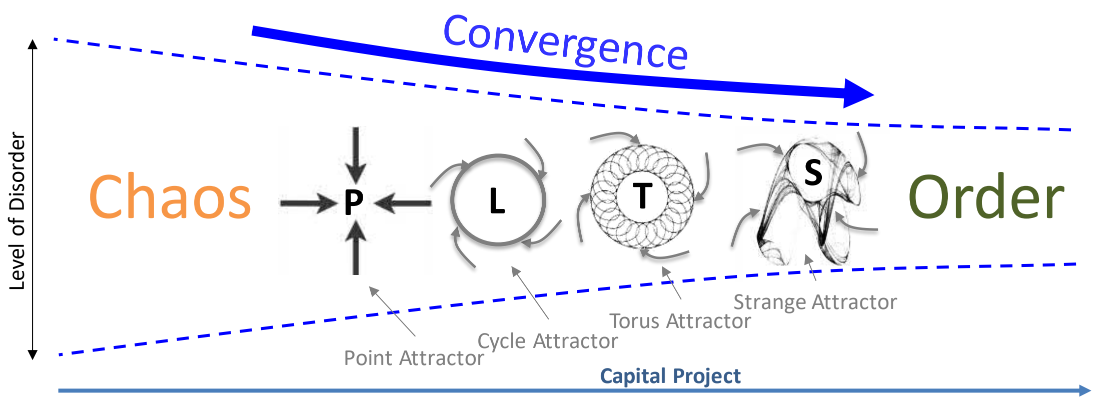

Figure 1-12: Construct for Chaos Theory and Chaos Attractors Applied to the Capital Project Environment for Producing Project Convergence from Chaos to Order

Translating the definitions given of chaos attractors in Table 1-7 it is assumed that these four chaos attractors are working in concert with each other across the capital project life cycle as shown in Figure 1-12 to produce order from chaos. It is also assumed that the effect of the chaos attractors on a capital project is to reduce the overall level of disorder. Therefore, based on the definitions given in Table 1-7 and the construct shown in Figure 1-12, chaos theory applied to the capital project domain could therefore be formulated as follows for this research: *Project convergence from chaos to order in capital projects is brought about by point, cycle, torus and strange chaos attractors*.

Definitions for the concepts related to chaos theory such as chaos, order and convergence are required to better understand the desired outcome of applying this theory to capital projects and to use a common terminology.

1.5.2 Definitions for Chaos, Order, Convergence and Divergence

Definitions for chaos, order, convergence, divergence and project convergence are provided in Table 1-8.

Table 1-8: Definitions for Chaos, Order, Convergence and Divergence

No.	Definitions	Reference
1	**Chaos**: "An ancient word originally denoting a complete *lack of form or systematic arrangement*, but now often used to imply the absence of some kind of order that ought to be present"	Lorenz (1995:3)
2	**Order**: "The arrangement or disposition of people or things in *relation to each other according to a particular sequence, pattern, or method*… a state in which everything is in its correct or appropriate place".	Oxford Dictionaries (2018:1 of 7)
3	**Convergence**: "The act of converging and especially *moving toward union or uniformity*… the merging of distinct technologies, industries, or devices into a unified whole".	Merriam Webster (2018:1 of 1)
4	**Divergence**: "Separating, or branching off... *becoming different in form or kind*... departure from a particular viewpoint, practice...".	Collins (2018:3 of 3)
5	**Project convergence**: "convergence is created not just by a *convergence of interests* (i.e. political convergence), but also by a *convergence of sense making* around what the end goals of the project are (cognitive convergence)… It is argued that success and failure [of a project] can be characterized in terms of a continuum between project convergence and divergence".	Alderman and Ivory (2011:22)

The definitions as shown in Table 1-8 are not exhaustive, but were chosen as a starting point for definitions that might be applicable to the capital project environment for this research. Part of the scope of this research will be to obtain a "new" understanding for these terms from capital project managers during the empirical investigations as will be shown in chapters 5, 6 and 7.

1.5.3 Local and Overall Convergence Effect of Chaos Attractors

The School of Wisdom (No Date:1 of 4) speculates that the strange chaos attractor is responsible for the hidden order in society and "governs the fourth dimension of space-time" while the other three chaos attractors are responsible for creating a hidden order out of chaos from the first, second and third dimensions of life. Gharajedaghi (2011:51) is of the opinion that "point chaos attractors represent the behaviour of social beings in pursuit of their natural instincts; [such as] fear, love, hate, desire to share, or self-interest". He further states that cycle chaos attractors represent "complimentary but opposite tendencies" such as stability vs change; security vs freedom, and differentiation vs integration (p. 51). The torus chaos attractor works in open systems such as "growth patterns of biological systems" (p. 51). Finally, he states that the strange chaos attractor would represent the multi-final, self-organising and purposeful behaviour of sociocultural systems. Robertson (2014:37) is of the opinion that "values might be seen as strange attractors" as it results in "the focus of a pattern of seemingly chaotic behaviour".

There seem to be widely differing views by researchers on what the functions of chaos attractors are, what they represent and what they should be. This exploratory research also considers the views on chaos theory, chaos attractors and complexity that originate from non-scientific resources such as School of Wisdom (No Date), (Lucas, 2004) and (Lucas, 2006) to ensure that exploration, ideation and formation of new theory is unconstrained by set paradigms. All theory and models that were derived for chaos attractors were tested using a rigorous research data collection and data analysis methodology as indicated in Chapter 4. Moreover, for this exploratory research on the convergence from chaos to order in capital projects it is decided that the individual effects of each chaos attractor will be researched as well as their combined effect.

1.6 Research Gap and Relevance

Eoyang and Olson (2001:5) are of the opinion that "attractors are one of the most powerful, but least understood, aspects of human systems". There is thus a research gap and need for a systematic study and rigorous research of chaos attractors in order to unlock the potential of attractors as convergence mechanisms in capital projects. According to Begun et al. (2003:17) research in the complexity sciences focuses on the understanding and application of attractors as "a rich set of poetic metaphors: the strange attractor, the butterfly effect, self-organized criticality, fractal, etc.". They refer to the work of Hallyn and Leslie who states that metaphors may have different value in terms of "a discursive status (valid in the case that aims to enlighten or convince), a methodological status (implying a heuristic function), and a theoretical status (linked to a vision of the world that poses a priori the existence of a real analogy)". Begun et al. (2003:16) state that the discursive use of attractor metaphors was used in abundance by the pioneers in the complexity sciences, such as "leadership is a strange attractor" without applying methodological *rigor* and an understanding of the "underlying science". They therefore identify the need for future research on chaos attractors to progress towards achieving methodological and theoretical status.

This research aims to derive chaos theory for the capital project environment, derive chaos attractor models and obtain empirical evidence for the mapping of the chaos attractor metaphors to the capital project environment. This research will therefore apply methodological rigor, as suggested by (Begun et al., 2003), to explore if chaos theory concepts could be recognised by capital project managers and if capital project managers could benefit from a better understanding of their capital projects and possibly predict capital project behaviour using chaos theory and related concepts.

1.7 Key Attributes of Chaos Theory and Chaos Attractor Models for Capital Projects

The key attributes of desired chaos theory and chaos attractor models for capital projects would be to have a theories and models that are:

a) Simple to understand by the project managers
b) Universally applicable to all types of capital projects
c) Practical and easy to use by the capital project managers.

1.8 Research Objective and Scope

The objective of this research is to explore if chaos theory and chaos theory concepts as described in various other human sciences are transferrable and usable by capital project managers.

The scope of this research will be limited to:

a) Deriving chaos theory for capital projects
b) Empirically testing the transferability of chaos attractor metaphors to the capital project environment
c) Deriving chaos attractor variance models for capital projects
d) Empirically testing derived chaos attractor models for potential use in capital projects.

However, in order to focus and guide the broad exploratory nature of this research, major and sub-research questions are formulated.

1.9 Research Questions

"Theory-based empirical research" (Walwyn, 2016:4) will be used to answer the two main research questions and a number of sub-research questions.

1.9.1 Main Research Questions

The two main research questions pertaining to the convergence from chaos to order in capital projects are formulated as follows:

Main Research Question 1:
Does the use of individual chaos attractors lead to local convergence from chaos to order of capital project elements and their trajectories?

Main Research Question 2:
Does the use of combinations of different types of chaos attractors lead to overall convergence from chaos to order of capital projects?

1.9.2 Research Sub-Questions

The following sub-research questions are formulated on chaos attractor behaviour that will be investigated to gain a better understanding of the characteristics of chaos attractors:

a) Which attractor types and classes could be identified from the literature?
b) What are the characteristics and functions of each attractor based on the literature?
c) What empirical studies have been done to demonstrate the effect of attractors?
d) Do attractors only appear in chaotic types of systems, or also in random, complex and ordered system types?
e) Do attractors appear simultaneously in systems, and what are the effects of attractors on each other and on the overall system behaviour?
f) Do attractors only appear naturally in systems or could they be pre-designed?
g) Are there strong and weak attractors?
h) Where in the project life cycle do attractors occur naturally?
i) What is the effect of naturally occurring attractors on overall project behaviour and

as part of the project life cycle?

j) Could attractors be designed and positioned as part of the pre-project architecture to have an overall project convergence effect?

1.10 Contributions and Limitations of this Research

The contribution of this research is on a theoretical and practical level. On a theoretical level this research enables the gathering of data, information, knowledge and insight into chaos attractors, their characteristics, functions, structure as well as their effect on simple and complex project environments. Theories and models based on chaos theory are also derived and exploratory tested. On a practical level the contribution of this research pertains to an understanding of the potential of naturally occurring or pre-designed chaos attractors as part of the capital project life cycle and their ability to aid project convergence and overall project performance when employed by the project manager.

This research aims to identify context independent mechanisms to aid project convergence in an ever increasingly fast- changing VUCA world. The potential theoretical and practical research contribution should enable capital project managers to plan and execute their current and future projects with an additional applicable theory and model, that has the potential to minimise or avoid likely capital project cost overruns and failure.

The results of this research are limited to capital projects and further research should be done to test the generalisation of the derived theories and models. A small sample of experienced capital project managers were used to obtain the exploratory research results and this sample should be expanded in future research to test the validity of results obtained for this research.

1.11 Thesis Structure and Research Roadmap

The structure and layout of the Chapters of this research is shown in Figure 1-13.

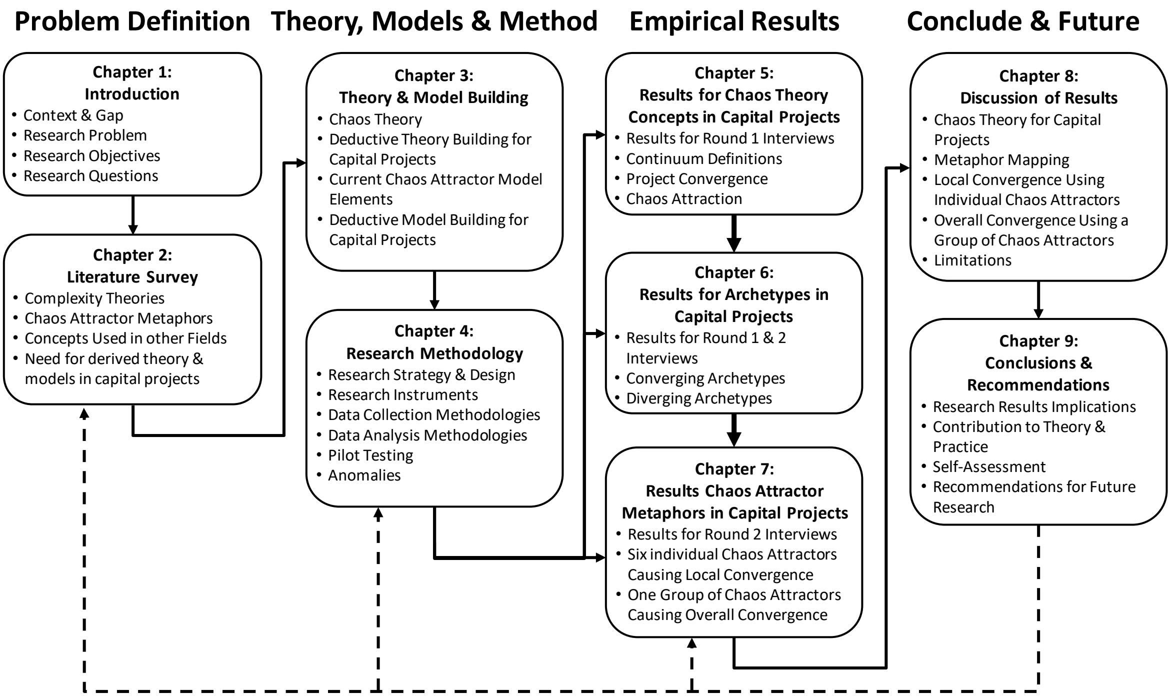

Figure 1-13: Structure of Research and Roadmap

The introduction (Chapter 1) and literature survey (Chapter 2) form part of the problem definition for this research. Theory and model building (Chapter 3) is based on the content of the literature survey (Chapter 2) after which a research methodology is defined (Chapter 4) that is suitable for exploratory research in the capital projects domain. Theory, model and research methodology is therefore covered in Chapters 3 and 4. The empirical research results are given in three separate chapters although they originate from two rounds of interviews. Chapter 5 provides a summary of the results on chaos theory concepts in capital projects. The results for Chapter 6 on archetypes in capital projects originate from both rounds of interviews with capital project managers. Chapter 7 gives the results for chaos attractor variance models that were tested during the second round of interviews. Discussion of the results and limitations are done in Chapter 8 as well as answers to the major and sub research questions. Conclusions and recommendations on the research results are provided in Chapter 9.

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CHAPTER 2: LITERATURE SURVEY

2.1 Introduction

The objective of this literature survey is to summarise information related to chaos attractors and to build a foundation from which theory and model building can be done in Chapter 3. The first section gives an account of the nature of the problem field – that is the nature of real-world complex problems. This is followed by an explanation of the classical linear manner in which complex problems are solved and the reason why this approach is not deemed suitable for exploratory research of chaos theory in complex capital projects. The next section provides information on domains of randomness, chaos, complexity and order as found in the literature to allow for the generation of the Randomness-Chaos-Complexity-Order continuum. This continuum provides the context within which chaos attractors and the trajectories of systems, organisations and projects could be studied. Information, references, applications and examples of chaos attractors are then summarised and categorised in the following section. The next section provides information on the trajectories of systems, organisations and projects – some with clear evidence of their trajectories being influenced by chaos attractors. This Chapter is concluded with an attempt to provide preliminary answers to some of the major and sub-research questions as stated in Chapter 1. It is concluded that this literature survey on chaos attractors and related information are deemed sufficient to allow for theory and model building in Chapter 3

2.2 The Nature Of Real-World Complex Problems

This section focuses on gaining a better understanding of the difficulties of real-world complex problems. The environment in which real-world problems exists, is characterised and a description of the manner in which the free-will of human beings make decisions and choices and the difficulty in modelling this aspect of human sciences.

2.2.1 The VUCA World

In Chapter 1 of this research it was shown that the internal and external project environment is currently subjected to accelerative and exponential influences. These changes seem to occur in the business and societal environments as a result of trends, megatrends, paradigm shifts, disruptive technologies and Black Swan events. These individual, combined and simultaneously occurring environmental influences and changes are believed to increase in intensity and to cause an increase in the overall level of complexity of the project-internal and external environment. Reference was made in Chapter 1 to the

VUCA world and a further description of the characteristics of the VUCA world is provided.

During the 1990's the US Army War College described the dangerous war-like conflict conditions in Afghanistan and Iraq as volatile, uncertain, complex and ambiguous and they created the term "VUCA" (Gandhi, 2017). The concept was transferred to the business world in 2006 to describe the "chaotic, turbulent, and rapidly changing business environment" (Gandhi, 2017:2). This VUCA condition in the business world prevents diagnosis with confidence, "befuddles executives" and "render useless any efforts to understand the future and to plan responses" according to Bennett and Lemoine (2014:311). Definitions for each of the VUCA dimensions are given in Table 2-1.

Table 2-1: Definitions for VUCA Dimensions

No.	Dimension	Description	Reference
1	Volatility	"More instability, wilder fluctuations, very rapid and unexpected change…change as the only constant"	Garrow (2015:1)
		Unstable and unpredictable change, "does not necessarily involve complex structure [or] critical lack of knowledge"	Bennett and Lemoine (2014:313)
2	Uncertainty	"The future unlikely to be much like the past, but the present is often very different too… information is incomplete"	Garrow (2015:1)
		"Lack of knowledge as to whether an event will have meaningful ramifications… unknown if an event will create significant change"	Bennett and Lemoine (2014:313)
		"Uncertainty is much less susceptible to analysis; it is what is left behind when all the risks have been analysed… unknown unknowns… unknown knowledge, unknown relationships between key variables and unpredictable events"	Cleden (2009:4, 13)
3	Complexity	"The technological ease of connecting with people far and wide has created more interdependencies and feedback loops than ever before. Within those intricate and multi-layered networks, actions can have unintended consequences which cannot be predicted"	Garrow (2015:1)
		"Many interconnected parts forming an elaborate network of information and procedures; often multiform and convoluted"	Bennett and Lemoine (2014:313)
4	Ambiguity	"Where no precedents exist, it becomes ever harder to reach clarity and agreement about the meaning and significance of events"	Garrow (2015:1)
		"A lack of knowledge as to 'the basic rules of the game' "	Bennett and Lemoine (2014:313)

In the real world the VUCA dimensions occur simultaneously (Garrow, 2015) and therefore the effect could be expected to be compounded complexity. Not only do organisations need to operate in this VUCA world, but capital projects need to be planned and executed in the current and future VUCA world. Garrow (2015:3) is of the opinion that organisations experience a paradox in that they “cannot predict the future, [but] they must make sense of it to survive”. What is the contribution of the human free will in this VUCA world?

2.2.2 Human Choice and Free Will in Complex System Analysis

Kurtz and Snowden (2003:464-465) are of the opinion that the reasons why it is difficult to model human behaviour compared to an ant colony if both systems are considered to be of a complex nature are that:

a) “Humans are not limited to one identity”
b) “Humans are not limited to acting in accordance with predetermined rules”
c) “Humans are not limited to acting on local patterns”.

Snowden (2005:49) states that humans do not take rational decisions based on deep analysis of all available data but base their decisions on a “first-fit pattern” that matches either their individual experiences or collective experiences of the culture that they belong to. Remington and Pollack (2007:1) confirm that the behaviour of people is unpredictable as they are “self-determining, self-willed, self-motivated and selfish”. Thietart and Forgues (1995:19) note the limitations of the “rational” and “mechanistic” view of organisations as “political games between organizational actors, intuition, and random events” are all interrelated and contribute in shaping the organisation’s future and therefore makes deterministic prediction of behaviour impossible. Thietart and Forgues (1995:22) describe reality as containing elements of “rationality, formality and order mixed with intuition, informality and disorder”. Laszlo (2009:205) states that “reality is not an absolute given” as it depends on the perception of reality as perceived by community members and their leaders. This perception of reality then shapes and plays out in social institutions, political states and economic systems according to Laszlo.

Purposeful systems such as humans express themselves by their free will and choice according to Gharajedaghi (2011:33). He is of the opinion that “choice is the product of interactions among the three dimensions: rational, emotional and cultural” as shown in Figure 2-1.

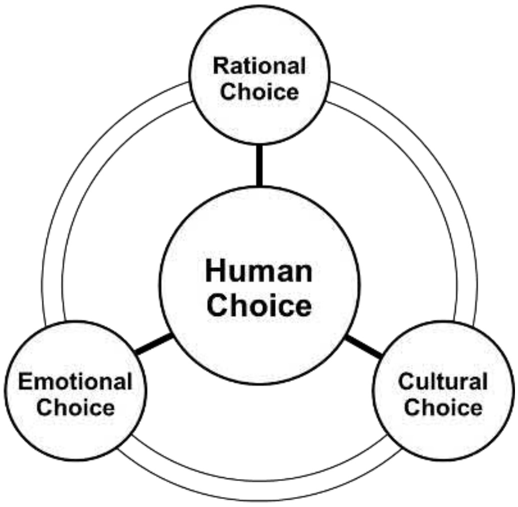

Figure 2-1: Dimensions of Human Choice (Reproduced from Gharajedaghi (2011:34))

Gharajedaghi (2011) explains that a rational choice is self-serving, focused on the interest of the decision maker and risk averse. The emotional choice is about risk taking, beauty and excitement. The cultural choice is the default decision of the collective, group or community. If no deliberate choice is made by an individual, then the default ethical norms, values and belief of the collective, group or community becomes the automatic choice. Laszlo (2009:205) confirms that human social systems are "culturally conditioned" and therefore distinguish them from other biological systems.

It seems that there might be a low probability of deterministically calculating which choice a free-willed human is going to make in the same or different contexts as part of a socio-cultural-technical system. Capital projects and the project environment contain free-willed humans. But, a values and belief based strange attractor as described by Bums (2002) holds the promise to cause, influence or guide a human to make his free-will choices towards an "orbit" around this chaos attractor.

This research is about the exploration of chaos attractors that may be able to attract free-willed human decisions toward a pre-determined attractor and in this manner aid project convergence from chaos to order. But, before trying to understand different types of chaos attractors that form part of systems, a better understanding is required about methodologies to study real-word complex problems such as capital projects.

2.3 Methodologies to Study Real-World Complex Problems

There are limits in the application of mathematical modelling to solve real-world complex problems due to inherent uncertainties in these types of problems. Reductionism is generally used by researchers to analyse complex problems, but this approach leaves an unresolved root problem. The chosen methodology for this research to solve real-world complex capital project problems is complexity sciences, as this approach deals with both the divisible and indivisible parts of complex problems.

2.3.1 Limits to the Mathematical Description of Real-World Complex Problems

The question arises if mathematical modelling could describe and aid our understanding of the role and behaviour of chaos attractors in a complex capital project internal and external environment with free-willed humans. Allen (2001:39) studied the co-evolution of twenty human populations over time and noted that “it would be extremely difficult to discern the ‘correct’ model equations” for all possible population behaviours as “any single behaviour could be playing a positive or negative role in a self, pair, triplet or larger combination… interaction”. Radu et al. (2014a:1544) on the other hand, have shown that the simple equation that is used by ecologists to predict species population growth and decay ($x_{t+1}=kx_t(1-x_t)$) display both chaotic and ordered behaviour depending on the value k used in the equation. Beyond the third iteration of period doubling, they have shown that the system behaviour is in a state of full-blown chaos but with islands of order (refer to Figure 2-25 that will be discussed later). Based on this mathematical observation, Radu et al. (2014a:1547) conclude that “more than three uncertainties can destabilize even the best employee, client or provider. More than three uncertainties may create full blown chaos”. Their conclusion may imply the impossibility in modelling human behaviour using mathematical equations in capital projects. Despite these limitations for mathematical description of real-world problems the default methodology for analysis remains simplification and reductionism.

2.3.2 Reductionism as the Default Methodology to Deal with Real-World Complex Problems

Cicmil et al. (2009:12) are of the opinion that our understanding of project management emerged from the “Cartesian / Newtonian / Enlightenment paradigm” and is based on the mechanistic and control framework ‘lens’ that viewed the universe for three centuries as a “clockwork masterpiece” (p. 22). It was only with the advent of modern computers in the 1960s and 1970s that more research could be done on non-linear system behaviour and that it was realised by researchers that the clockwork ‘lens’ only provides answers to the linear part of our universe.

The default method to study complex problems and ‘messes’ seems to be reductionism. In this regard, Eisner (2011:95) states that “when confronted with what appears to be a difficult or complex problem, many people begin by shredding the problem into many pieces and then shredding the pieces into even smaller pieces”. This approach causes, according to Eisner, an unbalanced emphasis on analysis in lieu of synthesis and instead of getting “some sense of the forest as a whole, we wind up looking at each and every tree”. Meadows (2011:83-84) confirmed this observation that “much can be learned by taking apart systems at their hierarchical levels” but care should be taken “not to lose sight of the important relationships that bind each subsystem to the others and to the higher levels of the hierarchy”. Cleden (2009) provides a graphical view of the reductionism approach and result when applied to both a divisible and indivisible problem as shown in Figure 2-2. For simple linear problems this approach works well, as all the sub-problems are solved as shown in Figure 2-2(a). But, the reductionism approach appears not to work when solving an indivisible or complex problem as shown in Figure 2-2(b) as an unresolved root problem remains.

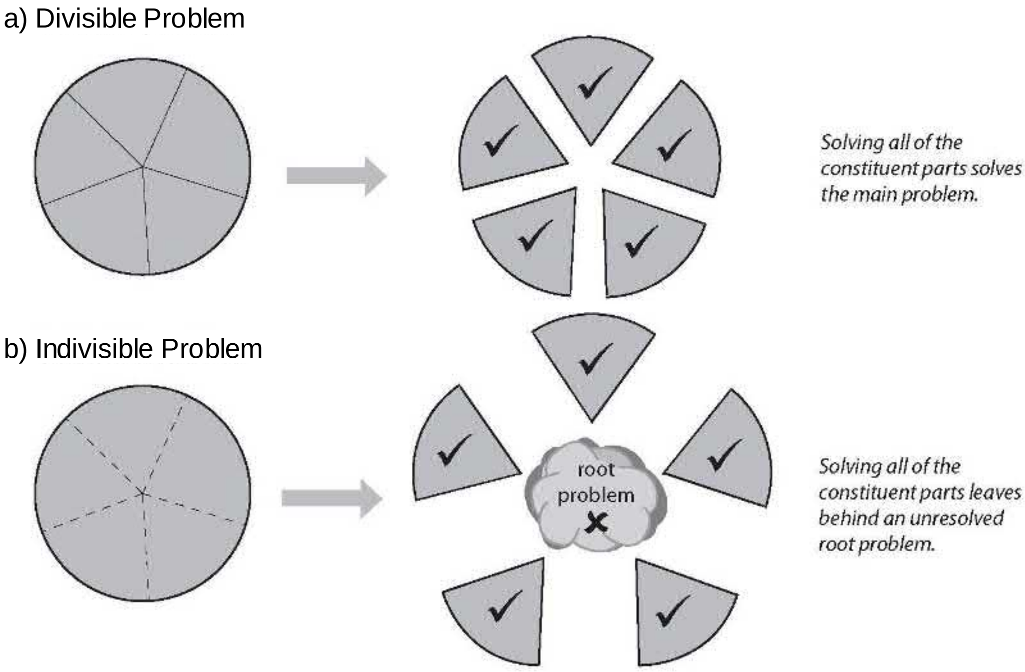

Figure 2-2: Complex Problems tend to be Treated as a) Divisible Problems instead of b) Indivisible Problems that Results in a Remaining Unresolved Root Problem (Cleden, 2009:44, Figure 3.2)

Vallacher and Nowak (2007:13) confirm that for a nonlinear system the "system-level behaviour cannot be decomposed into separate additive influences. Rather, the relations among variables depend on the values of other variables in the system". Meade and Rabelo (2004:669) are also of the opinion that the "true complexity" and "emergent nature" of a system is brought about by the *interaction and adaptation* of the individual elements with each other and therefore the emergent behaviour of a complex system cannot be deduced from the behaviour of the individual elements separately. According to them, the "typical reductionist method of problem solving" (p. 669) fails the moment when the individual parts are isolated and studied in isolation because it was this adaptation behaviour of the individual elements that created the emergent system behaviour. The default method of reductionism is therefore deemed unsuitable in analysing complex system behaviour such as capital projects with properties such as interconnectedness, hierarchy and emergence (Remington and Pollack, 2007) and will not be considered in gaining an understanding of the convergence behaviour of chaos attractors in complex projects environments.

2.3.3 Complexity Sciences as a Methodology to Deal with Real-World Complex Problems

Ramalingam et al. (2008:ix) are of the opinion that complexity science can help to engage what were previously known as "messy realities". He summarises the work of Ackoff (1974) who stated that there are three different types of challenges at three levels that have to be dealt with by scientists and policymakers in solving real world system challenges. These are messes, problems and puzzles. Messes are systems that have no well-defined structure or form. An example of a mess is how to deal with HIV/Aids in China and the related difficulties in politics, policy and society. Problems are not well understood and multiple dimensions such as technology, economics, ethics, politics or other similar dimensions, have to be dealt with "simultaneously and as a whole" (Ramalingam et al., 2008:11). Problems, on the other hand, do have form or structure, their dimensions and variables are known and the interactions of the dimensions may be partly understood. An example of a problem is a sewage system of a city. Systems that are classified as problems may have many alternative solutions depending on the constraints. The final level is known as puzzles – these are systems with well-defined structures and "specific solutions that can be worked out" (Ramalingam et al., 2008:11) such as to fit the maximum amount of chairs into an Auditorium.

According to Ramalingam et al. (2008:11), Ackoff indicated that one of the fundamental problems in real world problem analysis is a bias towards "puzzle solving" in which "real-world, complex, messy nature of systems is frequently not recognised, leading to simple puzzle-based solutions for what are in fact complex messes".

Ramalingam et al. (2008:8) defined complexity science as:

> "phenomena that arise in systems [that have] interconnected and interdependent elements and multiple dimensions [with] both positive and negative feedback processes [that acts to] dampen or amplify change [and where] emergent properties result from the interactions of the elements but are not properties of the individual elements themselves"

Complexity sciences thus offer capital project managers a potential theoretical foundation and methodology to study messes and problems that are part of the current and future VUCA world (refer to Table 2-1). For this research it will be assumed that capital projects are real-world complex problems and messes that contain both ill-defined and sometime well-defined structure and form.

Complexity science is therefore the chosen methodology for this research to gain a better understanding of chaos attractors and their ability to aid project convergence from chaos to order and minimise or avoid project cost overruns.

2.4 Ordered, Complex, Chaotic and Random Systems

The literature on complex non-linear dynamic systems refers to system states such as ordered systems, complicated systems, complex systems, chaotic systems and random systems. An attempt is made in this section to summarise the relevant theories and attributes of these system states in order to better understand and define these differences. The summary at the end of this section should also help to create terminology for different states that may be present in capital projects.

2.4.1 Ordered and Simple Systems

Remington and Pollack (2007) refer to ordered systems as having fixed structures with fixed relationships between their elements. Snowden and Boone (2007) described the domain of simpleness to have the characteristic of clear cause-and-effect relationships between system elements. They state that a single right answer can be deduced from simple analysis and simple systems are found in domains that are "heavily process orientated" (p. 2). Thietart and Forgues (2011:58) refer to order as an "equilibrium or a recognizable configuration" and also as "stability or sense-making regularity".

2.4.2 Complicated Systems

Whitty and Maylor (2007:2) referred to the confusion in the project management fraternity about the distinction between complex and complicated. They state that synonyms for the word complex may include “complexity, complicated, intricate, involved, tangled, and knotty”. According to them, examples of complicated systems are gas and oil pipelines, railroads, flight control centres, space shuttle engines, combat ships, missile software, civil engineering and offshore structures. These complicated systems are “inert” as “their behaviour as a whole may be entirely understood by reducing them to their parts” (Whitty and Maylor, 2007:3). Similarly, Cooke-Davies et al. (2011) refer to an aircraft engine as a complicated system because it can be deconstructed into its original parts – this is not the case with making Mayonnaise as it cannot be separated into olive oil and egg yolk once created. Hass (2008) describes the characteristics of complicated systems to operate on cause-effect relationships. They can be well-understood as a whole and can be disassembled into its parts. Understanding of the parts allows understanding of the whole system. But, complicated systems can fail as a result of a single small problem “since complicated systems do not adapt” (Hass, 2008:20). Complicated systems therefore seem similar to the divisional type of problem as indicated in Figure 2-2(a). Importantly, Whitty and Maylor (2007) stress that when this complicated system is immersed in a social environment, the overall system becomes complex.

2.4.3 Complex Systems

Cooke-Davies et al. (2011:2) explain what a complex system is by referring to the Latin meaning of the word as “woven together” and that one part of the system has an influence on another part. He states that if this “woven togetherness” (p. 2) can result in changes in the individual elements that is not predictable, and this unpredictable behaviour can lead to further changes in the other elements. A summary of the attributes of complex systems is shown in Figure 2-3.

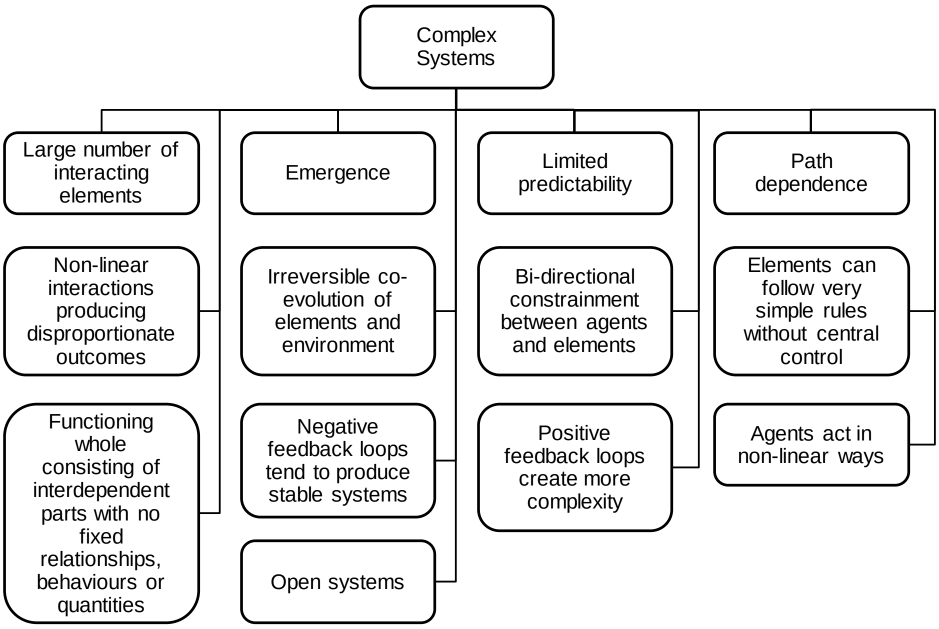

Figure 2-3: Summary of Attributes of Complex Systems Based on Lucas (2006); Snowden and Boone (2007) and Vasileiadou and Safarzyńska (2010)

Definitions of complexity, a complex system and complexity theory are given by researchers in Table 2-2.

Table 2-2: Definitions of Complexity, a Complex System and Complexity Theory

No.	Definition Type	Description	Reference
1	Definition of Complexity	"Complexity, very generally, is a result of interrelationships and feedback between increasing numbers of areas of uncertainty of ambiguity… It is this ambiguity (uncertainty) between different interconnected aspects (areas) of a project which creates the perception of complexity"	Remington and Pollack (2007:20)
		"a simple deterministic model, under certain conditions, was able to generate behaviours as complex as those observed in nature… Simplicity and determinism could, therefore, lead to complexity"	Thietart and Forgues (1995:20)
2	Definition of a Complex System	"Complex systems typically have a large number of small parts or components that interact with similar nearby parts and components. These local interactions often lead to the system organizing itself without any master control or external agent being 'in charge'. Such systems are often referred to as being self-organizing. These self-organized systems are also dynamic systems under constant change, and short of death or destruction, they do not settle into a final stable 'equilibrium' state"	Galanter (2003:5 of 21)
		"Complex systems consist of a large number of elements, or individual components, which can follow very simple rules, with no centralized control. These elements, often referred to as agents (e.g. firms,	Vasileiadou and Safarzyńska (2010:1179)

No.	Definition Type	Description	Reference
		consumers, institutions etc.), interact in non-linear ways. Non-linearity implies that changing conditions underlying communication and exchange between individual agents renders not proportional, difficult to foresee, changes in outcomes of such interactions"	
3	Definition of Complexity Theory	"Complexity theory states that critically interacting components *self-organize* to form potentially evolving structures exhibiting a hierarchy of emergent system properties"	Lucas (2006:1 of 8)

2.4.4 Complex Adaptive Systems

Many researchers employ complex adaptive systems (CAS) as a theoretical foundation when studying healthcare systems (Begun et al., 2003), transition of current systems towards sustainable systems (Vasileiadou and Safarzyńska, 2010) and complex projects (Remington and Pollack, 2007). These types of systems are 'adaptive' as they have the "capacity to change and learn from experience" (Hass, 2008:23) and are able to survive as they "maintain coherence in relation to the environment" (Remington and Pollack, 2007:6). A summary of attributes of CAS is shown in Figure 2-4.

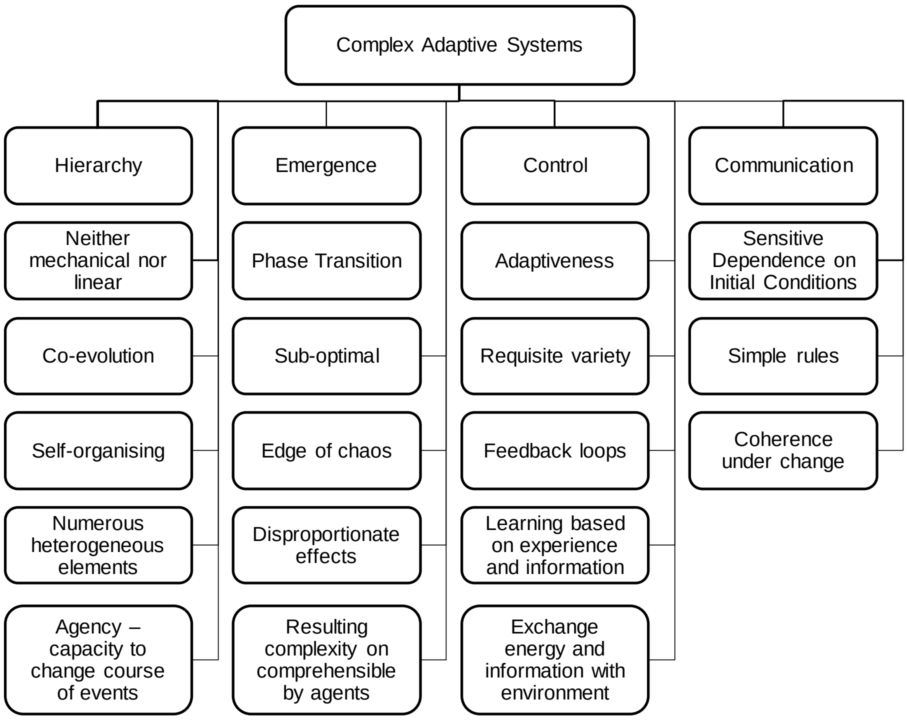

Figure 2-4: Summary of Attributes of Complex Adaptive Systems Based on Remington and Pollack (2007); Hass (2008); Cooke-Davies et al. (2011) and (Kuhmonen, 2017)

Remington and Pollack (2007) noted that CAS have the characteristics of all systems, but it is their additional attributes such as agency and sensitive dependence on initial conditions that make them difficult to understand and manage. Definitions for CAS are given in Table 2-3 and it is noteworthy that Kuhmonen (2017:218) states that "*attractors are the most stable and robust elements of complex adaptive systems*".

Table 2-3: Definitions for Complex Adaptive Systems

No.	Definition Type	Description	Reference
1	Definition of a Complex Adaptive System	"These self-organized systems are also dynamic systems under constant change, and short of death or destruction, they do not settle into a final stable 'equilibrium' state. To the extent these systems react to changes in their environment so as to maintain their integrity, they are known as complex adaptive systems"	Galanter (2003:5 of 21)
		Complex Adaptive Systems (CAS) "have agency, which energises and directs their emergence and evolution and distinguishes them from 'just' complex systems… [they] unfold and self-organise without central command on the basis of non-linear and mostly local interactions among their heterogeneous elements… attractors are the most stable and robust elements of complex adaptive systems… *They do not end up in chaos or randomness, but organise themselves around various attractors*"	Kuhmonen (2017:215, 218)

2.4.5 Chaotic "Systems"

Lorenz (1995) is recognised by researchers for his contribution to chaos theory for his discovery that the atmosphere never reaches a state of equilibrium and is therefore always in a state of chaos. He showed that atmospheric disturbances were drawn to areas known as attractors in the form of a 'Butterfly' (hence the Butterfly effect). Lorenz referred to the work by Prigogine and Stengers and concluded that that there existed indeed "order out of chaos" as referenced by them. Lorenz (1995:4) applied chaos theory to processes such as the tumbling of a rock down a mountainside and the breaking of waves on a shore as "variations [that] are not random but look random" and whose "behaviour is in fact determined by precise laws". Radu et al. (2014b:1550) applied chaos theory to the field of management to deal with the "complex harmonies and disharmonies in social and natural systems". Eoyang and Olson (2001:3) applied the metaphorical concept of strange chaos attractors to human system behaviour for cases when the "system is bounded, includes infinite freedom within the bounds, and generates coherent patterns over time". A summary of attributes of chaotic systems is given in Figure 2-5.

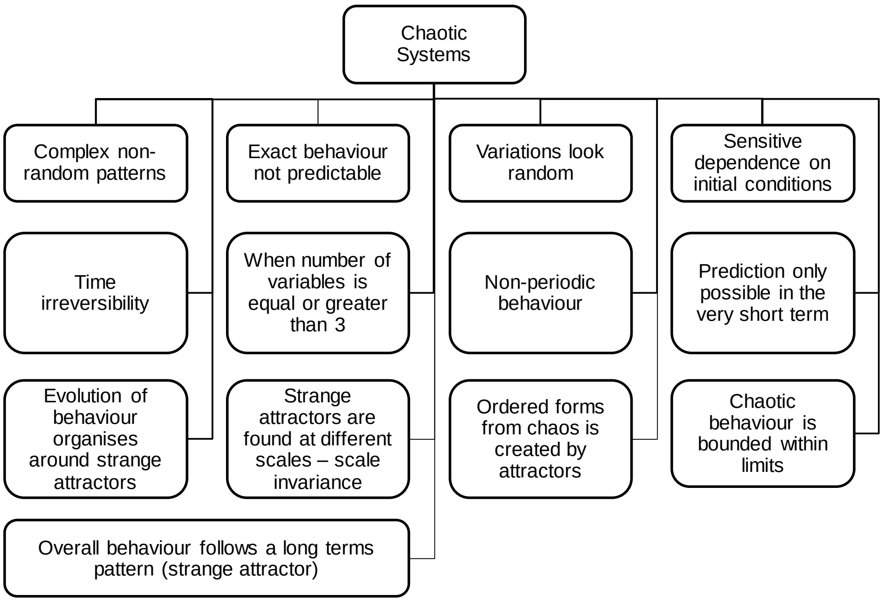

Figure 2-5: A Summary of Attributes of Chaotic Systems Based on Lorenz (1995); Thietart and Forgues (1995) and (Bums, 2002)

Definitions of chaos, chaotic systems and chaos theory by various researchers are given in Table 2-4.

Table 2-4: Definition of Chaos, a Chaotic System and Chaos Theory

No.	Definition Type	Description	Reference
1	Definition of Chaos	"behaviour that is deterministic, or is nearly so if it occurs in a tangible system that possesses a slight amount of randomness, but it does look deterministic"	Lorenz (1995:8)
		"system behaviour which is apparently random even though it is driven by deterministic rules"	Thietart and Forgues (1995:20)
2	Definition of a Chaotic System	With reference to information theory: "A truly random stream of characters is maximally disordered and has no underlying structure. Thus, there are no patterns and redundancy to take advantage of, and no compression is possible"	Galanter (2003:8 of 21)
3	Definition of Chaos Theory	"Chaos theory is an explanation of the behaviour of a system that can be described by nonlinear equations where the output of one calculation is taken as the input of the next. After multiple iterations the calculation takes on the characteristics of non-linearity and becomes specifically unpredictable while all the time remaining in a determined pattern. The chaotic patterns that emerge seem to be bound by the influence of a 'strange' attractor. The behaviour within the system is a paradox in that it defies specific long-term prediction while at the same time demonstrating consistent long-term pattern of organization"	Bums (2002:44)

No.	Definition Type	Description	Reference
		"despite its name, chaos theory considers the tendency toward order a natural phenomenon produced by the action of four types of attractors: point attractors, cycle attractors, torus attractors and strange attractors"	Gharajedaghi (2011:57)
		"Chaos theory is a set of ideas about the transformation from order to disorder and about the birth of order out of disorder applied in nonlinear system dynamics. Although a system displaying nonlinear behaviour may seem random over time, the studies of chaotic regimes have demonstrated the existing of patterns"	Radu et al. (2014b:1550)
		"Chaos theory is the qualitative study of unstable, aperiodic behaviour in deterministic nonlinear dynamical systems"	Radu et al. (2014a:1544)

2.4.6 Random "Systems"

Lorenz (1995:5) explains that real-world "tangible physical systems generally possess at least a small amount of true randomness". He defined randomness as "the absence of determinism" (p. 7) and a random sequence of events as "one in which anything that can ever happen can happen next" (p. 6). This is in contrast to a deterministic (and chaotic) sequence where "only one thing can happen next; that is, its evolution is governed by precise laws" (p. 7). Bums (2002:44) confirms that randomness is not the same as chaos as "randomness exists outside the pale of chaotic system behaviour" – chaos instead yields complex patterns.

2.4.7 Summary of Definitions for Ordered, Complicated, Complex, Chaotic and Random Systems

Based on the literature survey done in paragraph 2.4 the following conclusions can be made on the differences between for ordered, complicated, complex, chaotic and random systems:

a) Ordered and Simple Systems

Ordered system have fixed structures with fixed relationships between their elements, are in equilibrium, have clear cause-effect relationships between elements and a single right answer can be obtained by simple analysis (Remington and Pollack, 2007; Snowden and Boone, 2007; Thietart and Forgues, 2011).

b) Complicated Systems

An example of a complicated physical system is, for example, an aircraft engine that can be decomposed into its individual parts and then reassembled from its individual parts to give the same required performance. Complicated systems cannot adapt to environmental changes and the moment this complicated system is immersed in a social environment, the overall system becomes complex (Whitty and Maylor, 2007; Hass, 2008; Cooke-Davies et al., 2011).

c) Complex Systems

A complex system contains a large number of elements that are woven together, and one part influences the other via positive and negative feedback loops in a non-linear manner which results in disproportionate outcomes and emergent irreversible behaviour with limited predictability (Lucas, 2006; Snowden and Boone, 2007; Vasileiadou and Safarzyńska, 2010; Cooke-Davies et al., 2011).

d) Complex Adaptive Systems

In addition to the characteristics of complex systems, complex adaptive systems have the capacity to change, are adaptive, are able to learn from experience, could self-organise to maintain coherence and chaos attractors are the most stable and robust elements determining the behaviour of these systems (Remington and Pollack, 2007; Hass, 2008; Cooke-Davies et al., 2011; Kuhmonen, 2017).

e) Chaotic Systems

The behaviour of chaotic systems looks random but they have irreversible complex non-random patterns that cannot be predicted exactly, the behaviour is sensitive to initial conditions but bounded within limits and order can be produced from chaos by chaos attractors (Lorenz, 1995; Thietart and Forgues, 1995; Eoyang and Olson, 2001; Bums, 2002).

f) Random Systems

A random system does not produce patterns and is not predictable, determinism is absent and anything that can ever happen, could happen next (Lorenz, 1995; Bums, 2002).

2.5 The Randomness-Chaos-Complexity-Order Continuum

This paragraph will summarise descriptions by researchers for different system domains. All the literature findings will then be collated in a single continuum ranging from randomness to order with domain and sub-domain descriptions.

2.5.1 Continuum from Anarchy to Simpleness for Organisational Decision Making

Stacey (1996b) proposed a conceptual framework to aid managers to select appropriate management tools according to the state of complexity of their environment. He suggested a two-dimenstional agreement-certainty map with different complexity zones. Zimmermann (2001) produced a simplified matrix based on Stacey's work as shown in Figure 2-6.

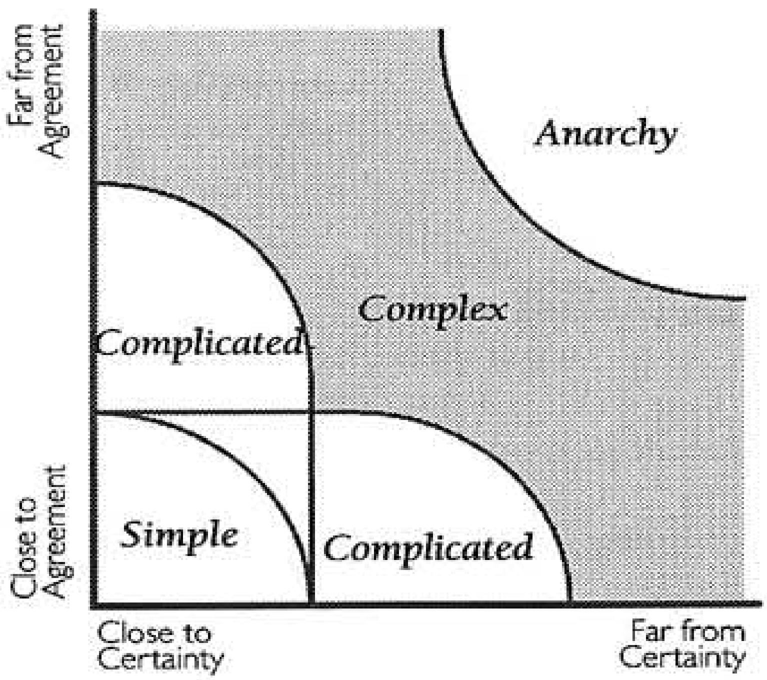

Figure 2-6: The Stacey Matrix Showing a Continuum from Anarchy to Simpleness to Aid Managerial Decision Making and Control (Zimmermann, 2001:6 of 10, No Figure Number)

Stacey refers to "simple" situations where managers are close to agreement and certainty (regularity, predictability and stability) and where standard tools and techniques of management could be used. In the two "complicated" zones, as shown in Figure 2-6, different management approaches should be used. When close to certainty but intermediately far to agreement – political decision making should be employed. Similarly, when close to agreement but where intermediate certainty exists – judgemental decision making should be used. The region of 'anarchy' exists when managers are far from agreement and far from certainty. Stacey recommends that organisations should avoid this situation as much as possible. The region between anarchy (disorder) and the two complicated regions (order) is called "the zone of complexity" where "paradoxical dynamic of regularity and irregularity, predictability and unpredictability [exist] at the same time" (Stacey, 2012:1 of 2). He states that the standard tools and techniques for management cannot be used in the complexity zone. Stacey stated that this type of contingency approach requires managers to be able to accurately, rationally and instrumentally detect in which zone they are and then apply the appropriate managerial tool. This ability of zone identification by managers was questioned by him in his subsequent research. In his research since 2000, Stacey changed from thinking of organisations as systems to organisations as patterns of relationships and coined the term “a complex responsive processes of interaction” (Stacey, 2012:2 of 2). Stacey’s matrix therefore identified zones of increased order along a continuum categorised as anarchy, complex, complicated and simple.

2.5.2 Continuum from Randomness to Stability for Organisations

Bums (2002) developed his model of the chaotic organisational environment as shown in Figure 2-7 based on the ideas portrayed by (Stacey, 1996a). He states that: “Stacey's zone of phase transition can actually be described as a middle zone between a zone of stability leading eventually to ossification and a zone of randomness, or complete anarchy and disintegration” (Bums, 2002:45).

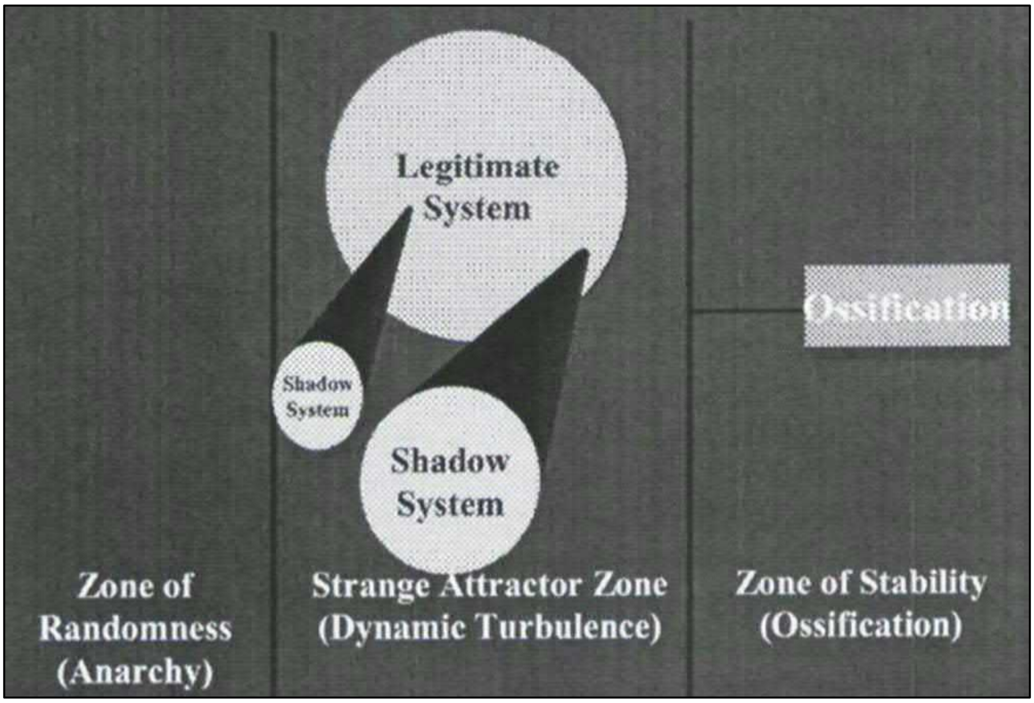

Figure 2-7: Model for Different Zones in an Organisational Environment (Bums, 2002:47, No Figure Number)

The zone of randomness or anarchy is where the environmental demands on the legitimate system of the organisation is too extreme and could cause the organisation to “explode into anarchy and the complete random behaviour of its agents” (Bums, 2002:48). This could happen to organisations that are obsessed with meaningless addiction to novelty or that allows freedom to radical individuals to steer the organisation away from its purpose and core values.

The strange attractor zone or chaotic zone is characterised by dynamic turbulence. This is where a healthy organisation functions and self-organises “in and around a strange attractor” represented by its core values in an ‘orbit’ of behaviour to fulfil its primary purpose (Bums, 2002:45). Bums states that “as long as the organization remains bound to its ultimate purpose and values (the strange attractor) it will discover successful ways to adapt to the demands of the environment and will fly neither into zone of randomness nor be sucked into the zone of stability” (Bums, 2002:45). Closer to the zone of randomness is where the organisation is creative and experiments with novel combinations of schema that are imported from shadow systems. Shadow systems are potential new ways an organisation could be configured to and function in a changing dynamic environment. The strange attractor zone is where the single and double loop learning takes place in an organisation. Single loop learning is when individual members adjust their individual behaviour in order to optimise its performance relative to other members. Double loop learning is when the individual members adjust their individual behaviour in order to optimise their performance relative to other members as well as against changes in the surrounding environment.

The zone of stability (ossification) is where the organisation is completely isolated from the environment and where only single loop learning takes place. This is also the zone where organisations stagnate, becomes unable to survive in a changing environment, settles around a fixed-point attractor and dies, according to Bums. Lastly, Bums (2002:50) states that in his understanding "chaos theory teaches that long-term success is not ensured by the plan, but by sticking to the purpose and core values of the organization”. The aim is therefore to manage an organisation to remain in the zone of the strange attractor and avoid either the zone of randomness (far left) or the zone of stability (far right). Bum’s model therefore identified 3 zones along the continuum from disorder to order as randomness, dynamic turbulence and stability.

2.5.3 Continuum from Chaos to Simpleness for Organisations

Snowden (2010b) developed a circular continuum framework that was initially based on a knowledge management framework. His framework incorporates complexity theory and the principles of catastrophe theory (shown as cusps between the domains) to represent five states of systems of the same system as shown in Figure 2-8. The system states increase in complexity from simple, to complicated, to complex, to chaotic and a disordered state is located in the centre of the model. This framework is known as the “Cynefin” framework (Snowden and Boone, 2007:2). The name stems from the Welsh word that refers to a multitude of factors in the environment and the human experiences that can never be fully understood (Snowden and Boone, 2007).

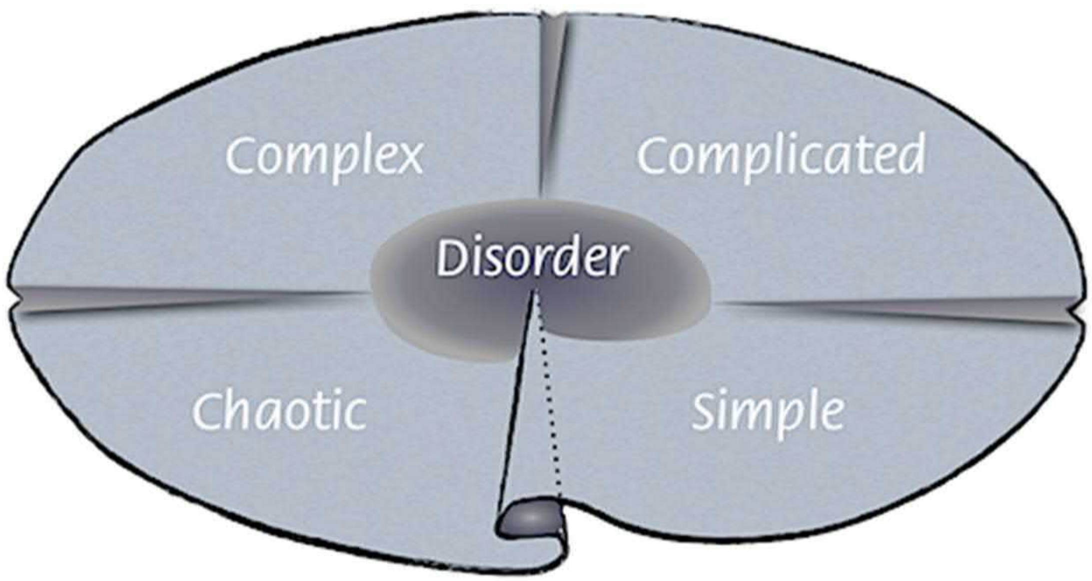

Figure 2-8: Cynefin Framework Showing Domains which Characterise the Current State of an Organisation (Snowden, 2010b:1 of 2, No Figure Number))

The system states or domains in the Cynefin framework are configured in a circular manner as it originates from the social learning cycle as explained by Boisot and Cox (1999). An organisation could transverse from a chaotic domain, to a complex domain and then to the complicated and simple domains. The 5th disorder domain is located in the centre of the model and represents the condition when there is uncertainty about which of the other domains are dominant (Snowden, 2010a). It should be noted that the chaotic (disorder) domain lies next to the simple (order) domain and is separated by a cusp similar to the cusps described in catastrophe theory (Thom, 1975). Snowden and Boone (2007) explain that when complacency in the ordered organisational domain together with a sudden change in the organisation environment occurs, perhaps due to disruptive technologies, this could lead to a sudden shift of the whole organisation from the ordered domain to the chaotic domain with the probable outcome of a catastrophic failure. The typical characteristics and a suitable management approach for each of the Cynefin domains as described by Snowden, are shown in Table 2-5. Interestingly, Snowden provides no suggested management approach for the Disorder domain.

Table 2-5: Characteristics for Each of the Cynefin Framework Domains and a Suggested Management Approach per Domain (Snowden and Boone, 2007)

No.	Characteristic	Disorder	Chaotic	Complex	Complica-ted	Simple
1	Domain Type	• No Description	• Pattern-Based Management Domains		• Fact-Based Management Domains	
2	Knowledge Category	• No Description	•Unknowable	• Unknown - Unknowns	• Known-Unknowns	• Known-Knowns
3	Solution	• No Description	• No answer	• No right answer	• Many right ideas	• One right idea
4	Linearity	• No Description	• Cannot determine cause-effect due to high turbulence	• Whole is more than the sum of the parts • Flux and unpredictability	• Not clear cause-effect to everyone	• Stability • Clear cause-effect
5	Management response	• No Description	• Act, sense, respond	• Probe, sense, respond	• Sense, analyse and respond.	• Sense, categorize, and respond
6	Solution response	• No Description	• Manage crises and innovate in parallel • Stabilise	• Experiment to allow patterns to emerge • Need for creative and innovative approaches	• Investigate options and apply good practice	• Best practice and process engineering

Snowden and Boone (2007) describe the simple domain as part of the fact-based domain in which the environment is stable with clear cause-effect relationships and all issues and appropriate responses are known (known-known). The suggested management response for this domain is to sense, categorise and then respond, usually with applying the appropriate best practice (which is past practice) as well as process engineering principles.

The complicated domain also belongs to the fact-based type of domain but here the cause-effect relationships between system elements are not clear to everyone and specific risk or issues are known but are not yet manifested in the system (known-unknowns). The appropriate management approach is suggested by Snowden as 'sense-analyse-respond' with emphasis to use the services of experts that needs to analyse the context, identify options, evaluate options, choose an appropriate option and apply good practice. It is believed that at least one right answer exists for the complicated domain.

The complex domain is based on pattern-based management principles as the elements and their behaviours are in a flux. Emergence appears as a new property of the organisational system that is not displayed by the individual parts and therefore the whole is more than the sum of its parts. Due to the flux and unpredictability of this domain, there is no right answer as a solution to problems and it is not possible to identify risks but there are many uncertainties (unknown-unknowns). The suggested management response would be to experiment (and sometimes fail) and thus probe, sense the system behaviour and then respond with innovative and creative approaches.

The chaotic domain is the most difficult to manage as it is in constant high flux with high turbulence according to Snowden and Boone (2007). No cause-effect relationships exist, and the management approach is suggested by Snowden to act immediately, sense the outcome and only then respond based on learning. A high degree of innovation is required in this environment. Snowden and Boone (2007) provide very limited information on their characterisation of the disordered domain except to mention that this is the domain for a system where there is not a clear dominant system state present. The Cynefin framework therefore identifies organisational system domains that range from disorder to order as disorder, chaotic, complex, complicated and simple.

2.5.4 Continuum from Chaos to Order for Projects

Remington and Pollack (2007) discussed four types of complexity that may occur in projects as structural, technical, directional and temporal complexity. They view projects as systems and specifically as complex adaptive systems (CAS) and state that “all complex systems exist somewhere between order and chaos” (p. 9). A summary of the change in system characteristics such as adaptability, rules, relationships, efficiency, equilibrium and prediction across the chaos-complexity-order continuum, as described by Remington and Pollack, is shown in Figure 2-9.

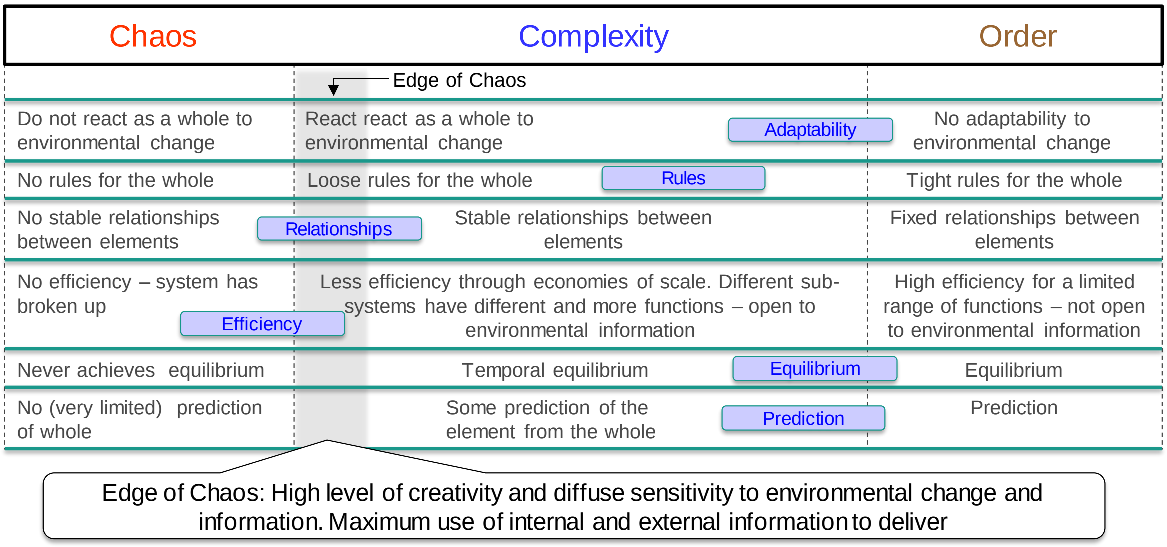

Figure 2-9: Summary of the Characteristics of the Chaos-Complexity-Order Continuum for Complex Adaptive Systems such as Projects. Based on Remington and Pollack (2007:9-11)

Systems and projects in the chaotic domain do not, as a whole, react to environmental changes, have no rules, have no stable relationships between the elements, has no efficiency as it has broken up, never achieves equilibrium and have limited or no prediction of the overall behaviour. Chaotic systems therefore lack “internal coherence” (Remington and Pollack, 2007:9).

Systems and projects in the complexity domain react as a whole to environmental changes, have loose rules, stable relationships between the elements, have less efficiency, achieve temporal equilibrium and some form of prediction of the behaviour of the whole is possible. They also refer to the “edge of chaos” (p. 11) zone as part of the complicated domain. This zone is located at the end of the complexity domain and next to the chaotic domain. This is the zone where a system is able to engage with the inputs of a changing environment and internalise some of these learnings as the system structure is partly flexible. But, if management loses the coherence of this type of system, it can quickly move towards the left of this continuum and plunge into chaos.

Systems and projects in the ordered domain cannot adapt to environmental change, have tight rules for the whole, have fixed relationships between the elements, achieve a high efficiency for a limited range of functions, is in equilibrium and their behaviour can be predicted. Remington and Pollack (2007) state that it is very difficult for ordered systems to adapt to environmental changes due to the tight configuration between the system elements. In contrast, complex systems are able to react to environmental changes while chaotic systems are not able to react as a whole to environmental changes. Remington and Pollack (2007) therefore describe a ‘chaos-complexity-order’ continuum that is applicable to projects when they are viewed as complex adaptive systems (CAS).

2.5.5 Continuum from Disorder to Order

Generative art is defined by Galanter (2003:4 of 21) as “any art practice where the artist uses a system, such as a set of natural language rules, a computer program, a machine, or other procedural invention, which is set into motion with some degree of autonomy contributing to or resulting in a completed work of art”. Examples of generative art that is created by a system are electronic music created by an algorithm, computer graphics and animation, industrial design and architecture using Computer Aided Design (CAD) algorithms. Phillip Galanter (Galanter, 2014; Galanter, 2003) developed his definition of generative art by considering complexity theory as well as the organising principles of disorder, effective complexity and order. He noted that systems exist on a spectrum ranging from highly disordered to highly ordered. Complexity, that exists between these two extremes, “exhibit both order and disorder” (Galanter, 2003:1 of 21). He reasoned that music that is produced as highly ordered music (playing the same note over and over again) or highly disordered music (playing random notes) is of no “intrinsic aesthetic interest” (Galanter, 2003:8 of 21) . In comparison, music that is generated to contain both elements of order and disorder have a high effective complexity and intrinsic aesthetic value. Galanter portrayed his understanding of the disorder-order continuum for generative art as shown in Figure 2-10.

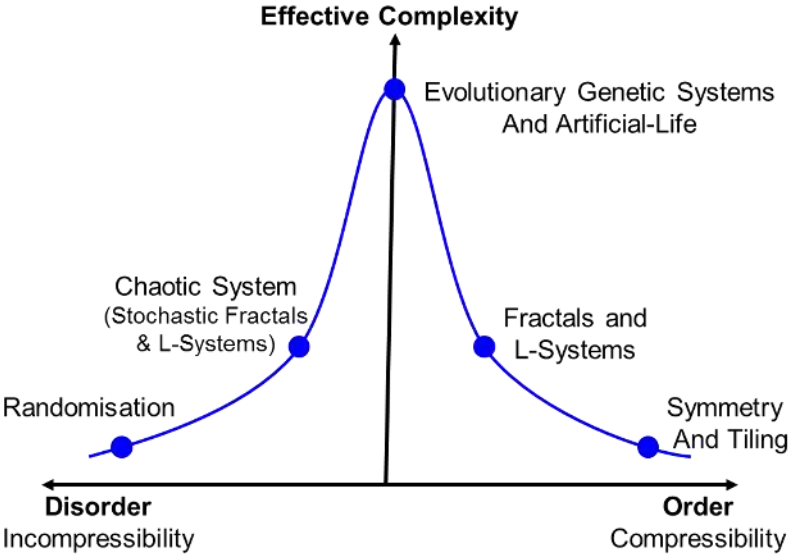

Figure 2-10: Continuum from Disorder to Order for Generative Art Systems. Reproduced from Galanter (2014)

Galanter (2014) states that the information contained in a disordered and random domain is incompressible as there are no repeating patterns or structure. On the other hand, the information contained in the ordered domain are highly compressible due to symmetry, tiling and repeatable patterns. Galanter explained that random systems do not have any sense of history while a chaotic system has. Patterns, structure and form can be created by chaotic systems based on a few simple rules and principles using stochastic (random) fractals and Lindenmayer Systems (L-Systems). This principle is confirmed by Prusinkiewicz et al. (1995) who demonstrated that by sampling from a stochastic source and using parametric algorithms for trees as L-Systems, that it is possible to generate trees and plant growth cycles that resemble real world equivalents. Galanter (2014:2 of 10) states that "life itself combine order and disorder" and therefore biological life has the highest effective complexity. Similarly, by combining order and disorder, he states, is the highest level of effective complexity reached for regenerative art. Fractals and L-Systems (without stochastic or random input) are forms and patterns that are the building blocks for ordered systems such as the Koch snowflake that is composed of the repeated triangle form (Prusinkiewicz et al., 1995). The most ordered systems are composed of symmetrical and tiled forms. Galanter therefore identified a disorder-complexity-order continuum for regenerative art.

2.5.6 Research Literature on the Randomness-Chaos-Complexity-Order Continuum

Researchers such as Lorenz (1995); Lucas (2006); Snowden and Boone (2007); Snowden (2010b) further divided the domains for randomness, chaos and complexity and defined sub-domains as shown in Appendix B, paragraph B1. Only short descriptions of these sub-domains were made. Further literature surveys could be done to better understand these individual sub-domains and their potential interaction with other sub-domains. Such work does not form part of this research.

A summary of all the information obtained during the literature survey on continuums and continuum elements is given in Appendix B, Table B-1 as the Randomness-Chaos-Complexity-Order continuum framework. A simplified sketch of this continuum is given in Figure 2-11 based on a similar sketch by Hass (2008).

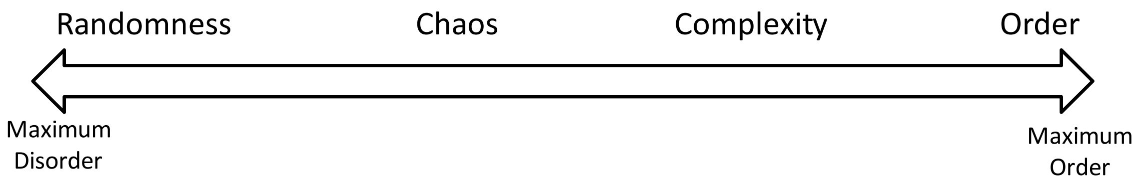

Figure 2-11: The Randomness-Chaos-Complexity-Order Continuum Representing Domains of a System or Project Ranging from Maximum Disorder to Maximum Order

2.5.7 Simultaneous Co-Existence of Multiple Continuum States

Kurtz and Snowden (2003:466) state that it is "useful to artificially separate order and un-order so that we can understand the different dynamics involved" when analysing system behaviour in a specific context. They continue to indicate that, reality ensures that "things are both ordered and un-ordered at once" (p. 466).

Care should be taken not to default to Newtonian reductionism and simplification where a complex system is broken up into elements and where the assumption is made that the understanding of an element equates to the understanding of the whole, as this can lead to blinding scientists to the real life processes (Bums, 2002:43). Remington and Pollack (2007) refer to an example of an organisational change project for a telecommunication company in which they point out that the different types of complexity (i.e. structural, technical, directional and temporal) are experienced by different parts of the organisation and needed a different management approach. According to Remington and Pollack (2007:2) a single complex project may display various kinds of "systemicity" as some parts may behave orderly and other parts chaotic and therefore requires a "pluralistic" management approach.

It therefore seems that a system, an organisation or a project (when viewed as a CAS) as a whole could find itself in any of the continuum domains, or that any of its parts of divisions may find themselves in different continuum domains at any point in time. A simultaneous co-existence of multiple continuum states therefore seems possible for a single complex system such as a capital project.

2.5.8 Summary on the Randomness-Chaos-Complexity-Order Continuum

The following summary could be done based on the literature review on continuums:

a) Types of Continuums

The following types of continuums were identified:

i. Anarchy-Complex-Complicated-Simple continuum for decision making that is known as the Stacey Matrix (Zimmermann, 2001)
ii. Randomness-Strange-Attractor-Stability continuum for organisational behaviour (Bums, 2002)
iii. Disorder-Chaotic-Complex-Complicated-Simple continuum for organisational behaviour (Snowden, 2010b)
iv. Chaos-Complexity-Order continuum for projects seen as CAS (Remington and Pollack, 2007)
v. Randomisation-Chaos-Complexity-Fractals-Symmetry for generative art (Galanter, 2003; Galanter, 2014).

b) Additional Continuum Sub-Domains

The following additional continuum sub-domains were identified:

i. Sub-domains for completely random and not deterministic for the randomness domain (Lorenz, 1995)
ii. Sub-domains of full chaos and limited chaos for the chaos domain (Lorenz, 1995)
iii. Sub-domains of self-organising complexity, evolving complexity, dynamic complexity and static complexity for the complexity domain (Lucas, 2006)

iv. Sub-domains of complicated and simple for the order domain (Snowden and Boone, 2007; Snowden, 2010b).

c) The Randomness-Chaos-Complexity-Order Continuum
A summary of the contributions of various researchers was done for the Randomness-Chaos-Complexity-Order Continuum domains that could represent the current state of a system or project (Figure 2-11).

d) Simultaneous Co-Existence of Continuum States in a Single System
It seems possible for a parts of the same system (or project) to reside in different domains and any point in time (Remington and Pollack, 2007).

2.6 Chaos Attractors

The objective of this paragraph is to summarise and conclude on the literature on chaos attractors. General definitions, visualisation techniques and a description of the four prominent attractors are given. This is followed by attractor categorisation, examples and attributes for the different attractors. It is shown that it is possible to quantify attractors, with examples from time-based data in the services industry and the use of attractors in various management sciences. A view is given of attractor landscapes and reference is made to the harmonious resonance theorem for attractors. It is shown that attractors could be found at different levels in systems and system domains and that it seems possible to design and create attractors. After recording the disadvantages of attractors, an attempt is made to summarise and conclude on the literature surveyed on attractors.

2.6.1 Definitions for Attractors or Chaos Attractors

Different terminology is used for attractors or chaos attractors. Most of the literature surveyed for this research refers to “attractors” while Dolan et al. (2000) use the term “attractors of chaos” and the School of Wisdom (No Date) employs the term “chaos attractors”. For the literature survey the original term “attractors” as used by researchers will be used but for the theory and model building in Chapter 3, the term “chaos attractor” will be employed.

Lucas (2004) captures the quest for the understanding of attractors by stating: “In what circumstances [can] order result from the random interactions of multiple agents?” Gilstrap (2005:58) states that attractors "act as magnetic forces that draw complex adaptive systems towards given trajectories". A summary of general definitions of attractors as used by researchers in the complexity sciences is provided in Table 2-6.

Table 2-6: General Definitions of Chaos Attractors

No.	Description	Reference
1	"Attractors are phenomena that arise when small stimuli and probes (whether from leaders or others) resonate with people. As attractors gain momentum, they provide structure and coherence"	Snowden and Boone (2007:6)
2	"An attractor is a state or a reliable pattern of changes (e.g. oscillation between two states) toward which a dynamical system evolves over time, and to which the system returns after it has been perturbed. In a system governed by attractor dynamics, a relatively wide range of starting points (initial states) will eventually converge on a much smaller set of states or on a pattern of change"	Vallacher and Nowak (2007:6)
3	"The constellations in complex adaptive systems tend to accumulate around specific junctures or nodes called attractors… Configurative location in a dynamical system toward which or around which, the system tends to evolve in the state space"	Kuhmonen (2017:215)
4	"An attractor is a set of values in phase space to which a system migrates over time, or about which the system iterates. An attractor can be a single fixed point, a collection of points regularly visited, a loop, a path, a complex orbit, or an infinite number of points. It need not be one- or two-dimensional. Attractors can have as many dimensions as the number of variables that influence its system"	Meade and Rabelo (2004:671)
5	"The term attractor is used because the system's temporal evolution appears to be consistently 'pulled' to identifiable mathematical points. The attractor functions as an abstract representation of the flow or motion of a system. In short, the attractor stores information about a system's temporal behaviour"	Kiel (1993:147)

The main attributes of attractors based on the references in Table 2-6 are summarised as follows:

a) Resonate with people
b) Provision of structure and coherence
c) Reliable pattern of changes towards which a dynamical system evolves
d) System returns to attractor if perturbed (disturbed)
e) Wide range of starting points converge to a small set of attractor states
f) Constellations converge around attractors
g) A set of values towards which a system migrates over time
h) Systems temporal evolution is "pulled" to identifiable mathematical points (attractors)
i) Attractors store information about a systems temporal behaviour.

From the above general definitions, it appears as if attractors could be used within human systems and are able to provide structure and coherence and patterns of dynamical systems. Is also seems that attractors cause attraction toward itself for system elements with different initial starting points and even if perturbed (disturbed) during the attraction process. The question arises if it would be possible to view these attractors and under which circumstances could they become visible.

2.6.2 Visualisation of Attractors and System Behaviour

It will be shown in this section that attractors are difficult to visualise using pure time-based data as their location and system patterns are not easy recognisable. As attractors seem to occur in the multiple domains (refer to Table 2-9) and because systems seem to be moving between ordered and unordered domains (refer to paragraph 2.7), visualisation methods such as 'Phase-Space' and 'Phasegrams' are used to manipulate time-based data into graphs that are able to show the existence of attractors, their progression as well as system trajectories.

2.6.2.1 Attractor Visualisation Using the Phase-Space Method

Phase-Space is a method that is used to "turn numbers into pictures" and "a point in phase space represents the complete state of knowledge about the system at a single instant in time" (Bums, 2002:45). The data of non-linear dynamical systems is generally plotted with changes of variables on the y-axis and time on the x-axis as a time series. If these variables are plotted against each other using the Phase-Space method, the attractor can be visualised as a 'Phase Portrait'. The Phase Portrait (picture in Phase Space) for a simple pendulum is shown in Figure 2-12. The Phase Portrait reveals the cyclic attractor for the simple pendulum using the Phase-Space method.

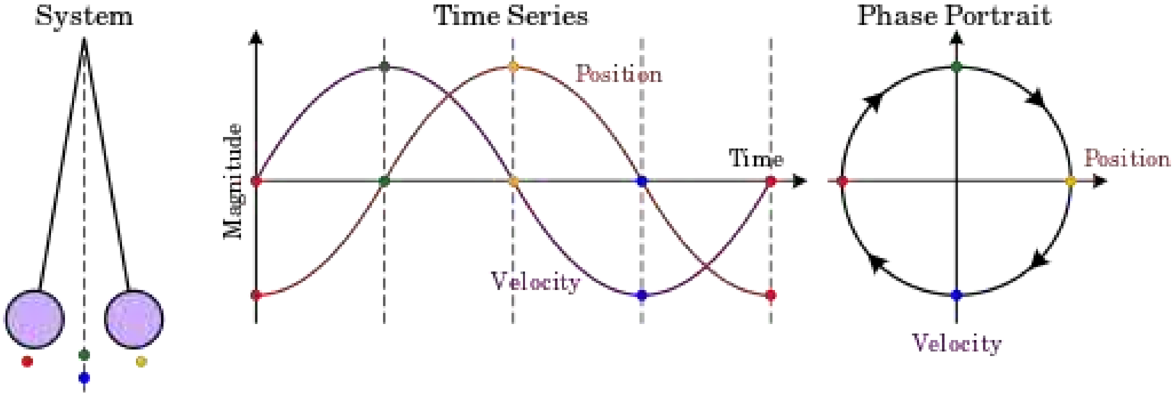

Figure 2-12: Phase-Space Method Applied to Produce a Phase Portrait of a Simple Pendulum (Wikiversity Contributors, 2018:1 of 5, Figure 1a)

Goldstein (2011:5) states that Phase-Space diagrams make it possible to view “ordered patterns” for systems that normally display ”chaos” in the time domain. But, different and new insights into the behaviour of systems may be obtained if the variables are plotted against each other (i.e. variable 1 on the y-axis and variable 2 on the x-axis) and not against time, as time becomes an implicit variable in the so called Phase-Space diagram (Goldstein, 2011). Another advantage of the Phase-Space method is that the system’s long term stable behaviour could become visible once the transient effects have passed as well as the system’s attractors (Goldstein, 2011).

The Phase-Space method could be used to map weather conditions for a specific region in the absence of time i.e. a time-independent “picture” of behaviour is revealed. Ramalingam et al. (2008:38 & 39) states that “although the weather is unpredictable, it remains bounded within a certain ‘space of the possible’”. Summer and winter temperatures of a specific region normally remain within certain values year after year. According to Ramalingam et al. (2008:31) the value of the Phase-Space method is that “it does not seek to establish known relationships between selected variables” but attempts to reveal the overall shape of the system behaviour when looking at patterns across all key dimensions of the system. The Phase-Space method could also be used to gain an understanding of the evolutionary nature of a system as the “points can start to form recognisable patterns… known as attractors” (Ramalingam et al., 2008:33). This viewpoint may be valuable when thinking of capital projects as evolutionary systems.

2.6.2.2 Attractor Visualisation Using the Phasegram Method

The Phasegram method has been published by Herbst et al. (2013) and allows for the visualisation of deterministic, non-linear system trajectories. It also provides a method to visualise attractor evolution as a function of time in a single two-dimensional graph, as shown in Figure 2-13 for the voice recording of a deer. The original sketches are available from Herbst (2013:2-3, Figures 1-3) and labels were added by the researcher. This methodology is described as an "empirically derived bifurcation diagram in time" (Herbst et al., 2013:12 of 14).

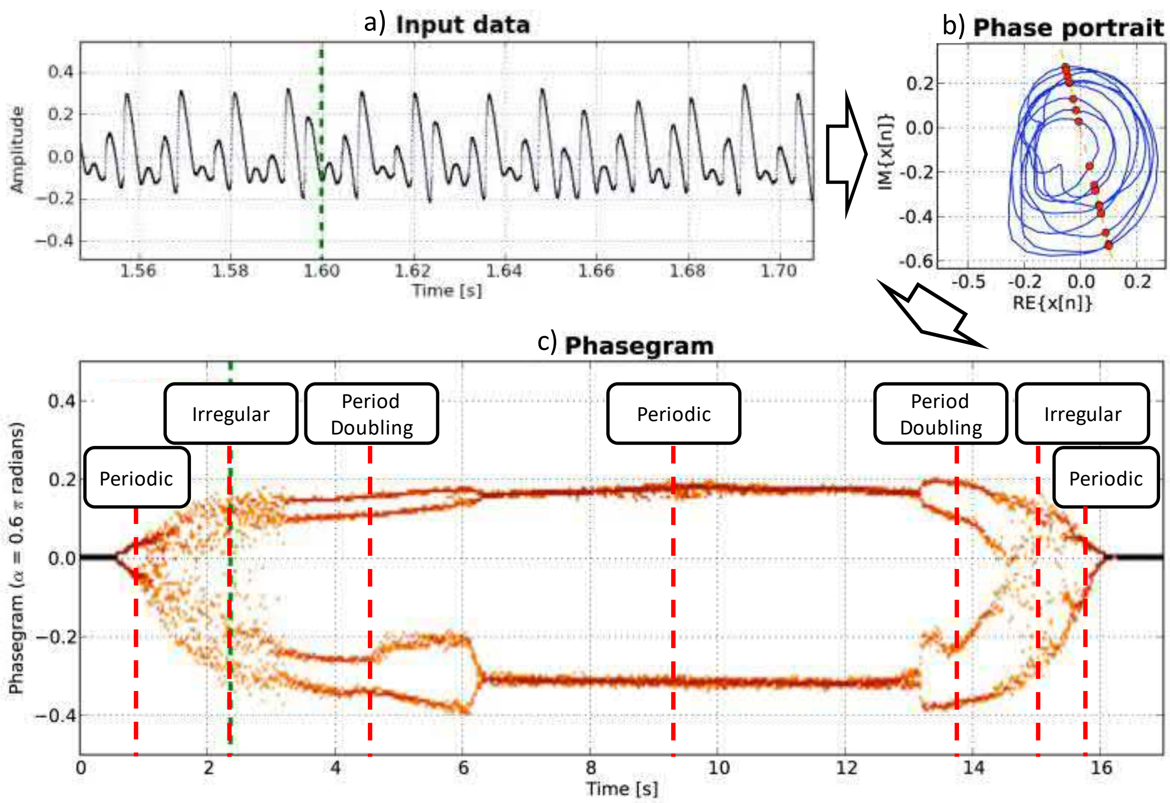

Figure 2-13: Analysis of the Voice Signal of a Deer Showing a) Time-Based Data, b) Attractor in Phase Space and c) Phasegram Showing the Evolution of Attractors as a Function of Time

The time-based signal in Figure 2-13(a) is transformed into the Phase-Space domain as shown in Figure 2-13(b) (showing the cyclic attractor) and then into the Phasegram as shown in Figure 2-13(c). The Phasegram is able to show the evolution of the attractor. The Phasegram shows the signal as it starts (single line) then period doubling followed by the irregular domain (chaos), then moves to the period doubling stage and then into an irregular (chaos) mode followed by periodic mode. The pressure in the voice signal of the deer is increased for the first 9 seconds and thereafter decreases. The authors state that an advantage of the Phasegram method, in comparison with the "traditional" bifurcation map approach (refer to Figure 2-25), is that it requires only the time-base signal data without an understanding of the underlying system parameters. Herbst et al. (2013) note that although the use of this method has been demonstrated for vibratory voice systems to reveal periodic oscillation, subharmonics and chaos, it also has a potential to be used in the fields of physics, biology and medicine.

This raises the questions if the visualisation of oscillating system behaviour and attractors "on the way to chaos" (Herbst, 2013:2) could perhaps, in future, be used to analyse capital project time based data to reveal project behaviour and attractors in a manner that facilitate a "capital project on the way to convergence".

2.6.2.3 Attractor Visualisation Using Rate of Change of the Same Variable in Phase-Space

Meade and Rabelo (2004) provided a method for high tech firms to quantitatively determine and understand their position in the technology adoption life-cycle in their industry using the rate of change of a key variable. The 'industry attractor' is exposed for different products by mapping historical industry data for the rate of change in product market share (y-axis) versus the product market share (x-axis) as shown in Figure 2-14(a-b). Labels were added by the researcher. The authors claim that the position of product in the technology life cycle can be calculated by identifying the inflection point of the rate of change in market share using only two sets of time-based market share data.

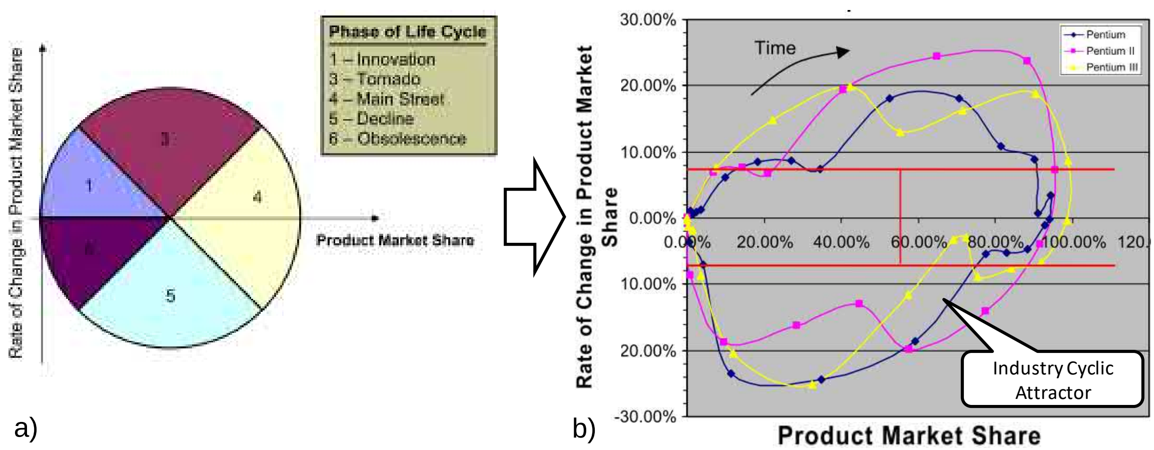

Figure 2-14: Time Based Product Adoption Life Cycle Phases as a) a Function of Product Market Share and b) Phase-Space Map of Industry Attractor for Various Products in the Computer Industry (Meade and Rabelo, 2004:674, 677, Figures 4, 8)

Kiel (1993) was able to identify a cyclic attractor for a service organisation by transforming labour cost data from the time domain in the Phase-Space domain as shown in Figure 2-15(a-b). Labels were added to the Figure by the researcher. He notes that it was possible to employ chaos and complexity theory concepts in this manner to a dynamical organisational context as "people in motion engaged in various activities [processes] for various periods of time represent these dynamics" and that attractors expose the "oscillation and rhythms of organizational work" (Kiel, 1993:151).

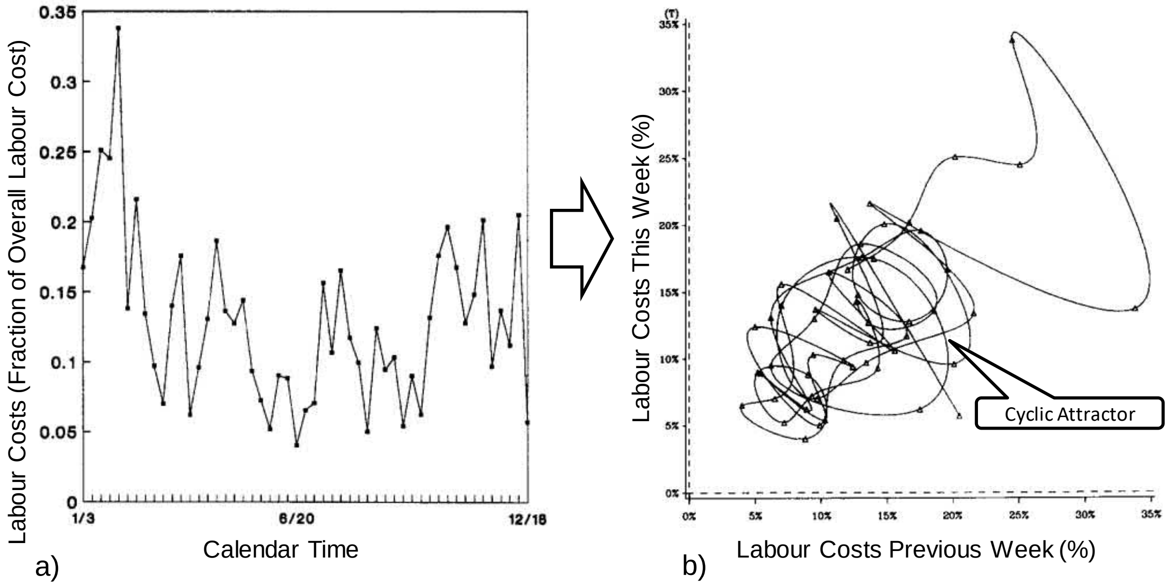

Figure 2-15: Graphical Display of Labour Cost Behaviour when Viewed from a) Time-Based Perspective and b) Phase-Space Perspective with the Associated Cyclic Attractor (Kiel, 1993:147, 148, Figures 2, 3)

Similarly, Green Jr and Twigg (2014:22) used control map data for service requests received by service organisations and transformed these in the Phase Space domain to identify "service request attractors, attractor ranges and out-of-control situations". A stable cyclic attractor, with its centre and boundary for hardware and software installation requests for a services company has been derived from process control chart data using the Phase-Space transformation as shown in Figure 2-16(a-b). The researcher added the attractor boundary and labels to the Figure. By analysing different sets of process control data, they were able to identify three conditions for attractors as: a) a stable system in terms of the attractor and variations; b) an unstable system in terms of both attractor and variations; and c) a moving attractor. Green Jr and Twigg (2014:28) concluded their research by noting that "systems that appear chaotic to participants may in fact have stable attractors and variation".

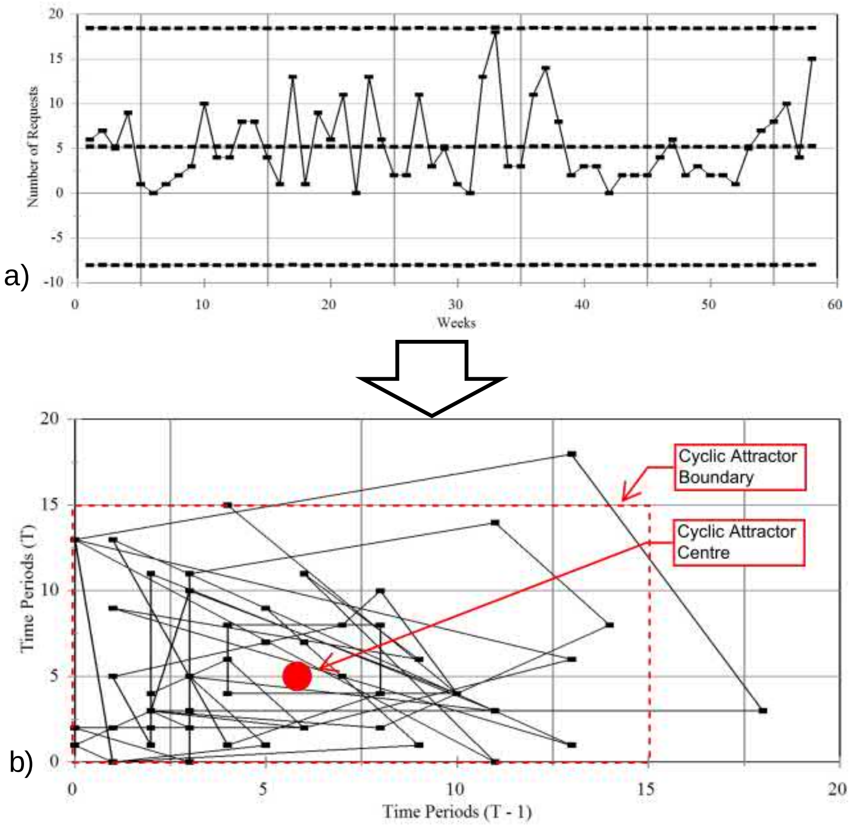

Figure 2-16: Process Control Data (a) Displayed as Time-Based Chart and b) as a Phase-Space Map to Identify the Cyclic Service Attractor, Its Centre and Boundary for Hardware and Software Installation Requests of a Services Firm (Green Jr and Twigg, 2014:26, Figures 5, 6)

The significance of the evidence presented in this paragraph demonstrates the potential to use Phase-Space methods to explore the non-linear and dynamic behaviour in capital project internal and external environments. It seems possible to employ historical project data to identify existing attractors, their positioning in capital projects as well as their behaviour.

2.6.3 Four Prominent Attractors

Attractors seem to come in many forms and shapes. Meade and Rabelo (2004:671) state that "an attractor can be a single fixed point, a collection of points regularly visited, a loop, a path, a complex orbit, or an infinite number of points. It needs not be one- or two-dimensional. Attractors can have as many dimensions as the number of variables that influence its system". This raises the question if some attractors are more important than others. The School of Wisdom (No Date) is of the opinion that the four attractors (point, cycle, torus and strange) are "cosmos attractors" (p. 1) that balance entropy and chaos on both macrocosmic and microcosmic scales and are responsible for the production of order from chaos. They state that a "full understanding of the attractors requires a new understanding of space and time" and that time is not so much defined by the clock but by "intensity and rhythms" (p. 1). Gharajedaghi (2011) confirms this view that *chaos theory is about the production of order from chaos as a natural phenomenon that is brought about by four types of attractors i.e. point attractors, cycle attractors, torus attractors and strange attractors*.

The remainder of this section will describe these four attractors and refer to them as the "prominent attractors".

2.6.3.1 Point attractors

The concept of a point attractor, or as called by Crandall et al. (2013:56) the "pendulum attractor", could perhaps be best explained by examining the behaviour of a pendulum with friction as shown in Figure 2-17(a-c). The sketches were partly obtained from Crutchfield et al. (1986:49) and Gleick (2008:136) and the red arrows were added by the researcher.

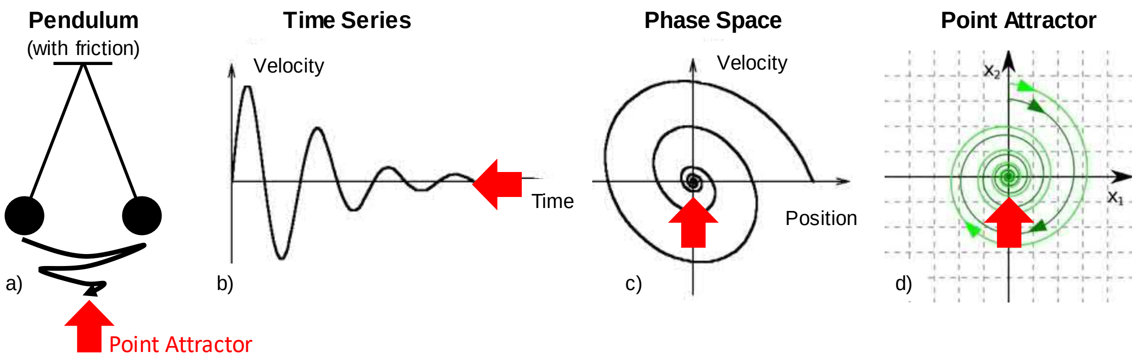

Figure 2-17: Topology of a Point Attractor Represented by a Pendulum with Friction (Crutchfield et al., 1986; Gleick, 2008; Wikipedia Contributors, 2017)

Friction will cause a dissipation of the systems total energy and the pendulum bob will ultimately come to rest at the bottom centre. This point is known as the point of attraction and therefore called a "point attractor" (Gilstrap, 2005:58). The behaviour of the pendulum bob as a function of time could be described by two variables that change continuously, namely velocity (shown in Figure 2-17(a-b)) and position (not shown) (Gleick, 2008). But, when these variables are transformed into the Phase-Space domain (where time is absent) they may be plotted as indicated in Figure 2-17(c) as a spiral that curls inward towards the point of attraction at position 0 and velocity 0. For different initial starting positions of the pendulum bob, different inwards curling trajectories will be traced as indicated in Figure 2-17(d) (Wikipedia Contributors, 2017:10 of 20). Ultimately all these different trajectories are moving towards and end up at the point attractor at position 0 and velocity 0.

2.6.3.2 Limited cycle or periodic attractors

The concept of the limit-cycle or periodic attractors may also be explained by using a pendulum but this time without friction as shown in Figure 2-18(a-c). The sketches were partly obtained from Crutchfield et al. (1986:49), Gleick (2008:136) and (Wikipedia Contributors, 2016) and the red arrows were added by the researcher.

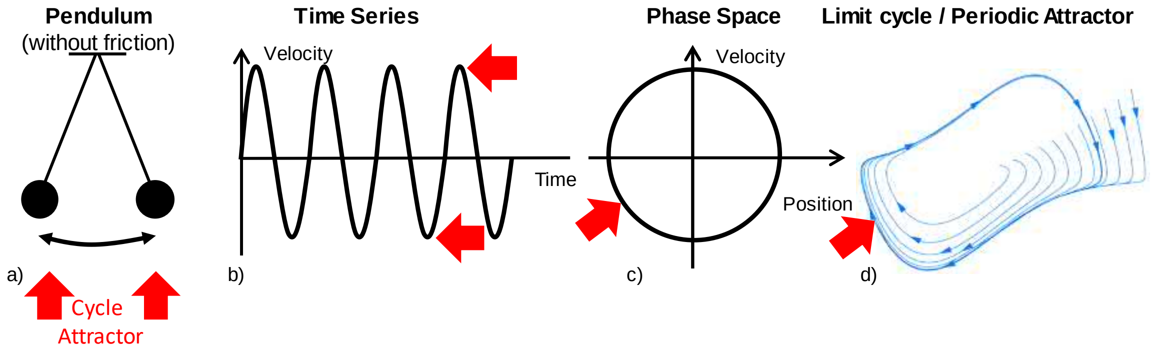

Figure 2-18: Topology of a Limit-Cycle / Periodic Attractor Represented by a Pendulum without Friction (Crutchfield et al., 1986; Gleick, 2008; Wikipedia Contributors, 2016)

The time series behaviour of the pendulum bob will trace a sinusoidal graph with a phase difference between velocity and positions as a function of time (Figure 2-18(b), only velocity is shown). The Phase-Space plot for a certain level of energy of the pendulum is given in Figure 2-18(c) for all possible values of velocity and position. Should the pendulum start at a higher initial position, it will trace another full circle but with a bigger circle diameter. In complex dynamical systems where such limited cycle attractors exist, they serve as attractors for nearby system trajectories as shown in Figure 2-18(d) such as the Van der Pohl oscillator (Wikipedia Contributors, 2016:1 of 3). Where attraction is towards a fixed point for a point attractor (Figure 2-17(d)), the attraction for a limit cycle or periodic attractor is towards an established and repeatable cycle (Figure 2-18(d)).

2.6.3.3 Torus Attractor

The behaviour of a torus attractor could be explained by a swinging pendulum (without friction) of which the base also swings around a fixed point but at a different and much lower frequency as shown in Figure 2-19(a). The sketches were obtained from Rubin (1995) and (Young and Kiel, 1994) and numbering was added by the researcher.

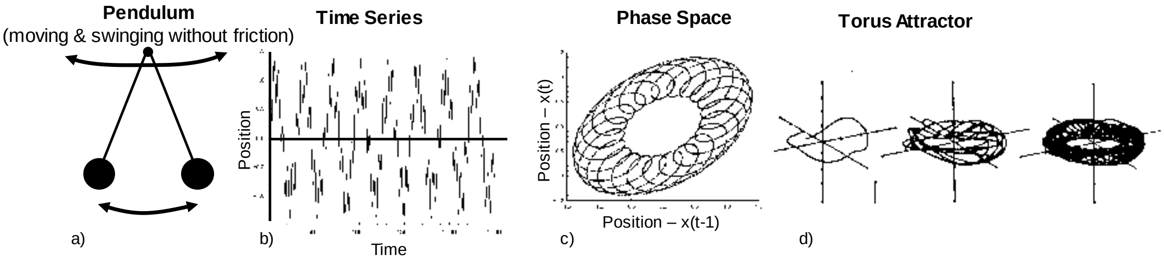

Figure 2-19: Topology of a Torus Attractor (Rubin, 1995; Young and Kiel, 1994)

It is difficult to discern any meaningful pattern from the time-based data of the two superimposed periodic components of the pendulum as shown in Figure 2-19(b) (Rubin, 1995:6, 7 of 7, Figure 5.3). But, as soon as this data is mapped in the Phase-Space domain as shown in Figure 2-19(c) (Rubin, 1995:6, 7 of 7, Figure 5.3) a donut-shaped object appears that is known as the torus attractor. The multiple inner cycles of this attractor are repeated and bounded by the single outer cycle. An example of a real-life torus attractor as shown in Figure 2-19(d) (Young and Kiel, 1994:4 of 20, Figure 1) might be the temperature variations during the four seasons every year of a specific area. The temperatures are never exactly the same year-in and year-out, but they are bounded by certain values and are repeated every year in a self-similar manner. Other examples may be the routine dynamics "inside a factory, an office, a hospital, a school or a prison" (Young and Kiel, 1994:3 of 20).

2.6.3.4 Chaotic or Strange Attractor

The concept of a strange attractor could perhaps be best explained by a model of a real-world example in which the trajectory of a snow ski board is mapped along a down-hill ski slope with moguls for different initial positions and velocities when starting along the top horizontal line of the ski slope, as indicated in Figure 2-20 by Lorenz (1995). The sketches were obtained from Lorenz (1995:27, 30, 40, 44, Figures 4, 5, 10, 11) and the researcher added labels and numbering.

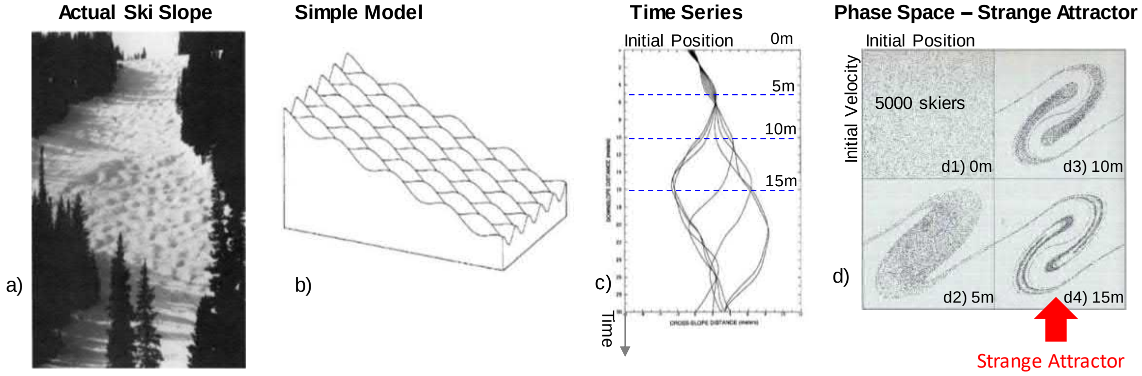

Figure 2-20: Topoloy of a Strange Attractor Represented by Skier behaviour on a Ski Slope Lorenz (1995)

The computer model of the real-world ski slope (Figure 2-20(a)) is simplified by including only three forces (gravity, friction and reaction of the slope on the board) and excluding the effect of the human skier, the effect of lift-off and aerodynamic forces in order to have a set of solvable partial differential equations (Figure 2-20(b)). The trajectories of seven snow ski boards as a function of time with identical starting velocities spaced 100 mm apart at the top of the ski slope that is approximately 18 m wide is shown in Figure 2-20(c). The motions of the boards are chaotic and sensitively dependent on small changes in initial conditions – this is chaos theory in action! After 10 m downslope from the starting line the original 0.6m spread of the boards has more than doubled and after 25 m the spread in the boards has increased more than tenfold. To visualize the strange attractor for this dynamical system, a collection of 5,000 points each with different initial positions across the top of the slope and with different initial velocities are chosen (refer to Figure 2-20(d)). These points are plotted in the Phase-Space diagram for velocity against position as shown in Figure 2-20(d1) and are a random collection of equal spaced points. Now release these 5,000 boards and let them develop their trajectories downhill. The Phase-Space diagram is plotted in Figure 2-20(d2) after just 5m downhill for velocity against position of all 5,000 boards. The attractor becomes visible as an elliptical shape with two thin arms extending from it. The empty spaces as shown in Figure 2-20(d2) are states which cannot occur except as transient conditions. The Phase-Space diagrams when the 5,000 boards have descended 10 m downhill is shown in Figure 2-20(d3) and when descended 15 m shown in Figure 2-20(d4). It is clear that the shape of the strange attractor is developed when comparing the images as shown in d2 – d4. The invisible set towards which these 5,000 points will ultimately be attracted for an infinitely long ski-slope, will form the cross section of the strange attractor.

The discovery of the strange attractor was made by Lorenz (1995) when he modelled atmospheric conditions using a computer and slightly changed the initial conditions for the same set of equations. He found that a small initial change had a dramatic effect on the outcome of the weather forecast. Hence, he discovered that chaotic systems were sensitively dependent on initial conditions.

2.6.4 Attractors Categories

The literature on attractors show more variants of the four prominent attractors (point, cycle, torus and strange attractors). A summary of attractors and their characteristics as portrayed by various researchers is given in Appendix B, Table B2. These attractors are categorised in addition to the prominent attractors as shown in Figure 2-21.

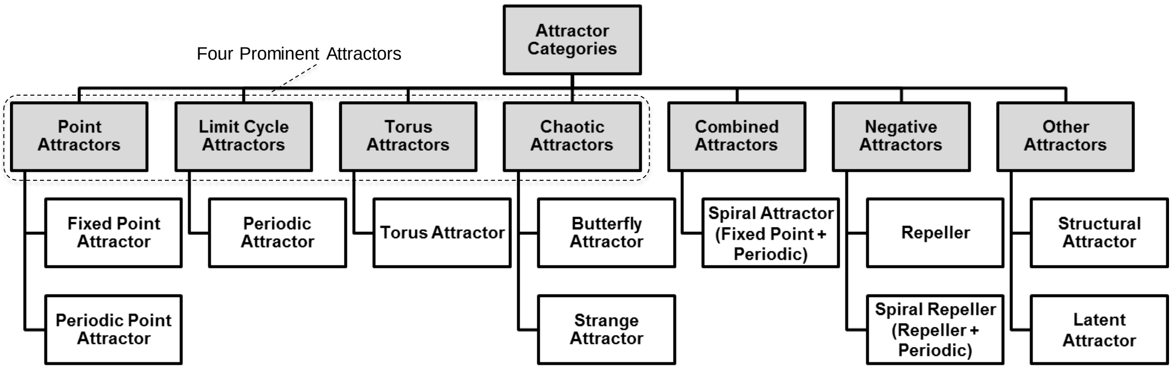

Figure 2-21: Attractor Categories Based on Literature Survey as Given in Appendix B, Table B-2

Besides the four prominent attractors (point, limit cycle, torus and chaotic), references were found for combined attractors (spiral attractors), negative attractors (repeller and spiral repeller) as well as other attractors such as the structural and latent attractors. Note that the literature refers interchangeably to chaotic and strange attractors – it was decided for this research to keep chaotic attractors as the category name with butterfly and strange attractors as sub-categories.

2.6.5 Attractor Attributes and Examples

The characteristics of the eleven types of attractors as shown in Figure 2-21 are summarised in Table 2-7. The objective of this table is to be able to gain a better understanding of the metaphorical nature of an attractor when combined with an example and typical characteristics. Combined attractors, negative attractors and other attractors seem to remain derivatives, variants or combinations of the four prominent attractors i.e.

point, limit cycle, torus and chaotic attractors.

Table 2-7: Summary of Examples and Attributes for Individual Attractors

No.	Attractor Type	Attributes
A. Point Attractors		
1	Fixed Point Attractor (Pendulum Attractor)	• Example: Pencil balancing on its head and then falling over • Moves towards highly equilibrium state (e.g. zero velocity) • A state towards which a system returns after a perturbation • Wider attractor basin potentially captures more system dynamical states compared to a narrower attractor basin • Steeper attractor basin potentially retains system dynamical states better compared to shallower attractor basin • Systems inside deep attractors are less prone to dislodgement by external influences
		References: Bums (2002); Gilstrap (2005); Vallacher and Nowak (2007); Ramalingam et al. (2008); Pruitt and Nowak (2014)
2	Periodic Point Attractor	• Example: Piston position (not an orbit) • Moves towards and away from a set point • Sustained rhythmic behaviour • A pattern on which the system converges • System returns to pattern after small perturbations
		Reference: Gilstrap (2005)
B. Limit-Cycle Attractors		
3	Periodic Attractor	• Example: Planets orbiting the sun • Attraction towards a cyclical pattern • Sustained rhythmic behaviour • A pattern on which the system converges
		References: Lorenz (2000); Gilstrap (2005); Vallacher and Nowak (2007); Butner et al. (2015)
C. Torus Attractors		
4	Torus Attractor	• Example: Four season cycles within a one-year cycle • Repeat smaller cycles bounded by larger cycle • Self-similarity
		References: Young and Kiel (1994); Fractal Foundation (2009)
D. Chaotic Attractors		
5	Butterfly Attractor	• Example: Mood swings • Formation of two causality fields • Sudden jump from one causal domain to another
		References: Pruitt and Nowak (2014); Radu et al. (2014b)
6	Strange Attractor	• Example: Cross section of skier trajectories down a slope (Lorenz, 1995) • System never settles at a specific point – orbits around the attractor • Long term prediction not possible but remains within long term pattern • System trajectory never repeats itself exactly • System that never returns to the same place • Behaviour follows a non-repeatable pattern • Underlying pattern of order • Displays order at the level of its trajectory but unpredictable in detail • Similar patterns / attractors at multiple deeper levels • System behaviour is pulled towards attractor • System behaves in ways not as expected by Newtonian physics, propositional logic or rational numbering systems

No.	Attractor Type	Attributes
		References: Lorenz (1995); Bums (2002); Ramalingam et al. (2008); Lucas (2004); Radu et al. (2014b)
E. Combined Attractors		
7	Spiral Attractor	• Example: Pendulum with friction • Combination of a fixed piont and limit cycle attractors
		References: Gleick (2008); Butner et al. (2015)
F. Negative Attractors		
8	Fixed Point Repeller	• Example: Pen balancing on its tip (peak of a mountain) • Unstable state • System or variables moves away in time from this position or state • A system is unstable at the location of a fixed point repeller
		References: Kent and Stump (No Date); Vallacher and Nowak (2007); Butner et al. (2015)
9	Spiral Repeller	• Example: Resonance (Harmonic force applied to an undamped system) • System spirals away from a set point
		References: Rao (1990); Butner et al. (2015)
G. Other Attractors		
10	Structural Attractor	• Example: High performance working teams • Agents with attributes that provide for positive feedback onto themselves • Highly cooperative system with low competition and high synergy
		References: Allen (2001); Porath (2016)
11	Latent Attractor	• Example: Stereotyping of outgroup members (not visible) • Attractors that are not visible but become available when conditions change
		References: Vallacher and Nowak (2007)

The next section provides more examples for attractors that have been used in various fields of science.

2.6.6 Attractors in Various Fields of Science

Researchers have employed different attractors in many applications, in several fields of science, as shown in Table 2-8.

Table 2-8: Summary of Attractors Used in Various Fields of Science

No.	Discipline	Attractor Descriptor	Reference
A. General Use of Attractors			
1	Sustainable Development	Future images of a sustainable food system trajectory	Kuhmonen (2017)
2	Paradigm Transition Management	From non-renewable to renewable energy sources	Vasileiadou and Safarzyńska (2010)
3	Socio-Economic Systems	Habits, routines, norms, dominant designs, preferences, ideals, innovations, demand trends	Kuhmonen (2017)
4	Pedestrian Dynamics	Visual attractors such as visual displays and street performances	Wang et al. (2014)

No.	Discipline	Attractor Descriptor	Reference
5	Socio-Economic Systems	Milestones and Genes	Kuhmonen (2017)
6	Leadership	Values, identity, brand, image, loyalty, flexibility, emotion, happiness, sadness, changeability, service, motivation, culture, climate, beauty, spirit, and uniqueness	Robertson (2014)
7	Environmental Criminology	Crime generators and crime attractors	Kinney et al. (2008)
B. Use of Point Attractors			
1	Sociocultural System	Pursuit of natural instincts fear, love, hate, desire to share or self-interest	Gharajedaghi (2011)
2	Conflict Management	Escalation and de-escalation of social conflict	Pruitt and Nowak (2014)
3	Corporate and Social Organisation	Death	Levick (2002)
C. Use of Limit Cycle Attractors			
1	Sociocultural System	Dialectic and self-maintaining cycling between opposite but complimentary tendencies such as stability and change	Gharajedaghi (2011)
2	Human Behaviour	Returning to the original cycle after a disrupted sleeping pattern	Vallacher and Nowak (2007)
3	Corporate and Social Organisation	Hunger – eat - hunger	Levick (2002)
D. Use of Torus Attractors			
1	Sociocultural System	Equifinal, neg-entropy and goal-seeking behaviour guided by DNA	Gharajedaghi (2011)
E. Use of Chaos Attractors – Butterfly Attractors			
1	Emotional Behaviour	Mood swings (sudden jumps)	Pruitt and Nowak (2014)
F. Use of Chaos Attractors – Strange Attractors			
1	Sociocultural System	Multi-final, self-organising and purposeful behaviour	Gharajedaghi (2011)
2	Organisational Behaviour	Organisation behaviour orbits around purpose and core values	Bums (2002)
3	Corporate and Social Organisation	Love	Levick (2002)
4	Change Management	Create a new understanding (new context information) and/or new actions (experiments, prototypes, changes in rewards, changes in key personnel, fiscal crises and layoff)	Morgan (2006)
5	Leadership and Management	Organisation purpose and values	Bums (2002)
6	Educational Leadership	Shared vision, team processes and information flows	Gilstrap (2005)
7	Organisational Dynamics	Purpose as reflected in the vision, mission and strategies	Dimitrov (2000)
G. Use of Other Attractors – Latent Attractors			
1	Social Psychology	Racist attitudes present themselves when self-regulation is disrupted	Vallacher and Nowak (2007)

Examples of research on the use of some attractor's categories could not yet be identified in a literature survey. These included combined attractors (spiral attractor), negative attractors (repeller and spiral repellers) and structural attractors. Many of the cited research on the use of attractors, as indicated in Table 2-8, are limited to a metaphorical level and is lacking in thorough rigorous methodical investigation (Begun et al. (2003). This section considered individual attractors and the next section will consider groups or constellations of individual attractors.

2.6.7 Attractor Landscapes

Attractor landscapes may be constructed in which fixed point attractors (valleys) and fixed point repellers (hills) form a three-dimensional landscape as shown in Figure 2-22. The sketches were obtained from Harrison (2013), MacArthur et al. (2009) and (Pruitt and Nowak, 2014) while numbering was added by the researcher.

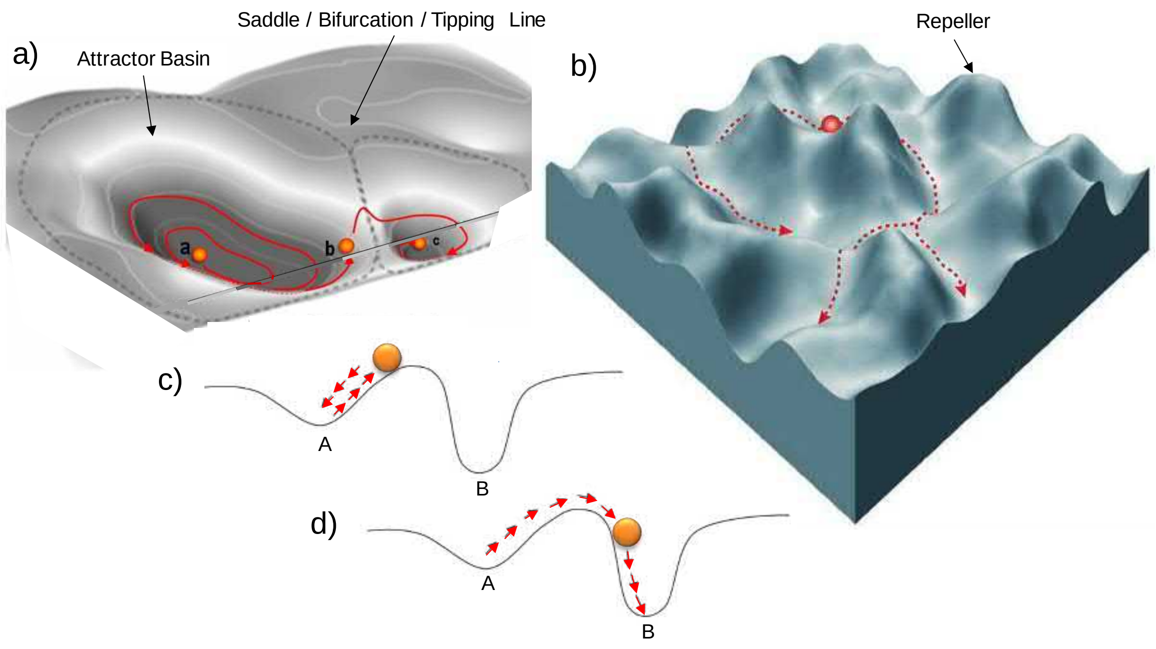

Figure 2-22: Three-Dimensional Landscapes of Attractors and Trajectories of Dynamical Systems (Harrison, 2013; MacArthur et al., 2009; Pruitt and Nowak, 2014)

Butner et al. (2015:3) state that in attractor landscapes "the mountains and ridges, in essence, guide the likely paths we would follow. It is important to realize that they do not entirely constrain where we might go, but rather capture a degree of likelihood". The trajectory of a dynamical system is traced from inside the fixed point attractor basin crossing the bifurcation or tipping line at the area of the attractor saddle into the neighbouring attractor as shown in Figure 2-22(a) (Harrison, 2013:3 of 6, Figure 3). A repeller will push the trajectory of the dynamical system away from the specific point in the attractor landscape as shown in Figure 2-22(b) (MacArthur et al., 2009:677, Figure 2). If the external environmental forces that act on the dynamical system are smaller than the system's internal forces, the dynamical system will remain in the attractor basin as shown in Figure 2-22(c) and hence attractors can be thought of as "quasi stable states" (Pruitt and Nowak, 2014:389). But, if the external forces are stronger than the internal dynamical system forces, the saddle region will be reached, that represents the tipping point (line), and the system will bifurcate and move to another attractor as shown in Figure 2-22(d) (Pruitt and Nowak, 2014:389, Figure 1). Lucas (2004) states that "once this bifurcation point has been passed it may take a very large perturbation (a hidden stone say) to switch attractors again, we say the system has become 'locked' into a particular attractor". He also mentions that the effectiveness of an attractor is limited to the area that is marked with the tipping point line.

Pruitt and Nowak (2014) further explain that the cross section of the attractor basin (A) as shown in Figure 2-22(c), is greater compared to (B) as shown in Figure 2-22(d), which means that a wider variety of dynamical system states will potentially be attracted to attractor (A) compared to (B). The depth and steepness of attractor basin (B) is greater compared to (A) which means that it is more difficult for the dynamical system to change from basin (B) to another attractor basin and it has therefore more resilience and strength to remain in the current attractor basin. This steepness of the attractor basin can be calculated for certain deterministic systems as a mathematical quantity known as the Lyapunov Exponent (Butner et al., 2015). This cross section of a stationary fixed point attractor and repeller landscape as shown in Figure 2-22(b) is also known as the fitness landscape (Kauffman and Levin, 1987). The peaks in the landscape are an indication of the "fitness" of a system with higher peaks and valleys indicating a higher level of survivability compared to a lower lying peak (Remington and Pollack, 2007). In order for a system to progress towards a higher peak it needs to leave the current valley and descend through a lower level of fitness and climb up the next peak. Sometimes a system remains in a lower lying valley – a state known as "local equilibrium" (Gribbin, 2005:233 of 436) and which is in effect sub-optimisation.

Another imaginary view of an attractor landscape is given by Allen (2001) as shown in Figure 2-23.

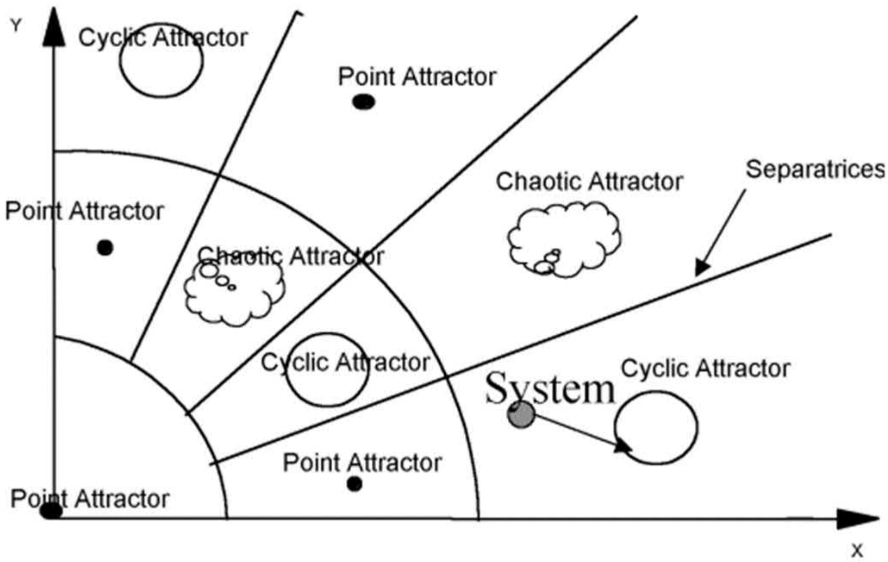

Figure 2-23: Imaginary View of an Attractor Landscape (Allen, 2001:30, Figure 2)

Allan is of the opinion that the final long-term end state of the trajectories of a non-linear dynamical system could either be a fixed-point attractor, a cyclic attractor or chaotic motion (strange attractor). The system trajectory, according to him, will be dependent on the starting point (sensitive dependence on initial conditions) and also on the "richness" (p. 30) of the system behaviours, as a result of the non-linear set of equations that describe the system behaviour. The attractor landscape may thus exist of many different types of attractors, but the system is driven towards the "long-term stationary attractor" (Allen, 2001:30) i.e. towards x = 0 and y =0 in Figure 2-23. The point made by Allen may be important in the study of attractor landscapes for capital projects as projects need to be attracted towards clearly defined cost, schedule and scope end-goals. Perhaps an attractor landscape could be designed for capital projects similar to the one in Figure 2-23 that will "guide" the non-linear dynamical behaviour of a capital project towards a stationary end goal. This research will aim to test this possibility.

Lorenz (1995) reasons that for any dynamical system, after the transient effects have been removed as a result of a chosen set of initial conditions, a unique set of attractors will form in the attractor landscape. He states that "certain conceivable modes of behaviour simply do not occur "such as a pendulum that suddenly starts to swing violently, a flapping flag will not hang limp when a breeze is blowing and subfreezing temperatures will not suddenly appear in Honolulu" (Lorenz, 1995:39). Kuhmonen (2017:215) confirms that CAS have multiple attractors of various different types. The behaviour of the system that occurs again and again or that are approximated over and over, is part of a restricted set of attractors for a specific dynamical system operating in a specific environment and forms the "heart of the dynamical system" (Lorenz, 1995:39).

The underlying assumption in the discussion on attractor landscapes in Figure 2-22 and Figure 2-23 is that the landscape remains rigid and stationary while the dynamical non-linear system transits. The attractor landscape represents the system external environment but this is seldom static and can be "thought of as a moving sea, or shifting sand dunes in desert" (Remington and Pollack, 2007:10). The attractor landscape therefore may not only change as a result of an increase in overall environmental complexity but also as a result of the movement of the system itself in the landscape. In this regard Gharajedaghi (2011:61) adds that "man creates his culture and his culture creates him". This change in the attractor landscape also implies that new attractors are created, and existing attractors are diminished. This notion is confirmed by Dimitrov (2000:418) when he states that a "strange attractor is able to expand, shrink, merge with other attractors, collapse, or 'explode' into new dynamic patterns in the [individual member's] agent's mental space".

2.6.8 Attractors in Harmonious Resonance

Dimitrov (2000:418) states that if individuals in organisations act as purposeful agents and they are "oriented towards attainment of a certain goal or objective", then their purpose could represent a strange attractor towards which all their actions, thoughts and feelings are attracted to. This strange attractor becomes the focus point in the agent's mental space and affect its behaviour as it "informs, motivates, and inspires the actions of the agent". Ackoff and Emery (2008) defined a system or individual as purposeful if it is able to simultaneously choose and change its structure, function and processes in order to achieve an objective, goal or ideal. They state that a purposeful system or individual is ideal seeking if and only if it is able to "on attainment of any of its objectives, it chooses another objective that more closely approximates its ideal" (p. 241). Thus, purposeful individuals or actors in organisations may have multiple attractors that may guide its choices and behaviour in order to achieve an ideal. Organisations also have strange attractors in terms of their purpose, vision, mission and strategies (Bums, 2002; Gilstrap, 2005) and the question arises what could happen when the strange attractor of the agent (individual) coincides with the strange attractor of the organisation. Dimitrov (2000:419) formulated the Harmonious Resonance Theorem to describe this condition as follows:

> *"Harmonious resonance in an organization occurs if and only if the agents' strange attractors representing their purposes are 'tuned':*
>
> *1. in harmony with one another, and*
>
> *2. in accord with the strange attractor of the overall purpose of the organization."*

This theorem implies that if the strange attractors, that represent the ideals of the agent (individual) and the strange attractor(s) of the organisation (purpose, vision, mission and strategies) are the same or "tuned", a condition of "resonance" or an amplified output occurs. Perhaps this resonance condition could be designed for capital projects and help to focus and align the efforts of individuals to better achieve capital project convergence.

2.6.9 Attractors at Different Levels

Benoît Mandelbrot investigated his proposition that simplicity breeds complexity (Gleick, 2008) and defined the concept of a fractal. A fractal is defined by the Fractal Foundation (2017:19) as:

> *"a never ending pattern that repeats itself at different scales… Fractals are extremely complex, sometimes infinitely complex - meaning you can zoom in and find the same shapes forever… A fractal is made by repeating a simple process again and again"*

Mandelbrot (Fractal Foundation, 2009) demonstrated that very complex fractal patterns could be created by a very simple equation as shown in Figure 2-24(a-b).

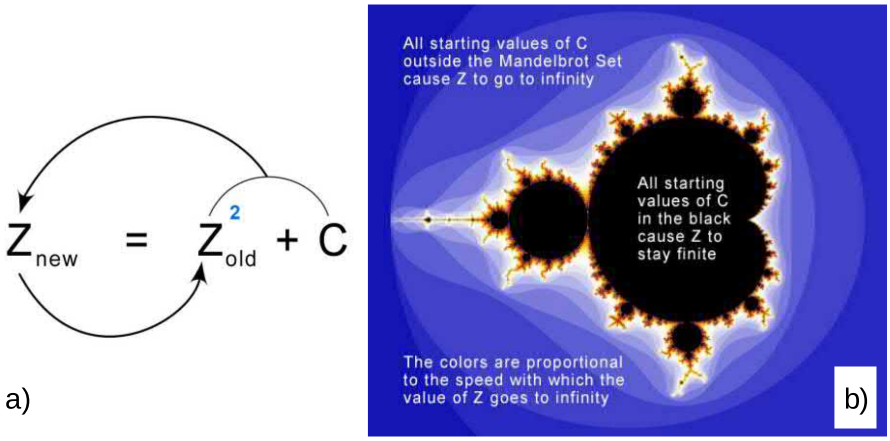

Figure 2-24: How a Simple Equation (a) is Able to Create a Complex Mandelbrot Fractal Structure b) with Multiple Levels of Self-Similar Patterns at the Borders (Fractal Foundation, 2009:7 of 19, No Figure Number)

The border of this fractal shown in Figure 2-24(b) also represents the boundary of the strange attractor. The shape of the strange attractor at the boundary is repeating itself in a nearly-similar manner for deeper levels at that boundary. Lorenz (1995:176) declared that “strange attractors are fractals” while Ramalingam et al. (2008:38) confirmed “If any part of the strange attractor were magnified, it would reveal a multi-layered sub-structure in which the same patterns are repeated. Complexity plays out in identical ways at different levels of a system”. This finding was also confirmed by Thietart and Forgues (1995:19) in their analysis of organisational behaviour using chaos theory as they stated that “similar patterns should be found at different scales” in organisations. The question now arises if attractors are also found in the different continuum domains.

2.6.10 Attractors Presence in Different Continuum Domains

Based on the citations from researchers as shown in Table 2-9, attractors are found in the chaotic and complex system domains. If the reference to ‘equilibrium-orientated systems’ could be assumed to represent the ordered domain, then attractors could be assumed to exist also in the ordered domain. No reference could be found for the presence of attractors in the randomness domain.

Table 2-9: Citations from Researchers on the Existence of Attractors in Various Domains

No.	Domain(s) of System	Evidence of Attractors in Various Domains	Reference
1	Near-Equilibrium and Chaotic Systems	"Attractors are pervasive in both near-equilibrium and chaotic systems in the scientific world"	Gilstrap (2005:58)

No.	Domain(s) of System	Evidence of Attractors in Various Domains	Reference
2	Equilibrium-Orientated Systems	"Periodic attractors also are considered to operate in equilibrium-oriented systems, as their patterns exist in bounded stability"	Gilstrap (2005:59)
3	Equilibrium-Orientated Systems	"The most basic attractor is the point attractor. This attractor can be described as operating in a phase space that moves towards a highly equilibrium state. They 'lure systems to a stable position of rest'"	Gilstrap (2005:59)
4	Complex Systems	"A transition from the chaotic to the complex is a matter of creating multiple attractors, or swarming points, around which un-order can instantiate itself, whereas a transition from the chaotic to the known requires a single strong attractor"	Kurtz and Snowden (2003:477)
5	Complex Adaptive Systems (CAS)	"Attractors are the most stable and robust elements of complex adaptive systems"	Kuhmonen (2017:218)
6	Chaotic Systems	"despite its name, chaos theory considers the tendency toward order a natural phenomenon produced by the action of four types of attractors: point attractors, cycle attractors, torus attractors and strange attractors"	Gharajedaghi (2011:57)

Snowden and Boone (2007:2) stated that "using the Cynefin framework can help executives sense which context they are in so that they can not only make better decisions but also avoid the problems that arise when their preferred management style causes them to make mistakes".

Does the capital project manager have the ability and time to meticulously analyse his complex internal and external project domains? Context independent theories, models and methods offer a real advantage and power to a project manager. If attractors work in all types of project internal and external environments, then the capital project manager could design and position these attractors, by default, when commencing with project development as part of the project architecture. This should cause the desired attraction i.e. convergence from chaos to order on the project, irrespective of an environment with a dominant random, chaotic, complex, ordered domain or in an VUCA project environment with mixed domains.

2.6.11 Attractor Activation Causes Movement from Order to Chaos

Ordered systems can become chaotic when a key parameter value is continually increased. At certain threshold parameter values, attractors are 'activated' and cause erratic and then chaotic system behaviour (Rohde, 2011). An example of this type of behaviour is displayed by the prediction of the species population size (x) at different reproduction growth rates (r) using the population logistic equation $x_{t+1} = rx_t(1- x_t)$ as shown in Figure 2-25. The researcher added the vertical line at the value of 3.0.

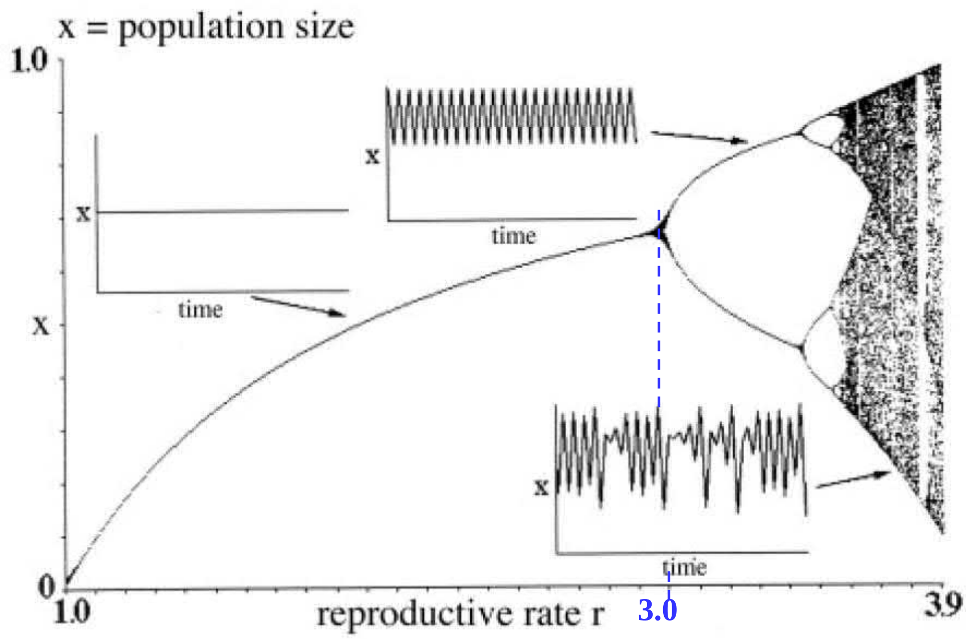

Figure 2-25: System Behaviour from Order to Chaos with an Explosion of Attractors when a Key Variable Reaches Specific Values (Rohde, 2011:2 of 8, Figure 1)

As long as the reproduction rate as shown in Figure 2-25 is low i.e. below 3 the result of the logistic equation is a single value x for the total species population size. As soon as the reproduction rate is further increased, the value of the total population jumps to one of two values as shown at 3.0. At higher values of r, the value of the total population size jumps to any of four values and with further increases of r to a chaotic number of different values for the overall population. This behaviour was also proven in a laboratory setup for various single-species populations (Hassell et al., 1976).

Radu et al. (2014b:1552) state, with reference to Figure 2-25, that a "butterfly attractor is being formed, through the formation of two causality fields, when a key parameter of a torus [attractor] increases its value more than three times". This implies that the number of attractors found for a specific dynamical system increases at the bifurcation points when key parameters of the dynamical system increases with more than three times (3.56 as calculated by Feigenbaum (Radu et al., 2014a). Radu et al. explain that at each bifurcation point, the attractor fields (number of attractors) duplicates and the dynamical system can be found in any one of those fields or basins. The number of attractor fields, zones or basins in which a system can be found, increases rapidly according to the range: 1, 2, 4, 8, 16, 32, 64, 128, 256, 512 and 1024. A single attractor field may contain a torus attractor while the butterfly attractor is contained in two fields and from then onwards for multiple strange attractors. There is thus an “explosion” of attractors and a movement “from order to full blown chaos” (Radu et al., 2014b:1553) with an increase in a key parameter.

Interestingly, in the chaotic zone Figure 2-25 (right hand side of the sketch), ordered sub-zones can be seen – the formation of order in chaos! Radu et al. (2014b) reasoned that this multiplication of attractors that are associated with an increase in some key variables of an organisation might mean that a leadership style that was used and worked effectively for one attractor basin (organisational setting and behaviour) might not work when some key parameter in the organisational environment has increased in magnitude as the organisation (dynamical system) might find itself in another or in any of different and multiple attractor basins.

The behaviour described above might mean that a capital project that experiences an increase in turbulence and complexity in its internal and external environment (perhaps due to the influences of a fast-changing VUCA world) may transition automatically from order to chaos, as this increase in energy causes the project to change from one set of attractors to another. This raises the question if these attractors are then by default or automatically present in a system or project and the possibility to design and position attractors in a capital project to pre-empt the required overall behaviour.

2.6.12 Design and Positioning of Attractors to Guide Organisational Behaviour

Kuhmonen (2017:214) states that “attractors configure the evolution of complex adaptive systems”. Morgan (2006) used this principle to explain how change management from an old paradigm A to a new paradigm B in an organisation could be guided by positioning, activation and de-activation of attractors as shown schematically in Figure 2-26. The Butterfly attractor metaphor is used to describe the two organisational paradigms A and B and the jump that occurs from A to B that is a typical characteristic of such an attractor (Pruitt and Nowak, 2014).

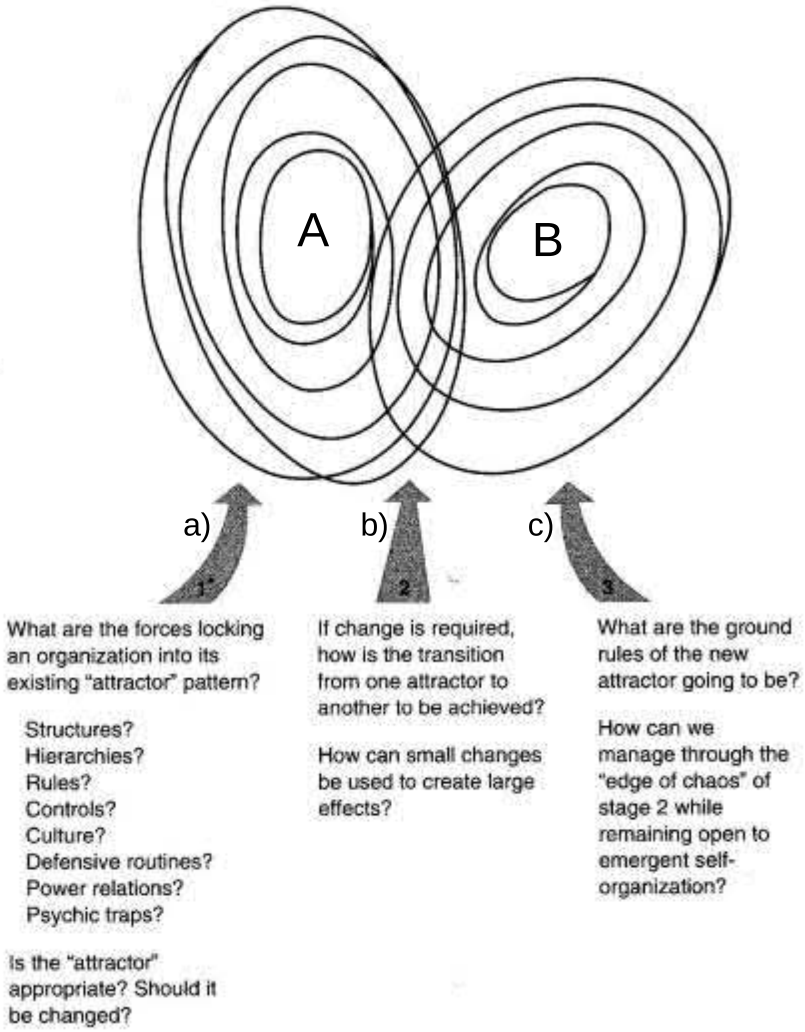

Figure 2-26: Design and Creation of Attractors to Guide Desired Organisational Change from the Old Paradigm A towards a New Paradigm B using Attractors a) and c) as Given by Morgan (2006:258, Exhibit 8.4)

Morgan (2006) states that it is important to understand what forces lock an organisation into the its current paradigm A and consideration should be given to structures, hierarchies, rules, controls, culture, defensive routines and psychic traps as shown in Figure 2-26(a). He reasons that it is negative feedback loops that keep the behaviour of the organisation and its trajectory captured in the left wing of the butterfly attractor. In order to create the 'flip' or 'jump' from the left wing to the right wing of the butterfly attractor (i.e. from the old paradigm A to the new paradigm B) as shown in Figure 2-26(c), it is necessary to identify small changes that could have a large and 'flipping effect' (i.e. sensitive dependence on initial conditions) and steer or 'shape' the system towards the edge of chaos. Morgan continues to indicate that if the new attractor is not actively designed and created (i.e. the new paradigm B) then the system might flip into another new state or paradigm which is not desired. Therefore, the elements of the attractor in the right butterfly wing as shown in Figure 2-26(c) must be actively created. Morgan (2006:259) suggests two methods to design and create the new attractor in the right wing of the butterfly as a "new understanding" and "new actions". New understandings could entail the sharing of new information of the desired context by powerful champions and possibilities it might hold for the organisation as a whole and future perspectives for individuals. New actions may include the demonstration of successful piloting or prototyping, changes in future rewards, and changes in future management and staff. Butner et al. (2015:5) note that control or key parameters "have the ability to alter topological features" of a dynamical system in three ways. These are: a) strengthening or weakening of an attractor or repeller; b) move a set-point and therefore the attractor to a different location; and c) extinguishing a set-point or "change an attractor into a repeller, or vice versa".

To prevent the organisation from falling back into the old paradigm A, the old attractor (i.e. left butterfly wing) must be destroyed by actions such as a fiscal crises or staff layoffs. These actions might act as repellers and help drive and trigger the bifurcation jump between the left-wing and right-wing of the butterfly attractor. Repellers have the function to push the system behaviour away from a specific point in the state pace attractor landscape (Butner et al., 2015) but can also function as a set barrier to guide system behaviour to self-organise and self-regulate within set boundaries (Snowden and Boone, 2007). Vallacher and Nowak (2007:10) are of the opinion that it is sometimes easier to predict the actions "people are likely to avoid than about actions they are likely to perform".

Ramalingam et al. (2008:41) confirm that this transition between attractors could be facilitated by a crises condition that will drive the system to the edge of chaos as shown in Figure 2-26(b) because a crisis creates "a change in an environmental or human stress that is destabilising enough so that the original set of attractors is supplanted by a new set of attractors". It is important, according to Gareth (1986), to note that the change management process cannot be "controlled" but can only be "shaped" (p. 259) or influenced by the change manager and the design and creation of new attractors when the theory of chaos and complexity is taken as the theoretical foundation. Lucas (2006) confirms this view when he states that "we can design the environment (constraints) rather than the system itself, and let the system evolve a solution to our needs, without trying to impose one". Ramalingam et al. (2008) refers to the work of Gareth who state that "The new pattern of the attractor cannot be precisely defined – it is only possible to nurture elements of the new context, and create conditions under which the new context can arise".

It is suggested in this paragraph that it seems possible to create attractors to pull organisations to a desired behaviour. It also seems necessary to destroy old attractors and even create repellers to prevent organisational behaviour to fall-back to a previous state. It is therefore implied that some attractors are present by default in organisations and others could be created and positioned to cause the desired outcome or behaviour. The question arises if these principles could be applied to capital projects and would it be possible to design an attractor landscape to move the project forward towards convergence from a chaotic state to an ordered state?

2.6.13 Disadvantages of Attractors

Attractors have the function to create order from chaos (Gharajedaghi, 2011) and thereby limit the number of "directions in which a system can unfold" as described by Vasileiadou and Safarzyńska (2010:1178). These authors caution however about the disadvantage of strong attractors as they could limit the "overall diversity and flexibility of the system" thereby endangering the survival of a system in a changing context.

2.6.14 Summary and Conclusions on Chaos Attractors

The following summary is done based on the literature review on attractors or chaos attractors:

a) Chaos Attractor Categorisation, Examples and Attributes
   Categorisation of chaos attractors indicated that:

   i. The terms attractors, attractors to chaos or chaos attractors are used to describe the phenomenon where behaviour of systems are guided or influenced as a result of their presence (Table 2-6)
   ii. The four prominent attractors (point, limit cycle, torus and chaotic) form the basis for further identified attractor types (combined attractors, negative attractors and other attractors) (Paragraph 2.6.3)
   iii. A total of 11 attractor types could be identified during the literature survey (Figure 2-21) – more types may exist
   iv. References to attractors were found for the chaotic and complex domains and systems but not for the random domain. If the reference to 'equilibrium-

orientated systems' could be assumed to be the ordered domain then attractors could be assumed to exist in this domain (Table 2-9)

v. Initial attractor descriptions seem to originate from mathematical modelling (Figure 2-17 - Figure 2-20)

vi. Most applications identified for attractors in the management and social sciences were to use attractors as metaphors (Table 2-8) – whilst evidence was found in the services industries on the quantification of attractors (Figure 2-16)

vii. The properties for chaos attractors were derived by Lorenz (1995) using mathematical simulation of a weather system that is considered to be deterministic, dissipative and non-linear dynamical system. The principles of attractors as metaphors have been widely applied to biological systems and socio-cultural systems. Human systems are considered to be non-deterministic and of a random type due to its free-will characteristics (paragraph 2.2.2). It therefore appears as if human socio-cultural systems also display random, chaotic, complex and ordered behaviour. This notion needs to be further investigated in the current research.

b) Visualisation of Chaos Attractors

The following methods were identified for the visualisation of attractors:

i. The Phase-Space method allows for the visualisation of attractors that are not visible using time-based data (Figure 2-12)

ii. The Phasegram visualisation method reveals the evolution of multiple attractors of a non-linear deterministic dynamical system, in a single two-dimensional time-based graph (Figure 2-13).

c) Quantification of Chaos Attractors

Attractors could be exposed in the Phase-Space domain by using the following methods:

i. Two non-time related dimensions such as velocity vs position (Figure 2-17 - Figure 2-20)

ii. Rate of change of a key variable vs the key variable, for example rate of change in product market share vs product market share (Figure 2-14)

iii. One variable in the current time period vs the same variable in the previous time period for example labour costs this week vs labour costs last week (Figure 2-15).

d) Appearance of Chaos Attractors in the Randomness-Chaos-Complexity-Order Continuum

The existence of attractors was identified by researchers as follows (Table 2-9):

i. Near equilibrium systems (ordered systems?)
ii. In the complex domain and complex systems
iii. As part of complex adaptive systems (CAS) (covering both the chaos and complex domains)
iv. In the chaotic domain and chaotic systems
v. No references to attractors could be found for the randomness domains.

e) Design and Creation of Attractors

The following conclusions can be made on the design and creation of attractors:

i. Multiple types of attractors seem to exist in any attractor landscape (Figure 2-23)
ii. Similar types of attractors seem to exist at different system levels as Mandelbrot fractals (Figure 2-24)
iii. Latent or hidden attractors seem not to be immediately visible in an attractor landscape (Figure 2-23)
iv. Adding more energy to a system may lead to the activation and transformation of attractors from point to limit cycle to torus to chaos i.e. order to chaos and chaos to order (Figure 2-25)
v. It seems possible to actively design and create attractors to ‘pull’ a system forward to a desired state and design repellers to avoid a system from moving back to an undesired state (Figure 2-26).

2.7 Time-Based Trajectories of Systems in the Continuum

The premise of this research is to establish if and how the course or trajectory of a capital project from initiation to successful close-out could be influenced by existing or designed attractors to aid project convergence from chaos to order. Attractor types and attributes as found in the published literature were portrayed in the previous section. The objective of this section is to display life-cycle trajectories of various systems and projects and any references to attractors or frameworks that could aid convergence. Evidence was found for pedestrian trajectories, research trajectories, organisational trajectories, technology adoption trajectories as well as project trajectories.

2.7.1 Trajectories of Dynamical Systems

Morgan (2006) describes the trajectory of complex systems through a landscape that contains different sets of reference points or attractors. He describes these complex system trajectories as traversing through “competing contexts” (p. 254). He also states that the ultimate trajectory or detailed behaviour of a system is determined by the strongest attractor i.e. by the dominating context or attractor. Kuhmonen (2017:215) defined the trajectory of a dynamical system as the “cumulative change of the evolving system in the state space”. When the time-based data of a dynamical system is transformed into the Phase-Space domain using the Phase-State method (refer to paragraph 2.6.2.1) then “each possible state of the system corresponds to one unique point” (Herbst et al., 2013:2). The individual points form the system trajectory and the attractors that influence the system trajectory become visible. The trajectory of a dynamical system may also be displayed in the time domain for a single variable (such as cost) or a collection of variables (such as value) without the visibility of the attractors that are influencing this trajectory.

2.7.2 Trajectories of Pedestrians in Relation to Visual Attractors

Wang et al. (2014) developed and tested a simulation tool that predicts pedestrian behaviour based on a visual attractor’s attractiveness, distance to the attractor and visibility of the attractor. The attractors investigated by the researchers are typically window displays and street performances. Their simulation results for pedestrian trajectories, in a typical shopping street with 12 shops, are shown in Figure 2-27. The text for “entrance” and “exit” was added to the sketch by the researcher.

Figure 2-27: Simulation Results for Pedestrian Behaviour as a Result of Visual Attractors (Wang et al., 2014:29, Figure 9d)

Wang et al. (2014) have developed a model to simulate three modes of pedestrian behaviour in terms of internal demand and external stimuli. A random pedestrian movement is observed when the trip purpose is unclear and leads to pedestrians randomly stopping and their trajectories are scattered among shops. Purposeful pedestrian movement is directed towards specific types of shops and the third mode is where pedestrians have no demand and would not be influenced by visual attractors. The reliability of their model was demonstrated by good agreement between simulation and actual pedestrian trajectory behaviour in a Christmas Day exhibition in a Hong Kong mall. Impulsive stops of pedestrians as a result of the exhibition (the attractor) was demonstrated.

2.7.3 Trajectories of Complexity Science Research

Castellani (2013), a professor in sociology and an expert in complexity studies, mapped the macroscopic transdisciplinary research contributions of the complexity sciences spanning a period from 1940 – 2015 (75 years) as shown in Figure 2-28. Labels were added to this sketch by the researcher for the five attractors.

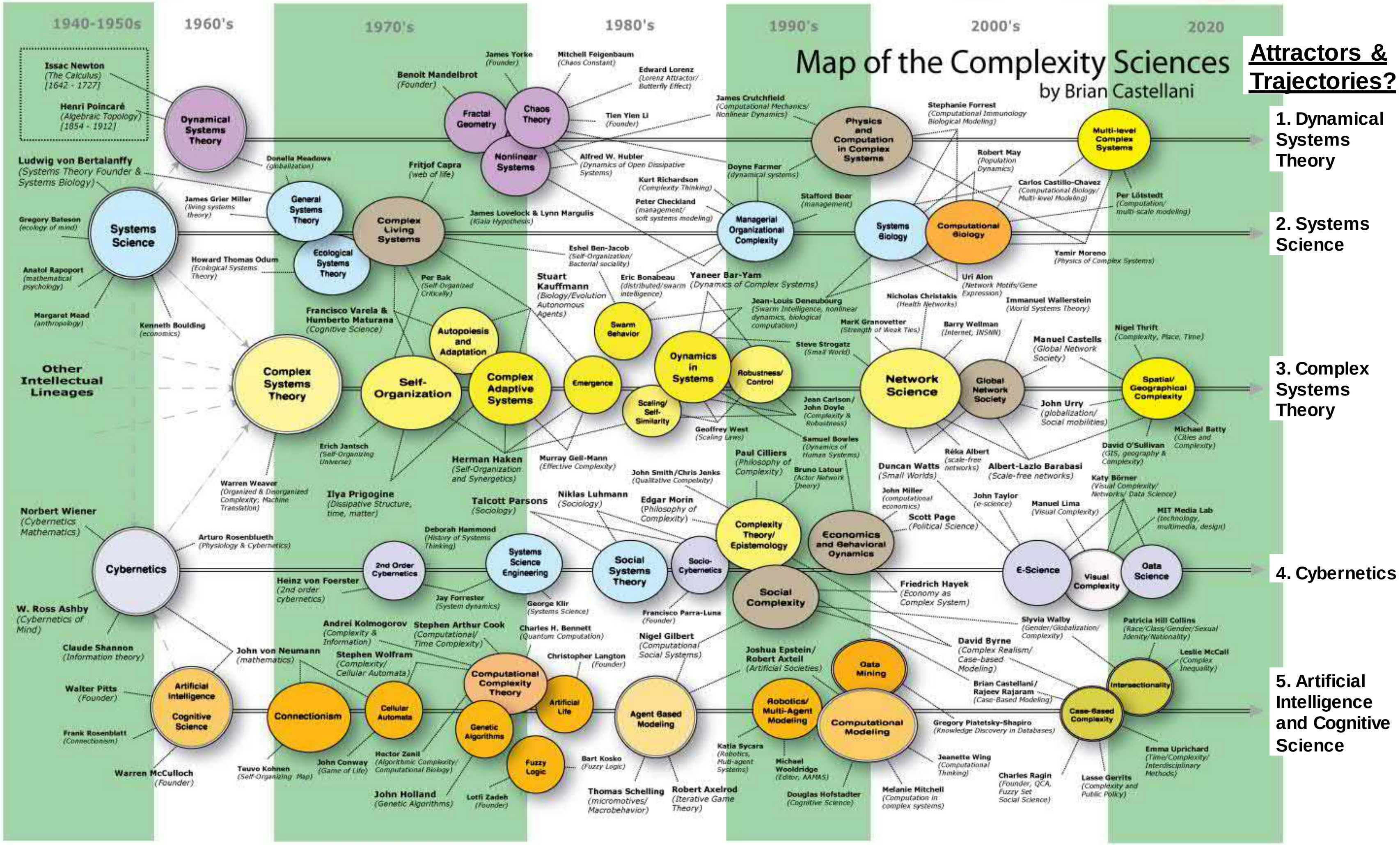

Figure 2-28: Map of Key Concepts, Theories, Methods and Researchers in the Complexity Sciences Spanning 1940 – 2015 (75 Years) with "Trajectories" that are "Attracted" around Five Major Intellectual Traditions (Castellani, 2013:1 of 2)

The contributions of scholars in terms with their pioneering work, theories, concepts, methods and tools over a period of 75 years evolved “along the field’s five major intellectual traditions” of: a) dynamical systems theory; b) systems science; c) complex systems theory; d) cybernetics; and e) artificial intelligence and cognitive science (Castellani, 2013:1 of 2). Although Castellani did not mention it, these five directions in which the research converged could be seen as attractors and the work of researchers as trajectories guided by these attractors when considered from a viewpoint of complexity and chaos theories.

2.7.4 Trajectories of Organisations through Their Life-Cycle Phases

A system may not necessarily remain in a specific state for long periods of time because of its dynamic nature or the dynamic nature of its environment, as a result of the interconnection between the system boundary elements with its environment. Green Jr and Twigg (2014:21) state that due to wold-wide competition, managers are required to manage “complex adaptive supra-systems made up of individuals that are themselves complex adaptive systems” and that these systems “cycle through periods of order, complication and chaos”. They also state that the cycling of organisations through periods of “order, complexity and chaos” (p. 21) are opportunities to change strategy and ensure survival in a changed environment. Greiner (1998:56) indicated that organisations experience periods of evolution characterised by “steady growth and stability” followed by periods of revolution that is characterised by “substantial organizational turmoil and change” during its life as shown in Figure 2-29. The researcher added an arrowhead to this sketch to indicate the organisational trajectory direction.

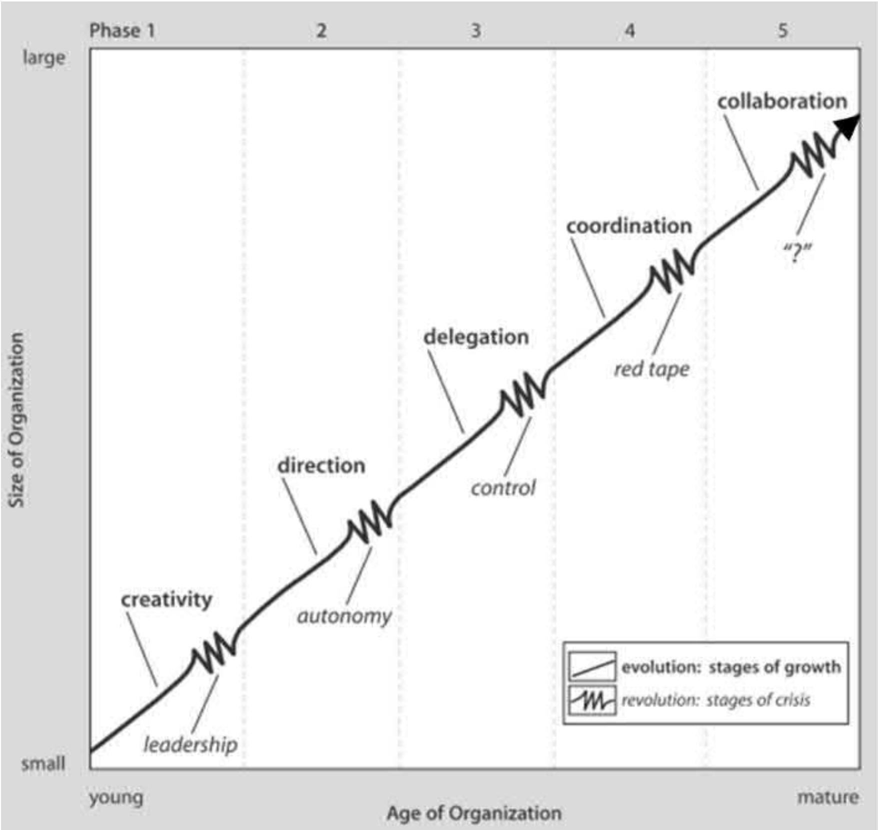

Figure 2-29: Cycling and Transition Through Stages of Evolution and Revolution of the Organisational Trajectory as a Result of Life-Cycle Age (Greiner, 1998:5)

The stages of evolution might be similar to an "ordered stage" and the period of revolution similar to "complexity and chaos stages" when compared with the identified continuum stages as described in paragraph 2.5. The cycling through successive evolutionary and revolutionary stages confirms the transition behaviour between stages of organisations.

2.7.5 Trajectories of Systems in the Cynefin Framework

Kurtz and Snowden (2003) provided a summarised explanation of organisation behaviour in the form of a system trajectory through the five different contexts of the Cynefin framework as shown in Figure 2-30. The researcher combined elements of sketches from Kurtz and Snowden (2003:467, Figure 4) and Snowden (2010b:1 of 2) and added text to create this sketch.

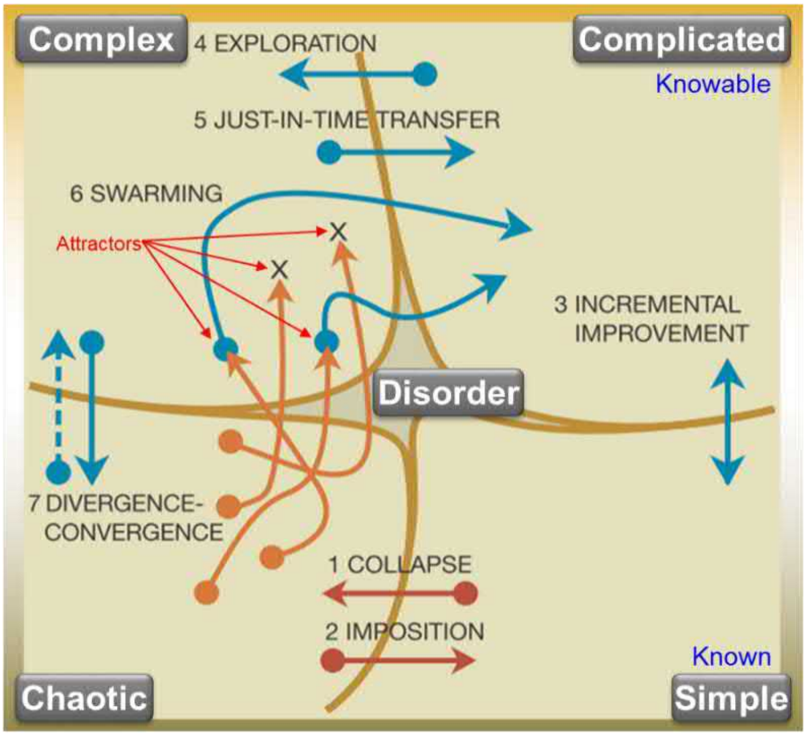

Figure 2-30: Swarming Trajectory (6) of a System from the Chaotic Domain towards Attractors in the Complex Domain and towards the Complicated Domain (Kurtz and Snowden, 2003:467, Figure 4; Snowden, 2010b:1 of 2)

Both Kurtz and Snowden have categorised the typical system trajectories (organisational behaviours) by considering the crossing of the four domain boundaries of simple, complicated, complex and chaotic as shown in Fig 2-31. They indicate two possible trajectories when crossing the boundary between chaotic and order (simple or known) as collapse (1) and imposition (2). A system trajectory from simple to chaotic (1) is associated with catastrophic collapse (Thom, 1975; Zeeman, 1976) when a system is too rigid, complacent and is not able to adapt to a changing environment. A system trajectory of imposition (2) means abruptly moving from chaos to order, for example dictatorial leadership during a crisis. System trajectories back-and-forth between the known (simple) and knowable (complicated) domains typifies incremental improvement (3). This cyclic information exchange between these domains fuels "technology growth" and is an "engine of technological and scientific order" (Kurtz and Snowden, 2003:476, 477). System trajectories crossing the complicated-complex boundary are in essence a crossing between a fact-based domain (complicated) and a pattern based domain (complex) (Snowden and Boone, 2007) and is depicted by Kurtz and Snowden (2003:476) as the "engine of new ideas". Selective exploration (4) allow portions of a company to obtain knowledge from its environment by loosening central control. Just-in-time knowledge transfer (5) is to move knowledge as it is needed from the complex space to the complicated space.

The fluid complex-chaos boundary is known as the “engine of organic order” and system trajectories may move back-and-forth across this boundary as convergence (7) (from chaos to complexity) and divergence (7) (from complexity to chaos).

The most relevant trajectory for this research is shown as ‘swarming’ (6) that indicates system trajectories from the chaotic domain through the complex domain to sometimes end in the complicated domain. Kurtz and Snowden (2003) explain this transition as a two-step process. First create multiple attractors in the complex domain to allow the system trajectory to latch and self-organise onto these attractors and to form patterns. The attractors with desirable patterns are stabilised “through a transfer to the exploitable domain of the knowable” and the other attractors are destroyed (Kurtz and Snowden (2003:477). This reference by the researchers to the purposeful and active creation and destruction of attractors agrees with the notion as suggested in paragraph 2.6.12 in terms of the creation and design of attractors for a pre-conceived and desirable attractor landscape.

2.7.6 Trajectory for New Product Adoption by Individuals through the Technology Adoption Life Cycle

Rogers (1983) defined a bell-shaped curve with standard distributions as a model representing the adoption of innovation (new products and technologies) by individuals. He labelled the categories as: Innovations; Early Adopters; Early Majority; Late Majority; and Laggards. Moore (2002) indicates the existence of a chasm between the stages of the early adopter and the early majority that leads to the failure of the individuals in the market to further adopt new products beyond the early adopter stage and the stagnation of new products sales. Moore (1999) renamed the technology adoption life cycle stages to: Techies (for Innovators); Visionaries (for Early Adopters); Pragmatists (for Early Majority); Conservatives (for Late Majority); and Sceptics (for Laggards). He then described a strategy to cross the chasm (bowling alley) that, if successful, lands the entrepreneur inside the ‘Tornado’ of rapid sales and hyper growth. He named the successful survival of the Tornado in the progression to the next stage as ‘Main Street’. Nielson (2014) combined the technology adoption life-cycle graphs of Rogers and Moore and indicates the trajectory of adoption of new products by individuals through the technology adoption life cycle as indicated in Figure 2-31. The researcher added x-y axes and labels to this sketch.

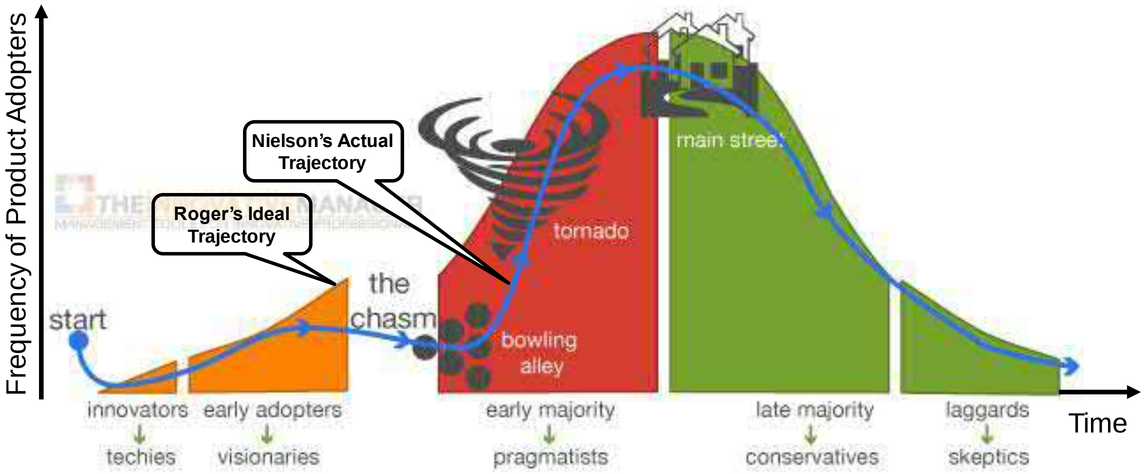

Figure 2-31: Trajectory of Product Adoption by Individuals during the Technology Adoption Life Cycle (Nielson, 2014:6 of 7)

The hypothetical trajectory of the actual adoption of a new product in a market as shown by Nielson (2014) (blue line in Figure 2-31) does not exactly follow the ideal trajectory of product adoption as indicated by Rogers but approach or 'attracts' to this profile during its transition through the life cycle. Similarly, the quest of this research is to identify, create and design attractors to influence the convergence of the dynamical system trajectory towards a desired future state.

2.7.7 Trajectories of Projects through their Life Cycles in terms of Value Created

Van Der Weijde (2006:iii) conducted a master's degree thesis to "provide a scientific basis for understanding and analysing the front-end development phases of capital expenditure projects". Front End Loading (FEL) has been defined by Independent Project Analysis (IPA) as the work being done to develop a project before the Financial Investment Decision (FID) (Merrow, 2011). The FEL process comprises of three stages that include "business case development and appraisal, scope development, and front-end engineering design (FEED), which also includes execution planning" (Merrow, 2012:40). The IPA has analysed their database of world-wide oil and gas as well as other megaproject performance in terms of cost overruns and schedule overruns. They have identified a direct correlation between the quality of FEL (best, good, fair, poor and screening) and the percentage of project overall cost growth (cost overrun) relative to the baseline cost at the time of FID. Poor FEL development led to high cost overruns (>40%) and the best implementation of FEL led to zero or even negative cost overruns (less than FID) (Merrow, 2012).

Different trajectories of a project are thus possible through its life cycle depending on the quality of the FEL. Royal Dutch Shell adopted a project value framework (Hutchinson and Wabeke, 2006) that shows different project trajectories through the project life cycle, based on the quality of project definition (FEL) and the resulting value created for stakeholders, as shown in Figure 2-32. The researcher added the time axis and trajectory numbers to this sketch.

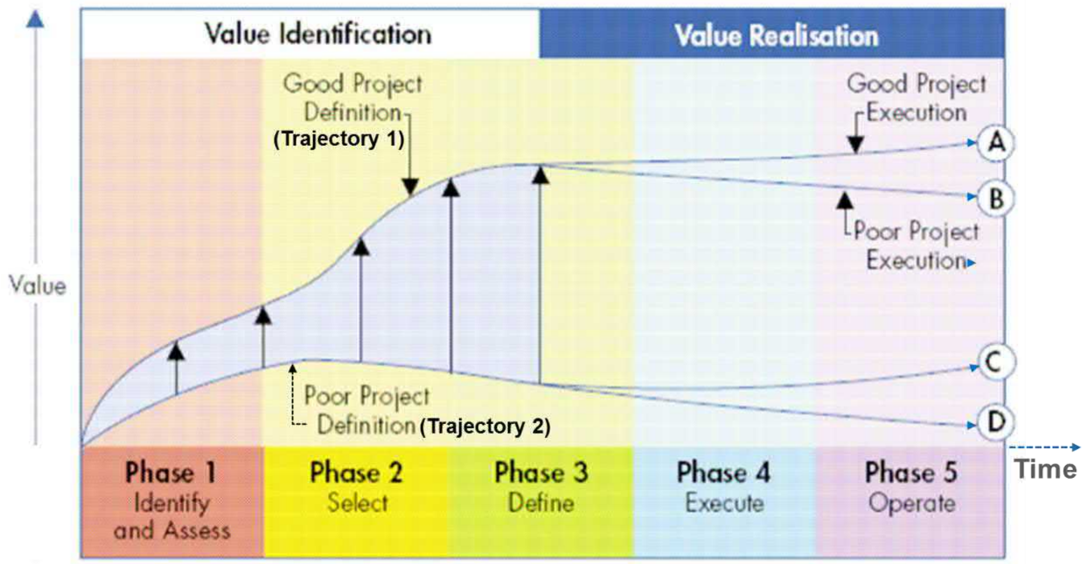

Figure 2-32: Two Possible Trajectories of Projects that Depends on their Level of Development (Front End Loading) (Hutchinson and Wabeke, 2006:4, Figure 2)

Trajectory 1 shows good project definition (FEL) and value identification during phases 1, 2 and 3 with maximum value realised when good project execution is done (A). Good project development followed by poor project execution may lead to reduced value realisation (B). Another extreme, trajectory 2 is shown when poor project definition (FEL) and value identification is done during phases 1, 2 and 3 of a project with two possible outcomes of this trajectory for value realisation. The worst value realisation is when a project is poorly developed (trajectory 2) and poorly executed (D). Even if a project is well executed but poorly defined the value realised (C) is just slightly higher in comparison to poorly planned and executed project (D). Four possible project trajectories are shown from the same point of origin (phase 1) with different quality of FEL and quality of execution. These project value trajectories indicate two possible extremes. A continuum of possible project trajectories could be imagined existing between these extremes for various qualities of FEL and execution. It would be difficult to imagine a project trajectory that lies outside and above the trajectory line 1 – A. All possible project trajectories may possibly be bounded to occur below this line.

2.7.8 Trajectory of a Project in terms of Achieving a Higher Level of Overall Complexity

Saynisch (2010b) developed a new paradigm for project management known as 'Project Management Second Order' (PM-2). He states that this is a new way of thinking about project management in a world that is unpredictable, discontinuous, unstable and nonlinear. He reasons that to successfully execute projects in such a world requires a "cooperation of systemic-evolutionary (self-organizing) and system-technological (constructive) determined principles" (Saynisch, 2010b:4). He led a multi-year research program to develop an architecture and process model for PM-2 based on and taking cognisance of a multitude of theories originating from system and complexity sciences, life sciences, physical sciences, mathematics and logic, social and psychological sciences as well as philosophical sciences (Saynisch, 2010a). The developed model consists of four worlds or paradigms that need to be used during the project life cycle, from project initiation to project close out. World 1 covers the traditional project management approach (command and control). World 2 is about complexity management (self-evolutionary and self-organising behaviour). World 3 is about collaborators and World 4 about ways of thinking (systemic views and networking principles). These four worlds act on the common product and project processes during its transition from project initiation towards project close-out.

During project execution, the overall level of complexity increases and the overall project reaches a higher level of organisation (state). This notion of "evolutionary order at a higher level" (Saynisch, 2010a:34) is based on the General Evolution Theory (GET) that states that "the universe constitutes a 'cosmic process' specified by a fundamental universal flow toward ever increasing complexity" (Laszlo (2009:211). The overall trajectory of a project towards higher levels of complexity and organisation during its life cycle is shown in Figure 2-33(a). The project life-cycle is composed of different phases with cyclic work and problem solving processes for system development, at different levels of the system breakdown structure, as shown in Figure 2-33(b). The researcher added the blue lines to the sketch to show a correlation between the project life-cycle phases (b) and the overall project maturity trajectory (a).

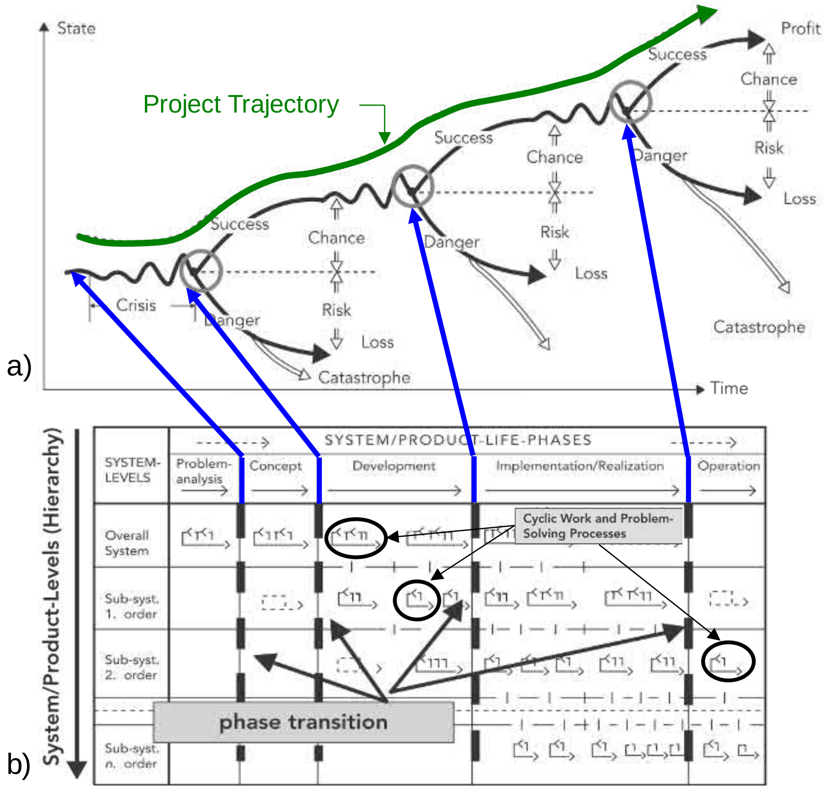

Figure 2-33: Project Time-Based Trajectory (Green Line) based on a) Evolution of System States of Increased Complexity that Coincide with b) Multiple Bifurcation Points at Project Stage-Gates for the System / Product Life Phases (Saynisch, 2010a:30, 33, 34, Figures 5, 8, 10).

Between each of the project phases, an “evolutionary jump” or “bifurcation” (Saynisch, 2010a:29) is occurring. Laszlo (2009) explains the nature of bifurcations as an attribute of the General Evolution Theory that has multiple manifestations in social systems. He states that “societal bifurcations can be smooth and continuous, explosive and catastrophic, or abrupt and entirely unforeseeable” (Laszlo, 2009:212). Saynisch (2010) then incorporated this attribute to explain phase transition in projects at stage gates. These bifurcations that are proposed to happen during the transitioning of project phases contributes towards the profile of the overall project trajectory as shown in Figure 2-33(a). Note that the outcome of an evolutionary jump could be successful in terms of reaching a higher overall state (chance) and a lower overall state (risk) or a catastrophic failure of the project. The overall project trajectory (shown in green) in Figure 2-33(a) depicts the cumulative result of successively successful evolutionary jumps. Once again, it may seem possible to depict the best achievable successful project trajectory as the green line that bounds all other possible project trajectories below this line. Less successful projects may possibly bifurcate at the stage gates and have as an outcome a lower overall state. This graph also indicates an overall trajectory that represents a failed project either during the project life-cycle or at the end (indicated as catastrophe in Figure 2-33(a)).

2.7.9 Trajectory of Projects towards Convergence through the Stacey and Cynefin Maps

An interesting presentation on an overall project life-cycle trajectory in terms of investment value and the transition of a project through the Stacey matrix (refer to Figure 2-6) and Cynefin framework (refer to Figure 2-8) was done by Rossouw (2011), as shown in Figure 2-34.

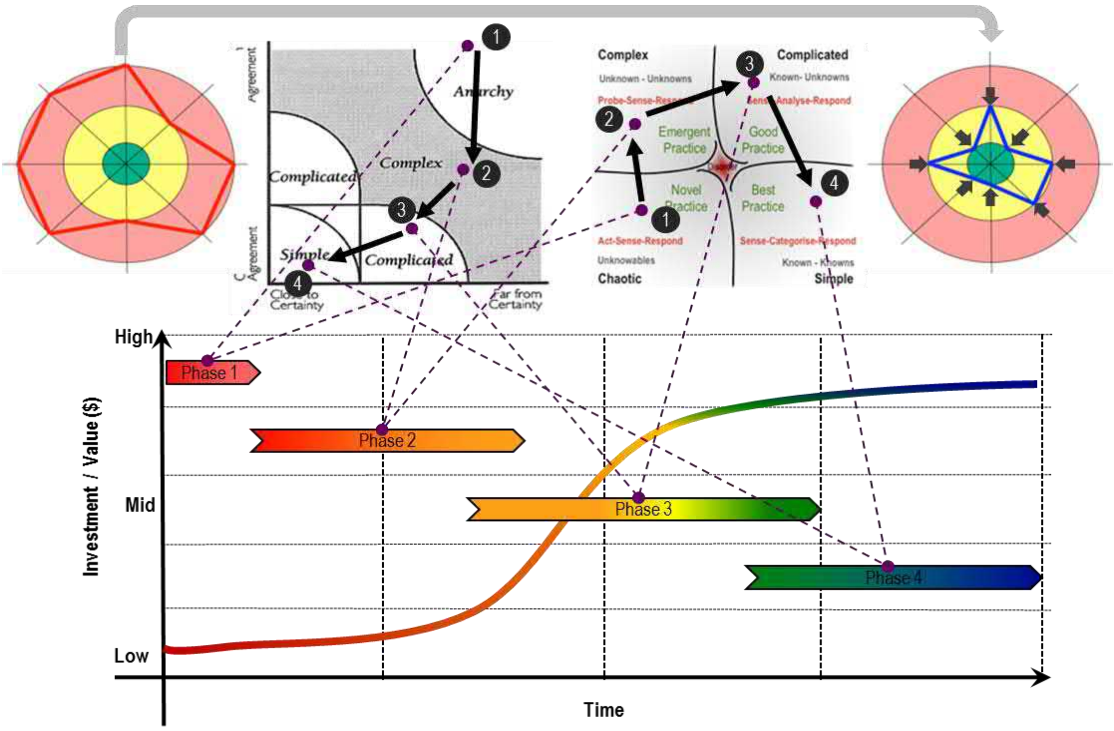

Figure 2-34: Project Trajectory from Anarchy (Chaos) through Complexity and Complicated Domains and Finally to the Simple State (Order) Using both the Stacey Matrix and Cynefin Framework (Rossouw, 2011:Slide 36 of 39)

Rossouw (2011) seems to imply that a successful project, in terms of investment value, progresses through its life-cycle from chaos to order and traverses from a chaotic / anarchy domain (1), through a complex domain (2), then a complicated domain (3) and finally towards a simple or ordered domain (4). Rossouw further indicates in the two spider diagrams (top left and right sides of the Figure 2-34) a convergence in certain (unknown) project dimensions from project commencement towards project close-out. Rossouw's presented sketch may provide a theoretical basis on capital project convergence for this research as it depicts project evolution from chaos to order as a result of attractors, as was suggested in the overall research question in Chapter 1.

2.7.10 Summary on Time-Based Trajectories

Based on the literature survey done in paragraph 2.7 on time-based trajectories the following summary and conclusions can be made:

a) Time-Based Trajectories and the Visibility of Attractors

i. Time-based signals (trajectories) of deterministic systems do not normally show the presence of attractors

ii. Time-based signals need to be transformed using the phase state method to reveal dynamical system trajectories and possible attractors.

b) Types of Trajectories

i. Pedestrian trajectories as shown in Figure 2-27

ii. Research trajectories as shown in Figure 2-28

iii. Organisational life-cycle trajectories as shown in Figure 2-29 and Figure 2-30

iv. Technology adoption life-cycle trajectories as shown in Figure 2-31

v. Project life-cycle trajectories as shown in Figure 2-32, Figure 2-33 and Figure 2-34.

c) Trajectories Progressing Though Different Domains

i. Evolutionary and revolutionary domains as shown in Figure 2-29

ii. Chaotic, complex, complicated and simple domains as shown in Figure 2-30 and Figure 2-34

iii. Low growth (before the chasm) and hyper growth (tornado) domains as indicated in Figure 2-31

iv. Slow evolution (before a stage gate) and evolutionary jump (after a stage gate) as shown in Figure 2-33.

d) Trajectories Progressing from a Low Indicative Value to a Higher Value

i. Increased size of organisation during its life cycle as shown in Figure 2-29

ii. Increased frequency of product adoption during the technology adoption life cycle as shown in Figure 2-31

iii. Increased overall value, maturity state and investment of projects during the project life-cycle as shown in Figure 2-32, Figure 2-33 and Figure 2-34.

2.8 Summary on Literature Survey on Chaos Attractors

A literature survey was done in this Chapter to gain a better understanding of the theories, attributes and context that are related to chaos attractors. A summary is provided of all the major aspects that were covered on chaos attractors. An attempt is then made to provide preliminary answers to the major and sub-research questions that were stated in Chapter 1 based on this literature survey. This Chapter is concluded with a description of the need for theory and model building and testing relating to chaos attractors in the capital project environment.

2.8.1 Summary on Chaos Attractors

This Chapter provided results of a literature survey as well as summaries on chaos attractors and the following related aspects:

a) The nature of real-world complex problems
b) Methodologies to study real-world complex problems
c) Ordered, complex, chaotic and random systems
d) The Randomness-Chaos-Complexity-Order Continuum
e) Chaos attractors
f) Time-Based trajectories of systems in the continuum.

This information could be used to provide preliminary answers to some of the major and sub-research questions.

2.8.2 Preliminary Answers to Major-Research Questions

Based on the literature survey in this chapter, preliminary answers are provided to the major-research questions as indicated in Table 2-10.

Table 2-10: Preliminary Answers from the Literature Survey to Major-Research Questions

No.	Major-Research Question	Preliminary Answers
1	Does the use of individual chaos attractors lead to local convergence from chaos to order of capital project	● The butterfly chaos attractor metaphor has been used by Morgan (2006) in Figure 2-26 to demonstrate organisational change management from one paradigm to another paradigm ● Saynisch (2010a) demonstrated the jump in project maturity at

No.	Major-Research Question	Preliminary Answers
	elements and their trajectories?	a stage-gate under the influence of a single butterfly chaos attractor as shown in Figure 2-33 ● Pedestrian behaviour was shown to be influenced by visual fixed-point chaos attractors as shown in Figure 2-27. Point attractors were able to attract local organisational behaviour to a fixed point in an attractor landscape as shown in Figure 2-22. ● A strange attractor was able to guide skier behaviour towards itself as was shown in Figure 2-20 ● Meade and Rabelo (2004) were able to identify a cyclic industry attractor to expose the current state of their product in the technology adoption life-cycle as shown in Figure 2-14
2	Does the use of combinations of different types of chaos attractors lead to overall convergence from chaos to order of capital projects?	● The movement of a whole organisation from the chaotic domain through the complex domain under the influence of chaos attractors was shown in Figure 2-30 (Kurtz and Snowden, 2003; Snowden, 2010b) ● The presentation by Rossouw (2011) as shown in Figure 2-34 combines both the Stacey Matrix (Figure 2-6) and the Cynefin framework (Figure 2-8) to imply that a complete project trajectory could be guided under the influence of chaos attractors from chaos towards order

2.8.3 Preliminary Answers to Sub-Research Questions

Preliminary answers to the sub-research questions were formulated based on the literature survey that was done in this Chapter as indicated in Table 2-11.

Table 2-11: Preliminary Answers from the Literature Survey to Sub-Research Questions

No.	Sub-Research Question	Preliminary Answers
a	Which attractor types and classes could be identified from the literature?	● Eleven different attractor types were identified as shown in Figure 2-21. All types of attractors seem to originate from the four prominent attractors: point, cycle, torus and chaotic (strange).
b	What are the characteristics and functions of each attractor based on the literature?	● Attractor attributes and examples for each attractor type are given in Table 2-7
c	What empirical studies have been done to demonstrate the effect of attractors?	● A summary of attractors being applied in different fields of science is given in Table 2-8
d	Do attractors only appear in chaotic types of systems, or also in random, complex and ordered system types?	● Attractors have been found to appear the ordered, complex and chaotic domains as shown in Table 2-9.
e	Do attractors appear simultaneously in systems, and what are the effects of attractors on each other and on the overall system behaviour?	● The simultaneous appearance of fixed-point attractors and fixed-point repellers were shown in a three-dimensional attractor landscape in Figure 2-22 ● The simultaneous appearance of point, cyclic and chaotic attractors were shown in a two-dimensional attractor landscape in Figure 2-23

No.	Sub-Research Question	Preliminary Answers
f	Do attractors only appear naturally in systems or could they be pre-designed?	● Attractors both appear naturally in systems with an increase in a key variable as shown in in Figure 2-25 ● For organisation change management it was shown in Figure 2-26 that attractors need to be created and destroyed to obtain the desired outcome ● Multiple attractors could be created in the complex domain to guide organisational behaviour and undesirable attractors could be destroyed as show in Figure 2-30 ● A natural butterfly attractor seems to exist at the project stage-gate that could lead to either success or catastrophy as shown in Figure 2-33
g	Are there strong and weak attractors?	● A strong butterfly attractor at a project stage-gate leads to a successful gate transition but a weak attractor leads to a catastrophe and failure as shown in Figure 2-33
h	Where in the project life-cycle do attractors occur naturally?	● It seems that a Butterfly attractor appears naturally at the project stage-gate as shown in Figure 2-33
i	What is the effect of naturally occurring attractors on overall project behaviour and as part of the project life-cycle?	● This information could not be derived from the literature survey
j	Could attractors be designed and positioned as part of the pre-project architecture to have an overall project convergence effect?	● This information could not be derived from the literature survey

2.9 The Need for Chaos Attractor Theory Development and Application

The literature survey that was done in this Chapter and the information obtained on chaos attractors is deemed sufficient to allow for the further development of these concepts for capital projects. These concepts will be used to build a theory and associated attractor models in Chapter 3.

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CHAPTER 3: THEORY AND MODEL BUILDING

3.1 Introduction

The problem of project cost overruns and the increase in the overall complexity and rate of change in the capital project environment was discussed in Chapter 1. It was also shown that chaos attractors seem to hold the promise to cause convergence from chaos to order using four chaos attractors. A literature survey was done in Chapter 2 to gain some understanding of the fast changing VUCA world, linear and non-linear worldviews and the identification of eleven types of chaos attractors. It was shown that various researchers' studies on chaos attractors were predominantly on a metaphorical level and that very few empirical tests were done. This Chapter attempts to build theories and models for chaos attractors that could be used for explorative testing in the capital project environment to contribute towards improving overall capital project performance.

3.2 Structure for Theory and Model Building

The structure for theory and model building for this Chapter is shown in Figure 3-1.

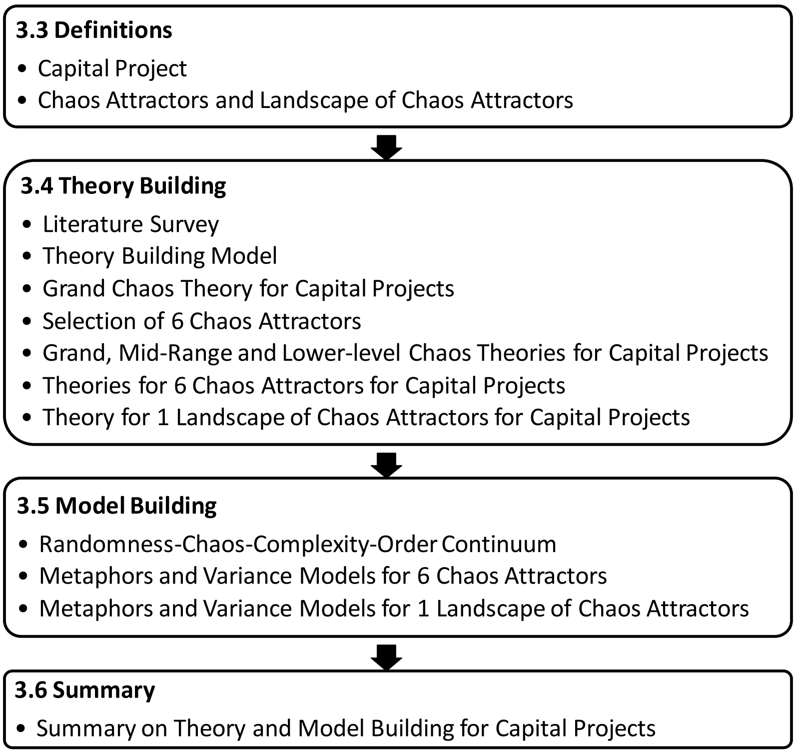

Figure 3-1: Structure for Theory Building and Model Building for this Chapter

Definitions for capital projects and for chaos attractors are given in paragraph 3.3. This is supplemented with definitions for three-dimensional chaos attractor landscapes. Theories, metaphors and variance models are built in this Chapter using these definitions.

The paragraph on theory building (3.4) is started with a literature survey on aspects relevant to the building of theories such as levels of theory, limitations, expectations, schools of thought and the use of metaphors in theory building of organisations and projects. A specific theory building model is selected to conceptualise theories for the capital project environment. This theory building model is then used to derive a grand chaos theory for capital projects. Six chaos attractors are chosen from a total of eleven, as was identified in the literature survey in Chapter 2, for theory and model building in the capital project paradigm. A mid-range chaos theory is then derived for the capital project domain in order to increase the utility of the theory. Lower-level theories are then conceptualised for six chaos attractors and one theory for a combination of chaos attractors in a chaos attractor landscape.

A model is derived in paragraph 3.5 for the Randomness-Chaos-Complexity-Order Continuum based on the literature survey that was done in Chapter 2, but for application in the capital project environment. Metaphors and variance models are generated for six chaos attractors as well as for a chaos attractor landscape. The lower-level theories that were derived in paragraph 3.4 for the six chaos attractors, enlighten these metaphors and variance models.

This Chapter is concluded and summarised in paragraph 3.6.

3.3 Definitions

Definitions are provided for capital projects with the aim to get to a common understanding on the context of this research. An attempt is also made to define terminology relating to chaos attractors, their context and three-dimensional chaos attractor landscapes.

3.3.1 Definition of Capital Projects

The objective of this research is to better understand chaos theory and to derive and test the convergence effect of models that could be applied to capital projects to aid in improving their performance. But what is meant by capital projects? A number of definitions for capital projects are given in Table 3-1.

Table 3-1: Definitions for Capital Projects

No.	Terminology	Description	Reference
1	Capital Project	"Capital projects involve designing and delivering new assets that are planned to operate for several decades, but over the project and operating lifetimes, design requirements are likely to change"	Biesek and Gil (2012)
		"A project is classified as capital if total expenditure on the project exceeds £50,000 including VAT. A capital project can be either a new build, acquisition of land or property, lease of property, the refurbishment of an existing building or the purchase of a new piece of equipment"	University of Sheffield (No Date)
		"The planning, engineering, procurement, construction and operation of predominantly large-scale buildings, plants, facilities and infrastructure…"	Fiatech (2004:7)
		"A capital project is a lengthy investment used to build, add or improve on a project. It is any task that requires the use of significant capital, both financial and labor, to start and finish. Capital projects are defined by their large scale and large cost relative to other investments that involve less planning and resources."	Investopedia Staff (2012)
2	Capital Project Industry	"The capital project industry includes both the delivery and the maintenance of facilities (e.g., institutional, commercial, and residential buildings; communication, transportation, and energy systems; as well as environmental and industrial facilities)"	Chen (2015:1394)
		"The capital projects industry (i.e. the industry that executes the planning, engineering, procurement, construction and operation of predominantly large-scale buildings, plants, facilities and infrastructure) is a critical element of the industrial base, providing the physical infrastructure that supports our economy and our way of life."	Fiatech (2004:7)
3	Capital Projects in the Process Industries	"Capital projects in the process industries involve the construction of physical plant facilities and materials processing equipment, either to produce a new product for expected profit or alternatively to maintain or develop operating-level capabilities"	Scott-Young and Samson (2008)
4	Capital Project Life Cycle	"The lifecycle of the plant or facility, consisting of the phases 'feasibility - design - construct - startup - operate – renew'."	Fiatech (2004:7)

Definitions for capital projects were not found in the Project Management Institute (PMI), Association for Project Management (APM) or in the project management journals such as Project Management Journal (PMJ), the International Journal for Project Management or in the International Journal of Managing Projects in Business (IJPMB), but rather in one of the proceedings of the PMI (Biesek and Gil, 2012), from the University of Sheffield (University of Sheffield, No Date) website and other organisations (Fiatech, 2004). It thus seems that the concept of capital projects is not as widely used in the project management research community as expected. However, the definition of a capital project as provided by the University of Sheffield as indicated in Table 3-1(1) indicates that capital projects are all projects for which the capital value exceeds £50,000 (about 64,000 USD when converted in 2018) and is sufficient for the purpose of this research. The theories and models that are built in this chapter should be as widely applicable as possible and should not be constrained by further classifications. Flyvbjerg (2014), for example, provided a classification in terms of monetary value as projects (10’s Million USD), major projects (100’s Million USD), mega projects or major programs (1bn USD), giga projects (50bn – 100bn USD) or tera projects (1000bn USD).

From the definitions provided in Table 3-1 it is noted that capital projects include both new (greenfield) and upgrade or renovation project types (brownfield), spans multiple decades, involve substantial financial capital as well as human capital and forms the physical infrastructure that supports any economy.

3.3.2 Typology and Nomenclature for Chaos Attractors

The typical nomenclature for chaos attractors and the configurations that will be investigated in terms of a single chaos attractor (refer to main research question 1 in Chapter 1) and a group of different types of chaos attractors (refer to main research question 2 in Chapter 1) are graphically shown in Figure 3-2.

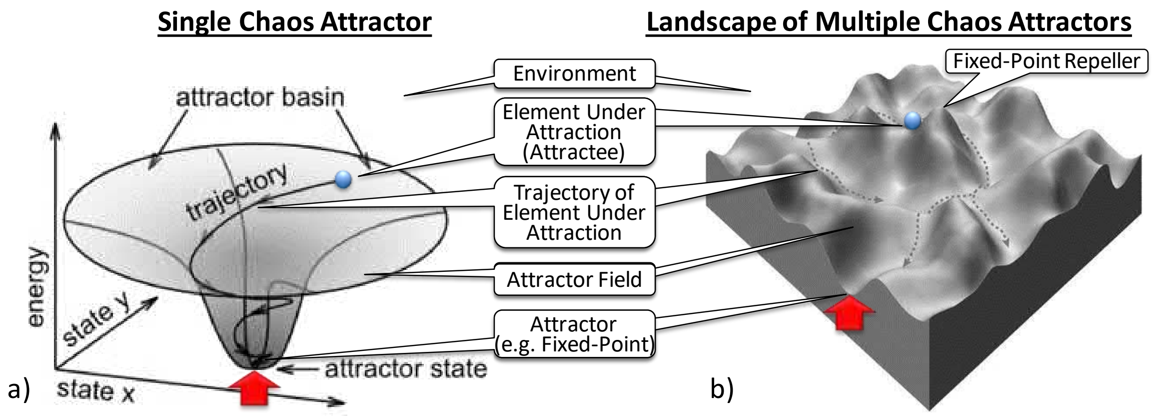

Figure 3-2: Typology and Nomenclature for a) a Single Chaos Attractor and b) a Landscape of Two Types of Chaos Attractors. Sketches adapted from Computational Cognitive Neuroscience Wiki Contributors (2015:p.10 of 14, Figure 3.14) and MacArthur et al. (2009:677, Figure 2)

The graphical representation of one of the many types of chaos attractors i.e. the fixed point chaos attractor, is shown in Figure 3-2(a) and is known as the “ball in basin” metaphor (Harrison, 2013:2 of 6). Multiple graphical representations of the different types of chaos attractor metaphors, as well as for the chaos attractor landscapes, are referred to in the literature. A chaos attractor landscape may consist of only two types of chaos attractors such as, fixed-point chaos attractors and fixed-point chaos repellers as indicated in Figure 3-2(b). A chaos attractor landscape may also consist of any combination of the eleven identified types of chaos attractors as shown later in this chapter in Figure 3-5.

For capital projects, this research attempts to indicate that these chaos attractor combinations are scattered across the span of project development and project execution landscape or life cycle and their effect is believed to steer the detail and overall behaviour of capital project elements and their trajectories towards convergence. The trajectory of project elements such as an individual or a group (elements under attraction) passes through the chaos attractor landscape and is influenced by the attractor field and depending on the strength of this field the trajectory of the element under attraction may be changed. Chaos attractors are considered to be metaphors and as stated by Callahan (2005) “regardless of how we define attractors they are simply a metaphor to help us better understand how organisations work”. This research will aim to gain an understanding of chaos attractors in capital projects.

3.4 Theory Building

The objective of this research is to develop and build theories and models that could be tested on capital projects. However, all theories have limitations and originate from a way of thinking about the world i.e. school of thought (Richardson, 2008). Theories also exist at different conceptual levels with the associated difference in practical application and generalisability. Furthermore, it will be shown that metaphors such as chaos attractors form an important part of theory building and that metaphors have been used in both organisational and project management research, as a means for gaining a better understanding of “how organisations work” Callahan (2005). A theory building model is chosen for this research that forms the basis for theory building for the capital project environment. This section is concluded with the conceptualisation of theories for chaos attractors suitable for the capital project environment.

3.4.1 What is Theory, the Objectives and the Process?

Theorists translate their understanding of reality into abstract ideas and these ideas may be generated at different levels of abstraction known as the "ladder of abstraction" (Zikmund, 2003:42). Also, a number of concepts form a construct and many constructs allow for the formulation of propositions and propositions contribute to theory building or theory development (Zikmund, 2003). When theories are developed in this manner i.e. bottom-up, or from a specific instance to a broad generalisation, an inductive theory building process is employed (Page and Meyer, 2003). Similarly, a deductive theory building process is followed when the starting point for theory derivation is a broad generalisation. A few definitions of what a theory is, and the process of theory construction is shown in Table 3-2.

Table 3-2: Definitions of a Theory

No.	Dimension	Description	Reference
1	Theory	"A theory is a coherent set of general propositions used to explain the apparent relationships among certain phenomena. Theories allow generalizations beyond individual facts or situations"	Zikmund (2003:41)
		A theory explains relations between elements of an event or phenomenon and "make predictions arising from the theory"	Page and Meyer (2003:5)
		"By theory we mean 'an ordered set of assertions about a generic behavior or structure assumed to hold throughout a significantly broad range of specific instances'"	Sutherland as quoted by Weick (1989:517)
		"a theory tries to make sense out of the observable world by ordering the relationships among elements that constitute the theorist's focus of attention in the real world"	Dublin as quoted by Weick (1989:519)
2	Theory Construction	"…the concurrent development of concepts, propositions that state a relationship between at least two properties, and contingent propositions whose truth or falsity can be determined by experience"	Homans as described by Weick (1989:517)
3	Theory Building Process	The theory building "process continuously should weave back and forth between intuition and data-based theorizing and between induction and deduction"	Bourgeois as described by (Weick, 1989:518)

Based on these definitions it seems that a theory must be able to explain the ultimate effect of the relationships of the elements of a phenomena, it has to predict the future behaviour of such phenomena, be generally applicable and be verifiable by experimental data. The theory-building process therefore seems to be an iterative process between, data, induction and deduction.

A literature survey was done in Chapter 2 on chaos theory and related concepts. This information will be used deductively to derive a theory for capital projects.

3.4.2 Levels of Theory

Zikmund (2003:41) states that a theory should enable "generalizations beyond individual facts or situations". However, Bacharach (1989) is of the opinion that theory building could be done at different levels with different implications for generalisation as shown in Figure 3-3.

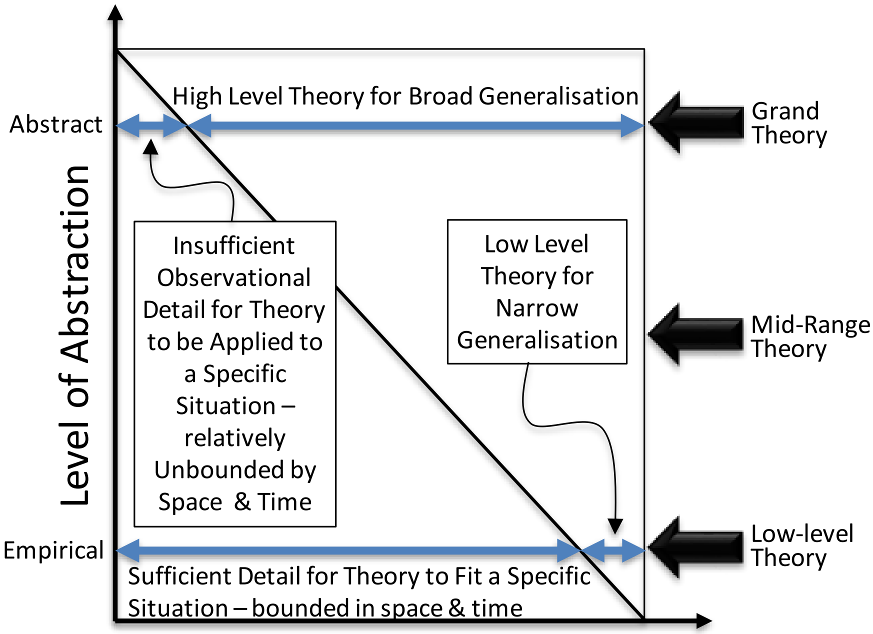

Figure 3-3: Three Levels of Theory-Building and the Impact on Generalisation. Sketch Constructed Based on Information from Bacharach (1989:500) and Noyes et al. (2016:80, Fig. 1)

Bacharach (1989) explains that theories could be generated along the level-of-abstraction continuum, that range from empirical theories to abstract theories as shown in Figure 3-3 on the y-axis. He continues to state that a high-level theory is suitable for broad generalisation but lacks in detail to be applied to a specific situation (highest on the y-axis). The high-level theory is relatively unbound by space and time. On the other side of the level-of-abstraction continuum is a low-level theory. This type of theory, according to Bacharach, is bounded by space and time and could be applied to a specific situation (lowest on the y-axis). A low-level theory could only be generalised in a narrow field of application. The chosen level of theory development therefore determines the level of generalisation to be either broad or narrow or in-between. Noyes et al. (2016) refers to three types of theories along this continuum as Grand Theories, Mid-Range Theories and Low-Level Theories as indicated in Figure 3-3.

Based on this classification of theories, chaos theory as explained in both Chapters 1 and 2, could be considered as a grand theory. For this research, chaos theory as a grand theory will be derived for capital projects but then further deducted to mid-range and lower-level theories in order to allow for explorative testing in a capital project environment.

3.4.3 The Limitations and Expectations of Scientific Theory

Richardson (2008:13) states that no general theory of organisational management exists and that “management is as much an art as it is a science”. He asserts that these types of systems are not merely complicated but complex. He states that the properties of complex systems and specifically complex adaptive systems (CAS) such as nonlinear feedback loops, emergence, self-organization, adaptation, learning and the complex behaviour of the individual parts make it impossible to “compress” (p. 16) such systems into a single frame of understanding. He concluded that there are therefore “multiple valid representations of the same complex system” and that "there exists an infinitude of equally valid, non-overlapping, potentially contradictory descriptions" for organisations (Richardson, 2008:17). This line of reasoning is supported by Maxwell who states that:

> ***“Any scientific theory, however well it has been verified empirically, will always have infinitely many rival theories that fit the available evidence just as well but that make different predictions, in an arbitrary way, for as yet unobserved phenomena.” (Maxwell, 2000:17)***

Richardson (2008:17) also refers to the Complementary Law as formulated by Weinberg to emphasise the value of plurality in theory using multiple perspectives as follows:

> ***“The complementary law from general systems theory suggests that any two different perspectives (or models) about a system will reveal truths regarding that system that are neither entirely independent nor entirely compatible.”***

Richardson (2008) concluded that from this line of argumentation that a multi-perspective approach and a view from multiple directions are therefore necessary in research, in order to have a chance of beginning to understand complex organisational systems.

The theory of chaos attractors in capital projects that are derived in this Chapter will therefore have a limitation that it will merely describe one viewpoint of a complex phenomenon, but with the aim to contribute to enlightening some important aspects of this phenomenon. Are theories developed from specific viewpoints by different researchers?

3.4.4 Schools of Thought in Complexity Science and the Use of Chaos Theory and Metaphors

Could theories be derived from physical, natural, non-social systems and be applied directly to social systems? Could the chaos theories be transposed from other fields to capital projects? Richardson (2008) noted that there are currently three schools of thought in the complexity sciences evolving that support organisational management. He notes that these three schools are "isolated from each other, but themselves form a complex system of interrelationships" (p. 18). These schools of thought in the complexity sciences relevant to management are the Neo-Reductionist school, Critical Pluralist's school and the Metaphorical school as shown Table 3-3.

Table 3-3: Three Schools of Thought in the Complexity Science Relevant to Management

No.	Descriptor	Neo-Reductionist School	Critical Pluralists School	Metaphorical School
1	Science	Hard Reductionist Complexity Science	Critical Thinking	Soft Complexity Science
2	Belief System	• The social world is the same as the natural world (Logic derived from Richardson (2008:20))	• The social world is in some instances the same and in other instances different than the natural world (Logic derived from Richardson (2008:20))	• "The social world is intrinsically different from the natural world" (Richardson, 2008:20)
3	World View	• "The Newtonian view of the Universe leads to… Universe is a really big machine" (Richardson, 2008:24)	• "There are more than one or more than two kinds of ultimate reality" (Glynn et al., 2000:726)	• "The world is viewed metaphorically as an organic entity" (Raisio and Lundström, 2017:301)
4	Theory Building	• Search for a "Theory Of Everything (TOE) similar to physics • A-contextual explanation for the existence of everything (Richardson and Cilliers, 2001:5) • "Mimic the aim of the physical sciences in trying to reduce the wide richness of reality to a handful of	• "Some natural phenomena cannot be fully explained by a single theory or fully investigated using a single approach… multiple approaches are required for the explanation and investigation of such phenomena." (Kellert et al., 2006)	• "The theories of complexity, which have been developed through the examination of primarily natural systems, are not directly applicable to social systems, although their language may trigger some relevant insights into the behaviour of the social world" (Richardson, 2008:20)

No.	Descriptor	Neo-Reductionist School	Critical Pluralists School	Metaphorical School
		powerful, all-embracing algebraic expressions." (Richardson and Cilliers, 2001:6)		• "We believe that chaos theory can be applied in the social sciences at least on a metaphorical level and that it helps us better understand the many complexities of social systems as opposed to natural systems" (Raisio and Lundström, 2017:303)

The Neo-Reductionist school of thought is considered a hard reductionist complexity science that believes the social world is the same as the natural world, that the world and the universe work like a big machine (clockwork) and that there exists, in the social world, a single Theory of Everything (TOE) that is context independent (a-contextual) similar to the world of physics (Richardson, 2008; Richardson and Cilliers, 2001). Under this paradigm the "world is viewed as deterministic and reductionistic" with clear causality with which the future could be predicted (Raisio and Lundström, 2017:301). The social world could be expressed in the form of algebraic formulae and complicated numerical models (Richardson, 2008). The problem with this school of thought is the assumption that the random and non-deterministic human freewill (refer to Chapter 2) could somehow be modelled and predicted deterministically (Raisio and Lundström, 2017). Oreskes et al. (1994) demonstrated that the verification and validation of numerical models of natural systems are impossible, because natural systems are not closed and the results are always partial and non-unique. At best the predicted value of these models lies in some form of agreement and its heuristic value.

On the other side of the spectrum is the Metaphorical School of thought of the soft complexity sciences. This school believes that the social world is fundamentally different from the natural world, that the world should be understood as an organism that constantly changes shape and size and that the theories of the natural systems cannot be transferred to the social systems. However, the value of the use of metaphors in social system research lies in the "language [that] may trigger some relevant insights into the behaviour of the social world" and provides researchers a lens to "see" organisational behaviour (Richardson, 2008:20). They believe that chaos theory could be applied to social sciences to improve the "understanding of complexities of social systems" (Raisio and Lundström, 2017:303).

The Critical Pluralist school, using the critical thinking science, forms the third school of complexity thinking between the extremes of the "neo-reductionists" and the "metaphorticians" (Richardson, 2008:18). Based on the logic classification of Richardson, this school of thought believes that the social world is in some instances the same and in other instances different from the natural world and that there is always more than one "kind of reality" or theory that will fit a specific set of research data (Glynn et al., 2000:726) i.e. plurality of theories and methods.

Richardson (2008:18) notes that these schools of complexity thought are not independent from each other but form a "complex system of interrelationships" i.e. theories that are formulated by researchers may contain elements of the different schools of thought.

For this research the convergence effect of chaos attractor metaphors is explored and therefore the dominant school of complexity thought will be the Metaphorical School. However, it will be shown that the physical sciences are used in many cases to explain the metaphors (Neo-Reductionist school) and in many cases both schools of thought will be used. Further explanation is required on the nature of a metaphor.

3.4.5 Metaphors Used in Organisational Theory Building

Morgan and Reichert (1999:1) refer to the definition of a metaphor as defined by Lakoff and Johnson as "statements and/or pictures which cause a receiver to experience one thing in terms of another". Morgan et al. (1997) used various metaphors to describe the complex multi-dimensional behaviour of an organisation and to gain a diagnostic or first order understanding of this organisation's behaviour. For example, he described the company Multicom's behaviour as a machine ("drifting into a mechanistic mode of operation"), as a brain ("team-based, learning organization that is being bureaucratized"), as an organism ("drifting out of alignment with the challenges of the external environment") or as a psychic prison ("organization that has been shaped by conflicting ideologies") (Morgan et al., 1997:360). These known metaphors that are understood by researchers in one particular context (source domain), are then transferred to another context (target domain) to gain an understanding of the complex characteristics of the target domain in terms of the source domain (Boxenbaum and Rouleau, 2011). Morgan and Reichert (1999:1) are convinced of the explanatory power of metaphors when they state that "a single metaphor can be worth a hundred words". Some advantages and disadvantages of using metaphors in the theory building process are indicated in Table 3-4.

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Table 3-4: Advantages and Disadvantages of Using Metaphors in Theory Building

No.	Dimension	Citation	Reference
A. Advantages			
1	Part of Cognitive Processing	“metaphors constitute a core component in cognitive processing”	Boxenbaum and Rouleau (2011:273) referring to the work of Cornelissen et al. (2005) and Cornelissen and Kafouros (2008)
2	Sense Making Vehicles	"As vehicles of sense making, metaphors operate as creative catalysts in organizational theory building. They embody images that stimulate the imagination and enable theorists to generate novel perspectives on organizational life"	Boxenbaum and Rouleau (2011:276)
3	Compact Description of Complex Phenomena	“Metaphors are not just catchy phrases designed to dazzle an audience. Instead, they are one of the few tools to create compact descriptions of complex phenomena”	Weick (1989:529)
4	Source of Imagination	Metaphors are a “valuable source of imagination, one that inspires theorists to generate novel propositions”	Boxenbaum and Rouleau (2011:273) referring to the work of Bacharach (1989)
5	Continually Shape the Theories Under Development	Metaphors continually “shape the knowledge product… [and] remain integrated with the theoretical concepts and empirical material” development	Boxenbaum and Rouleau (2011:273) referring to the work of McKinley (2010)
6	Metaphor Mappings Provide Theoretical Insight	“we can only know what an organization is by mapping structure and meanings from other domains, such as machines, politics or evolution, onto it, with each of these mappings providing different insights and understandings of what an organization is”	Cornelissen and Kafouros (2008:365) referring to the work of Morgan et al. (1997)
7	Creation of a Network of Theoretical Concepts	“Metaphor is not merely the first step in transforming tacit knowledge into explicit knowledge; it constitutes an important method of creating a network of concepts which can help to generate knowledge about the future by using existing knowledge.”	Nonaka (1994:21)
B. Disadvantages			
1	Source of pollution	Metaphors are a “source of pollution in scientific thinking and writing”	Boxenbaum and Rouleau (2011:273)
2	Absence of Legitimacy of Metaphor Importation - Grounding Required	“The concern is with its use in the absence of criticism - metaphors are being imported left, right and centre with very little attention being paid as to the legitimacy of such importation… playful activity in academic circles, but if such playfulness is to be usefully applied in serious business then some rather more concrete grounding is necessary.”	Richardson (2008:20)

The advantages of using metaphors in theory building, according to Table 3-4, include aiding cognitive processing, sense making, compact description of complexity, sources of imagination, continuous shaping of theories under development and provision of concepts and theoretical insight.

Morgan and Reichert (1999) studied the use of metaphors in advertising. They found that an effective metaphor must be easy to comprehend to avoid misinterpretation. They also found that a verbal metaphor that is supported by a visual image “enhanced the comprehensibility of the metaphor” (p. 8). They refer to the work of McCabe on concrete and abstract metaphors. Concrete metaphors can be experienced through the five senses of “touch, taste, sight, smell and hearing” (p. 2) while an abstract metaphor contains intangible qualities such as “grace” (p. 2). Morgan and Reichert (1999) found in their research that respondents with high cognitive processing skills were able to correctly comprehend both concrete and abstract metaphors.

An effective metaphor must not only be correctly understood but the mapping or transfer of the metaphor from the source domain to the target domain must lead to the creation of new meaning in the target domain. Cornelissen et al. (2005:1551) state that the process of creation of “new meaning” occurs through the process of “seeing-as” or “conceiving-as” in the target domain. This new insight contributes to theory building concepts in the target domain. Bacharach (1989: 497) cautions that “metaphors are not theories but may well serve as precursors to theories” and could therefore be deemed valuable for theory building.

The use of metaphors in theory building also has disadvantages as shown in Table 3-4, in terms of the indiscriminative application in research without the required rigor. Cornelissen et al. (2005) indicated that chaos metaphors, as a root metaphor in organisational studies, had only been used 11 times during the period 1993 – 2003 in their research data set. This is in comparison to a frequency of 851 for the same period for the ‘organisation-as-a-machine’ metaphor. This research will attempt to use metaphors for chaos attractors to demonstrate convergence from chaos to order in capital projects. The research methodology should therefore be designed in Chapter 4 to test for comprehensibility and the creation of new insight when using chaos metaphors in the capital project domain to demonstrate rigor in the research results.

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3.4.6 Metaphors Used in Theory Building of Project Management

Metaphors are also used to gain a better understanding of project behaviour. Bredillet (2008) summarised the progress and trends in the study of project management for the period 1940 to approximately 2000 by categorising nine schools of thought. For each school of thought, a dominant metaphor describes the key ideas about the characteristics of a project as shown in Table 3-5.

Table 3-5: Metaphors Used in the Nine Schools of Project Management Thought (Bredillet, 2008:4, Table 1)

School	Metaphor	Key Idea	Came to Prominence	Influence
Optimization	The project as a machine	Optimize the outcome of the project using mathematical processes	Late 1940s	Operations research
Modeling	The project as a mirror	Use of hard and soft systems theory to model the project	Hard systems: mid-1950s Soft systems: mid-1990s	Systems theory, Soft systems methodology
Governance	The project as a legal entity	Govern the project and the relationship between project participants	Contracts: early 1970s Temporary organization: mid-1990s Governance: late 1990s	Contracts and law, Governance, Transaction costs, Agency theory
Behavior	The project as a social system	Manage the relationships between people on the project	OB: mid-1970s HRM: early 2000s	OB HRM
Success	The project as a business objective	Define success and failure Identify causes	Mid-1980s	Internal to project management
Decision	The project as a computer	Information processing through the project life cycle	Late 1980s	Decision sciences, Transaction costs
Process	The project as an algorithm	Find an appropriate path to the desired outcome	Late 1980s	Information systems, Strategy
Contingency	The project as a chameleon	Categorize the project type to select appropriate systems	Early 1990s	Contingency theory, Leadership theory
Marketing	The project as a billboard	Communicate with all stakeholders to obtain their support	Stakeholders: mid-1990s Board: early 2000s	Stakeholder management, Governance, Strategy

It should be noted that the ‘project-as-a-machine’ metaphor was used to gain an understanding of organisational behaviour as discussed in paragraph 3.4.5 by Morgan et al. (1997) as well as for project behaviour as shown in Table 3-5. Other metaphors were also used to describe project behaviour such as the project as a mirror, legal entity, social system, business objective, computer, algorithm, chameleon and billboard as shown in Table 3-5.

Svejvig and Andersen (2015) studied the Rethinking Project Management (RPM) literature between 1983 and 2012 as found in certain chosen databases and compared the differences between classical project management with RPM. They found that “a project as a tool” to be the dominant metaphor describing classical project management characteristics and “a project as a temporary organisation” to be the dominant metaphor describing the rethinking project management paradigm (p. 297). Alderman and Ivory (2007:388) researched partnering as an alternative contractual approach in projects. They used partnering as a metaphor to describe the “the less tangible aspects of contemporary social relationships” between contractors, clients, consultants and supply chains. They found that the partnering metaphor helped to map the characteristics of human relationships from the source domain to the commercial relationship in the target domain and generated new insight of this phenomenon. Hekkala et al. (2018) conducted a longitudinal study on the use of metaphors by project team members, managers, users and developers in public sector IT projects. They found that different metaphors were used at different stages of the project and that metaphors had a “significant power in sensemaking, influencing action and project outcomes” (p. 142). However, they also found that when metaphors were used with unclear intentions and a lack of purpose in “highly ambiguous, knowledge-intensive situations” (p. 143) it resulted in “more chaos than order” (p. 166).

It could be concluded from this paragraph that the use of metaphors to gain an understanding of project management is not a new practice to researchers. However, the selection of appropriate metaphors is a prerequisite for the contribution to theory building in project management.

3.4.7 Theory Building Model

Cornelissen and Kafouros (2008:365) state that “our ability to theorize and reason about organizations is significantly influenced by the metaphorical representations of organizations”. Bacharach (1989: 497) cautions that metaphors are not theories but just “precursors to theories”. What role do metaphors then play in theory generation? Boxenbaum and Rouleau (2011) argue that metaphors, together with empirical material and borrowed theoretical concepts, are the components and building blocks of theory building as shown schematically in their organisational theory building model in Figure 3-4.

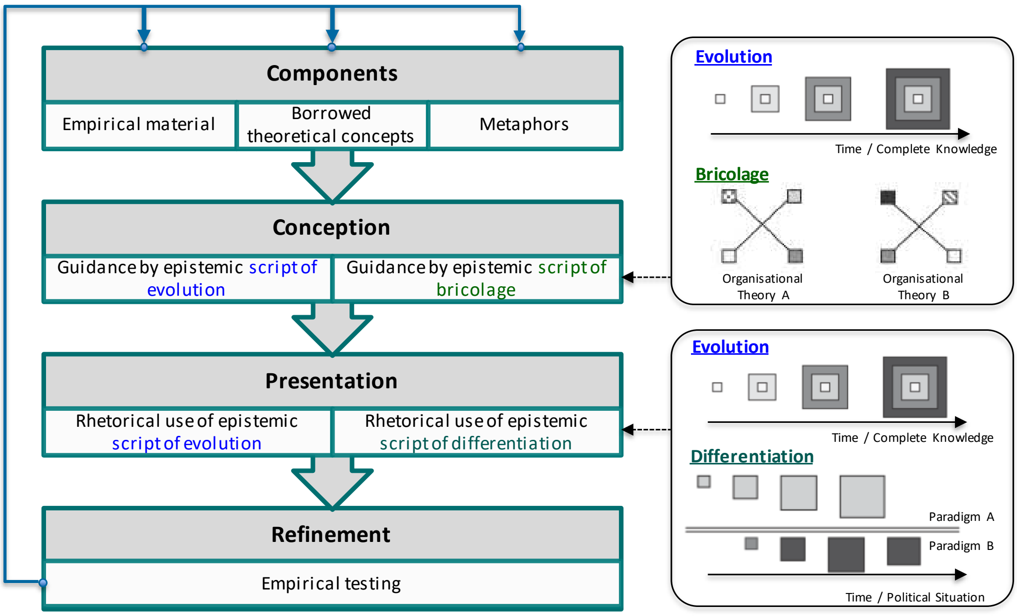


Figure 3-4: Theory Building Model for Organisations (Reproduced from Boxenbaum and Rouleau (2011:278, 288, Figure 1, 2))

Empirical material is obtained from practice using Grounded Theory principles (Eisenhardt, 1989; Corbin and Strauss, 1990; Gioia et al., 2013) to ensure a "systematic recording of empirical observations and a rigorous analysis" of these observations (Boxenbaum and Rouleau, 2011:274). Empirical material alone is not sufficient to build theories due to the complexity and abstract nature of organisational behaviour – theoretical concepts are also required (Weick, 1989). Whetten et al. (2009) revealed the common practice among theory builders to borrow concepts from psychology and sociology in organisational theory building. They distinguish between "horizontal borrowing", when theoretical concepts are borrowed from social context and applied to another context and "vertical borrowing" where theoretical concepts are borrowed in the same social context but from different levels of analysis (p. 538). The "superimposition" of metaphors from a source domain to a target domain "stimulate the imagination" and "enable theorists to generate novel perspectives on organizational life" (Boxenbaum and Rouleau, 2011:276).

The next step in theory building is to generate theoretical concepts from the available theoretical components and to then present these theories to the academic environment for acceptance. Boxenbaum and Rouleau (2011:279, 281) reasons that the manner in which theories are conceptualised comprise either "a script of evolution" (knowledge evolvement through trial-and-error) or a "script of bricolage" (assembly of different knowledge elements"). When newly generated theories are presented to the academic environment, they found that researchers used either "a script of evolution" or a "script of differentiation" (different paradigms) (p. 280). Formulated theories are then tested and refined in an iterative process as shown in Figure 3-4.

3.4.8 Summary of Theory Building Concepts

Concepts important in theory building are summarised in this section to form a basis for theory building for capital projects as follows:

a) Theories, Objectives and Processes

i. The objective of a theory is to explain and predict the behaviour of phenomena; it is composed of a set of propositions, tries to make sense of the observable, allows for generalisations beyond individual facts and are created in an iterative manner (Table 3-2)

ii. Deductive theory building is derived top-down from a high level of abstraction towards reality (Zikmund, 2003)

iii. Inductive theory building is constructed bottom-up from reality-observations toward higher abstract levels (Zikmund, 2003).

b) Levels of Theory

i. A grand theory has the highest level of abstraction, could be generalised broadly but lacks application to a specific situation in space and time (Figure 3-3)

ii. A mid-range theory fits between a grand and low-level theory and could be generalised moderately and moderately applied to a specific situation

iii. A low-level theory has the lowest level of abstraction and could be applied to a specific situation in space and time but lacks generalisation.

c) Limitations and Expectations of Theory

i. Any scientific theory will always have infinitely many competing theories that could be fitted to the empirical data but that will make different predictions (Maxwell, 2000)

ii. The complementary law states that any two different models of a system will reveal truths that are not completely independent but also not completely compatible (Weinberg, 1975)

iii. A multi-perspective view on any phenomena is required in order to have a chance to begin to understand complex organisations.

d) Schools of Thought in the Complexity Science

i. The Hard Reductionist School of thought believes that the social world is exactly the same as the natural world, that the world works like a big clock and scholars are in search of a single Theory Of Everything (TOE) (Table 3-3)

ii. The Pluralist School of thought believes that the social world is only in some instances the same as the natural world, that there is more than one kind of reality and that natural phenomena cannot be explained by a single theory

iii. The Metaphorical School of thought believes that the social world is different from the natural world, the world behaves as an organic entity and that chaos theory helps to better understand the many complexities of the social world.

e) Metaphors in Organisational Theory Building

i. Nine dominant metaphors have been used to describe project management behaviour for the period between 1940 – 2000 (Table 3-5)

ii. Classical project management could be described by the project-as-a-tool metaphor in comparison with the rethinking project management scholars who describe project management as a temporary organisation (Svejvig and Andersen, 2015)

iii. Different metaphors are used at different stages of a project for sense making, influencing actions and achieving project outcomes (Hekkala et al., 2018)

iv. Metaphors with unclear intentions and lack of purpose, that are used in highly ambiguous and knowledge intensive situations create more chaos than order (Hekkala et al., 2018).

f) Theory Building Model

i. Components of theories may consist of empirical observations, borrowed theoretical concepts as well as metaphors (Figure 3-4)

ii. Theoretical concepts are formed by new arrangements of theoretical components either in an evolutionary format or by joining different concepts as bricolage

iii. Academic presentation of theoretical concepts is done either as evolution or showing paradigmatic differences

iv. Once theories are tested, the theory building process remains iterative.

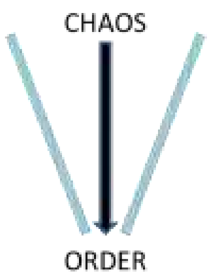
3.4.9 Theory Building for the Capital Project Environment

In this section the principles of theory building are used to conceptualise theories for the capital project environment. A grand theory for capital projects is derived. Six chaos attractors are selected for this research and mid-range and lower-level theories are derived for capital projects. Theories are derived for individual chaos attractors but also for a landscape of chaos attractors.

3.4.9.1 Grand Theory Building for Capital Projects

The theory building model as proposed by Boxenbaum and Rouleau (2011) and as shown in Figure 3-4 is used to build a grand chaos theory for social systems as shown in Table 3-6.

Table 3-6: Building a Grand Chaos Theory for Social Systems

1	**Theory-Building Components**	
a	Empirical Material (Observations)	● Multi-final, self-organising and purposeful behaviour of socio-cultural systems (Gharajedaghi, 2011) ● Rebuilding of societal order after war (Ikenberry, 2009) ● Reconstruction of societal order after catastrophic events such as Hurricane Katrina (Kates et al., 2006)
b	Borrowed Theoretical Concepts	● “Despite its name, chaos theory considers the tendency toward order a natural phenomenon produced by the action of four types of attractors: point attractors, cycle attractors, torus attractors and strange attractors” Gharajedaghi (2011:57) ● “Although known as the four ‘chaos attractors’, they are really the opposite - they are cosmos attractors that balance chaos. The four ‘attractors’ bring order out of chaos… these attractors balance entropy, providing order from out of chaos.” School of Wisdom (No Date:1 of 4) ● “Attractors configure the evolution of complex adaptive systems… since attractors are the most stable and robust elements in these systems... they [the systems] do not end up in chaos or randomness, but organise themselves around various attractors.” Kuhmonen (2017:214, 218)
c	Metaphor (Verbal and Visual)	● Convergence from chaos to order (Rubinstein and Firstenberg, 1999)  ● Sketch from Rubinstein and Firstenberg (1999:99, Figure 5.1)
2	**Theory Conceptualisation**	
a	*Chaos theory considers the convergence from chaos to order a natural phenomenon in social systems that is brought about by point, cycle, torus and strange attractors*	

Adding empirical observations to borrowed theoretical concepts and a metaphor for convergence from chaos to order, using the principle of bricolage (refer to Figure 3-4), allows for the conceptualisation of chaos theory for social systems as shown in Table 3-6. The building of a theory using “different knowledge elements that are readily available” (Boxenbaum and Rouleau, 2011:281) i.e. bricolage, make it possible to take leaps of faith (Langley, 1999) or jumps from the various source domains to a new target domain in the conceptualisation process. This is how new theories are born.

The components of a theory include theoretical observation as shown in Figure 3-4. Gharajedaghi (2011) observed that socio-cultural systems that have plurality of structure, process and functions, are able to reach multiple ideals, are interactive, can self-organise, can re-design themselves, can re-create the future and serves itself, its members and the environment and is known as the Developmental Theory of Purposeful Systems (p. 70 - 73). War is normally associated with destruction, but every war’s destruction is followed by re-construction. Defeated societies are re-constructed and re-build from a situation of destruction and chaos to a new order after a war (Ikenberry, 2009). The destruction of the environment and society as a result of natural catastrophes is followed by a period of reconstruction and a new order (Kates et al., 2006).

Three theoretical concepts are chosen that relate to the movement from chaos to order. Firstly, Gharajedaghi (2011) is convinced that the formation of order from chaos is a natural phenomenon that is brought about by four chaos attractors i.e. point, cycle, torus and strange. Secondly, the School of Wisdom (No Date) is of the opinion that chaos attractors balance entropy i.e. a chaos attractor injects negative entropy into a system that drifts naturally to increased entropy and thereby produces new and different outcomes. Thirdly, chaos attractors are considered the most stable and robust elements of complex adaptive systems and ensure the production of order from chaos (Kuhmonen, 2017).

Rubinstein and Firstenberg (1999) describe a metaphor of a converging cone for the movement of a system from chaos to order as shown in Table 3-6(1c). Adding the empirical observations to the theoretical concepts with a descriptive metaphor allows for the conceptualising of a chaos theory for social systems as follows:

> ***Chaos theory considers the convergence from chaos to order a natural phenomenon in social systems that is brought about by point, cycle, torus and strange attractors.***

Using the principle of horizontal theory borrowing from one social context to another as described by Whetten et al. (2009), and assuming that the capital project environment could also be described as a social context (Lundin and Söderholm, 1995; Packendorff, 1995; Turner and Müller, 2003), a grand chaos theory for the capital project paradigm could be formulated as shown in Table 3-7.

Table 3-7: Formulating a Grand Theory for the Capital Project Management Paradigm Using the Principle of Horizontal Paradigmatic Theory Borrowing

No.	Social Paradigm		Capital Project Management Paradigm
1	*1a) Chaos theory considers the convergence from chaos to order a natural phenomenon in social systems that is brought about by point, cycle, torus and strange attractors*	➔	*1b) Chaos theory considers the convergence from chaos to order a natural phenomenon <u>in capital projects</u> that is brought about by point, cycle, torus and strange attractors*

This grand theory for capital projects could be considered to be broad in its generalisation but limited in its application to a specific capital project situation as shown in Figure 3-3. To enhance the utility, explanatory and predictive value of this theory, lower level theories have to be derived for different chaos attractor metaphors for capital projects based on this grand theory.

3.4.9.2 Selection of Chaos Attractors for this Research

Four prominent chaos attractors and eleven derived types were identified during the literature survey in Chapter 2, Figure 2-21. To limit the scope and maximise the exploratory value of this research, it was decided to select only six chaos attractors for mid-range and lower-level theory and model building as shown in Figure 3-5.

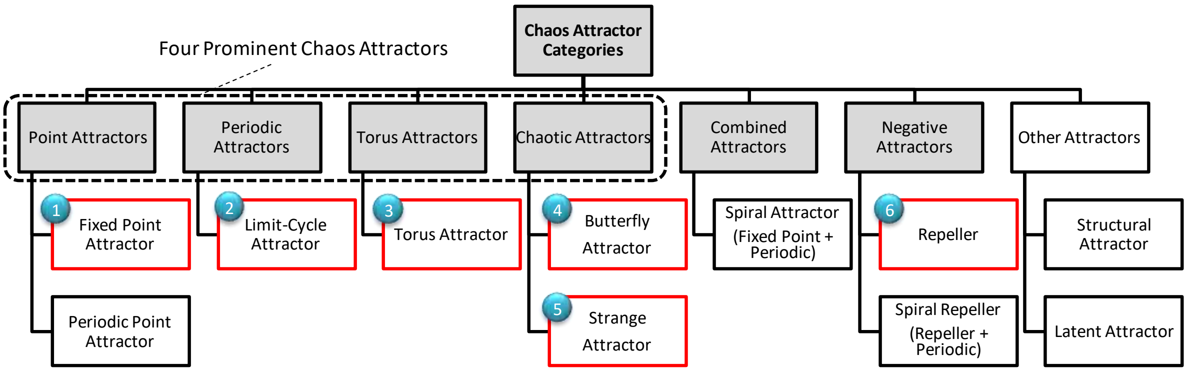


Figure 3-5: Selection of Six Chaos Attractors for Mid-Range and Lower-Level Theory and Model Building for this Research

The first five chaos attractors were chosen to be sub-categories of the four prominent chaos attractors. The Butterfly chaos attractor was chosen because Saynisch (2010) indicated that chaos attractor may explain the maturity jump at project stage-gates as shown in Chapter 2, Figure 2-33. The chaos repeller was chosen because of the guidance effect in a three-dimensional landscape on system trajectories when only chaos attractors and repellers are used as shown in Figure 3-2.

It is important to note that although the chaos theory as stated by Gharajedaghi (2011:57) refers to the strange chaos attractor as one of the prominent chaos attractors, it appeared from the literature survey in Chapter 2 that there are actually two types of chaotic attractors: a) butterfly attractors and b) strange attractors. In the remainder of this research the term strange chaos attractor will be used to represent any one of two types of chaotic chaos attractors. It should also be noted that in the literature and in this research that when a repeller is considered as part of the other selected chaos attractors they are all referred to as “chaos attractors”.

3.4.9.3 Mid-Range Theory Derivation for Capital Projects

A mid-range theory for capital projects could be derived in a top-down manner using the principle of vertical theory borrowing within the same context (Whetten et al., 2009) as shown in Table 3-8.

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Table 3-8: Mid-Range Theory Derivation for Capital Projects Using the Principle of Vertical Theoretical Borrowing

No.	Description	Capital Project Management Paradigm
A. Grand Theories		
1	Grand theory (Table 3-7(1b))	*1a) Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by point, cycle, torus and strange attractors*
2	Eleven chaos attractor types were Identified (Figure 3-5)	↓ 2a) Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by eleven types of chaos attractors
3	Only six chaos attractors will be used in this research (Figure 3-5)	↓ 3a) Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by the following six chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange
B. Mid-Range Theories		
4	Differentiate between separate and combined effects i.e. local convergence and overall convergence	↓ 4a) Chaos theory considers the local convergence from chaos to order a natural phenomenon in capital projects that is brought about by the following six individual chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange
		↓ 4b) Chaos theory considers the overall convergence from chaos to order a natural phenomenon in capital projects that is brought about by different configurations of the following six chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange

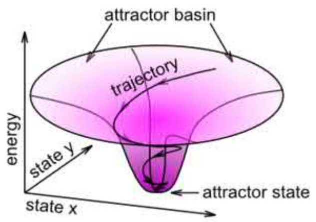
The grand theory for capital projects is successively deductively transformed into a mid-range theory with the aim to broaden the application to different elements of capital projects as shown in Table 3-8. The first derivation is from the four prominent attractors (point, cycle, torus and strange) to the eleven types as found in the literature survey in Chapter 2 and then a reduction to only six chaos attractors that will be considered for this research (Table 3-8(2,3)). The next level derivation is to divide the theory to address the local convergence effect of individual chaos attractors but also the combined convergence effect of combinations of chaos attractors in a landscape for overall convergence in capital projects. This division into separate and combined effects is also done in order to have mid-range theoretical formulations that could be tested to provide answers to the two main research questions for this research (refer to Chapter 1, paragraph 1.9.1). The main research questions refer to individual and combined effects.

In the following paragraphs, mid-range to lower-level theories are be built for individual chaos attractors and for a group of chaos attractors to cause local and overall convergence in capital projects.

3.4.9.4 Lower-Level Theory Building for an Individual Fixed-Point Chaos Attractor for Capital Projects

Using the theory building model as described in Figure 3-4, a conceptual theory is built for fixed-point chaos attractors as shown in Table 3-9. The principle of bricolage (Boxenbaum and Rouleau, 2011) has been applied in the theory conceptualisation.

Table 3-9: Lower-Level Theory-Building for the Fixed-Point Chaos Attractor in Capital Projects

1	**Theory-Building Components**	
a	Empirical Material (Observations)	● Milestones in food supply chain studies (Kuhmonen, 2017) ● Habits, norms, dominant designs, preferences, ideals, innovations, demand trends (Kuhmonen, 2017)
b	Borrowed Theoretical Concepts	● “The point attractor describes behaviour when the object in question (a thing or person) is attracted to one specific thing or point” (Bright and Pryor, 2005:300) ● “A fixed-point attractor describes a particular state to which the given system returns regardless of perturbation” (Vallacher et al., 2013:168)
c	Metaphor (Verbal and Visual)	● Metaphor for convergence through “ball-in-basin” cone (Harrison, 2013:2 of 6)  ● Sketch from Computational Cognitive Neuroscience Wiki Contributors (2015:10 of 14, Figure 3.14)
2	**Theory Conceptualisation**	
a	*A fixed-point chaos attractor generates an attractor basin and causes capital project elements and their trajectories to converge to a fixed-point in the basin even if they are perturbed*	

Empirical observations were made by Kuhmonen (2017) when he noticed that emerging food systems organise themselves around fixed point attractors in the form of milestones. He then realised that many other forms of fixed-point chaos attractors are evident from every-day-life such as habits, norms, dominant designs, preferences, ideals, innovations and demand trends.

Bright and Pryor (2005) studied chaos theory in careers with application in career counselling in terms of individual goal setting. Their theoretical concept for a fixed-point chaos attractor is that an object or person could be attracted to a specific thing or fixed point. A career of an individual could thus be optimised if a fixed-point goal is set. Vallacher et al. (2013) studied mental dynamism in psychology and the habits and behaviour of persons that repeat. They state that when a person defaults to the same pattern of thought or an emotional state over a period of time, that a fixed-point chaos attractor is at work. They also mention that regardless of a change in environment, the person kept on returning to this “habitual” (p. 168) behaviour.

Harrison (2013) used the “ball-in-basin” metaphor to describe the characteristics of a fixed-point chaos attractor to explain equilibrium and tipping points of ecological systems. A wide and deep basin represents a resilient system and the ball is likely to remain in that basin even if perturbed (disturbed) as shown in Table 3-9(1c).

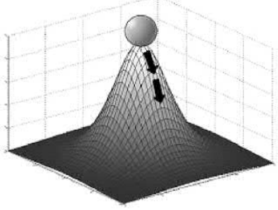
The theory for a fixed-point chaos attractor is compiled of the above elements and formulated for capital projects as follows:

> ***A fixed-point chaos attractor generates an attractor basin and causes capital project elements and their trajectories to converge to a fixed-point in the basin even if they are perturbed.***

3.4.9.5 Lower-Level Theory Building for an Individual Fixed-Point Chaos Repeller for Capital Projects

The elements to build a theory for a fixed-point chaos repeller for capital projects is shown in Table 3-10.

Table 3-10: Lower-Level Theory-Building for the Fixed-Point Chaos Repeller in Capital Projects

1	**Theory-Building Components**	
a	Empirical Material (Observations)	● Unstableness of a system at a fixed-point (Kent and Stump, No Date) ● System moves quickly away from a fixed point (Butner et al., 2015)
b	Borrowed Theoretical Concepts	● “A repeller is a point from which a given system is forced away within an attractor landscape” (Vallacher et al., 2013:169)
c	Metaphor (Verbal and Visual)	● Metaphor for divergence away from a mountaintop (Butner et al., 2015) 

		● Sketch from Vallacher et al. (2013:170, Figure 3)
2	**Theory Conceptualisation**	
a	*A fixed-point chaos repeller generates a fixed point-of-repulsion and causes capital project elements and their trajectories to be diverted away from the fixed-point*	

Kent and Stump (No Date) state that the unstableness of a system at a fixed point such as a pen balancing on its tip, represents the characteristics of a fixed-point chaos repeller. A small change in any environmental condition, will cause the pen to fall over. Butner et al. (2015) used a topological landscape with mountains and valleys to represent statistical theories. They found that a system that is located on a mountaintop quickly moves away from that position as soon as it starts to move. The metaphor for a fixed-point repeller is suggested by Butner et al. (2015) as a ball that is located at a mountaintop and moves away from that position with any slight disturbance as shown in Table 3-10(1c). These elements are combined to formulate a theory for a fixed-point chaos repeller for capital projects as follows:

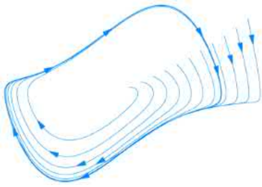
A fixed-point chaos repeller generates a fixed point-of-repulsion and causes capital project elements and their trajectories to be diverted away from the fixed-point.

3.4.9.6 Lower-Level Theory Building for an Individual Limit-Cycle Chaos Attractor for Capital Projects

The theory building elements and newly generated theory for a limit-cycle chaos attractor for capital projects is shown in Table 3-10.

Table 3-11: Lower-Level Theory-Building for the Limit-Cycle Chaos Attractor in Capital Projects

1	**Theory-Building Components**	
a	Empirical Material (Observations)	● Systems that display repeated rhythmic behaviour (Vallacher and Nowak, 2007) ● Hunger causes the intake of regular / cyclical meals (Levick, 2002) ● Habits, routines and automatic pattern of thinking (Vallacher et al., 2013)
b	Borrowed Theoretical Concepts	● “A [cyclical] pattern on which the system converges, and to which it returns after small perturbations” (Vallacher and Nowak, 2007:11)
c	Metaphor (Verbal and Visual)	● Metaphor for the convergence towards an established repetitive cycle (Vallacher and Nowak, 2007)

		 ● Sketch from Wikipedia Contributors (2016:1 of 3)
2	**Theory Conceptualisation**	
a	*A limit-cycle chaos attractor generates a cyclical pattern and causes capital project elements and their trajectories to converge towards the limit-cycles and to which it returns after small perturbations*	

Vallacher and Nowak (2007) refer to the repeated rhythmic behaviour as found in circadian (biological) rhythms that repeat itself in about 24 hours, psychological phenomena such as mood swings that seem to repeat within weekly cycles, and the cycling between positive and negative thoughts during self-evaluation that repeat within short periods of time. There is no convergence toward a fixed-point but convergence towards a cycle. Levick (2002) observes that hunger drives humans toward food. Once fed, humans move away from a food source to cyclically return toward it when hunger pains start to appear. Vallacher et al. (2013) observed that habits, routines and automatic pattern of thinking occur in cyclical patterns and human behaviour returns to these cycles even if they are perturbed for a short period of time.

These observations caused Vallacher et al. (2013:11) to formulate the theoretical concept of a limit-cycle chaos attractor as a “pattern on which the system converges, and to which it returns after small perturbations”.

The metaphor for this chaos attractor is a repetitive cycle that draw-in any other points close to it to become part of the limit-cycle as shown in Table 3-11(1c).

Addition of these observations, theoretical concept and metaphor allows for the conceptualisation of a theory (Boxenbaum and Rouleau, 2011) for a limit-cycle chaos attractor for capital projects as follows:

> ***A limit-cycle chaos attractor generates a cyclical pattern and causes capital project elements and their trajectories to converge towards the limit-cycles and to which it returns after small perturbations.***

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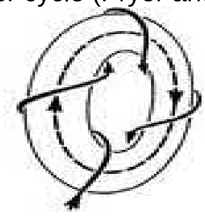
3.4.9.7 Lower-Level Theory Building for an Individual Torus Chaos Attractor for Capital Projects

A torus chaos attractor theory for capital projects is built from empirical observations, borrowed theoretical concepts and a metaphor as shown in Table 3-12.

Table 3-12: Lower-Level Theory-Building for the Torus Chaos Attractor in Capital Projects

1	**Theory-Building Components**	
a	Empirical Material (Observations)	● A number of self-similar activities repeating in a day, month, year, company or generations (Young and Kiel, 1994) ● Repetitive routine dynamics of a factory, office, hospital, school and prison (Young and Kiel, 1994) ● Indoor nursery producing plants by planting, nurturing, harvesting and selling in a single season (Bright and Pryor, 2005)
b	Borrowed Theoretical Concepts	● "Mathematically the Torus is depicted in the shape of a large donut or bagel as shown below. It is made up of a spiralling circle on many planes which may, or may not, eventually hook up with itself after completing one or more full revolutions" (School of Wisdom, No Date)
c	Metaphor (Verbal and Visual)	● Metaphor for the convergence towards multiple inner cycles as part of a single developmental outer cycle (Pryor and Bright, 2011)  ● Sketch from Shilnikov and Turaev (2007:2 of 6, Figure 7)
2	**Theory Conceptualisation**	
a	*A torus chaos attractor generates multiple spiralling inner cycles that form part of a single outer cycle and causes capital project elements and their trajectories to converge towards the cycles*	

Young and Kiel (1994) observed that a number of activities occur within and form part of a bigger activity or cycle. Examples are the repetitive routine dynamics of a factory, office, hospital, school and prison that occur in a single day, a single month or a single period. Bright and Pryor (2005) explained that within a single plant production season at a nursery that a number of smaller cycles occur such as planting, nurturing, harvesting and selling. The following plant production season contains the same smaller cycles but although activities are similar, they are never exactly the same or happen at exactly the same time.

The theoretical concept of a torus chaos attractor is described by a number of spiralling inner cycles contained within a single outer cycle (School of Wisdom, No Date).

The torus metaphor describes the development as a result of convergence towards the inner and single outer cycle as shown in Table 3-12(1c) and allows for the formulation of the following theory for capital projects:

> ***A torus chaos attractor generates multiple spiralling inner cycles that form part of a single outer cycle and cause capital project elements and their trajectories to converge towards the cycles.***

3.4.9.8 Lower-Level Theory Building for an Individual Butterfly Chaos Attractor in Capital Projects

The Butterfly chaos attractor metaphor together with empirical observations and theoretical concepts are used to conceptualise a theory for capital projects as shown in Table 3-13.

Table 3-13: Lower-Level Theory-Building for the Butterfly Chaos Attractor in Capital Projects

1	**Theory-Building Components**	
a	Empirical Material (Observations)	● Evolutionary jump as a phase transition in a project life cycle (Saynisch, 2010) ● Mood swings (Zeeman, 1976)
b	Borrowed Theoretical Concepts	● "Complex systems can have a chaotic dynamic, and develop through a series of sudden jumps (Feigenbaum, 1978). Such a jump, usually referred to as a bifurcation, is an abrupt change in the long term behaviour of a system, when the value of a particular dimension becomes higher or lower than some critical value." (Ramalingam et al., 2008:31)
c	Metaphor (Verbal and Visual)	● Metaphor for the sudden developmental jump from one outcome basin to another (Saynisch, 2010)  ● Sketch used with permission from Fink (2018)
2	**Theory Conceptualisation**	
a	*A butterfly chaos attractor generates two outcome basins and cause capital project elements and their trajectories to suddenly jump from one outcome basin to the other when a threshold value is reached*	

Saynisch (2010) distinguished between slow or first order evolution and fast or second order evolution and applied both phenomenon to a project under development. First order evolution is associated with the evolutionary variation-selection-retention principles of development as given by Darwin (1872). This type of evolution, according to Saynisch (2010:29), takes place at a slow pace to ensure stability "especially in biological evolution". In a project this process of slow development occurs between stage-gates. However, at the project stage-gate (across the stage-gate or phase change) a sudden jump in project maturity occurs – this is known as second order evolution (Saynisch, 2010). According to Saynisch (2010:29), second order evolution happens fast and occurs in sociocultural systems such as management, organisational and technical processes and "has more instability". He further states that second order evolution in projects at stage-gates may either lead to a successful jump towards higher levels of organisation and complexity or catastrophic failure if the jump fails. The two possible outcomes at the stage-gate are referred to as "bifurcation" (p. 32). Zeeman (1976) used the catastrophe theory of Thom (1975) to explain the mood swings in animal behaviour under different conditions. He showed that in a bifurcation zone, a sudden change in behaviour might occur from fight to flight. This bifurcation zone is synonymous with a butterfly chaos attractor.

Ramalingam et al. (2008) refer to the work of Feigenbaum and state that complex system development can display chaotic development and that such development happens through a serious of sudden jumps. They maintain that such jumps are triggered and occur when an important system variable reaches a critical value. Further, that when a system is close to a sudden jump, certain parameters start to fluctuate.

The metaphor for a butterfly attractor is the sudden jump from one outcome basin to another as explained by Ramalingam et al. (2008) and Saynisch (2010) and as shown in Table 3-13(1c).

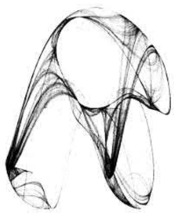
The butterfly chaos attractor theory for capital projects is formulated by the composition of empirical observations, theoretical concepts and a metaphor as follows:

> ***A butterfly chaos attractor generates two outcome basins and causes capital project elements and their trajectories to suddenly jump from one outcome basin to the other when a threshold value is reached.***

3.4.9.9 Lower-Level Theory Building for an Individual Strange Chaos Attractor for Capital Projects

A conceptualisation of a theory for the sixth chaos attractor, the strange chaos attractor, that is considered for this research, is shown in Table 3-14.

Table 3-14: Lower-Level Theory-Building for the Strange Chaos Attractor in Capital Projects

1	**Theory-Building Components**	
a	Empirical Material (Observations)	● Ultimate purpose and values (Bums, 2002) ● Shared vision (Gilstrap, 2005) ● Leadership (Gilstrap, 2005)
b	Borrowed Theoretical Concepts	● “Some attractors are called 'strange' attractors since a system behaves in ways not expected by Newtonian physics, propositional logic, rational numbering systems or Euclidean geometry” (Radu et al., 2014:1551)
c	Metaphor (Verbal and Visual)	● Metaphor for the convergence of complex and chaotic dynamics of a system as a whole (Dimitrov, 2000:418)  ● Sketch from De Jong (2004:2 of 4)
2	**Theory Conceptualisation**	
a	*A strange chaos attractor generates an attraction zone and causes capital project elements and their trajectories to converge towards this zone in strange ways*	

Bums (2002) observed that a company’s ultimate purpose and core values determine the behaviour of individuals. He notes that it is as if these two aspects of a company act strangely to bound, attract, influence and cause an organisation’s “orbit of behaviour” (p. 45). Gilstrap (2005:60) noted that educational leadership and shared vision causes “bounded instability” meaning that the complex dynamics of individuals unfold in an organisational setting, but that leadership and vision strangely causes all these dynamic patterns to converge within limits.

Radu et al. (2014:1551) maintain that the behaviour of non-linear systems over time have shown patterns of behaviour that are caused by strange attractors and it appears that a system is “pulled” towards these attractors “during its cycles or periods”. The complex behaviour of complex systems cannot be predicted with current linear thinking methods such as “Newtonian physics, propositional logic, rational numbering systems or Euclidean geometry” according to Radu et al. (2014:1551).

Dimitrov (2000:418) states that a strange attractor acts as a focal point and attracts the “swarm of thoughts and feelings” towards it through the formation of strange patterns. Refer to the sketch of a strange attractor metaphor as displayed in Table 3-14(1c).

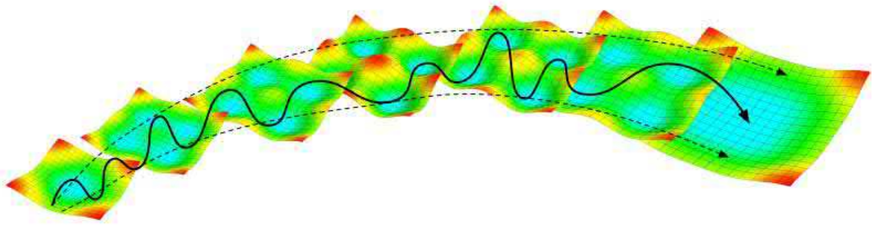
Combining the empirical observations, theoretical concepts and a metaphor, allows for the conceptualisation of a theory for a strange attractor for capital projects as follows:

A strange chaos attractor generates an attraction zone and causes capital project elements and their trajectories to converge towards this zone in strange ways.

3.4.9.10 Mid-Range and Lower-Level Theory Building for a Group of Chaos Attractors for Capital Projects

The final theory to be conceptualised for this research is for a group of chaos attractors that are configured in an attractor landscape as shown in Table 3-15.

Table 3-15: Mid-Range and Lower-Level Theory-Building for a Group of Chaos Attractors in Capital Projects

1	Theory-Building Components	
a	Empirical Material (Observations)	● Mountains and valleys guide the likely paths that will be followed (Butner et al., 2015) ● Different starting points produce totally different trajectories i.e. sensitive dependence on initial conditions (Lorenz, 1995) ● Personal developmental trajectories are bounded (Boker, 2013)
b	Borrowed Theoretical Concepts	● "thanks to the development of computer simulation models, the dependencies and constraints embodied by attractors can also be visualized as three dimensional adaptive landscapes depicting a series of changes in a system's relative stability and instability over time. The increased probability that a system will occupy in a particular state can be represented visually as a landscape's wells, dips or valleys that embody attractor states and behaviours; the deeper the valley the greater the propensity of its being visited and the stronger the entrainment its attractor represents. In contrast, sharp peaks are saddle points representing states and behaviours from which the system shies away. These landscape features capture the impact of context-sensitive constraints over time" (Juarrero, 2010:4 of 11) ● "several attractors of different types…drive the system toward the long-term stationary attractor" (Allen, 2001:30)
c	Metaphor (Verbal and Visual)	● Metaphor for the overall bounded convergence through an attractor landscape  ● Sketch from Boker (2013:7, Figure 3)

2	**Theory Conceptualisation**
a	*Mid-Range Theory Conceptualisation – Different Chaos Attractors:* *A landscape of chaos attractors consisting of a group of different types of chaos attractors, generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome*
b	*Mid-Range Theory Conceptualisation – Six Selected Chaos Attractors:* *A landscape of chaos attractors consisting of a group of six different types of chaos attractors, generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome*
c	*Lower-Level Theory Conceptualisation – Pre-Designed Landscape of the Six Selected Chaos Attractors:* *A specifically designed landscape of chaos attractors consisting of a group of six different types of chaos attractors [fixed-point, repeller, limit-cycle, torus, butterfly and strange], generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome.*

Butner et al. (2015) notes that a landscape of mountains and valleys influence the likely path that a traveller would consider following. Similarly, the flow of water on the same landscape is determined by the configuration of the mountains and valleys, their steepness, location and constellation. Lorenz (1995) discovered that prediction of complex systems such as atmospheric weather is sensitive to initial conditions. This means that a slight change in the initial starting point of a simulation to predict atmospheric properties such as temperature, causes totally different answers over a period of time. This is why, according to Lorenz (1995), it is not possible to predict the temperature of a location this time next year. Boker (2013:1) observed that the personal development of an individual over his lifetime is a continuous interaction between “internal states and capacities of an individual” and the “environmental demand and contextual opportunities” within which the “individual is immersed”. He implies that personal development could be visualised by a bounded trajectory through a landscape of mountains and valleys.

Juarrero (2010) states that an attractor landscape could theoretically be represented by mountains and valleys. The mountains will divert system behaviour and the system trajectory away from it, while a valley will attract system behaviour and the system trajectory towards it. Steeper mountains and steeper valleys will have a stronger diversion or attraction effects on system behaviour and will more strongly influence the trajectory of a system.

Boker (2013:1) created a visual metaphor for a chaos attractor landscape that consists of mountains and valleys that bounds and guides system behaviour as shown in the sketch in Table 3-15(1c).

Assembly of empirical observations, theoretical concepts and a chaos attractor landscape metaphor allows for the conceptualisation of the following theory for capital projects:

> **(a*) A landscape of chaos attractors consisting of a group of different types of chaos attractors, generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome.***

Morgan (2006) demonstrated in Chapter 2 Figure 2-26 that the careful creation and destruction of chaos attractors could cause the organisational change behaviour from a current state towards a desired future state. Similarly, Lucas (2006:3 of 8) states that "we can design the environment (constraints) rather than the system itself, and let the system evolve a solution to our needs". Therefore, for this research the mid-range theory for the six selected chaos attractors that causes overall capital project convergence could be stated as follows:

> ***(b) A landscape of chaos attractors consisting of a group of six different types of chaos attractors, generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome***

The lower-level theory that will also be exploratory tested for this research pertains to a specifically pre-designed landscape of the selected six chaos attractors as is formulated as follows:

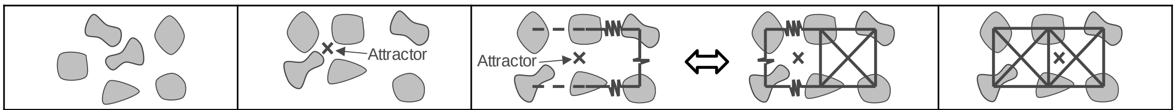
> **(c*) A specifically designed landscape of chaos attractors consisting of a group of six different types of chaos attractors [fixed-point, repeller, limit-cycle, torus, butterfly and strange], generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome.***

3.5 Model Building

In this section a model will be presented for the Randomness-Chaos-Complexity-Order (RCCO) continuum, six variance models for the chosen six individual chaos attractors and a single variance model for a group of different types of chaos attractors. The RCCO continuum is derived from the literature survey in Chapter 2 and Appendix B. The variance models are based on the lower-level theories that have been derived earlier in this Chapter as well as the literature on the six chaos attractors.

3.5.1 Model for the Randomness-Chaos-Complexity-Order Continuum for Capital Projects

Ramalingam et al. (2008:viii) state that the concepts in the complexity science could be described as a “loose network of interconnected and interdependent ideas”. This makes the application of such concepts difficult for the capital project management practitioner and it should be the objective of researchers to provide easy to grasp, easy to use and practical theories, models and methods. Therefore, an attempt is made to combine a “loose network of interconnected and interdependent ideas” for chaos theory concepts into a single continuum. A randomness-chaos-complexity-order (RCCO) continuum for capital projects is extracted from the framework that was done during the literature survey in Chapter 2 – refer to Appendix B, Table B-1 and as shown in Figure 3-6.



RANDOMNESS		CHAOS		COMPLEXITY				ORDER	
Completely Random	Not Deterministic	Full Chaos	Limited Chaos	Self-organising Complexity & Edge of Chaos	Evolving Complexity	Dynamic Complexity	Static Complexity	Complicated	Simple

Figure 3-6: Model for the Random-Chaos-Complexity-Order (RCCO) Continuum for Capital Projects. Extracted from the Continuum Framework Shown in Appendix B, Table B-1 with Contributions from Lorenz (1995); Lucas (2006); Snowden and Boone (2007); Snowden (2010)

The continuum domains of randomness, chaos, complexity and order have been selected for explorative testing in capital projects as shown in Chapter 5.

The continuum as shown in Figure 3-6 contains the following lower-level sub-domains:

a) Completely random and not deterministic for the randomness domain (Lorenz, 1995)
b) Full chaos and limited chaos for the chaos domain (Lorenz, 1995)
c) Self-organising complexity, evolving complexity, dynamic complexity and static complexity for the complexity domain (Lucas, 2006) and
d) Complicated and simple for the order domain (Snowden and Boone, 2007; Snowden, 2010).

This continuum for capital projects supposes a change in the type an nature of relationships between system (or project) elements as is schematically displayed in in the first row of Figure 3-6. The relationships vary from no relationship in the randomness domain between system elements to rigid relationships in the ordered domain. This idea stems from the description of the nature of relationships between system elements as described by Remington and Pollack (2007) and partially from a sketch by Valacich et al. (2011). Chaos attractors are also indicated as 'crosses' in the chaotic, complex and ordered domains of this continuum as was found to exist in these domains according to the literature survey in Chapter 2 (refer to Table 2-9).

However, categorisations have limitations. Crawford et al. (2005) warn the rich variety and complexity of reality may be reduced to a limited set of categories with considerable simplification, whereby parts of reality might not be revealed. The objective of the randomness-chaos-complexity-order continuum for capital projects is to distinguish between system types and states of dynamical systems, in order to gain an initial understanding of the characteristics of capital projects in each of these domains, under the influence of chaos attractors.

3.5.2 Model Types to Capture Phenomena Characteristics

Langley (1999) refers to the work of Mohr who made a clear distinction between using either variance theory or process theory as a basis when building models of phenomena as shown in Figure 3-7.

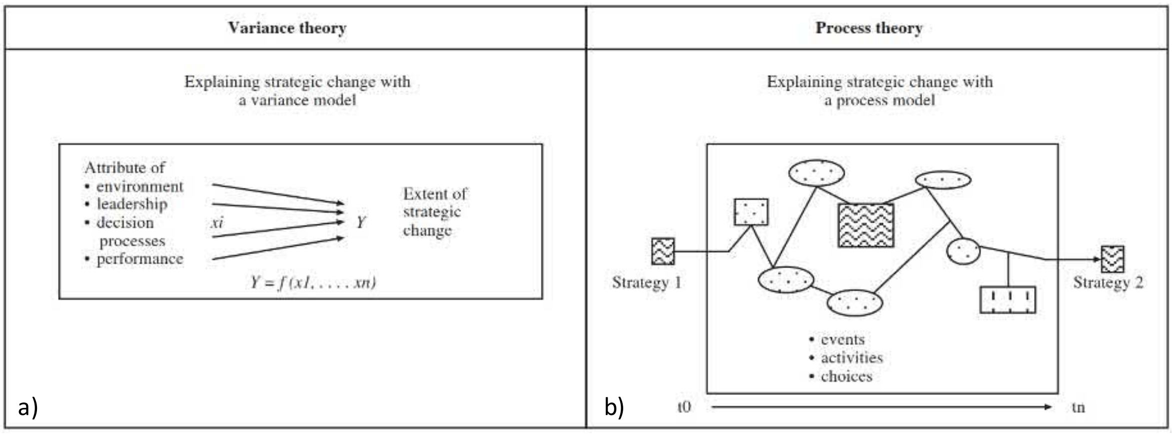


Figure 3-7: Two Types of Models for Describing Phenomena as either a) Variance Model based on Variance Theory or b) Process Model based on Process Theory (Langley, 1999:693, Figure 1)

Langley (1999) states that a variance model of a phenomenon describes the relationship between independent and dependent variables for a snapshot of time. In contrast, a process model gathers data over a long period of time and attempts to "provide an explanation" of the same phenomena "in terms of the sequence of events" (p. 692). Variance models generate "know that" type of knowledge and process models "know how" type of knowledge about a phenomenon (Langley et al., 2013:4). The differences in these two model building approaches are shown in Table 3-16.

Table 3-16: Differences between Variance Theorising and Process Theorising

No.	Dimension	Variance Theorising	Process Theorising
1	Explanatory Value	● "Know That" (Langley et al., 2013:4) ● Snapshot in time (Langley, 1999)	● "Know How" (Langley et al., 2013:4) ● Evolution over time (Langley, 1999)
2	Variables	"Whereas variance theories provide explanations for phenomena in terms of relationships among dependent and independent variables (e.g., more of X and more of Y produce more of Z)" (Langley, 1999:692)	"Process theories provide explanations in terms of the sequence of events leading to an outcome (e.g., do A and then B to get C)" (Langley, 1999:692)

Both types of models provide insight and knowledge about a phenomenon. For this research the variance model building process was chosen due to the availability of data for various fields of science on chaos attractor metaphors as shown in Chapter 2. This data was grouped during variance model building for each chaos attractor's independent variables into descriptions that best described the following attributes:

a) Metaphor geometry characteristics
b) Project management characteristics
c) Systems engineering characteristics
d) Psychology characteristics and
e) Sociology characteristics.

Due to the exploratory nature of this research, an ‘other’ category for the independent variables was indicated during the research interviews as there may be more categories that exist but that are not apparent during construction of the initial variance model. The six dependent variables for the first six models were the individually chosen chaos attractors as fixed-point, repeller, limit-cycle, torus, butterfly and strange. The chaos attractor landscape was chosen as the dependent variable for a group of chaos attractors.

3.5.3 Variance Models for Individual Chaos Attractors

Theories were built for each of the selected six chaos attractors and for a group of chaos attractors as shown in paragraph 3.4.9.4 - 3.4.9.10. Metaphors for these chaos attractors and a landscape of chaos attractors were also briefly explained. Partial metaphor descriptions for the four prominent chaos attractors was also done in Chapter 2, paragraph 2.6.3. In the following paragraphs the derived lower-level theory, expanded description of the metaphor and derived variance model are given together even if some information is repeated elsewhere. This combined information for each chaos attractor was described verbally in this manner to research respondents during the focussed interviews, and their responses requested (refer to Chapter 4).

3.5.3.1 Variance Model for Fixed-Point Chaos Attractors

The derived lower-level theory for a fixed-point chaos attractor was given in Table 3-9 as:

> ***A fixed-point chaos attractor generates an attractor basin and causes capital project elements and their trajectories to converge to a fixed-point in the basin even if they are perturbed.***

Various sketches for the fixed-point chaos attractor metaphor as displayed by various researchers are shown in Figure 3-8.

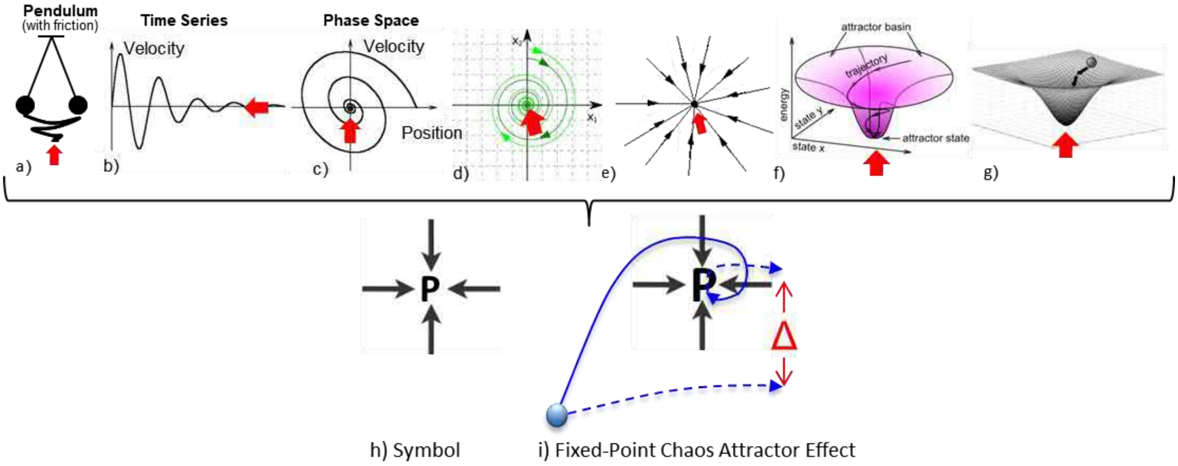


Figure 3-8: Sketches for a Fixed-Point Chaos Attractor Metaphor

The most common representation of a fixed-point chaos attractor is that of a pendulum with friction as shown in Figure 3-8(a) (Crutchfield et al., 1986:49; Gleick, 2008:136). The pendulum bob will ultimately come to rest at the 'bottom dead centre' position as shown by the red arrow. The time-based view of the bob velocity is shown in Figure 3-8(b) and the phase space plot in the absence of time, as Figure 3-8(c). In these cases, the pendulum bob will be 'attracted' towards the fixed point at the 'bottom dead centre position' as shown. The chaos attractor remains stationary for different starting positions of the bob as shown in Figure 3-8(d) (Wikipedia Contributors, 2017:p.10 of 20). A chaos attractor could also be viewed as the trajectories of "different possible states of a system" that merge into a single point as shown in Figure 3-8(e) (Principia Cybernetica, 2017:p.1 of 3). The "gravity well" (Computational Cognitive Neuroscience Wiki Contributors, 2015:10 of 14, Figure 3.14) as shown in Figure 3-8(f), represents a fixed-point chaos attractor to explain the behaviour of neurons in the human brain. The "ball-in-the-basin" (Harrison, 2013:2 of 6) representation of a fixed-point chaos attractor as shown in Figure 3-8(g) (Vallacher et al., 2013:169, Figure 2) conveys how individual thoughts or behaviours will converge to a specific fixed point. For this research the symbol for a fixed-point attractor is shown in Figure 3-8(h) as modified from a sketch of Butner et al. (2015:19, Figure 19). The anticipated attraction effect on a capital project element or trajectory in the presence of a fixed-point chaos attractor and in the absence of such an attractor is shown by Figure 3-8(i) for example a project milestone. The difference in trajectories is indicated by the delta symbol (Δ).

Using the source-target domain metaphor mapping technique as described by Cornelissen and Kafouros (2008), elements for the variance model for fixed-point chaos attractors are generated as shown in Appendix C, Table C-1.

The target domain elements as identified in Table C-1 are shown in the format of a variance model as shown in Figure 3-9. The format is casted in the form of concepts that make up the constructs for the independent variables of the fixed-point chaos attractor, the dependent variable (fixed-point chaos attractor) and then the effect or outcome of the dependent variable. This format for the variance model is suggested by Langley (1999), Page and Meyer (2003) and Zikmund (2003).

Using the source-target domain metaphor mapping technique as described by Cornelissen and Kafouros (2008), elements of the variance model for fixed-point chaos attractors are generated as shown in Figure 3-9.

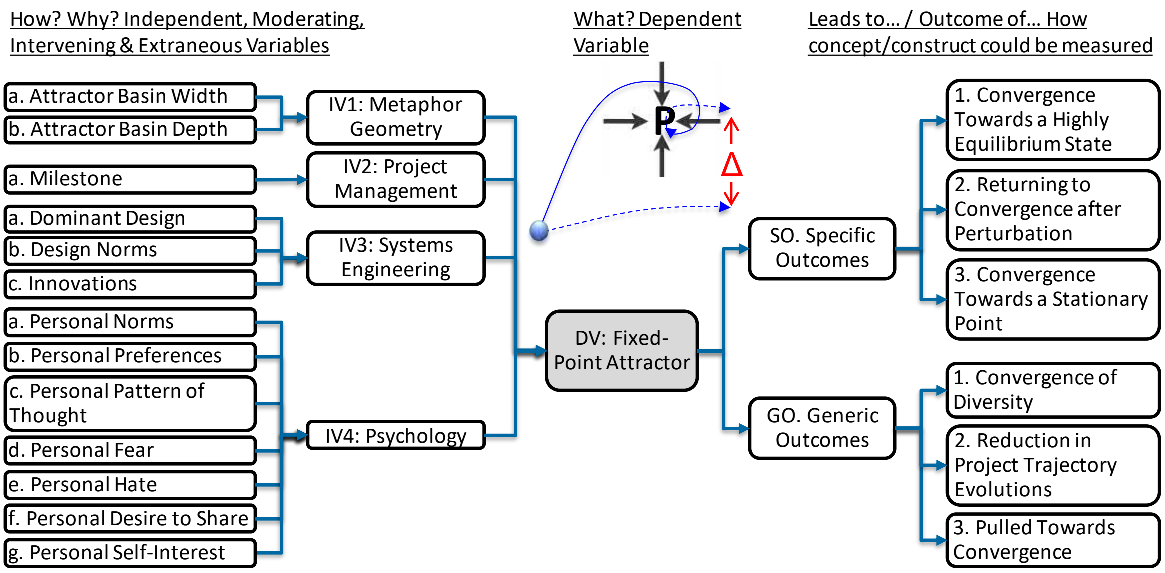


Figure 3-9: Variance Model for a Fixed-Point Chaos Attractor for Capital Projects

3.5.3.2 Variance Model for Fixed-Point Chaos Repellers

The derived lower-level theory for a fixed-point chaos repeller was given in Table 3-10 as:

> ***A fixed-point chaos repeller generates a fixed point-of-repulsion and causes capital project elements and their trajectories to be diverted away from the fixed-point.***

Various sketches for the fixed-point chaos attractor metaphor as displayed by various researchers are shown in Figure 3-10.

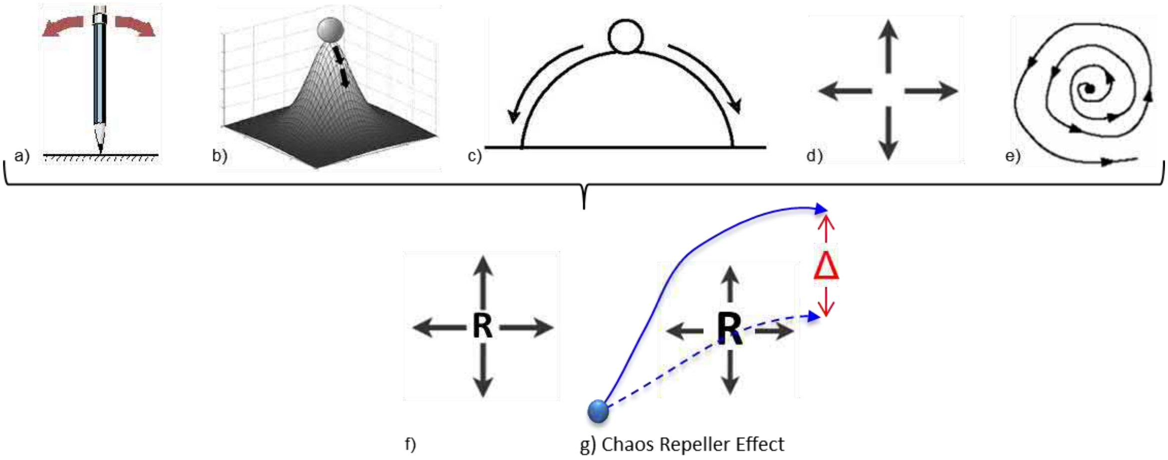


Figure 3-10: Sketches for a Fixed-Point Chaos Repeller Metaphor

A chaos repeller could be explained by a pen standing on its tip as shown in Figure 3-10(a) (Sharov, 2017:1 of 5). It is in an unstable state and as soon as there is any movement from the pen to either side, it will move quickly away from this point (Butner et al., 2015). A fixed-point repeller is also represented as a ball on a mountain top as shown in Figure 3-10(b) (Vallacher et al., 2013:170, Figure 3) and explained as thoughts and behaviours that move quickly away from this point. A ball on top of a bowl as shown in Figure 3-10(c) (University of Mumbai, 2017:8 of 11) is in an unstable equilibrium, for example in the economy where a small change will be exaggerated and the system will never return to the original starting point. A two dimensional symbol for a repeller is given by Butner et al. (2015:19, Figure 19) as shown in Figure 3-10(d). A representation of a spiral chaos repeller is shown in Figure 3-10(e) (Kent and Stump, No Date:7 of 15) where the trajectory of the system spirals away from the starting point. The chosen symbol for a chaos repeller is shown in Figure 3-10(f) and was modified from a sketch of Butner et al. (2015:19, Figure 19). The anticipated repelling effect on a capital project element or trajectory in the presence of a fixed-point chaos repeller as well as in the absence of such an repeller is shown Figure 3-10(g) for example the observed project behaviour away from a contractual penalty clause.

Using the source-target domain metaphor mapping technique as described by Cornelissen and Kafouros (2008), the elements of the variance model for a fixed-point chaos repeller are generated as shown in Appendix C, Table C-2. Note that the generic outcomes (GO1, GO2 and GO3) as shown in Table C-2 (No's 9, 10 and 11) were mapped in the target domain as the antithesis of the fixed-point attractors.

The results of the source-target domain mapping for capital projects of the chaos repeller metaphor as shown in Table C-2 is displayed in a variance model in Figure 3-11.

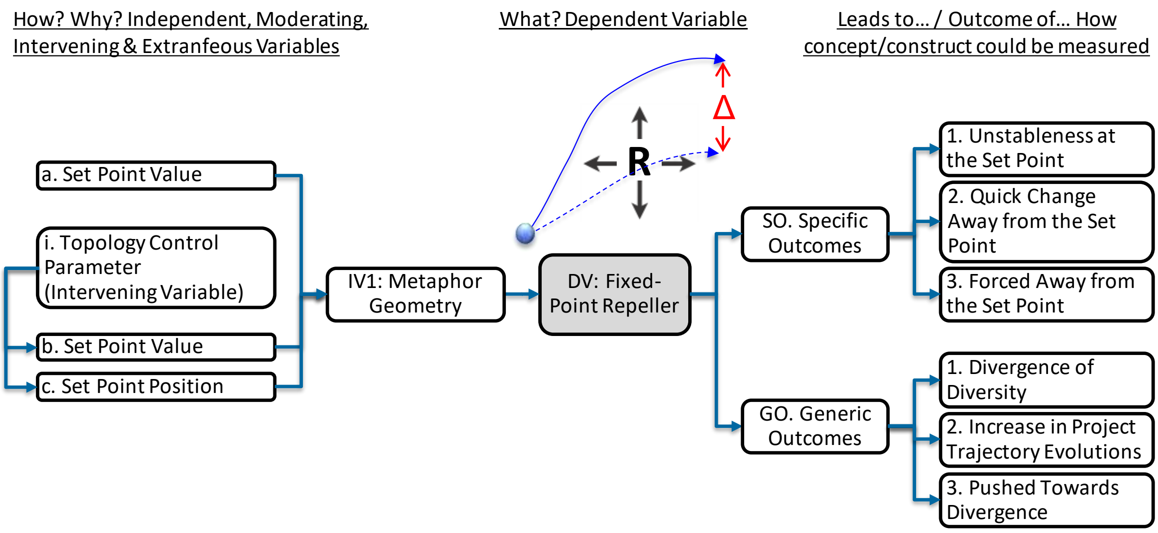


Figure 3-11: Variance Model for a Fixed-Point Chaos Repeller for Capital Projects

3.5.3.3 Variance Model for Limit-Cycle Chaos Attractors

The derived lower-level theory for a limit-cycle chaos attractor was given in Table 3-11 as:

> ***A limit-cycle chaos attractor generates a cyclical pattern and causes capital project elements and their trajectories to converge towards the limit-cycles and to which it returns after small perturbations.***

Graphical representations for a limit-cycle chaos attractor metaphor from various researchers are shown in Figure 3-12.

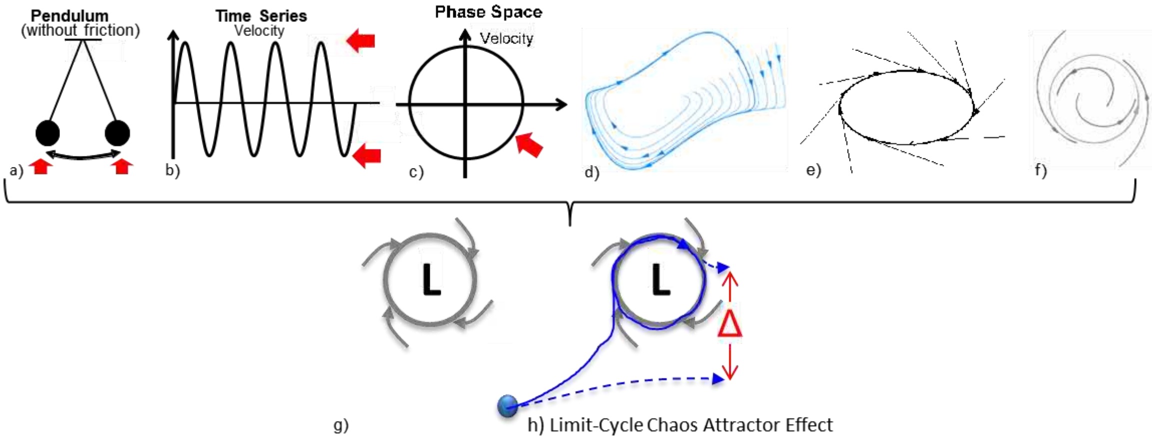


Figure 3-12: Sketches for a Limit-Cycle Chaos Attractor Metaphor

The representation of a pendulum without friction, its time series behaviour and circular phase space plot is used by researchers (Crutchfield et al., 1986:49; Gleick, 2008:136) to explain the characteristics of a limit-cycle chaos attractor as shown in Figure 3-12(a-c). The behaviour of a dynamical system based on the calculations of a van der Pol oscillator (Wikipedia Contributors, 2016:1 of 3) is shown in Figure 3-12(d). It is shown that the trajectories of particles with many different initial conditions converges to the dominant periodic trajectory of the limit-cycle attractor. When two opposing forces dampen and amplify each other in harmony, the result is a limit-cycle attractor (Principia Cybernetica, 2017:2 of 3) as shown in Figure 3-12(e). In the study of computational science, the theory of cellular automata is applied to program the evolution of a grid of cells based on a rule set and the information contained in neighbouring cells and reference is made that "periodic attractive systems are attracted to periodic attractor" (Avnet, 2006:5 of 10), as shown in Figure 3-12(f). These cyclic attractors seem to imply that nearby elements would be attracted to form part of a dominant cyclic trajectory. The chosen symbol for a limit-cycle chaos attractor is shown in Figure 3-12(g) and was modified from a sketch of Butner et al. (2015:19, Figure 19). The anticipated attracting effect on a capital project element or trajectory in the presence of a limit-cycle chaos attractor as well as in the absence of such an attractor is shown Figure 3-12(h) for example the observed convergence behaviour in an effective project meeting. The difference in trajectories is indicated by the delta symbol (Δ).

The references found for periodic or limit-cycle chaos attractors were mapped to the capital project environment according to the methodology of Cornelissen and Kafouros (2008) and the result is shown in Appendix C, Table C-3.

The results of the source-target domain mapping for capital projects of the limit-cycle attractor metaphor as shown in Table C-3 is displayed in a variance model in Figure 3-13.

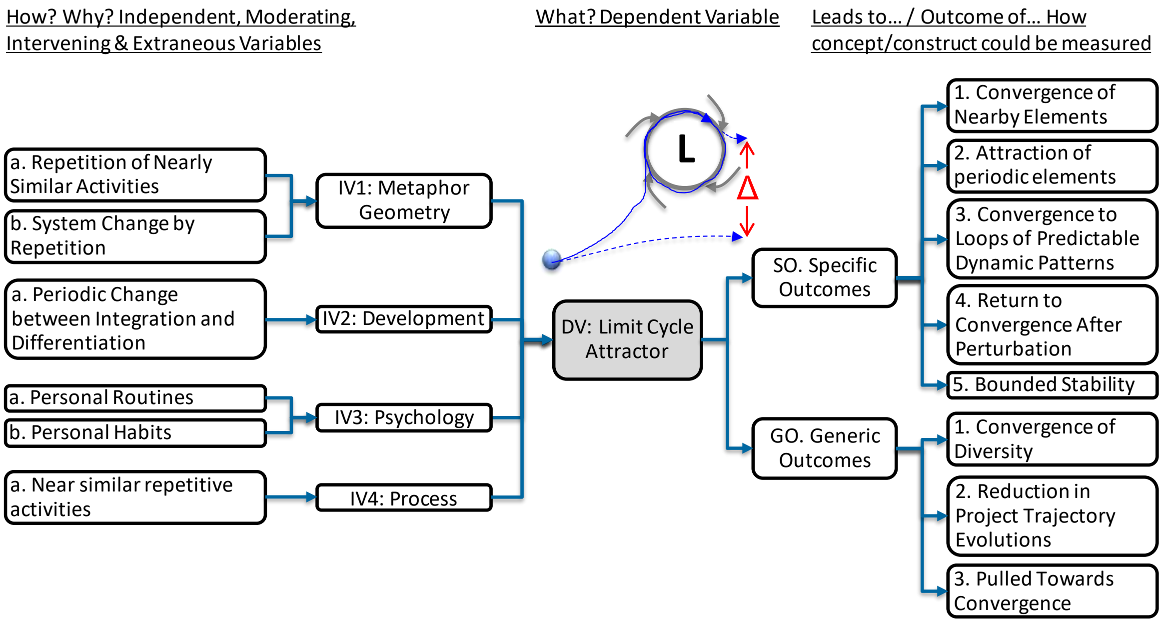


Figure 3-13: Variance Model for a Limit-Cycle Chaos Attractor for Capital Projects

3.5.3.4 Variance Model for Torus Chaos Attractors

The derived lower-level theory for a torus chaos attractor was given in Table 3-12 as:

> ***A torus chaos attractor generates multiple spiralling inner cycles that that forms part of a single outer cycle and causes capital project elements and their trajectories to convergence toward the cycles.***

A torus chaos attractor is represented graphically by different researchers as shown in Figure 3-14.

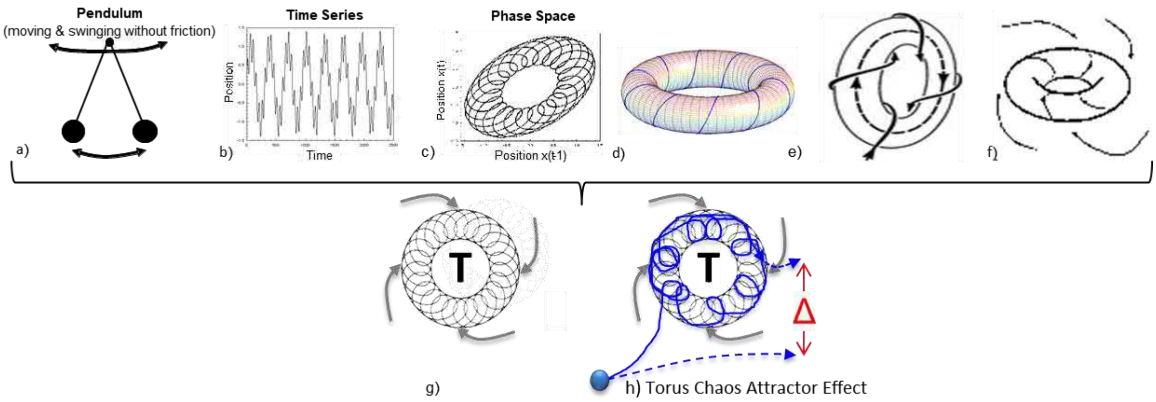


Figure 3-14: Sketches for a Torus Chaos Attractor Metaphor

The classical explanation of a torus chaos attractor is given by a swinging pendulum of which the base of the pendulum also swings, but at a much lower frequency, as shown in Figure 3-14(a). The time series data of these two superimposed frequencies are displayed in Figure 3-14(b) (Rubin, 1995:5 of 6, Figure 5.3A) while the phase space graph shows a donut shaped torus as shown in Figure 3-14(c) (Rubin, 1995:6 of 6, Figure 5.3B). A three-dimensional torus shape is shown with a particle traversing the outer rim as shown in Figure 3-14(d) (Springer Link, 2017:2 of 5, Figure 1.49). In essence, the torus chaos attractor is portraying multiple smaller cycles within one large cycle. The torus attractor forms when a number of periodic orbits are bounded by an outer manifold as shown in Figure 3-14(e) (Shilnikov and Turaev, 2007:2 of 6, Figure 7) that can also later dissolve. It has been shown in the study of non-linear dynamics that a torus chaos attractor is able to attract system behaviour from the environment to form part of the torus cycles inside the manifold as shown in Figure 3-14(f) (Bedford Astronomy Club, 2017:2 of 4, Figure 2c). The chosen symbol for this research is shown in Figure 3-14(g), and is modified from the sketch of (R.C.L, 2017:3 of 19) and the suggested trajectories of capital project elements in the presence or absence of a torus chaos attractor are presented in Figure 3-14(h), for example a project development process. The difference in trajectories is indicated by the delta symbol (Δ).

Using the metaphor mapping process as described by Cornelissen and Kafouros (2008), the source domain references as found during the literature survey are mapped to the capital project domain as shown in Appendix C, Table C-4 for the torus chaos attractor.

The results of the source-target domain mapping for capital projects of the torus chaos attractor metaphor are shown in Table C-4 is displayed in a variance model in Figure 3-15.

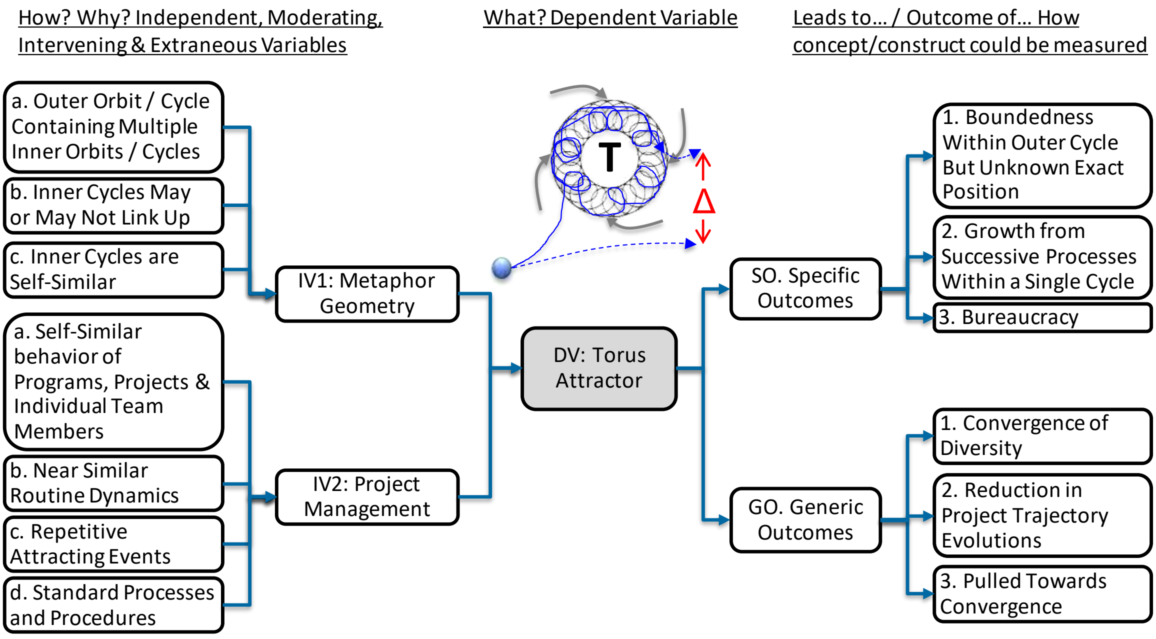


Figure 3-15: Variance Model for a Torus Chaos Attractor for Capital Projects

3.5.3.5 Variance Model for Butterfly Chaos Attractors

The derived lower-level theory for a butterfly chaos attractor was given in Table 3-13 as:

> ***A butterfly chaos attractor generates two outcome basins and cause capital project elements and their trajectories to suddenly jump from one outcome basin to the other when a threshold value is reached.***

Different representations for a butterfly chaos attractor are shown in Table 3-16.

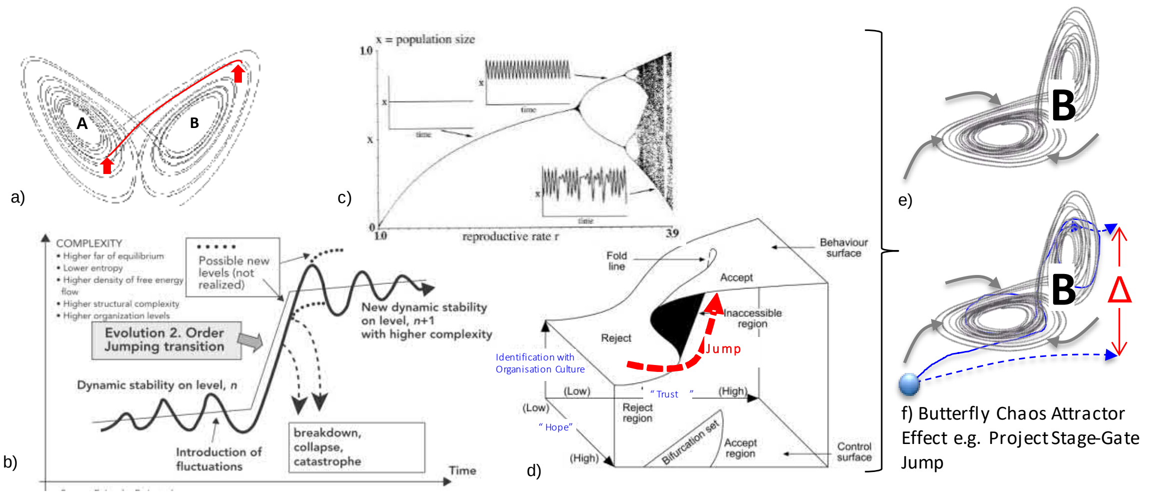


Figure 3-16: Sketches for a Butterfly Chaos Attractor Metaphor

A butterfly chaos attractor is one of the types of strange attractors discovered by Edward Lorenz (Lorenz, 1995; Lorenz, 2000) to indicate that the behaviour for some systems forms two causality fields and a sudden jump from one field to the next as shown in Figure 3-16(a) (Bradley, 2017:2 of 3). Saynisch (2010) developed a new model on the functioning of project management: Project Management Second Order (PM-2). One of the elements of this model refers to the development or evolution of projects as a slow rate of change (evolution first order) that is based on Darwin's mutation-selection-retention processes (Darwin, 1872). Rapid evolution may also occur and may include "jumping changes, creation of new formations (emergence), bifurcations, and dynamic chaos, as well as grand strides" (Saynisch, 2010:28) and is known as evolution second order. The evolutionary jump that is believed to take place at project stage gates is also seen as a jump from a lower state to a higher state or from a lower maturity level to a higher level of maturity as shown in Figure 3-16(b) (Saynisch, 2010:32, Figure 7). However, during this evolutionary jump the system may either reach a new higher level of complexity or collapse and break down catastrophically (Saynisch, 2010). The concept of bifurcations or a sudden split into two or more different values based on a trigger event value is displayed by the prediction of speies population values (x) at different reproduction growth rates (r) using the population logistic equation $x_{t+1} = rx_t(1- x_t)$ as shown in Figure 3-16(c) (Rohde, 2011:2 of 8, Figure 1). As long as the reproduction rate is low i.e. below 3, the result of the logistic equation is a single value x for the total population. As soon as the reproduction rate is increased, the value of the total population jumps to one of two values as shown. At higher values of r the total population jumps to any of four values and with further increases of r to a chaotic number of different values for the overall population. This behaviour was also proven for single-species populations in a laboratory setup (Hassell et al., 1976). Another example of a chaotic jump is given by the catastrophic theory and model, as developed by Zeeman (1976) in which he explained the sudden changes in possible behaviours of dogs ranging from flight to attack when confronted. He indicated that a bifurcation zone existed in which bimodal behaviour is possible and that behaviour could suddenly jump from one state to another. The cusp model of Zeeman was applied by Karathanos et al. (1994:18, Figure 1) as shown in Figure 3-16(d) to explain the sudden loss of meaning or identification of individuals with an organisation's culture. The model has three axes: a) hope and b) trust as independent variables and c) the identification with the organisation's culture as the dependent variable. All possible outcomes are given on the surface of the cusp model. However, the fold in the cusp forms a bifurcation zone when viewed from the top and two values are simultaneously possible when in the bifurcation zone. When the qualitative values of hope and trust for an individual is low his identification with the organisation is also low. But as these values increase and the perimeter of the bifurcation zone is reached, a sudden jump in identification with the organisation's culture is possible. The same holds when the values of trust and hope reach a lower threshold value which then could cause a jump to the bottom of the cusp surface. The symbol for the butterfly chaos attractor that will be used for this research is shown in Figure 3-16(c) (sketch used with permission from Fink (2018)). The suggested butterfly chaos attractor effect on capital project elements and their trajectories in the presence or absence of such an attractor is shown in Figure 3-16(f), e.g. for a stage gate maturity jump.

The literature was searched for references to the butterfly chaos attractor and these references were then mapped to the capital project domain as suggested by Cornelissen and Kafouros (2008) and as shown in Appendix C, Table C-5.

The results of the source-target domain mapping for capital projects of the butterfly chaos attractor metaphor as shown in Table C-5 is displayed in a variance model in Figure 3-17.

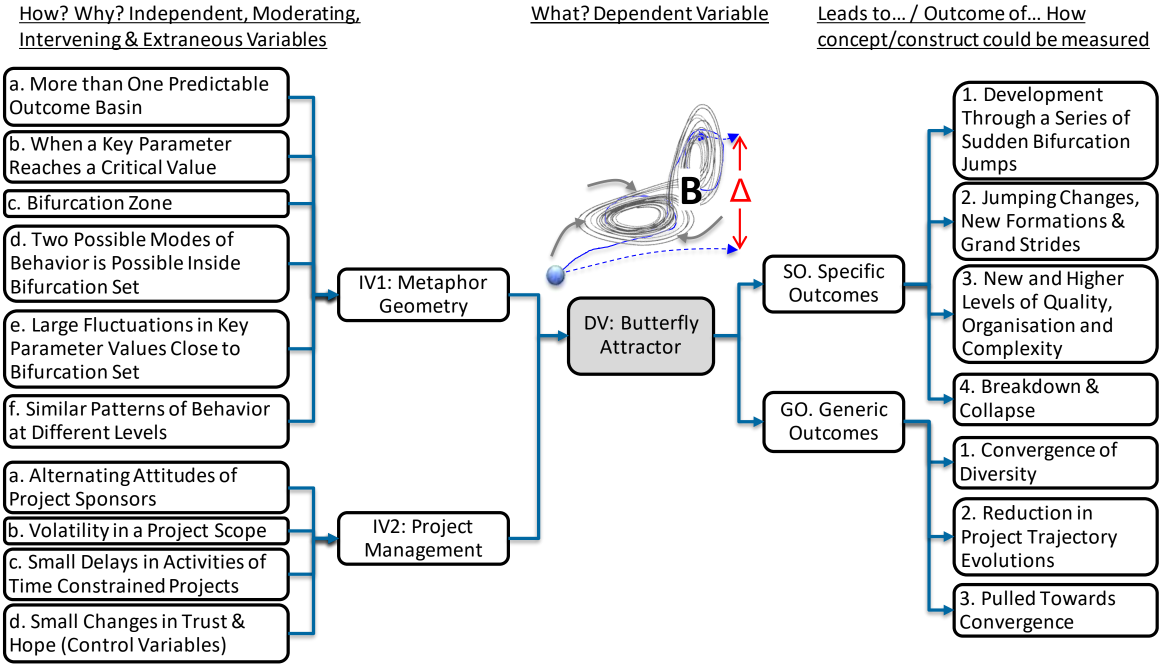


Figure 3-17: Variance Model for a Butterfly Chaos Attractor for Capital Projects

3.5.3.6 Variance Models for Strange Chaos Attractors

The derived lower-level theory for a strange chaos attractor was given in Table 3-14 as:

> ***A strange chaos attractor generates an attraction zone and causes capital project elements and their trajectories to converge towards this zone in strange ways.***

Graphic representations for the strange chaos attractor as found from various sources in the literature are shown in Figure 3-18.

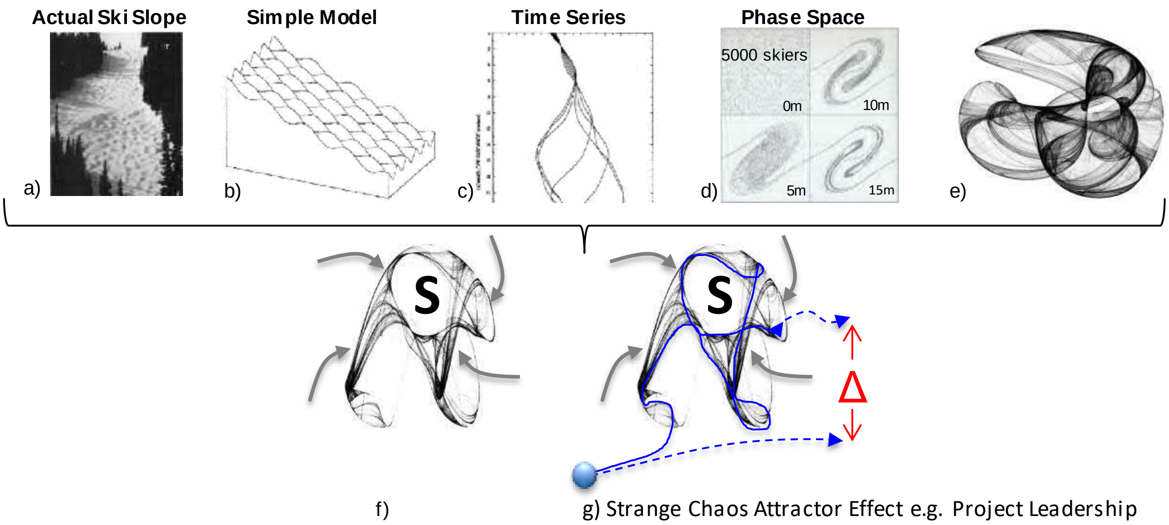


Figure 3-18: Sketches for a Strange Chaos Attractor Metaphor

One explanation of the formation of a strange attractor is given by Lorenz (1995) for the chaos attractor that is formed by skier trajectories on a downward ski slope as shown in Figure 3-18(a-d) (Lorenz, 1995:27, 30, 40 & 44, Figure 4, 5, 10, 11). A model of a real ski slope as shown in Figure 3-18(a), has been generated as shown in Figure 3-18(b) with equally spaced moguls. Seven skiers with their skis are started with the same initial velocities but spaced 10 cm apart on the top line. The trajectories that formed from nearly similar starting points are visible in Figure 3-18(c) and it is shown that initially the trajectories of the skiers are close together and then start to diverge. This is a demonstration by Lorenz of one of the characteristics of complex and chaotic systems – sensitive dependence on initial conditions. If the simulation is now done for 5,000 skiers with the different starting velocities and different starting positions, a cross section of the trajectories for position versus speed when the skiers have travelled 5 m, 10 m and 15 m down the slope is shown in Figure 3-18(d). The strange form is the actual attractor that is formed by the trajectories of 5,000 skiers! Another strange attractor that was computer generated is shown in Figure 3-18(e) (Bourke, 2004:2 of 6). The strange attractor symbol that will be used for this research is shown in Figure 3-18(f) (De Jong, 2004:2 of 4). The suggested effect of a strange attractor on a capital project element or its trajectory is shown in Figure 3-18(g) in the presence or absence of a strange chaos attractor for example project leadership. The difference in trajectories is indicated by the delta symbol (Δ).

References to the strange chaos attractor metaphor were searched in the literature and mapped to the capital project domains using the method as described by Cornelissen and

Kafouros (2008) as shown in Appendix C, Table C-6.

The results of the source-target domain mapping for capital projects of the strange chaos attractor metaphor as shown in Table C-6 is displayed in a variance model as shown in Figure 3-19.

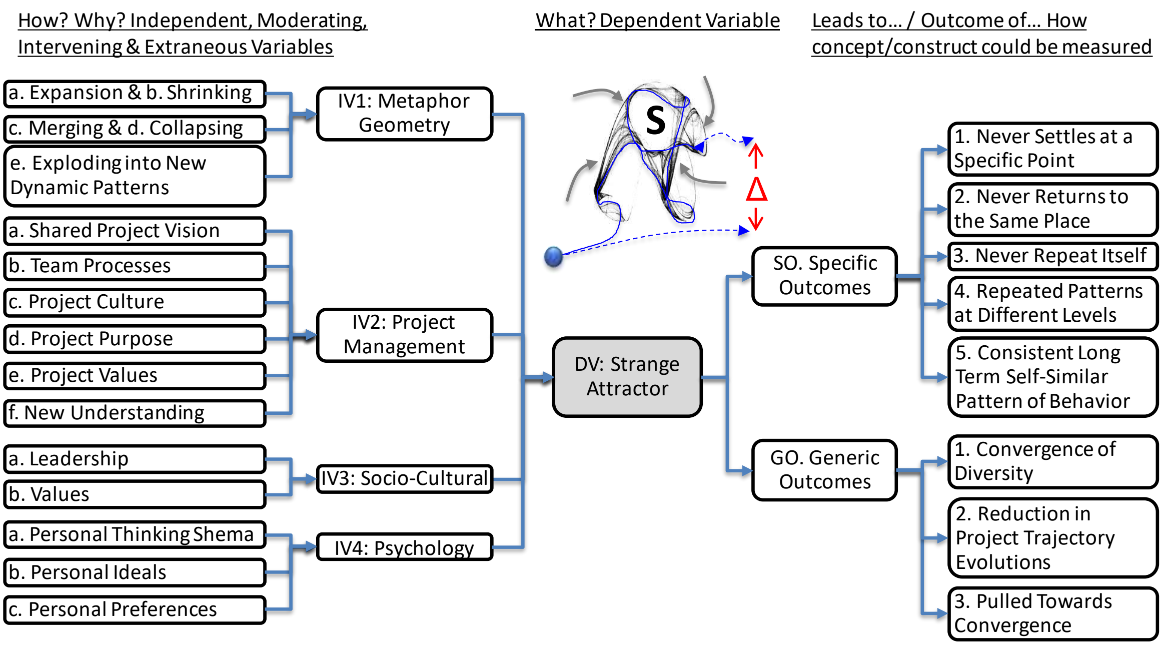


Figure 3-19: Variance Model for a Strange Chaos Attractor for Capital Projects

3.5.4 Variance Model for a Group of Different Types of Chaos Attractors

This section covers existing landscapes (static and dynamic) of groups of chaos attractors obtained from literature references as well as pre-designed landscape of the selected six chaos attractors applied to the life cycle of a capital project. A generic variance model is then derived based on literature for a landscape of chaos attractors.

3.5.4.1 Mid-Range Theory and Literature References for Landscapes of Chaos Attractors

The derived mid-range theory for a landscape containing a group of different types of chaos attractors was given in Table 3-15 as:

> ***(a) A chaos attractor landscape consisting of a group of different types of chaos attractors, generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome.***

Different schematic representations for chaos attractor landscapes as found in the literature are shown in Figure 3-20.

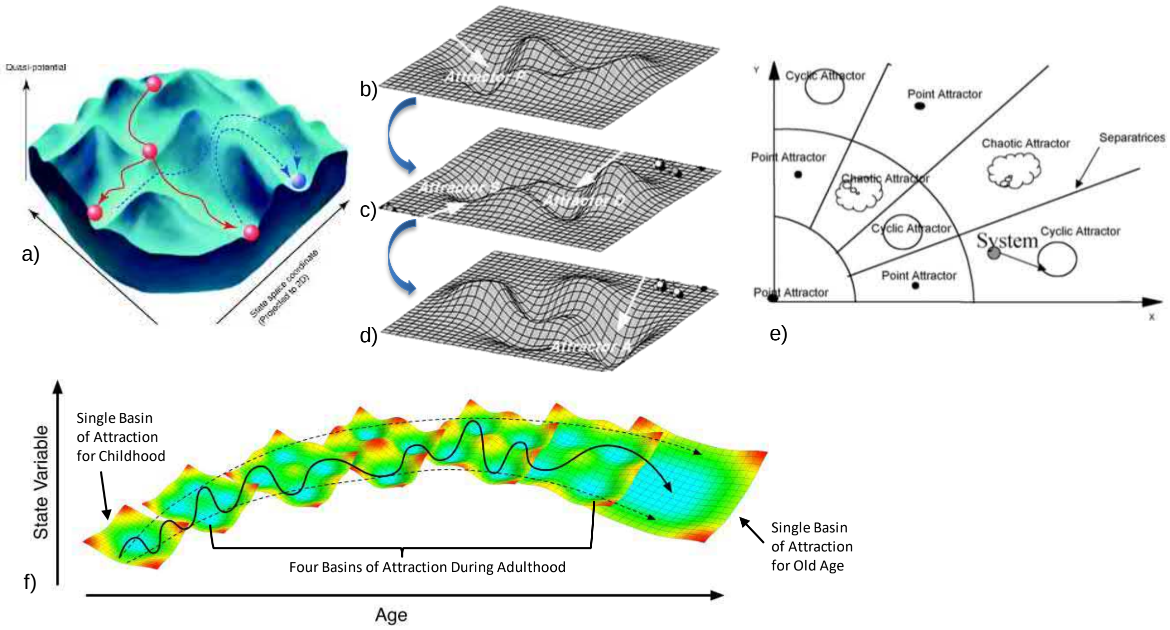


Figure 3-20: Sketches for the Landscapes of Chaos Attractor Metaphor

A stationary attractor landscape with multiple chaos repellers (mountains) as well as fixed-point chaos attractors (valleys) and potential trajectories representing the formation of genes (solid lines) and the potential gene reprogramming strategies (dotted lines) are shown in Figure 3-20(a) (Zhou and Huang, 2011:60, Figure 4). This attractor landscape is used in biological sciences to explain gene cell fate (what happens to a cell) and what can be done to reprogram or change the status of a gene cell. Refer also to Figure 3-20(b) for a similar chaos attractor landscape containing only chaos repellers and fixed-point attractors. However, attractor landscapes that contain only chaos repellers and fixed-point chaos attractors may also be dynamic or change as a function of time as shown in Figure 3-20(b-d) (Choi et al., 2012:10, Figure 6). This means that a mountain (chaos repeller) may become a valley (point chaos attractor) or vice versa as time progresses. The implication is that the trajectory of a system during this time could change dramatically and be very difficult or impossible to predict. A changing chaos attractor landscape or the similar concept of a fitness landscape (Kauffman and Levin, 1987) may also be perceived as a “moving sea or shifting sand dunes” (Remington and Pollack, 2007:10) and may be caused by changes in the system environment or the movement through the landscape of the system itself

(Remington and Pollack, 2007). In this regard Gharajedaghi (2011) states that a person is being formed by his surrounding culture and that the culture is simultaneously also being formed by the presence of a person. Yet another level of complication to the chaos attractor landscape concept could be added by considering other types of chaos attractors in addition to chaos repellers and fixed-point attractors as shown in Figure 3-20(e) (Allen, 2001:30, Figure 2) where cyclic (limit-cycle) and chaotic (strange) chaos attractors were added for a stationary chaos attractor landscape. Allen (2001) is of the opinion that different chaos attractors represents different nonlinear equations of a system and that all these equations drive the dynamic system towards a long-term attractor in the "basin in which it starts" (p. 30) and that the attractors represent a specific end state of the system. An example of a changing chaos attractor landscape that contains only fixed-point attractors and repellers and represent the journey of a person from childhood to old age as a function of time is shown in Figure 3-20(f) (Boker, 2013:7). During childhood and old age, a single fixed-point attractor basin guides behaviour in terms of space and time. However, as explained by Boker (2013), during young and middle adulthood a person has greater complexity in terms of choices available due to multiple fixed-point chaos attractors and chaos repellers. The late life chaos attractor basin, just before the last old age attractor basin, is also shallower compared to the middle adulthood basins and the trajectory of a person has less variability. It is interesting to note that the life cycle trajectory of a person as represented by this chaos attractor model remain bounded within the two dotted lines even with cyclic variability and therefore is bounded to convergence within this landscape. The question could be posed if an attractor landscape can be generated that would have the same bounded convergence effect for capital projects. The significance of this situation is that the chaos attractors represent the variables of the system and that only the values of the variables change but not the number or type of variables – thus producing a "constant dimensionality of the system" (Allen, 2001:30).

3.5.4.2 Suggested Pre-Designed Landscape of Six Chaos Attractors Around Capital Project Stage Gates

The derived mid-range theory for a group of six selected types of chaos attractors was given in Table 3-15 as:

> ***(b) A landscape of chaos attractors consisting of a group of six different types of chaos attractors, generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome***

The derived lower-level theory for a pre-designed landscape of the selected six chaos attractors was given in Table 3-15 as:

> ***(c)A specifically designed landscape of chaos attractors consisting of a group of six different types of chaos attractors [fixed-point, repeller, limit-cycle, torus, butterfly and strange], generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome.***

Based on the idea of (Saynisch, 2010) that a second order evolutionary jump takes place at project stage gates and that cyclical work and problem solving processes are done between project stage gates, a configuration of the six chaos attractors is proposed as shown in Figure 3-21, to represent one embodiment of chaos attractors for capital projects between stage-gates as part of a pre-design capital project landscape of chaos attractors.

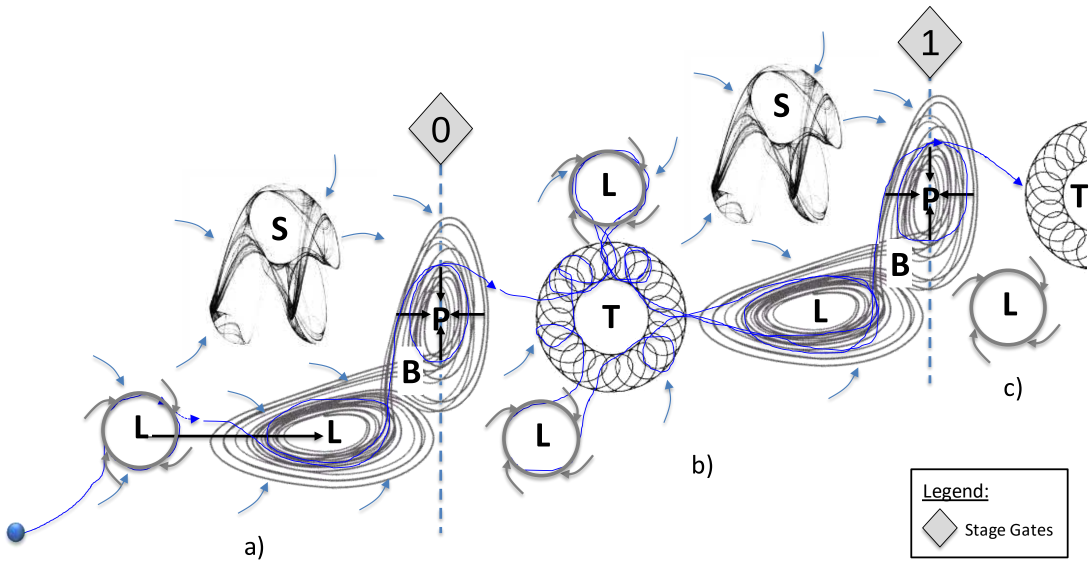


Figure 3-21: Suggested Pre-Designed Configuration of Chaos Attractors between Capital Project Stage-Gates to Achieve an Increased Level of Project Convergence and Maturity

It is suggested that the presence of a strange chaos attractor, of which strong leadership is one example, should always be present during the entire capital project life-cycle as shown in Figure 3-21. At the initiation stage of a project before stage-gate 0 as shown in Figure 3-21(a), the presence of strong leadership (strange chaos attractor (S)) defines a limit-cycle chaos attractor (L) (project charter) to get high level interested parties to discuss the objectives, context and deliverables for the foreseen capital project. A number of discussions take place (limit-cycle chaos attractors) and the limit-cycle chaos attractor becomes the basin of a butterfly chaos attractor (B). Upon a trigger event / point / maturity and with the influence of the strange attractor the evolutionary jump takes place at stage-gate 0 to a higher-level attractor basin with a fixed-point attractor positioned in the middle of this higher-level attractor basin as shown. The higher-level fixed-point attractor might be a signed-off project charter. Between stage-gate 0 and stage-gate 1 as shown in Figure 3-21(b), first order evolutionary development takes place according to the description by Saynisch (2010). This is achieved by a torus chaos attractor and project development processes. This might take the form of multiple cycles within the single stage development cycle such as the classical project management 'initiate-plan-execution-monitor-control-close-out' processes (PMI, 2017), the classical systems engineering management processes such as 'requirements-architecting-evaluation-specification-baseline' (INCOSE, 2015), the classical quality management processes such as 'plan-do-check-act' (ISO, 2015) or similar developmental processes used in capital projects. During the execution of the torus chaos attractor internal processes, a limit-cycle chaos attractor is used to ensure local and overall alignment. The limit-cycle chaos attractor could be seen as a steering committee meeting, a project meeting or an engineering discipline meeting. Due to the influence of the strange chaos attractor, a number of loose elements inside and outside of the project environment are constantly pulled towards the attractors and into convergence and development. Once sufficient development has taken place in the torus chaos attractor, the bottom causal basin of the butterfly chaos attractor is entered just before stage-gate 1. This may be seen as a project and engineering internal or external review meetings. The successful passing of these reviews may trigger the stage-gate 1 jump to a higher level of maturity in a new causal basin towards a specific gate objective in terms of a fixed-point attractor. The same chaos attractors in the same configuration is now repeated for the development between stage-gate 1 and 2 as shown in Figure 3-21(c) based on the self-similar concept of repeated patterns at different levels in systems according to Mandelbrot (Fractal Foundation, 2009). This basic pre-designed landscape using the selected six chaos attractors as defined in Figure 3-21, forms the basis of the suggested capital project landscape of chaos attractors across the full life-cycle.

3.5.4.3 Suggested Pre-Designed Landscape of Six Chaos Attractors for a Capital Project Life Cycle

The configuration of chaos attractors that was developed between two capital project stage-gates as shown in Figure 3-21 is now mapped across the complete capital project life-cycle as shown in Figure 3-22.

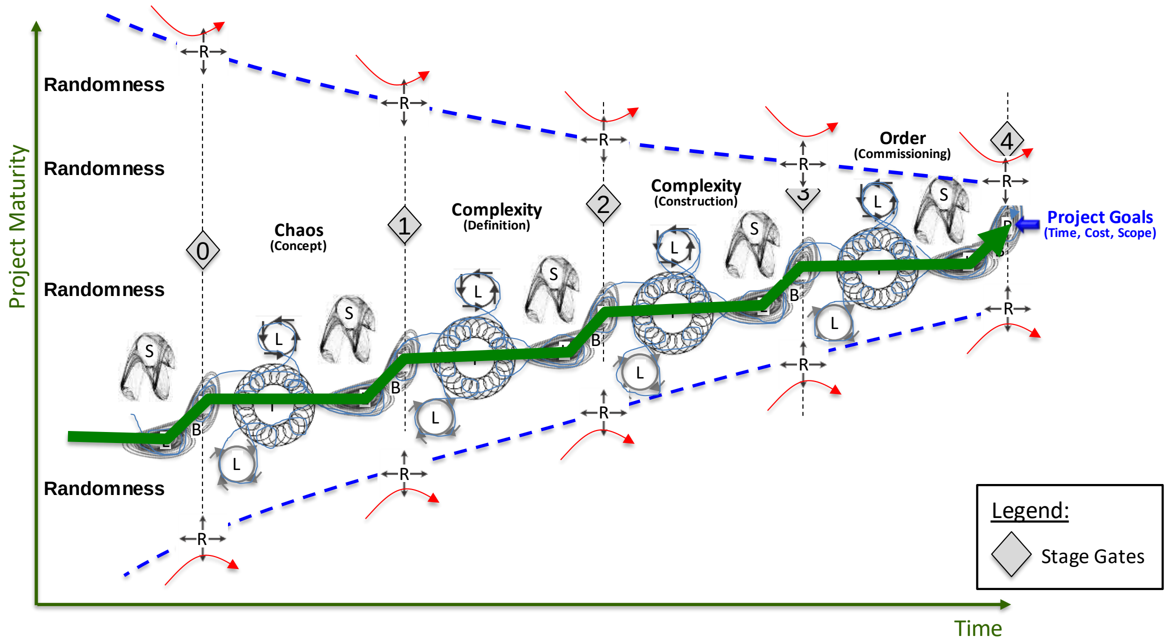


Figure 3-22: Proposed Landscape of Six Chaos Attractors across a Capital Project Landscape to Cause Local and Overall Capital Project Convergence

Fixed-point chaos repellers are positioned along the boundary of the capital project as shown in Figure 3-22. One embodiment of these repellers could be for example penalty clauses in project contracts or disincentives to contractors or external stakeholders that could cause project divergence. It is suggested that these six chaos attractors in this configuration enhances simultaneous local and overall convergence. The maturity of the project jumps at each stage-gate due to the influence of the butterfly chaos attractor as shown at the stage-gates. Overall the capital project converges from randomness to chaos to complexity and finally to order and the achievement of the project short term goals in terms of time, cost, quality and performance. This pre-designed landscape of chaos attractors is proposed (suggested) to have the same effect on generating increased overall value with proper front end loading as was proposed in the sketch of Hutchinson and Wabeke (2006:4) (Chapter 2, Figure 2-32) and increased project evolution "at a higher level" as was proposed in the sketch of Saynisch (2010:34) (Chapter 2, Figure 2-33). Chaos attractors and the landscape of chaos attractors also provide an alternative explanation of project evolution and may contribute to the theory of project management.

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3.5.4.4 Variance Model for a Chaos Attractor Landscape for Capital Projects

References to the chaos attractor landscape metaphor were reviewed in the literature and mapped to the capital project domains using the method as described by Cornelissen and Kafouros (2008) as shown in Appendix C, Table C-7.

The results of the source-target domain mapping for capital projects of the chaos attractor landscape metaphor as shown in Table C-7 are displayed in a variance model in Figure 3-23.

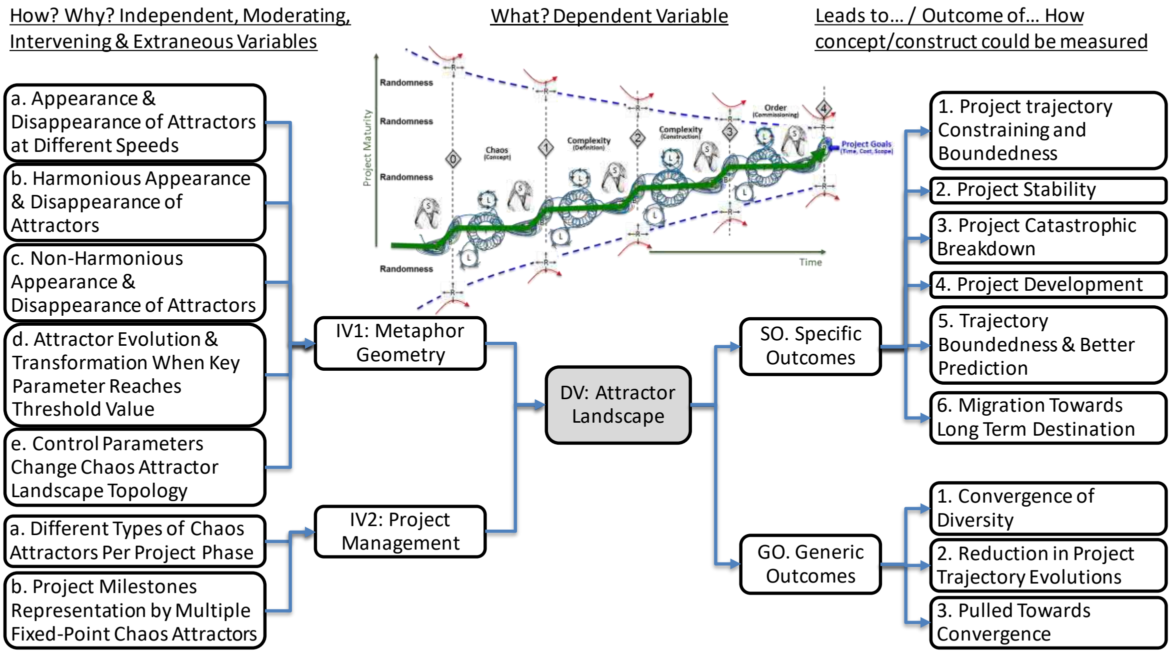

Figure 3-23: Variance Model for a Landscape of Chaos Attractors for Capital Projects

3.6 Summary on Theory and Model Building

The objective of this Chapter was to build theories and models of chaos attractors and a landscape of chaos attractors that could be used for explorative testing in the capital project environment.

Definitions as found in the literature were given for capital projects and a new definition for capital projects was composed for this research. The nomenclature for chaos attractors and chaos attractor landscapes was also defined for further use in this research.

The section on theory building was started with a literature survey on theory building practices. These covered definitions of theories, levels of theories, limitations and expectations of theories and the different schools of thought that are apparent in theories. It was shown that metaphors have been used by many researchers to gain insight from different perspectives into complex socio-cultural phenomena. Metaphors were also used previously to study projects and project management behaviour. However, the theory building model that was chosen for this research indicates that theories are conceptualised using three building blocks. These are empirical observations, theoretical concepts and metaphors. The principle of bricolage allows theorists to compose theories of building blocks that may seem not to belong together. Grand theories and mid-range theories for the capital project domain were then derived using the principles of horizontal and vertical theory borrowing. Six chaos attractors were chosen for this research and lower-level theories were derived as well as a theory for the behaviour of a group of different types of chaos attractors in a landscape of chaos attractors.

The theory building section was followed by a model building section. A model was constructed based on the literature survey from Chapter 2 for the Randomness-Chaos-Complexity-Order (RCCO) continuum. This model will be tested in the capital project domain as part of the scope of this research. For this research, variance theory was used to generate variance models in comparison to process theory and process models. The variance models give the relationship between independent and dependent variables for a snapshot in time of a phenomenon. Variance models also explain the "know that" character of a phenomenon in contrast to the "know why" character of a phenomenon that is captured by process models. Variance modelling was deemed to be sufficient for this exploratory research. Six variance models were generated based on the previous derived lower-level theories, expanded metaphor descriptions and in-depth literature survey on the specific chaos attractors. One variance model was generated for a group of different types of chaos attractors. These seven models will be tested in an exploratory manner in the capital project environment as part of this research. Chapter 4 will cover the research methodology.

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CHAPTER 4: RESEARCH METHODOLOGY, DATA COLLECTION AND DATA ANALYSIS

4.1 Introduction

Theories and models for chaos attractors that cause local and overall convergence from chaos to order in capital projects were derived in Chapter 3. This chapter provides the research methodology required to collect and analyse relevant data to test the viability of these theories and models. The scope of exploratory testing to be done for this research is defined after which the research strategy and research design are done. The defined methodology is then applied to two rounds of research interviews where data was collected and analysed. Due to the qualitative nature of this exploratory research, an attempt has been made to provide transparency in all the research steps followed in order to enhance research rigor. This chapter is concluded with a summary on the research methodology employed for this research.

4.2 Scope of Exploratory Testing to be done for this Research

The Randomness-Chaos-Complexity-Order (RCCO) continuum was composed from references in the literature in Chapter 2 and Appendix B and a model for exploratory testing in the capital project domain was defined in Chapter 3. Similarly, grand, mid-range and lower-level theories for chaos attractors and chaos attractor landscapes were built in Chapter 3 and variance models were derived for testing in the capital project domain. Therefore, a research strategy, methodology, instruments and analysis methodology need to be developed to test these models using respondents that are active in the capital project domain. The scope of empirical tests to be done for this research is shown in Table 4-1.

Table 4-1: Scope of Empirical Testing for Capital Projects

No.	Aspect to be Empirically Tested	Model
1	**Model Type 1: Relevance of the Randomness-Chaos-Complexity-Order Continuum (RCCO) in the Capital Project Domain**	
a	Definitions for randomness, chaos, complexity and order	Chapter 3: Figure 3-6
b	Ranking of continuum domains in terms of decreased disorder	
c	Movement of a successful project in the continuum from a state of randomness towards a state of order	
d	Movement of a failed project in the continuum from a state of order towards a state of randomness	
e	Definition of chaos attractors	
f	Relevance of a generic chaos attractor variance model	

No.	Aspect to be Empirically Tested	Model
2	**Model Type 2: Local Convergence Effect of Six Metaphors and Variance Models for Individual Chaos Attractors in the Capital Project Domain (Relevant to Main Research Question 1)**	
a	Explanation of the metaphors and testing for recognition of the metaphors and examples in the capital project environment	Chapter3: Figure 3-8 to Figure 3-19
b	Explanation of the variance model elements and testing for recognition of elements in the capital project environment	
3	**Model Type 3: Overall Convergence Effect of One Metaphor and Variance Model for a Group of Different Types of Chaos Attractors in the Capital Project Domain (Relevant to Main Research Question 2)**	
a	Explanation of the metaphor and testing for recognition of the metaphor and examples in the capital project environment	Chapter 3: Figure 3-20 to Figure 3-23
b	Explanation of the variance model elements and testing for recognition of elements in the capital project environment	
4	**Self-Assessment**	
a	Self-assessment on the understanding and effectiveness of metaphor mapping to the capital project environment	-
b	Ability to use the chaos attractor concept	
c	Duration of the interview	

Before attempting to test the local and overall convergence effect of chaos attractors in capital projects, the contextual definitions and chaos theory concepts need to be newly defined for the capital project domain. It was shown in Chapter 2, paragraph 2.7 that systems and projects seem to be able to move or transform from states of order to disorder and from chaos to order under the influence of chaos attractors. These bounded movements of a system or project also seem to occur from one domain to another as was shown in Chapter 2, paragraph 2.5 and these domains were identified as randomness, chaos, complex and order. The RCCO continuum as defined in Chapter 3, Figure 3-6 seem to provide the context within which systems or projects traverse. The first exploratory tests should therefore attempt to confirm if capital project managers are able to identify with the RCCO continuum concept, the different domains within the continuum and the movement of a project within the continuum and the presence of chaos attractors as shown in Table 4-1(1a-f).

The local convergence effect from chaos to order due to the presence of a chaos attractor in the capital project environment needs to be empirically tested. This will allow for an attempt to answer the first main research question: *Does the use of individual chaos attractors lead to local convergence from chaos to order of capital project elements and their trajectories?* (Chapter 1, paragraph 1.9.1). Six chaos attractors were selected for this research (Chapter 3, paragraph 3.4.9.2) and therefore six metaphors and variance models need to be empirically tested for their local convergence effect as shown in Table 4-1(2a-b).

The six selected chaos attractors were also arranged to form one of many configurations in the capital project domain to cause overall project convergence as was shown in Chapter 3: Figure 3-21 to Figure 3-23. This overall convergence effect needs to be tested to attempt to answer the second main research question: *Does the use of combinations of different types of chaos attractors lead to overall convergence from chaos to order of capital projects?* One metaphor and one variance model needs to be empirically tested as shown in Table 4-1(3a-b).

It was shown in Chapter 3, Table 3-5 that many metaphors were used previously to describe phenomena in the project management paradigm. The literature on metaphor mapping indicated that an effective metaphor for theory building has to be understood, be transferable from the source to the target domain and has to generate new insight (Cornelissen et al., 2005). To determine the effectiveness of the chaos attractor metaphor in the capital project domain, it is required to include a self-assessment as shown in Table 4-1(4a-c).

Therefore, scope for empirical tests is given in Table 4-1 and a research strategy is required to obtain the required empirical data.

4.3 Research Strategy and Design

A qualitative research strategy was chosen for this exploratory type of research. Based on this strategy, a research design that covers a detailed methodology layout, unit of analysis, variables, sampling, data collection, instrument design, data analysis and triangulation, follows. This section indicates the desired design characteristics for the two rounds of interviews that were conducted with selected capital project managers.

4.3.1 Research Strategy

The literature survey in Chapter 2 has indicated that chaos theory and specifically chaos attractors, were predominantly applied by researchers at a metaphorical level. References to the metaphorical use were identified in various sciences but not in the project management domain or capital projects. No references in the literature for variance models that contain chaos attractors could be found. A total of seven metaphors and variance models were derived in Chapter 3 for potential use in the capital project environment. Due to the novelty of the use of chaos attractors to generate order from chaos in capital projects, it was decided to employ a qualitative research strategy. The characteristics of qualitative and quantitative research strategies are shown in Table 4-2.

Table 4-2: Selecting a Qualitative Research Strategy Based on the Framework by Merriam and Tisdell (2016:20, Table 1.2).

Point of Comparison	*Qualitative Research*	*Quantitative Research*
Focus of research	Quality (nature, essence)	Quantity (how much, how many)
Philosophical roots	Phenomenology, symbolic interactionism, constructivism	Positivism, logical empiricism, realism
Associated phrases	Fieldwork, ethnographic, naturalistic, grounded, constructivist	Experimental, empirical, statistical
Goal of investigation	Understanding, description, discovery, meaning, hypothesis generating	Prediction, control, description, confirmation, hypothesis testing
Design characteristics	Flexible, evolving, emergent	Predetermined, structured
Sample	Small, nonrandom, purposeful, theoretical	Large, random, representative
Data collection	Researcher as primary instrument, interviews, observations, documents	Inanimate instruments (scales, tests, surveys, questionnaires, computers)
Primary mode of analysis	Inductive, constant comparative method	Deductive, statistical
Findings	Comprehensive, holistic, expansive, richly descriptive	Precise, numerical

Merriam and Tisdell (2016:6, 24) indicate that the focus of qualitative research is to gain a better understanding of the “nature”, “essence of the underlying structure” and “understanding of the meaning” of a phenomenon. In contrast, quantitative research focuses on the frequency of appearance of a phenomenon and tries to answer questions relating to “how much” or “how many” of a phenomenon (p. 6). Merriam and Tisdell (2016:6) refer to the simple distinction made by Braun and Clarke that qualitative research “uses words as data” and analyse them in various ways while quantitative research “uses numbers as data” and analyse them using statistical techniques. These definitions confirm that a qualitative strategy has to be employed for this research as the use of chaos attractors in capital projects is believed to be novel by the researcher.

The philosophical roots of qualitative research lie in the belief that phenomena is described as symbols (symbolic interactionism) and experienced through senses, that "reality is socially constructed" (constructivism) and therefore "multiple realities, or interpretations, of a single event" exist (Merriam and Tisdell, 2016:9). In contrast, the philosophical root of quantitative research assumes that "reality exists out there and that it is observable, stable and measurable" (positivist) (p. 9) can be counted by doing empirical research and analysed by statistical means. The literature survey in Chapter 2 indicated that chaos attractors were referred to mostly in metaphorical terms and many different interpretations were given by researchers for the same chaos attractor. The philosophical root of constructivism is therefore deemed to be a better strategy to investigate and better understand this phenomenon.

The goal of this research (investigation) was to better understand, describe and discover the meaning of chaos attractors in the capital project environment. The design of this research was flexible, evolving and emergent as shown in Table 4-2. It was found that the pilot questionnaire substantially influenced and changed the format of the semi-structured interview questionnaire for this research. Also, the results originating form for the first round of interviews using the Nominal Group Technique (NGT) influenced the methodology (deep individual interviews) for the second round of interviews.

Small samples were used for data collection (12 and 14 experienced project managers as shown in paragraphs 4.5 and 4.6) that were obtained in a non-random manner. However, this non-random sample proved to be purposeful in gaining a deeper level of understanding of the chaos attractor phenomenon in capital projects.

The researcher was the "primary research instrument" for data collection using interviews as per the qualitative research strategy in Table 4-2. The interviews were transcribed, and content analysis was done using a code book. The principles of an inductive methodology (Gioia et al., 2013) was employed to extract meaning and relevance of chaos attractors from the responses of experienced capital project managers. These results are comprehensively described in Chapters 5 – 8 of this research.

A qualitative research strategy is therefore chosen for this research. The research design uses the research strategy as the starting point.

4.3.2 Research Design

4.3.2.1 Research Design for a Qualitative Research Strategy

Flick (2007:36) defined research design as "a plan for collecting and analysing evidence that will make it possible for the investigator to answer whatever questions he or she has posed". Merriam and Tisdell (2016) showed that researchers described many different methods and practices for the design of a research strategy. They referred (p. 22) to Creswell that conclude that "there is no conclusion [among scholars] on the baffling number of choices and approaches in qualitative research". Therefore, based on the chosen qualitative research strategy as indicated in Table 4-2, a research design schema based on the ideas of (Buys, 2005) is proposed for this research as shown in Figure 4-1.

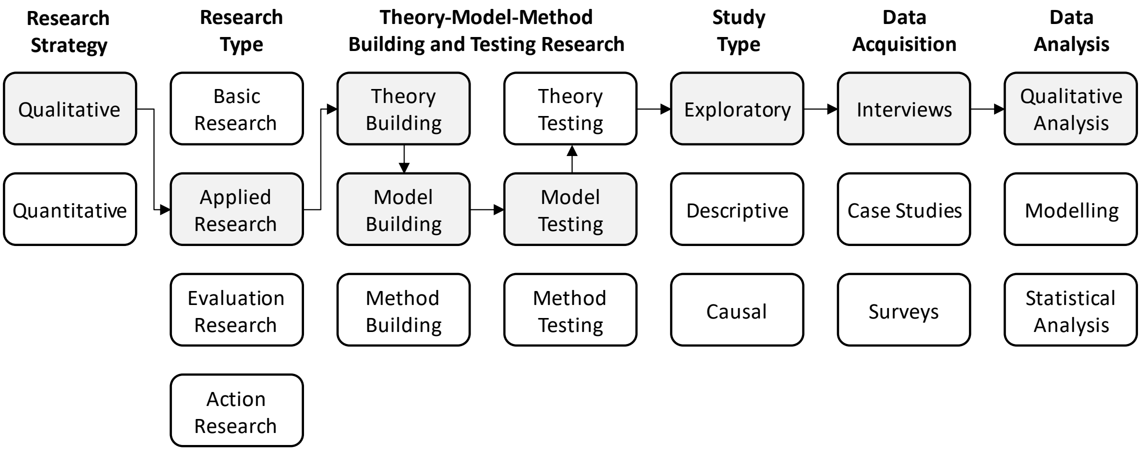

Figure 4-1: Qualitative Research Design According to the Schema from Buys (2005)

Merriam and Tisdell (2016:3, 4) state that the purpose of basic research is to "know more about a phenomenon", applied research is to "improve the quality of practice of a particular discipline" while action based research is to describe a problem in a "practise-based setting". Zikmund (2003) further elaborates that the findings of basic or pure research generally cannot be implemented immediately, while Page and Meyer (2003:19) are of the opinion that applied research is "research with a specific application in mind". The objective of this research is to gain a better understanding of chaos attractors and their converging effect in capital projects and the type of research is therefore classified as applied research as shown in Figure 4-1.

Walwyn (2016:7) stated that at the University of Pretoria in the Graduate School of Management, the preferred research design for students is "theory-, model- or method-building, -testing and -application empirical research". For PhD students the emphasis should be more on theory building and theory testing research and less on application research. In line with this notion, chaos theory and chaos attractor theories and variance models were derived in Chapter 2. Three models types (continuum, 6 variance models for local convergence and 1 variance model on overall convergence) are subject to exploratory testing in this research. For this research theory building, model building and model testing are done as part of the scope or work as shown in Figure 4-1.

The investigation into the plausibility of using chaos attractors as convergence mechanisms to create order from chaos in the capital project domain is believed to be novel. Therefore exploratory research is deemed a suitable research type as shown in Figure 4-1. Zikmund (2003:54, 55) is of the opinion that exploratory studies are required to “clarify ambiguous problems”, to “better understand the dimension of problems” and the expectation is that follow-on research will be required to “provide conclusive evidence” on a phenomenon. Page and Meyer (2003:22) confirm that exploratory research is normally the first step in a research program that aims to design a new theory or model and it explores the “phenomenon, event, issue [or] problem”. Descriptive research, according to Zikmund (2003:55), may for example use surveys to answer the “who, what, when, where and how” questions of a particular problem. Page and Meyer (2003) adds that the findings of descriptive research are not generalised to other settings. They state that case studies are examples of descriptive research. Both exploratory and descriptive research precedes causal research which has the objective to determine “cause-and-effect relationships among variables” (Zikmund, 2003:56). This research therefore employs the exploratory research principles as shown in Figure 4-1.

Data collection or acquisition for this exploratory research is done by interviews with experienced capital project managers in South-Africa representing various industries. The analysis of the transcribed interview data is done using a qualitative methodology as shown in Figure 4-1.

4.3.2.2 Detail Research Design

Flick (2007) states that their research had no fixed research design before commencement of their research. Their research design rather evolved during the duration of the research. This research unfolded in a similar manner. The Round 1 pilot data acquisition phase was started by generating and using a pilot questionnaire as shown in Figure 4-2(a).

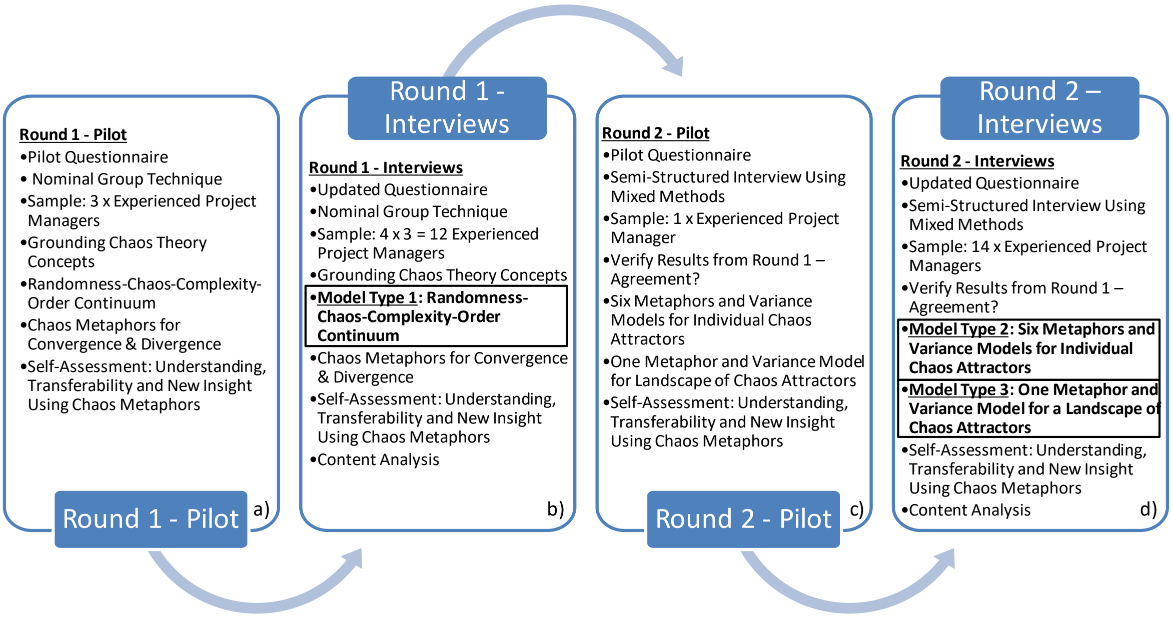

Figure 4-2: Detail Research Design for Empirical Testing of Three Chaos Theory Model Types for Capital Projects

All three model types under investigation (refer to Table 4-1) were included in the pilot questionnaire together with multiple semi-structured questions. The Nominal Group Technique (NGT) was used as the interview methodology to obtain data for grounding the chaos theory concepts for the RCCO continuum model. The metaphors and variance models as well as a self-assessment were also included.

Based on the learning from this pilot interview, the semi-structured interview questionnaire was substantially updated and shortened for the Round 1 interviews (Figure 4-2(b)). The same updated questionnaire was used for four group interviews using NGT with experienced capital project managers. The updated and reduced scope of the interview focused on grounding of chaos theory concepts by interviewees and obtaining views on the RCCO continuum in a capital project environment. Interviewees were also asked about their first impression of a chaos attractor, project convergence and divergence as a result of chaos attractors. A self-assessment was done to determine to what extent respondents understood and were able to transfer and generate new insight for the chaos attractor metaphor in the capital project environment. The written and voice recorded data was transcribed and content analysis was done to extract results.

Based on the learnings from the Round 1 pilot interviews as well as the Round 1 interviews, a pilot questionnaire was compiled for the Round 2 pilot phase as shown in Figure 4-2(c).

The focus of the interviews moved from the RCCO continuum and initial understanding of the chaos attractor concept to the exploratory testing of the two chaos attractor model types for local and overall capital project conversion as shown in Table 4-1(2 and 3). These two model types aim to provide answers to the two main research questions for this research. Due to the requirement to exploratory test a total of seven metaphors and variance models, it was decided to conduct in depth interviews for Round 2 with individual experienced capital project managers. The interview was started by summarising the results from the Round 1 interviews and asking respondents if they agree, disagree and would like to add to the results. In this manner the two sets of interviews were linked with each other although totally different respondents were used for Round 1 and Round 2 interviews. The pilot testing was concluded with a self-assessment to verify if the respondent was able to understand and transfer the chaos attractor metaphor concept to the capital project environment.

The pilot questionnaire was only marginally updated and used for the Round 2 individual in depth semi-structured interviews as shown in Figure 4-2(d). Individual interviews were conducted with 14 experienced capital project managers. Each interview was concluded with a self-assessment.

Due to the semi-structured nature of all interviews, the researcher provided substantial verbal input on the background and context of chaos attractors that were derived from Chapter 3. This detailed research design as shown in Figure 4-2 ensured full coverage of the scope of the exploratory testing that was envisaged for this research as shown in Table 4-1 (three model types and self-assessment). The level or unit of analysis for this research was emphasized throughout the interviews by the researchers as the capital project.

4.3.2.3 Unit of Analysis

Vasileiadou and Safarzyńska (2010) state that, the dynamics of complex systems occur at three levels. These levels are the context level, the system level and the agent level. They mention that these levels are similar to the Multi-Level Perspective framework (MLP) as described and used by other researchers. The MLP framework with the three levels of analysis applied to organisations and capital projects is shown schematically Figure 4-3.

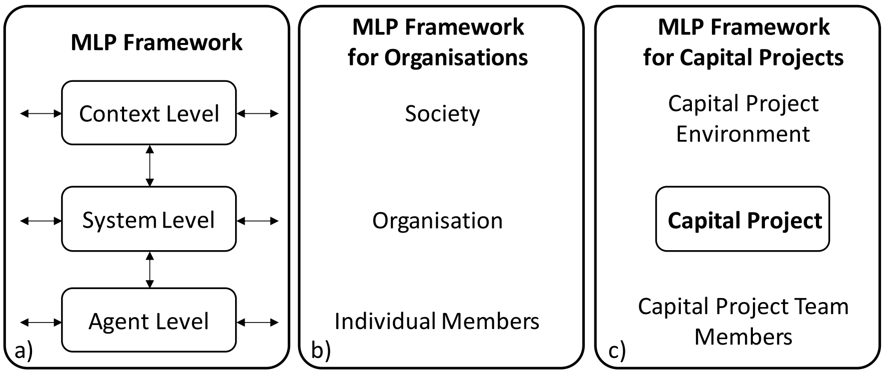

Figure 4-3: Unit of Analysis Based on the Multi-Level Perspective Framework Applied to Organisations and Capital Projects

Vasileiadou and Safarzyńska (2010) state that, these three levels of a complex system dynamic do not occur independently from each other in a complex system. They indicate that agent level dynamics influence system level dynamics but are also influenced by them. Similarly, the context level dynamics influence system level dynamics and are also influenced by them. There are therefore complex interactions at the same horizontal level in a complex system but also vertically as shown in Figure 4-3(a).

Gharajedaghi (2011) also refers to three levels of a purposeful socio-cultural system as: a) society; b) organisation; and c) individual members. If an organisation is viewed as a socio-cultural system, then the MLP framework could be applied to identify these three level of complex interactions as shown in Figure 4-3(b). Gharajedaghi (2011:12) continues to state that "these three levels are so interconnected that an optimal solution cannot be found at one level independent of the other two".

By transferring the MLP framework to the capital project environment, the three levels of complex interaction could be assumed to be the capital project environment, the capital project and the capital project team members as shown in Figure 4-3(c). It was shown in Chapter 1 that the environment of the capital project may be influenced by trends, megatrends, paradigm shifts, Black-Swan events and disruptive technologies. It was suggested that these variables could influence capital projects and increase complexity and chaos (Chapter 1, Table 1-6). However, the focus of this study will not be to determine the influence of a fast changing VUCA world on the capital project but on the chaos that is present in a capital project and the effect of chaos attractors to generate order from chaos. It is assumed that individual team members may play a role in the creation of order from chaos, but the research may indicate that other factors may also play a role in the creation of order form chaos.

The unit of analysis for this research will predominantly be the capital project without discarding the influences from the capital project environment or individual project team members.

4.3.2.4 Research Variables

In order to provide empirical answers to the main research questions, it is necessary to define "appropriate research variables" (Page and Meyer, 2003:41). The chaos attractors in capital projects are believed to function within the RCCO continuum (Chapter 2, Figures 2-30, 3-33 and 2-34). It is therefore necessary to gain an understanding of the RCCO continuum in the capital project environment and then to answer the two main research questions. The variables that are explored for this research are shown in Table 4-3.

Table 4-3: Identification of Research Variables

No.	**Research Elements**	**Research Variables**		
1	**Context for Chaos Attractors**	**Definition of Continuum Concepts**	**Statements on Continuum Characteristics**	**Chaos Attractor in Continuum**
a	Randomness-Chaos-Complexity-Order Continuum	● Randomness ● Chaos ● Complexity ● Order	● Ranking from Disorder to Order ● Movement from Disorder to Order (Convergence) ● Movement from Order to Disorder (Divergence)	● Multi-dimensionality ● How? ● When?
2	**Main Research Questions**	**Independent Variable Groups (Where Applicable)**	**Dependent Variables**	**Expected Outcomes**
a	Does the use of individual chaos attractors lead to local convergence from chaos to order of capital project elements and their trajectories?	● Chaos Attractor Metaphor Geometry ● Project Management ● Systems Engineering ● Process ● Socio-Cultural ● Psychology ● Other?	Fixed-Point Chaos Attractor Fixed-Point Chaos Repeller Limit-Cycle Chaos Attractor Torus Chaos Attractor Butterfly Chaos Attractor Strange Chaos Attractor	Local Convergence

No.	Research Elements	Research Variables		
b	Does the use of combinations of different types of chaos attractors lead to overall convergence from chaos to order of capital projects?	• Chaos Attractor Metaphor Geometry • Project Management • Other?	Landscape of Chaos Attractors	Overall Convergence

The RCCO continuum was identified during the literature survey in Chapter 2 and a model was extracted for testing the applicability in the capital project environment, as shown in Chapter 3, Figure 3-6. The variables for exploratory testing were selected to obtain definitions for the continuum domains from experienced capital project managers, to better understand project convergence and divergence in the continuum as well as the characteristics and functioning of a generic chaos attractor in this continuum, as shown in Table 4-1(1a).

To obtain an answer for the main research question (Chapter 1, paragraph 1.9.1), six individual chaos metaphors and variance models were defined in Chapter 3, paragraph 3.5.3. The independent variables of these variance models were identified and mapped from various scientific domains and then assigned to a group. The group categories were the chaos attractor metaphor geometry, project management, systems engineering, process, socio-cultural or psychology as shown in Table 4-1(2a). Due to the exploratory nature of this research a group category "other?" was added to enquire from the project managers if they would like to add a new category. The dependent variables are the six individual chaos attractors that were selected for this research (Chapter 3, paragraph 3.4.9.2) and <u>local convergence</u> is the expected outcome to be tested for.

One variance model was developed in Chapter 3, paragraph 3.5.4 to gain a better understanding of the <u>overall convergence</u> effect of a group of different types of chaos attractors in a chaos attractor landscape. Only two independent variable groups were identified comprising of the chaos attractor metaphor geometry and project management as shown in Table 4-1(3b). The dependent variable is the chaos attractor landscape and overall capital project convergence is the expected outcome to be tested for in this research.

4.3.2.5 Research Population, Sampling Frame and Sample

The research population, sampling frame and desired sample (Zikmund, 2003) for this research is shown in Table 4-4.

Table 4-4: Research Population, Sampling Frame and Desired Sample

No.	Sampling	Description
1	Research Population	All global capital project managers (All industries, all project sizes, all project complexity types, all sectors and both successful and unsuccessful projects)
2	Sampling Frame	All capital project managers in South-Africa with more than 15 years' experience (All industries, all project sizes, all project complexity types, all sectors and both successful and unsuccessful projects)
3	Sample	Selected capital project managers in South-Africa with more than 15 years' experience covering as many dimensions as possible of the research sampling frame

The research population includes all global capital project managers. However due to the exploratory nature of this research, that was conducted in South-Africa, the sampling frame reduces to all the capital project managers in South-Africa. Merriam and Tisdell (2016:97) refer to the work of LeCompte and Schensul where the attributes of a sample is determined before respondents are identified on a "criterion-based selection". Using this principle leads to purposeful sampling of "information rich cases" (p. 97) to acquire data to answer the research questions. Therefore, the desired experience profile of capital project managers for sample selection for this research in South-Africa should ideally have the following characteristics:

a) Different industries (power generation, infrastructure, mining, defence, petrochemical)
b) Different sectors (public, private and NGO)
c) Different sizes (projects, major projects, mega projects, giga projects and terra projects)
d) Different complexities (hierarchical, directional, technical and low complexity)
e) Successful or failed.

These characteristics are important to verify if the chaos attractor effect is present in multi-dimensional aspects of capital projects. Should the research results show that chaos attractors could be recognised by selected project managers to have exposure to these dimensions, then the possibility of the generalisation of this phenomenon may exist. Furthermore, if chaos attractors are a general phenomenon in capital projects, then they should work effectively in both successful and unsuccessful projects to generate order from chaos. They should also be effective in failed, divergent or chaotic projects as a turn-around mechanism to generate convergence from chaos to order.

It was decided to interview experienced capital projects managers for this research. This is due to the abstract nature of the chaos metaphors that requires individuals with high cognitive abilities to be able to understand the metaphors and be able to transfer them to the capital project domain and create new insight (Morgan and Reichert, 1999; Cornelissen et al., 2005). The objective of the sampling was to identify individual capital project managers in South-Africa that have the following broad experience:

a) Years of experience (>15)
b) Management responsibility (project manager, program manager, portfolio manager or project director)
c) Exposure to different management aspects (technical management, stakeholder relationship management, cost management, people management and schedule management).

Capital project managers are required to have at least 15 years' experience. It is assumed that such a long time of exposure to project management would have given sufficient exposure and experience to the many diverse aspects of capital projects. Such a tenure may also ensure that some capital project managers would have been promoted to program manager, portfolio manager or project director positions. A longer exposure to project management would also imply that the project manager could have been involved in multiple capital projects which normally have a long duration. A longer exposure to capital project management would also allow for assuming responsibility of various different management aspects. This purposeful desired sample has the objective to verify if the chaos attractor phenomenon is perhaps context independent within the capital project environment.

The principles described above in terms of a desired purposeful sample are in agreement with the "maximum variation sampling" principle as defined by Strauss and as referenced by Merriam and Tisdell (2016:98). This type of sample design, according to Strauss, leads to "grounding" in the "widely varying instances of the phenomenon".

The identification of respondents for this research was based on "non-probability samples" (Page and Meyer, 2003:99). A few of the experienced capital projects managers were known to the researcher and their ability to have high cognitive skills were judged to be sufficient for this research (judgemental sample). As the chosen project managers had acquired experience on multiple capital projects through their careers that originate from different industries, this chosen sample provided some form of stratification. The remainder of the experienced project manager respondents were identified by interviewees (snowball, chain or network sample) that provided some form of stratification to the selected sample.

In quantitative research the confidence level and confidence interval are important measures of reliability and accuracy of the selected samples in order to claim generalisation of research results (Zikmund, 2003). Also, in qualitative research non-probability sampling techniques are used to purposefully select a sample that reveals the phenomena under investigation (Merriam and Tisdell, 2016). Flick (2007:42) refers to the work of Maxwell that distinguishes between internal and external generalisation. Internal generalisation, according to Maxwell (as referenced by Flick (2007:42)), is the generalisation of a finding within the group selected and studied i.e. the selected sample population. External generalisation is generalising the research results of the sample population beyond that sample. Merriam and Tisdell (2016:101) refer to the work of Lincoln and Guba who stated that "sampling should continue until a point of saturation or redundancy is achieved". They continue to explain that information saturation is reached when "no new information is forthcoming from new sampled units" (Merriam and Tisdell, 2016:101). Sim et al. (2018) evaluated four distinct approaches to try and determine the sample size for qualitative research. These methods were rules of thumb, conceptual models, numerical guidelines from empirical studies and statistical formulae. They concluded that the sample size cannot be determined a priori i.e. before commencement of the research. This is, according to them, because the inductive exploratory research of a phenomenon is inherently iterative and context dependent. The "picture of the developed themes, the relationship between these themes, and where the conceptual boundaries of these themes lie" (p. 12) are unfolding as the research progresses. The sufficiency of the sample size for this research is therefore determined by the convergence of the results (saturation) during the data analysis process.

4.3.2.6 Research Data Collection Strategy

The data collection strategy that was employed for round 1 and 2 for this research is shown in Figure 4-4. The Nominal Group Technique (NGT) was selected for round 1 interviews while mixed methods as part of deep interviews were selected for round 2 interviews.

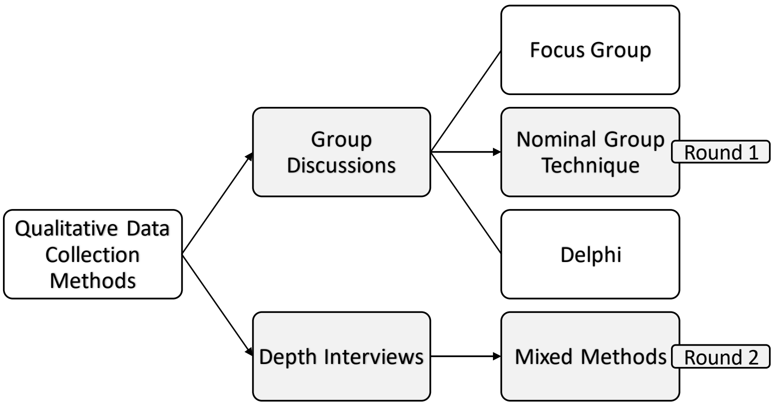

Figure 4-4: Selected Data Collection Methods

Group discussion as a method to collect data from respondents is referred to as a consensus type of method (Humphrey-Murto et al., 2017), with the objective of getting convergence on topics, ideas and responses. The Focus Group method to collect data, is best used as an "unstructured, free-flowing interview with a small group of people" Zikmund (2003:117). This method is used with a homogenous group, according to Zikmund, for screening, refinement and retesting of concepts. A number of questions on a chosen topic are asked from broad questions to more specific questions until questions and answers converge a "catch-all question" and responses (p. 120).

The Nominal Group Technique (NGT) is much more structured in comparison to the Focus Group Method. Harvey and Holmes (2012) explain that during the execution of the NGT, respondents are required to each generate ideas in writing after an introduction of the topic of discussion. Each respondent then gives verbal feedback in a round-robin manner followed by a group discussion and voting and ranking of concepts and ideas per question. Both the Focus Group and NGT are "face-to-face group meeting processes" (Potter et al., 2004) with the advantage of data richness originating from group dynamics and voice recordings of respondents.

The Delphi technique is a "consensus-building" technique where responses on specific questions are solicited from experts that are not co-located as explained by Hsu and Sandford (2007:1). During Round 1 a list of unstructured questions are prepared by the researcher and sent to experts to fill out. Upon returning these questions the responses are summarised. The updated structured questionnaire and summarised responses are again sent to all experts with the request indicating priorities of responses. The results are collated and in subsequent rounds experts are asked to indicate agreement and disagreement with the summarised and ranked responses of the group of experts. The number of Delphi-rounds depends on the "degree of consensus" required by the researchers (Hsu and Sandford, 2007:3).

The NGT was chosen as the data collection method for Round 1 of this research as the advantages and applicability of this method, as espoused by Harvey and Holmes (2012), seemed suitable to the exploratory nature of chaos theory and chaos attractors when interviewing experienced capital project managers. These advantages are (p. 190):

a) The opportunity to directly ask follow-up questions to respondents and clarify ambiguities "irrespective of the level of consensus" among respondents
b) The method forces equal contributions and ensures optimal participation by each group member "regardless of their discipline or level of appointment"
c) During the feedback of each member, other members continued discussions on emergent themes
d) Immediate availability of results for processing to verify suitability of interview questions
e) Little or no preparation is required by group members which is an advantage when interviewing experienced capital project managers with limited available time
f) The NGT is a "time efficient" process.

The Round 1 interviews, using the NGT, only covered exploratory testing of the Model Type 1 (RCCO continuum) and initial views of the respondents on chaos attractors as shown in Table 4-1. Group interviews and exploratory discussions among various respondents took a long time using the round-robin process of the NGT but sufficient data was collected for meaningful data analysis. It was therefore decided to use in depth interviews as the data collection method for the Round 2 interviews in order to be able to cover both Model Types 2 and 3 as shown in Table 4-1. It was also unexpectedly found that respondents identified capital project archetypes during the Round 1 interviews. The scope for the Round 2 interviews therefore comprised of three themes. These were the back-ward linking to the Round 1 research results, chaos attractor metaphor mapping and relevance of the variance models for chaos attractors in the capital project environment.

A Mixed Methods Research (MMR) design was chosen for Round 2 of this research because this method "is useful when a phenomenon being studied is complex and needs multiple methods to investigate it" (Cameron and Sankaran, 2013:383). During the first part of the Round 2 individual in depth interviews, respondents were asked about their understanding of the various chaos metaphors (fixed-point attractor, fixed-point repeller, limit-cycle, torus, butterfly, strange and chaos attractor landscape), as well as the transfer and application of these metaphors to the capital project domain to cause local and overall convergence. During the second part of the interview respondents were asked to do a Likert scale scoring (Page and Meyer, 2003) of all the elements of the various variance models. This scoring was done by respondents with supporting explanations by the researcher for each of the variance model terms and concepts.

The MMR employed for the Round 2 interviews used both qualitative and quantitative methodologies. The order of application was firstly to gain an understanding of the respondents' view on chaos attractors and the application to the capital projects environment and secondly to allow quantitative scoring of the variance models, with continuous support from the researcher. This practice ensured that a "common language or nomenclature" (Cameron and Sankaran, 2013:389) could be established of chaos attractor concepts despite using two different methods successively to collect research data. Therefore, the design typology of the MMR employed for Round 2 could be expressed as "QUAL → quan" as described by Cameron and Sankaran (2013:391). They explained that this design type means that sequential exploration was done of the phenomenon where emphasis is placed on the qualitative nature of the interview in the first part and followed by a quantitative method as the last part of the interview. According to Cameron and Sankaran (2013:392) this "sequential mixed model design" ensures that the first part of the interview is "exploratory" while the second part is "confirmatory".

4.3.2.7 Research Instrument Design Strategy

Onwuegbuzie et al. (2012:7) state that research information could be obtained from respondents "synchronously (e.g. face-to-face interviews, telephone interviews, Skype interviews, instant messenger, Second Life) or asynchronously (e.g., email, Facebook, MySpace.com, iTunes, iMovie, Youtube, Bebo, Friendster, Orkut, Flickr, Panoramio)". They indicate that "evidence-based interview practices" (p. 8) improve both legitimisation and representation of the collected data and contributes to the improvement of methodological rigor. Face-to-face interviews where evidence could be directly collected were therefore chosen as the data collection method.

A semi-structured interview design was predominantly used for both Round 1 and 2 interviews. The characteristics of a semi-structured interview design are shown in Table 4-5.

Table 4-5: Selected Research Instrument Design Strategy Based on the Framework of Merriam and Tisdell (2016:110, Table 5.1)

Highly Structured/ Standardized	*Semistructured*	*Unstructured/Informal*
• Wording of questions is predetermined • Order of questions is predetermined • Interview is oral form of a written survey • In qualitative studies, usually used to obtain demographic data (age, gender, ethnicity, education, and so on) • Examples: U.S. Census Bureau survey, marketing surveys	• Interview guide includes a mix of more and less structured interview questions • All questions used flexibly • Usually specific data required from all respondents • Largest part of interview guided by list of questions or issues to be explored • No predetermined wording or order	• Open-ended questions • Flexible, exploratory • More like a conversation • Used when researcher does not know enough about phenomenon to ask relevant questions • Goal is learning from this interview to formulate questions for later interviews • Used primarily in ethnography, participant observation, and case study

During the Round 1 interviews where the NGT was employed, respondents were asked to write down answers to the interview questions on an interview guide. Thereafter, they were each given an opportunity for group feedback based on their written answers (highly structured design). As soon as the group discussions started, the researcher probed and posed follow-up questions (semi-structured design) to gain a deeper understanding of the continuum concept and the chaos attractor phenomenon in the capital project domain. This approach allowed the researcher “to respond to the situation at hand, to the emerging worldview of the respondent, and to new ideas on the topic.” (Merriam and Tisdell, 2016:111).

During the Round 2 interviews an interview guide was used for the main questions. These questions were explained to respondents. Based on the responses of respondents, the researcher probed and asked follow-up questions with the objective to collect relevant data from responses of experienced capital project manager’s views on chaos attractor concepts in the capital project domain. A semi-structured instrument design was again employed during this round of interviews.

The choice of research instrument that was used for qualitative data collection for Round 1 and 2 of this research were deemed by the researcher to be "sensitive to underlying meaning when gathering and interpreting data" (Merriam and Tisdell, 2016:2).

4.3.2.8 Research Data Analysis Strategy

During the Round 1 interviews data was captured using hand-written answers to interview questions and voice recordings of discussions. Voice recordings were also captured for the Round 2 interviews. All voice recordings were transcribed using Atlas.ti software.

Dresing et al. (2005:22) expressed the challenge in transcribing data as follows:

> ***"The transcription process is obviously paradoxical: with the aspiration to accurately represent the multi-faceted verbal discourse, you create a written text that is a linear, one-dimensional document."***

The method of transcription should therefore be adequate to enable answering the research questions. Two approaches could be used for voice transcription namely a "simple" and "complex" transcription depending on the objective of the transcription (Dresing et al., 2005). The objective of a simple transcription method is to capture the literary context of the interview and to understand "what" the respondent is communicating. In contrast, the complex transcription method is used to capture "paraverbal and nonverbal elements of the communication" and also "how" the respondents are communicating (Dresing et al., 2005:23). A comparison between the simple and complex transcription methods is shown in Table 4-6.

Table 4-6: Comparison Between Simple and Complex Transcription Methods Based on Dresing et al. (2005).

No.	Dimension	Simple Transcript Method	Complex Transcript Method
1	Objective of Transcription	Focus only on "what was said" i.e. the semantic (literally) content of the conversation (p. 34)	Focus on "how something was said" i.e. "intonation, the exact length of pauses, overlapping speech, sudden cut-offs and informal contractions" (p. 34)
2	Para-verbal or Prosodic Elements	Not captured	Capturing of "intonation, primary and secondary emphasis, volume, speed and pitch" (p. 23)
3	Non-Verbal Aspects	Not captured	"Odor, room and time setting, visual aspects, facial expressions and gestures" (p. 22)
4	Dialect and Colloquial Language	"Approximated to standard language" (p. 28)	Captured using phonetics

No.	Dimension	Simple Transcript Method	Complex Transcript Method
5	Identification of Stakeholders	Interviewer as: “I” and Respondent as: “R” (p. 29)	Rules are stated in the Gesprächs Analytisches Transkriptionssystem (GAT2) or conversation analytic transcription system (Selting et al., 2009) that is mostly used in Europe. Simpler rules are also available from the American Sociological Association’s (ASA) (Schegloff, 2018)
6	Sentence Structure	“Sentence structure is retained despite syntactic errors, discontinuation of sentences is omitted, pauses are indicated by (…), words with emphasis are capitalised, (laughter and sighs in brackets), incomprehensible words indicated as (inc.), uncertain words as (unsure?), interruptions as: //interruption//” (p. 28 – 29)	
7	Paragraph structures	“Every contribution by a speaker in its own paragraph”, time stamps are added to each paragraph (p. 29)	

This research focussed on the literary responses from respondents in their perceptions of the existence and functionality of chaos attractors in a capital project environment and not the implied meanings of respondents. Therefore, the simple transcription method was chosen for this research.

Upon completion of the transcriptions of interview voice recordings, content analysis was performed to extract meaning from the transcribed data. Krippendorff (1989:403) defined content analysis as “a research technique for making replicable and valid inferences from data to their context”. He also defined a framework for content analysis as shown in Figure 4-5.

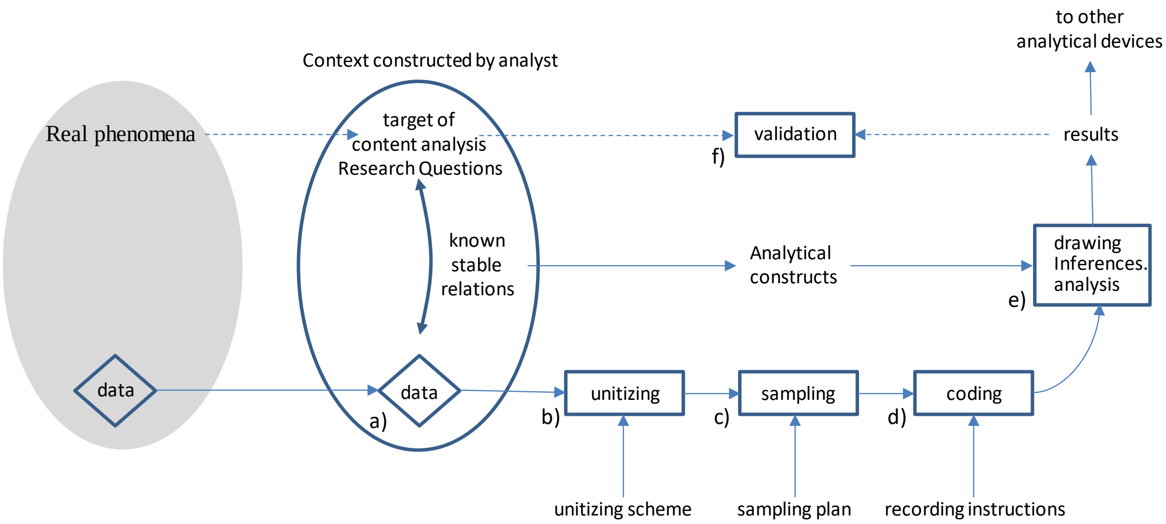

Figure 4-5: Reconstructed Framework for Content Analysis (Krippendorff, 1989:406, Figure 1). Numbering Added

This six-step framework for content analysis as shown in Figure 4-5 by Krippendorff (1989), demonstrates the challenge in research and specifically in qualitative research to collect valid data that represents or approximates the “real phenomena” under investigation. The collected data (a) is a function of the unit of analysis (b) the population, the sampling frame and the chosen sample (c). This collected data is then classified and coded (d) and then analysed (e). The analysed data in the form of results is then validated (f) with the target of the content analysis i.e. answering the research questions that aims to gain an understanding of the phenomena. This framework also shows the importance of the required rigor in terms of sampling data that is related to the phenomena and the formulation of valid research questions in order to have a valid and reliable answer from the data to the research questions.

Krippendorff (1989:405) states that “in order to minimize interviewer biases, open-ended answers to interview questions are often subjected to content analysis” with the purpose to compare the results of the content analysis to some form of measurable characteristics of the phenomena. Hsieh and Shannon (2005) compare the characteristics of three types of contents analysis techniques that are used by researchers with respect to the starting point of the study, the timing of keywords or coding and the source of codes or keywords as shown in Table 4-7.

Table 4-7: Selection of a Content Analysis Coding Approach Based on the Framework by Hsieh and Shannon (2005:1286, Table 4). Text Added

Type of Content Analysis	*Study Starts With*	*Timing of Defining Codes or Keywords*	*Source of Codes or Keywords*
Conventional content analysis	Observation	Codes are defined during data analysis	Codes are derived from data
Directed content analysis Round 2	Theory	Codes are defined before and during data analysis	Codes are derived from theory or relevant research findings
Summative content analysis Round 1	Keywords	Keywords are identified before and during data analysis	Keywords are derived from interest of researchers or review of literature

The summative type of content analysis as shown in Table 4-7 was predominantly used as the content analysis method for the coded data for round 1 of this research. Keywords were used before and during the data analysis and were derived from the literature survey. These keywords were captured in a code book that was used during the data analysis of both sets of data (round 1 and round 2). During the data analysis for round 2 data, the direct content analysis method was predominantly used. This method starts with theory (chaos theory) and codes were defined before and during the analysis and captured in the extended version of the code book.

During the analysis of collected and coded research data it was found that the mode of data analysis changed from inductive to both inductive and deductive and finally to primarily deductive as is shown by Merriam and Tisdell (2016:211) in Figure 4-6 as the “logic of data analysis”.

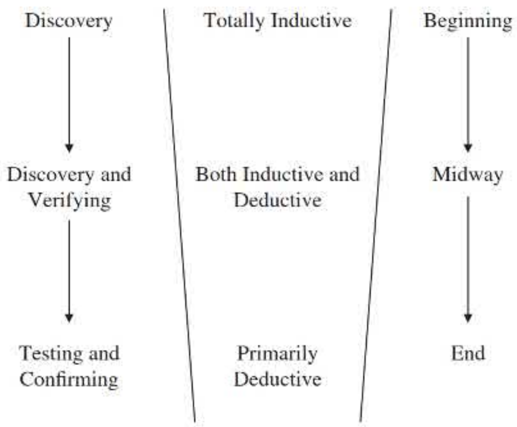

Figure 4-6: Framework for The Logic of Data Analysis by Merriam and Tisdell (2016:211, Figure 8.2)

Therefore, the data analysis for this research was done in both an inductive and deductive manner.

4.3.2.9 Research Triangulation Design Strategy - Rigor

Merriam and Tisdell (2016:260) state that "To a large extent, the validity and reliability of a study depend upon the ethics of the investigator. They refer to a quotation by Patton in this regard that stated the following (p. 260):

> ***"Methods do not ensure rigor. A research design does not ensure rigor. Analytical techniques and procedures do not ensure rigor. Rigor resides in, depends on, and is manifest in rigorous thinking - about everything, including methods and analysis."***

Weber (1990) is of the opinion that the central problem in data content analysis is mainly attributed to the reductionism process that is followed to extract meaning, concepts and categories from the spoken words. He states that "many words of texts are classified into much fewer content categories" (p. 15) and problems with reliability and validity are caused by "the ambiguity of word meanings, category definitions, coding rules… or variable definitions" (p. 15). In order to improve the reliability and validity of the research results, a triangulation design strategy was employed for both rounds of interviews as shown in Figure 4-7.

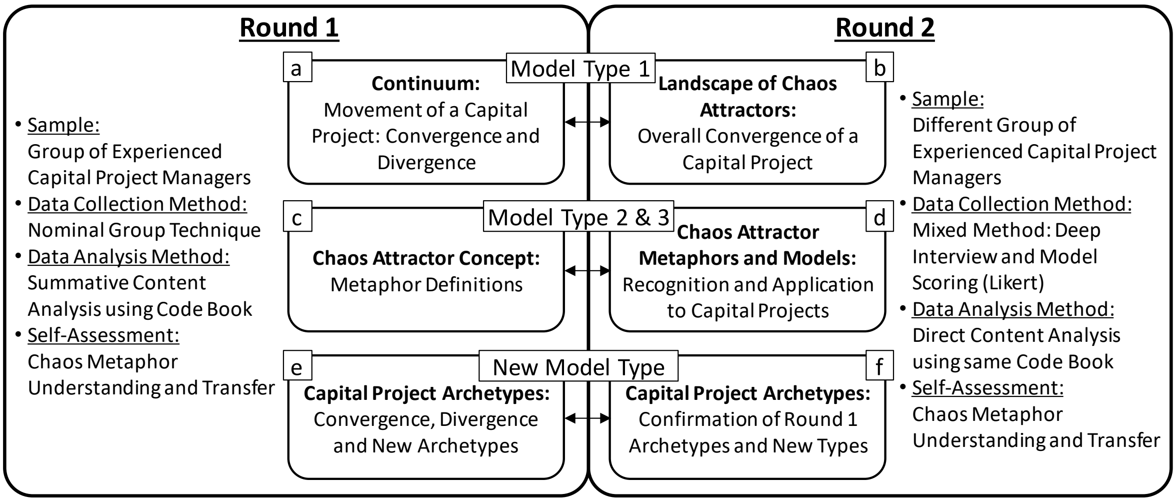

Figure 4-7: Research Triangulation Design Strategy – Testing of Three Model Types and the Emergence of a New Model Type

Three model types were defined as the scope of exploratory testing for this research as indicated in Table 4-1, at the beginning of this chapter. These three model types also facilitate obtaining answers to the two main research questions pertaining to the local and overall convergence effect of chaos attractors in capital projects. During the Round 1 and 2 interviews the same three model types were tested in an exploratory manner as shown schematically in Figure 4-7. Interestingly, a new unexpected model type emerged from the research findings – the capital project archetypes.

The first model type relates to the continuum and a capital project landscape of chaos attractors (refer to model type 1 in Table 4-1). During round 1 the first group of experienced capital project managers were asked to define chaos theory concepts relating to the continuum (Figure 4-7(a)). During round 2 a different group of experienced capital project managers were requested to confirm if a specific configuration of chaos attractors on a capital project continuum (landscape for chaos attractors) could cause overall project convergence (Figure 4-7(b)). This Model Type 1 was therefore tested in essence in both interview rounds for a response from experienced capital project managers to the second main research question "Does the use of combinations of different types of chaos attractors lead to overall convergence from chaos to order of capital projects?" (Chapter 1, paragraph 1.9.1). To enhance the rigor of the research process this Model Type 1 was tested in two rounds using a sample of different groups of experienced capital project managers, different data collection methods (NGT for Round 1 and mixed methods for Round 2), different but related content analysis techniques using the same code book and two individual self-assessments to verify the understanding and transferability of the chaos attractor metaphor to the capital project environment.

Model Types 2 and 3 were exploratory tested in both rounds of interviews and relate to the first main research question “Does the use of individual chaos attractors lead to local convergence from chaos to order of capital project elements and their trajectories?” (Chapter 1, paragraph 1.9.1). Respondents were asked during round 1 interviews to give their own definition and meaning (grounding principle according to Gioia et al. (2013)) of a chaos attractor in the capital project environment (Figure 4-7(c)). During the second round of in depth interviews, a different group of experienced capital project managers were exposed to the chaos attractor metaphors and variance models for the individual chaos attractors as well as a landscape of chaos attractors (Figure 4-7(d)). They were requested to transfer these concepts, that originate from various fields of science, to the capital project domain, to identify instances or occurrences of these chaos attractors and indicate their ability to cause local and overall capital project convergence.

Model types 2 and 3 are related to the chaos attractor concept and were exploratory tested in two rounds, using a sample of different groups of experienced capital project managers, different data collection methods (NGT for round 1 and mixed methods for round 2), different but related content analysis techniques using the same code book and two individual self-assessments to verify the understanding and transferability of the individual chaos attractor metaphor to the capital project environment, adding research design rigor.

A new model type emerged during the Round 1 interviews. It was found that experienced capital project managers not only associated with the converging and diverging capital project metaphors but identified new types of archetypes (Figure 4-7(e)). The second round of interview questionnaires were updated to show these archetypes to the second group of experienced capital project managers during the Round 2 interviews. The second group of experienced capital project managers not only confirmed the archetypes as identified during round 1 but also recognised additional new archetypes (Figure 4-7(f)). The rigor of this exploratory testing in both rounds of interviews was enhanced by choosing different groups of experienced capital project managers, using different data collection methods (NGT and mixed methods), using different data analysis techniques but the same code book and conducting self-assessments after each of the interviews to test the comprehension of the chaos attractor metaphor concept with both groups of capital project managers.

4.4 Summary on Research Methodology

The objective of the research strategy and research design was to provide a framework, methodologies and techniques to enable qualitative exploratory testing of the scope of this research. The scope for this research was defined to delimit the boundary within which qualitative exploratory testing could be done to obtain answers to the two main research questions. A summary is given as follows:

a) Two Main Research Questions

i. Main research question 1: “Does the use of combinations of different types of chaos attractors lead to overall convergence from chaos to order of capital projects?” (Chapter 1, paragraph 1.9.1)

ii. Main research question 2: “Does the use of individual chaos attractors lead to local convergence from chaos to order of capital project elements and their trajectories?” (Chapter 1, paragraph 1.9.1).

b) Scope of the Research

i. Model type 1: Model Type 1: Relevance of the Randomness-Chaos-Complexity-Order (RCCO) continuum in the capital project domain

ii. Model type 2: Local convergence effect of six metaphors and variance models for individual chaos attractors in the capital project domain

iii. Model type 3: Overall convergence effect of one metaphor and variance model for a group of different types of chaos attractors in the capital project domain.

c) Research Strategy

i. Qualitative research strategy.

d) Research Design Strategy

i. Applied research → theory building → model building → exploratory study type → data acquisition by interviews and qualitative data analysis.

e) Research Design

i. Unit of analysis - The capital project

ii. Research variables - Variables for the continuum, individual and landscape of chaos attractors

iii. Research sample - Capital project managers in South Africa with more than 15 years' experience

iv. Data collection strategy - Nominal Group Technique for round 1 interviews and mixed methods for round 2 interviews
v. Data instrument design – Semi-structured questions
vi. Data analysis strategy - Summative content analysis for round 1 and directed content analysis for round 2
vii. Research triangulation - Three model types were exploratory tested in round 1 and 2 interviews and the emergence of new archetypes in both rounds of interviews.

The remainder of this chapter provides evidence of the implementation of this research methodology during round 1 and 2 of the interviews, data collection and data analysis.

4.5 Round 1 Data Collection and Data Analysis

The chosen research design strategy and research design are implemented for the first round of interviews for this exploratory research. A pilot interview was done to test the workability of the research design elements. It was found that the Round 1 interview questionnaire needed substantial changes before it could be deemed suitable for data collection. This section captures the content of the pilot interview, the Round 1 interview for data collection and the methodology employed to analyse the captured data for the Round 1 interviews.

4.5.1 Round 1 Pilot Interview

4.5.1.1 Pilot Interview Methodology

The Nominal Group Technique was used as described by Harvey and Holmes (2012); (Potter et al., 2004) and the following steps were selected as the methodology for the pilot interview:

a) Introduction and explanation of research goal, purpose and outcome
b) Written silent generation of ideas and responses to written questions
c) Sharing of written ideas by each respondent in a round robin manner
d) Free-flow group discussion of ideas and follow-up questions by interviewer
e) Interviewer terminated discussions when saturation was achieved.

Potter et al. (2004:72) suggested that the fifth step of the NGT protocol should be "voting and ranking" of ideas discussed by the group. This step was not deemed necessary by the researcher as the objective was to "explore and collate expert opinion" and not force convergence on the exploratory topic of chaos theory and chaos attractors Harvey and Holmes (2012:190). This notion is confirmed by Harvey and Holmes (2012:190) when they state that applying the NGT "provided a unique and valuable opportunity for mutual clarification of issues important to all parties, irrespective of the level of consensus".

4.5.1.2 Pilot Interview Questionnaire Design

A pilot interview questionnaire was designed that covered the complete scope of this research as shown in Table 4-1. The following sections were included in the pilot interview questionnaire:

a) Objective and confidentiality
b) Demographic profile of respondents
c) Section A - Grounded information – personal perception of chaos and order concepts
d) Section B - Grounded information – personal perception with cognitive metaphor mapping
e) Section C - Visual chaos attractor metaphor variance models – local capital project convergence
f) Section D - Visual chaos attractor metaphor variance model – overall capital project convergence
g) Section E – Self-Assessment
h) Section F – Appendix of the questionnaire containing explanations of the terminology and frameworks related to project management, systems engineering, psychology, sociology and references.

This pilot interview questionnaire was submitted to the University of Pretoria ethics committee for approval. The pilot interview questionnaire is available on request and is not published as part of this thesis.

4.5.1.3 Ethics Committee Submission and Approval

It is a requirement of the University of Pretoria that "Research may not be done without the prior written approval by an Ethics Committee or other constituted Committee" (University of Pretoria, 2007:3). An application for conducting research was lodged with the Faculty of Engineering, Built Environment and Information Technology (EBIT) Ethics Committee on the 27 October 2017. The following documentation was submitted:

a) Application
b) Informed consent form
c) Interview questionnaire
d) Research declaration.

Conditional approval to conduct this research was obtained from the Ethics Committee on 6 December 2017. A copy of the letter of approval is provided in Appendix D. paragraph D.1. The conditional approval pertains to adding a clause in the informed consent form that respondents could choose to resign from the interview at any point in time. This clause was added to both the informed consent forms as well as on the interview questionnaires.

4.5.1.4 Pilot Interview Sample Selection

Three experienced capital projects managers known to the researcher were selected for the pilot interview. The chosen respondents were deemed to have high cognitive skills by the researcher (judgemental sample) and deemed a suitable sample representing the desired sample profile, as indicated in paragraph 4.3.2.5. Selected demographic information of the three respondents for the pilot interview is shown in Table 4-8.

Table 4-8: Selected Demographical Information of Respondents for the Round 1 Pilot Interview

No.	Respondent Code	Experience (Years)	Successful* Capital Projects Experience (%)	Failed* Projects Experience (%)
1	AB	25	60%	40%
2	MM	10	80%	20%
3	TK	15	75%	25%
4	**Average**	**16.7**	**71.7%**	**28.3%**

Table 4-8 Notes: Sample size: n = 3, * Refer to the IPA Definition for Failed and Successful Capital Projects in Chapter 1, Table 1-3

It is shown in Table 4-8 that the selected capital project managers for the pilot interview of Round 1 had, on average, more than 15 years' experience and were exposed to both successful (71.7%) capital projects as well as failed capital projects (28.3%). Further data on the demographic profile of respondents who participated in the Round 1 pilot interviews is available on request.

4.5.1.5 Pilot Interview Execution

The following steps were executed during the pilot interview that took place on 12 December 2017 in South-Africa:

a) Welcome and introductions
b) Explanation of the purpose of the research and expected outcomes
c) Interview process, duration, rules and questions from respondents
d) Explanation of what happens with the recorded data in terms of data analysis, results and publication of the thesis, post the interview (Respondents will receive copies of any publications).
e) Signing of informed consent form
f) Hand-out of interview questionnaire and obtaining demographic information from respondents
g) Start of voice recording
h) Explaining of interview questions and request for the generation of written responses by each respondent to each interview question
i) Respondents generated written responses to interview questions
j) Round-robin feedback on each question followed with open discussion
k) Self-assessment by respondents
l) End voice recording
m) Thanking respondents for their time, adjournment of interview.

The filled-out questionnaires were inspected for completeness, scanned and securely stored electronically. The quality of the voice recording was inspected, and a copy of the voice recording was securely stored electronically.

4.5.1.6 Pilot Interview Self-Assessment

After completion of the pilot interview the three respondents were requested to fill out a self-assessment questionnaire to gain insight into their understanding and transferability of the chaos attractor concept, their ability to apply the chaos attractor concept, the duration of the interview and their ability to contribute meaningfully. The self-assessment results are shown in Table 4-9.

Table 4-9: Self-Assessment Results After Completion of the Round 1 Pilot Interview

No.	Question	1*	2*	3*	4*	5*	Mode
1	Did your understanding of the chaos attractor concept improve throughout the interview?	0	0	0	1	2	**5**
2	Did the visualisation of the chaos attractor metaphors (sketches) help to better understand the objective of the metaphor?	0	0	0	2	1	**4**
3	Did the visualisation of the chaos attractor metaphors (sketches) help to better map the concept to the capital project environment?	0	0	0	0	3	**5**
4	Did the visualisation of the chaos attractor metaphors (sketches) as well as explanations help to better map the concept to the capital project environment?	0	0	0	1	2	**5**
5	Would you now be able to apply the concept of chaos attraction in capital projects?	0	1	0	1	1	**-**
6	The duration of the interview was sufficient to allow meaningful contribution?	0	2	1	0	0	**2**
7	The other respondents and facilitator allowed you an opportunity to contribute meaningfully?	0	0	0	0	3	**5**

Table 4-9 Notes: Sample size: n = 3, * Likert scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree and 5 = Strongly Agree

The mode of the Likert scale scores obtained from the three respondents is shown in the extreme right column of Table 4-9. The results indicated that respondents were able to understand and transfer the concept of chaos attractors to the capital project environment. Disagreement existed among respondents in terms of their ability to apply the concept of chaos attractors in the capital project environment with the newly gained knowledge (refer to Table 4-9(5). All respondents indicated that they would have liked more time for in-depth discussion on the chaos attractor concepts. This result indicated that a maximum of three respondents should be used for the Round 1 interviews using the NGT otherwise the set interview duration of 1.5 hours would not be sufficient to cover all the interview questions in sufficient detail. Finally, all respondents agreed that the NGT procedure that was used allowed each participant sufficient opportunity to contribute meaningfully during the round-robin and free-flow discussions.

4.5.1.7 Pilot Interview Observations and Lessons Learned

Observations and lessons learned from the pilot interview were recorded as shown in Table 4-10.

Table 4-10: Observations and Lessons Learned from the Round 1 Pilot Interview

No.	Aspect	Observation and/or Lesson Learned
1	Demographic Profile Format	Respondents indicated that the manner in which their demographic information was requested was not clear to them. They proposed changes to the demographic profile format. These changes were incorporated in the updated interview questionnaire.
2	Comprehension of the Continuum Concept	It was found that respondents were able to grasp the Randomness-Chaos-Complexity-Order continuum concept and provide their own definition for these domains for the capital project environment. The cognitive ability of the selected sample of respondents were therefore deemed sufficient for the remainder of the interview.
3	Ranking of Continuum Domains	Respondents were asked to "rank the above categories in order of increased disorder". All respondents misunderstood this question. In the updated questionnaire a ranking of domains was provided that ranged from order to disorder to avoid a misunderstanding of the question.
4	Comprehension of Chaos Attractor Concept	Respondents were able to comprehend the chaos attractor metaphor concept and were able to define a chaos attractor in the capital project environment. The cognitive level of the chosen respondents was therefore deemed sufficient to understand the chaos attractor metaphor as well as map and transfer the metaphor to the capital project environment.
5	Interview Time Duration	The interviews stretched over two days with two sessions of 1.5 hours each. After a total of 3 hours, the interviews were stopped. It was noticed that the respondents became tired and could not focus properly. Also, some of the respondents had to leave the interview during the last part of the second session as they had other commitments. It was decided to shorten the interview questionnaire to only cover section A and E (refer to paragraph 4.5.1.2). It was decided to keep the interview duration to 1.5 hours. This time duration is in agreement with 1 – 1.5 hours as suggested by Harvey and Holmes (2012) and a duration of "up to two hours" as suggested by Potter et al. (2004:70) when using the NGT.
6	Number of Respondents	Sufficient opportunity for individual written and verbal contribution was provided during the interviews with only 3 respondents present using the NGT. Harvey and Holmes (2012) indicated that the optimal group size when using the NGT is between 6 – 12 respondents while Potter et al. (2004) suggested a group size of between 5 – 9 respondents. It was decided to not increase the group size beyond 3 to ensure maximum participation by respondents within an interview duration time of 1.5 hours.

The Round 1 interview questionnaire was updated with the recommendations as shown in Table 4-10.

4.5.1.8 Updated Interview Questionnaire

Based on the results of the self-assessment (paragraph 4.5.1.6) as well as the observations and lessons learned from the pilot interview (paragraph 4.5.1.7), the interview questionnaire was updated, as shown in Appendix D, paragraph D.2.

4.5.2 Round 1 Data Collection

4.5.2.1 Round 1 Interview Period

The interviews for Round 1 were done during the period 22 January 2018 – 5 March 2018.

4.5.2.2 Round 1 Selected Sample

Four groups of three experienced capital project managers were selected for the Round 1 interviews using the NGT. Selected demographic information of the four groups of respondents is shown in Table 4-11.

Table 4-11: Selected Demographical Information of Respondents for the Round 1 Interviews

No.	Respondent Code	Experience (Years)	Successful** Capital Projects Experience (%)	Failed** Projects Experience (%)
1	**Group 1**			
2	SP	15	15%	85%
3	JL	15	30%	70%
4	IP	15	60%	40%
5	**Average**	**15.0**	**35%**	**65%**
6	**Group 2**			
7	JH	25	50%	50%
8	MG	25	85%	15%
9	JJ	15	80%	20%
10	**Average**	**21.7**	**72%**	**28%**
11	**Group 3**			
12	RE	25	80%	20%
13	WO	25	75%	25%
14	PG	25	80%	20%
15	**Average**	**25.0**	**78%**	**22%**
16	**Group 4**			
17	HB	25	50%	50%
18	CP	30	45%	55%
19	IS	15	15%	85%
20	**Average**	**23.3**	**37%**	**63%**
21	**AVERAGE**	**21.3**	**55%**	**45%**

Table 4-11 Notes: Sample size: n = 12, ** Refer to the IPA Definition in Chapter 1, Table 1-3

The capital project management experience of respondents ranged from 15 to 25 years with an average experience of 21.3 years. Similarly, their experience of successful projects ranged between 35% - 78% with an average of 55%. Their experience of failed projects ranged from 22% - 65% with an average of 45%.

Details on other demographic profile details of Round 1 respondents are given in Appendix D, paragraph D.3. A complete summary of the demographic profile characteristics is as follows:

a) Average number of years of capital project experience: 21.3
b) Average percentage of management responsibility:
   i. Project manager (71%)
   ii. Program manager (15%)
   iii. Portfolio manager (7%) and
   iv. Project director (7%)
c) Average size of capital project managed:
   i. Projects ($10's million) - (84%)
   ii. Major projects ($100's million) - (13%)
   iii. Mega projects ($1bn) - (2%)
   iv. Giga projects ($50bn - $100bn) - (0%) and
   v. Tera projects (>$1,000bn) - (0%)
d) Average exposure to capital project complexities:
   i. Hierarchical complexity (32%)
   ii. Directional complexity (29%)
   iii. Low complexity (24%) and
   iv. Technical complexity (16%)
e) Average exposure to specific management dimensions:
   i. Technical management (26%)
   ii. Cost management (22%)
   iii. Schedule management (19%)
   iv. People management (18%)
   v. Stakeholder relationship management (15%) and
   vi. Other management (2%)
f) Average exposure to capital project industries:
   i. Power generation and utilities (36%)
   ii. Infrastructure (21%)
   iii. Mining (20%)
   iv. Defence (19%) and
   v. Petro-chemical (3%)
g) Average exposure to capital project sectors:

i. Public (50%)
ii. Private (48%)
iii. NGO/NPO (2%) and
iv. Other (0%)

h) Average exposure to successful capital projects (55%) and failed capital projects (45%).

The experience and exposure profile of the Round 1 respondents were therefore deemed sufficient to enable demonstrative responses to the scope of interview questions on Model Type 1 and chaos attractor questions, as shown in Table 4-1.

A total of 12 respondents were interviewed during 4 group interviews. The captured data was analysed and it was found that internal saturation and redundancy of information (Merriam and Tisdell, 2016) occurred. Due to the limited new information that originate from the fourth group interview compared to the other three group interviews, the researcher decided not to conduct another group interview.

4.5.2.3 Round 1 Interview Questionnaire

The updated interview questionnaire as shown in Appendix D, paragraph D.2 was used for the four separate group interviews.

4.5.2.4 Round 1 Interview Execution

The same process as for the pilot interview was used for the execution of the group interviews as this process allowed for feedback from all respondents and in-depth follow-on discussions under the guidance of the researcher. Refer to paragraph 4.5.1.5 for the process.

4.5.2.5 Round 1 Self-Assessment Results

All twelve respondents that participated in the Round 1 interviews were requested to conduct a self-assessment after completion of the interview. The results are shown in Table 4-12.

Table 4-12: Self-Assessment Results after Completion of the Round 1 Interviews

No.	Question	1*	2*	3*	4*	5*	Mode
1	Did your understanding of the chaos attractor concept	0	0	0	7	5	**4**

No.	Question	1*	2*	3*	4*	5*	Mode
	improve throughout the interview?						
2	Did the visualisation of the chaos attractor metaphors (sketches) help to better understand the objective of the metaphor?	0	0	1	5	6	**5**
3	Did the visualisation of the chaos attractor metaphors (sketches) help to better map the concept to the capital project environment?	0	0	1	8	3	**4**
4	Did the visualisation of the chaos attractor metaphors (sketches) as well as explanations help to better map the concept to the capital project environment?	0	0	2	6	4	**4**
5	Would you now be able to apply the concept of chaos attraction attractors? in capital projects?	0	1	2	8	1	**4**
6	The duration of the interview was sufficient to allow meaningful contribution?	0	2	3	5	2	**4**
7	The other respondents and facilitator allowed you an opportunity to contribute meaningfully?	0	0	0	1	11	**5**

Table 4-12 Notes: Sample size: n = 12, * Likert scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree and 5 = Strongly Agree

The results of the self-assessment indicate that all twelve respondents from the four groups were able to understand and transfer the chaos attractor concept from the source domain to the target domain (capital project environment). Respondents indicated that they would be able to apply the chaos attractor concept in capital projects (refer to the mode of the Likert scale scores of 4 in Table 4-12(5)). This score during the Round 1 interviews improved in comparison with the score obtained after the pilot interview (refer to the mode of the Likert scale scores of 4 in Table 4-9(5)) and is attributed to the improved preparedness of the researcher and more comprehensive explanations provided during the Round 1 interviews.

4.5.2.6 Round 1 Observations and Lessons Learned

One observation and lesson learned was made during the Round 1 interviews as shown in Table 4-10.

Table 4-13: Observations and Lessons Learned from the Round 1 Interviews

No.	Aspect	Observation and/or Lesson Learned
1	Chaos Attractor Definition and	Some respondents thought that "chaos attractor" meant the attraction of chaos and had difficulty in understanding how this could lead to capital

	Understanding	project convergence. The researcher explained at the start of each interview that the term "chaos attractor" meant the generation of order from a chaotic environment that potentially leads to capital project convergence.

4.5.3 Round 1 Data Analysis

4.5.3.1 Round 1 Conversion of Hand-Written and Verbal Responses to Transcripts

Data collection in Round 1 of the interviews using the NGT was done by hand-written responses and voice recordings. Some notes on the conversion of this data to transcribed texts are listed in Table 4-14.

Table 4-14: Notes on Data Transcription for Round 1 Interviews

No.	Aspect	Notes
A. Converting Hand-Written Responses to Typed Transcripts		
1	Handwriting Recognition	Some of the respondents did not write legibly on the interview questionnaire. An effort was made to find similar looking hand-written responses further down in the questionnaire and then some of the illegible handwriting could be deciphered.
2	Illegible Handwriting	Once the transcriptions were done it was possible to decipher some of the illegible handwriting. In cases where hand-written notes could not be deciphered the word was coded with: [?].
B. Converting Voice Recordings to Typed Transcripts		
1	Quality of Voice Recording	Some portions of the voice recordings were difficult to transcribe as respondents spoke softly or were not speaking into the microphone. In some cases, the written responses of such respondents proved helpful to recognise phrases of the voice recording.
2	Non-Recognition of Voice Recording	In a few cases specific words or phrases could not be recognised by the researcher either by replay of the voice recording or by reading the associated handwritten response from the respondent. In such cases the text was marked with the symbol [?].
3	Atlas.ti Software	The voice recording transcription function of the Atlas.ti software was employed to convert voice recordings to typed transcriptions. It was found that a number of transcriptions had to be redone due to software malfunctioning. The researcher was not able to use the same software for voice recording transcription and content analysis. These two actions were then separated, and all transcribed data was recorded in a Word file as an intermediate step to avoid data loss due to software crashes.

4.5.3.2 Round 1 Code Book for Content Analysis

A code book was used to recognise keywords and terms during the content analysis. The international standard on project management ISO 21500 (ISO, 2012) was chosen as the basis of the code book for the Round 1 content analysis, as shown in Appendix D, paragraph D.4. The ten project management process subject groups were chosen as the basis of the code book. During the content analysis more terms from the international standard were added to this code book. In cases where keywords could not be found in the standard, they were newly defined and added to a relevant subject group.

4.5.3.3 Round 1 Content Analysis

The summative content analysis methodology (refer to Table 4-7) was predominantly used for Round 1 data analysis. Keywords in the transcribed texts were marked and a matched term from the code book was assigned to the keyword. This was done to ensure consistent coding of keywords in the transcribed text. A visual map was then plotted using the Atlas.ti software of all keywords, terms and codes as shown in Figure 4-8.

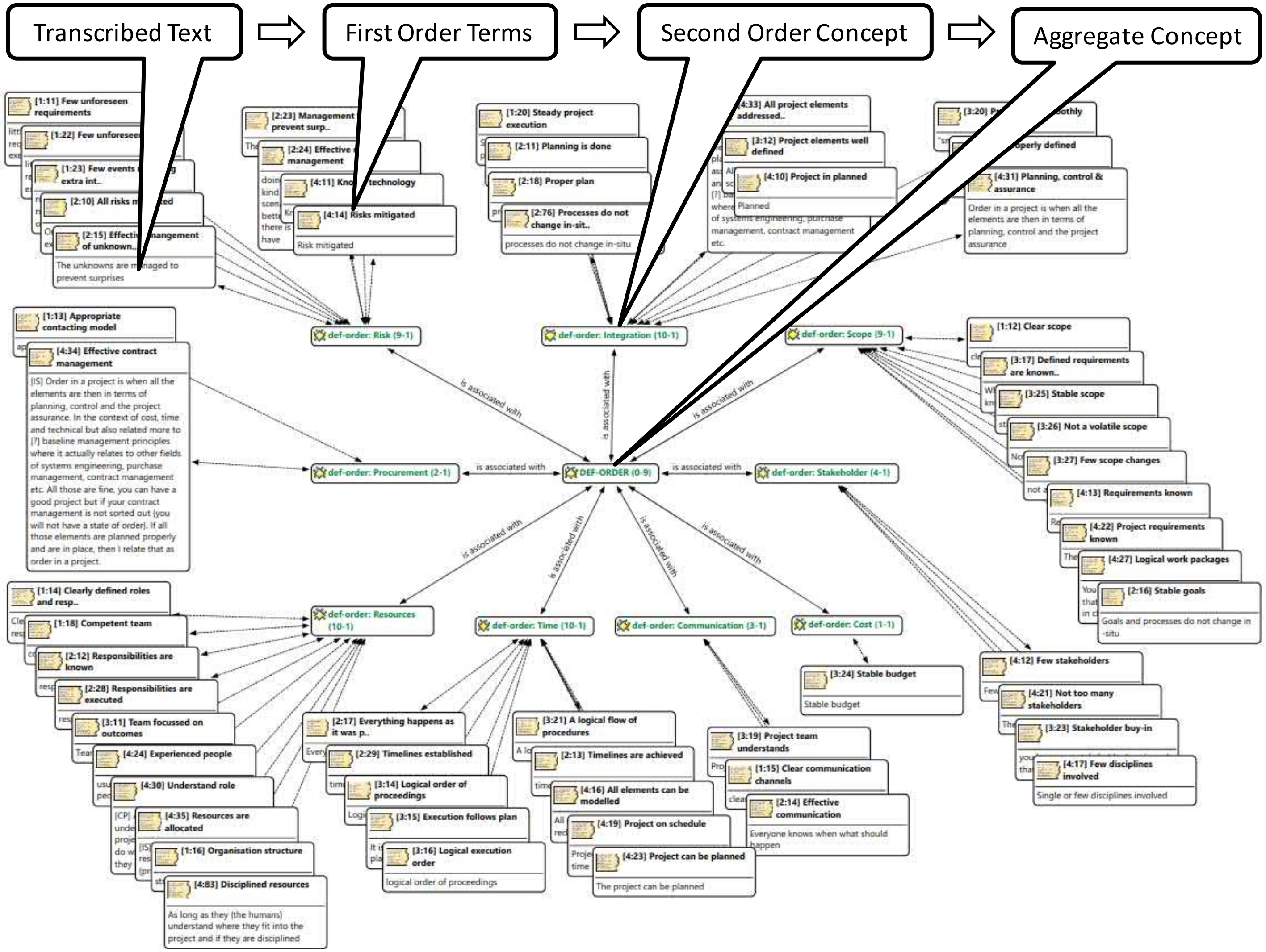

Figure 4-8: Example of the Summative Content Analysis Methodology Applied to Transcribed Text from the Round 1 Interviews for the Definition of "Order" by Capital Project Managers

The Gioia et al. (2013) method was used to identify first order terms from keywords in text, assignment of first order terms to second order concepts and then the formation of an aggregate concept. The visual network map of coded content as shown in Figure 4-8 helped to obtain an overview of the analysed content and categories for each of the relevant interview questions. This network helped to review and ensure the best assignment of keywords to first order concepts. Sometimes it was necessary to return to the original text in the transcript to make changes to keywords or assignments – the Atlas.ti software provided this functionality.

4.5.3.4 Round 1 Observations and Lessons Learned for Data Analysis

Two observations and lessons learned were made during the Round 1 content analysis as shown in Table 4-15.

Table 4-15: Observations and Limitations of the Round 1 Data Analysis

No.	Aspect	Observation and/or Lesson Learned
1	Iterative Content Analysis	It was found that summative content analysis was iterative in nature. Using the code book and keyword assignments (Atlas.ti) a number of transcribed texts were analysed before the results could be consistently extracted. Once this “methodology” was identified, the content analysis was completely redone to ensure consistent application of the “methodology”.
2	Code Book for Consistent Keyword Categorisation	The code book was found to be an important anchor to ensure maximum consistency during content analysis. Each respondent used both similar but also sometimes completely different terminology in their responses. Keywords were searched in the international standard (ISO, 2012) and added if they could not be identified.

4.5.3.5 Round 1 Limitations

A summary of the limitations for the Round 1 data collection and data analysis is given in Table 4-16.

Table 4-16: Limitations of Results for the Round 1 Data Collection and Data Analysis

No.	Aspect	Limitations
1	Sample	The selected sample of 12 experienced project managers had an average exposure of 21,3 years to capital projects and on average worked in 55% successful and 45% failed projects. However, 71% of the respondents occupied project manager positions with limited experience as program managers, portfolio managers or project directors. Also, 84% of the respondents managed projects with a maximum value less than R1,4bn ($10's million). Refer to Appendix D, Figure D-2. This means that the results of this sample predominantly pertain to smaller capital projects and the experience level of the respondents was that of a project manager. The results will therefore have limited representation of the views of program

No.	Aspect	Limitations
		managers, portfolio managers or project directors of capital projects.
2	Sample Size	A total of 12 experienced project managers were interviewed in four groups of three respondents each during Round 1. The cumulative experience of these respondents span successful (55%) and failed projects (45%), exposure to four different types of project complexities, exposure to various management aspects, various industries (power generation, infrastructure, mining, defence and petrochemical) in both public (50%) and private (48%) companies as shown for the selected sample in paragraph 4.5.2.2. Although the representation of the twelve respondents seems to cover a wide range of desired criteria, a larger sample size would have better confirmed all of these dimensions.
3	Data Collection	Although a mode score of 4 was achieved during the self-assessment from respondents, lower scores were also recorded as indicated in Table 4-12(6). This means that a number of respondents would have favoured more time to conduct the interview to explore the chaos concepts in the capital project environment. The time limit for interviews was set to 1.5 hours and could not be extended due to other commitments of the respondents. A limitation therefore exists that more relevant data may have been captured if respondents were allowed more time for free participation during the interviews.
4	Data Analysis	The limitations in terms of converting the hand-written responses as well as the voice recorded responses to transcribed text were shown in Table 4-14. Therefore, not all the collected data could be transcribed with absolute accuracy. Furthermore, the summative content analysis method required key words to be identified with the help of the code book and categorised as first order concepts. Although care has been taken to be consistent in the categorisation of keywords some errors may have occurred as all the data analysis was done by the researcher without the help or checks from an additional content analyst or by using computerised analysis.

The results for the Round 1 interviews are presented in Chapters 5 and 6.

4.6 Round 2 Data Collection and Data Analysis

Once the data for the Round 1 interviews was analysed the research strategy and design was further implemented to collect and analyse the data for round 2. This second round of interviews was preceded by a pilot interview to test the suitability of the research instrument. It was found that only minor changes were needed to the Round 2 interview questionnaire. The Round 2 interviews were conducted with a different group of experienced capital project managers. The design of the research instrument was done in such a manner as to assure continuation and linking of the themes under discussion during the Round 1 interviews. After completion of all interviews, a self-assessment was done to verify the suitability of the research instrument used. The collected data was transcribed and then analysed. This section is concluded by indicating possible limitations in the employment of this research methodology.

4.6.1 Round 2 Pilot Interview

4.6.1.1 Pilot Interview Methodology

The in-depth interview methodology was selected as the preferred method for data capturing during round 2 of this research. Round 1 covered the understanding of the continuum and chaos attractor concepts in the capital project environment using the NGT. Individual in depth interviews using semi-structured questions were used to explore the understanding of chaos attractor metaphors and models for local and overall convergence in the capital project environment.

4.6.1.2 Round 2 Pilot Interview Questionnaire Design

The questionnaire design consisted of the following sections:

a) Demographic profile
b) Review of Round 1 research results on archetypes and requests for respondent's opinion on these findings (linking Round 1 and Round 2) using semi-structured questions
c) Explaining the chaos attractor metaphors and requesting a response for examples of these metaphors in the capital project environment
d) Explaining the chaos attractor variance models and requesting respondents to do a Likert scoring on the elements of these models
e) Self-Assessment.

4.6.1.3 Round 2 Pilot Interview Sample Selection

An experienced capital project manager was recommended to the researcher by project managers known to him (snowball sample). The respondent occupied the position of portfolio manager at a large mining company in South Africa and he was deemed to have high cognitive skills suitable for this pilot interview (judgemental sample). Selected demographic information of the respondent for the pilot interview is shown in Table 4-17.

Table 4-17: Selected Demographical Information of Respondent for the Round 2 Pilot Interview

No.	Respondent Code	Experience (Years)	Successful* Capital Projects Experience (%)	Failed* Projects Experience (%)
1	DL	25	90%	10%

Table 4-17 Notes: Sample size: n = 1, *Refer to the IPA Definition for Failed and Successful Capital Projects in Chapter 1, Table 1-3

4.6.1.4 Round 2 Pilot Interview Execution

The following steps were executed during the pilot interview that took place on 10 April 2018 in South-Africa:

a) Welcome and introductions
b) Explanation of the purpose of the research and expected outcomes
c) Interview process, duration, rules and questions from respondent
d) Explanation of what happens with the recorded data in terms of data analysis, results and publication of the thesis, post the interview (Respondent will receive copies of any publications).
e) Signing of informed consent form
f) Hand-out of interview questionnaire and obtaining demographic information from respondent
g) Start of voice recording
h) Explaining of interview results obtained from Round 1 and request for a response in terms of agreement, disagreement or general comments
i) Explanation of each chaos attractor metaphor and request for applicability and examples in capital projects where these chaos metaphors are active
j) Explanation of each variance model for chaos attractors and request to respondents to do a Likert score for each element of each model
k) Self-assessment by respondent
l) End voice recording
m) Thanking respondent for his time, adjournment of interview.

The filled-out questionnaire was inspected for completeness, scanned and securely stored electronically. The quality of the voice recording was inspected, and a copy of the voice recording was securely stored electronically.

4.6.1.5 Round 2 Pilot Interview Self-Assessment

A self-assessment was filled-out by the Round 2 pilot respondent after completion of the interview and the results are shown in Table 4-18.

Table 4-18: Self-Assessment Results for the Round 2 Pilot Interview

No.	Question	1*	2*	3*	4*	5*
1	Did your understanding of the chaos attractor concept improve throughout the interview?				✓	
2	Did the visualisation of the chaos attractor metaphors (sketches) help to better understand the objective of the metaphor?				✓	
3	Did the visualisation of the chaos attractor metaphors (sketches) help to better map the concept to the capital project environment?				✓	
4	Did the visualisation of the chaos attractor metaphors (sketches) as well as explanations help to better map the concept to the capital project environment?					✓
5	Would you now be able to apply the concept of chaos attraction in capital projects?				✓	
6	The duration of the interview was sufficient to allow meaningful contribution?			✓		

Table 4-18 Notes: Sample Size: n = 1, * Likert scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree and 5 = Strongly Agree

The respondent was able to understand the chaos attractor metaphors as shown by the Likert score in Table 4-18(1). Furthermore, the respondent indicated that verbal explanations together with sketches that represent the metaphors caused a better metaphor transfer to the capital project domain as shown in Table 4-18(4). Also, the respondent agreed that he would be able to apply the concept of chaos attractors in capital projects as shown in Table 4-18(5). These three measures seemed to indicate the questionnaire design could be deemed to be suitable to achieve the purpose of the Round 2 interviews. However, the respondent was neutral on the adequacy of the time duration of 2 hours to allow a meaningful contribution during the interview as shown in Table 4-18(6).

4.6.1.6 Round 2 Pilot Interview Observations and Lessons Learned

During the execution of the pilot interview observations and lessons learned were recorded as shown in Table 4-19.

Table 4-19: Observations and Lessons Learned from the Round 2 Pilot Interview

No.	Aspect	Observation and/or Lesson Learned
1	Linking between Round 1 and Round 2	The respondent was able to recognise and agree with the Round 1 research results. He was able to elaborate on the results with more applications to the capital project environment. It is concluded that the pilot questionnaire design

No.	Aspect	Observation and/or Lesson Learned
	Interviews	was sufficient to allow linking between Round 1 and 2 interviews.
2	Comprehension of Chaos Attractor Metaphor	The respondent was able to understand all of the chaos metaphors and was able to map them to the capital project environment. However, the researcher had to explain the origin of these metaphors in detail.
3	Scoring of the Chaos Attractor Variance Models	The respondent was able to do a Likert scoring of all the variance models. The researcher had to explain each of the elements of each variance model. This helped the respondent to understand the origin of the variance model elements that allowed him to map and transfer these concepts to the capital project domain.
4	Variance Model for Fixed-Point Repeller	Although the respondent was able to understand and score the variance model for the fixed-point chaos repeller, he indicated that this model needed to be updated to be of practical use in the capital project environment. This variance model was updated with elements as suggested by the respondent. Refer to Appendix D, paragraph D.5.
5	Interview Time Duration	The duration of the interview was set to 2 hours and the full time was used for conducting the interview. The respondent indicated that more time may have contributed to a more meaningful contribution (refer to Table 4-18(6)). It was decided not to increase the interview duration beyond 2 hours because this led to respondent fatigue as was found during the Round 1 pilot interview that had a duration of more than 3 hours (refer to Table 4-10(5)).

The Round 2 interview questionnaire was updated with the recommendations as shown in Table 4-19.

4.6.1.7 Updated Interview Questionnaire

The updated questionnaire that was used for the Round 2 interviews is shown in Appendix D, paragraph D.6.

4.6.2 Round 2 Data Collection

4.6.2.1 Round 2 Interview Period

The individual interviews for Round 2 were conducted with experienced capital project managers from 17 April 2018 to 23 May 2018, in South Africa.

4.6.2.2 Round 2 Selected Sample

Selected demographic information for the 14 respondents for the Round 2 interviews is shown in Table 4-20.

Table 4-20: Selected Demographical Information of Respondents for the Round 2 Interviews

No.	Respondent Code	Experience (Years)	Successful* Capital Projects Experience (%)	Failed* Projects Experience (%)
1	KS	15	70%	30%
2	BC	15	50%	50%

No.	Respondent Code	Experience (Years)	Successful* Capital Projects Experience (%)	Failed* Projects Experience (%)
3	RS	15	40%	60%
4	KC	30	90%	10%
5	PR	25	70%	30%
6	PO	15	80%	20%
7	NM	15	40%	60%
8	LF	15	50%	50%
9	OZ	15	100%	0%
10	GB	15	40%	60%
11	JM	25	80%	20%
12	NP	15	60%	40%
13	SC	15	70%	30%
14	MW	15	100%	0%
15	**AVERAGE**	**17.5**	**67%**	**33%**

Table 4-20 Notes: Sample size: n = 14, * Refer to the IPA Definition in Chapter 1, Table 1-3

The average experience of respondents was 17.5 years as shown in Table 4-20. These selected capital project managers were exposed to on average 67% successful and 33% failed projects. One of the respondents worked on a single successful mega capital project and therefore recorded a 100% score on experience for successful projects as shown in Table 4-20(9).

The experience as well as exposure to successful and failed projects for the Round 1 and 2 capital projects managers could be compared with each other. The experience of the two groups were 21.3 years for Round 1 and 17.5 years for Round 2. The respondents were exposed to 55% successful and 45% failed capital projects for Round 1 and 67% and 33% for Round 2 respondents. This data indicated that both groups of respondents had on average more than 15 years' experience in capital projects and both groups were on average exposed to both successful and failed projects as was desired during the research design (refer to paragraph 4.3.2.5).

The complete demographic profiles for the 14 respondents are given in Appendix D, paragraph D.7.

A total of 14 deep interviews were conducted. The captured data was analysed and it was found that internal saturation and redundancy of information (Merriam and Tisdell, 2016) occurred. Due to the limited new information that originate from the last two interviews, the researcher decided not to conduct further individual interviews.

4.6.2.3 Round 2 Questionnaire

The questionnaire that was used for the Round 2 interviews is shown in Appendix D, paragraph D.6.

4.6.2.4 Round 2 Interview Execution

The same process for execution of the individual interviews was followed as for the pilot interview for Round 2. Refer to paragraph 4.6.1.4 for the process.

4.6.2.5 Round 2 Self-Assessment

All 14 respondents that participated in the Round 2 interviews were requested to conduct a self-assessment after completion of each interview. The results are shown in Table 4-21.

Table 4-21: Self-Assessment Results after Completion of the Round 2 Interviews

No.	Question	1*	2*	3*	4*	5*	Mode
1	Did your understanding of the chaos attractor concept improve throughout the interview?	0	0	0	8	6	**4**
2	Did the visualisation of the chaos attractor metaphors (sketches) help to better understand the objective of the metaphor?	0	0	1	9	4	**4**
3	Did the visualisation of the chaos attractor metaphors (sketches) help to better map the concept to the capital project environment?	0	0	0	9	5	**4**
4	Did the visualisation of the chaos attractor metaphors (sketches) as well as explanations help to better map the concept to the capital project environment?	0	0	0	6	8	**5**
5	Would you now be able to apply the concept of chaos attraction in capital projects?	1	0	5	7	1	**4**
6	The duration of the interview was sufficient to allow meaningful contribution?	0	0	0	10	4	**4**

Table 4-21 Notes: Sample size: n = 14, * Likert scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree and 5 = Strongly Agree

The self-assessment results as shown in Table 4-21 show that all 14 respondents were able to understand and transfer the chaos attractor concept from the source domain to the target domain (capital project environment). Respondents indicated that they would be able to apply the chaos attractor concept in capital projects (refer to the mode of the Likert scale scores of 4 in Table 4-12(5)) although one respondent of fourteen strongly disagreed.

The self-assessments done after completion of round 1 and 2 interviews for the understanding, transfer and application of the chaos metaphor in the capital project environment had achieved a mode of greater than 4 when reviewing the results in Table 4-12 and Table 4-21. This comparative result allows for the linking of the results of both rounds of interviews although different experienced capital project managers were interviewed for both rounds.

4.6.2.6 Round 2 Observations and Lessons Learned

During the execution of the Round 2 interviews, observations and lessons learned were recorded as shown in Table 4-22.

Table 4-22: Observations and Lessons Learned from the Round 2 Interviews

No.	Aspect	Observation and / or Lesson Learned
1	Linking of Round 1 and Round 2 Interviews	The respondents were able to recognise and agree with the Round 1 research results. They were able to elaborate on the results with more applications to the capital project environment. It is concluded that the Round 2 questionnaire design was sufficient to allow linking of Round 1 and 2 interviews.
2	Comprehension of Chaos Attractor Metaphor	The respondents were able to understand all of the chaos metaphors and were able to map them to the capital project environment. However, the researcher had to explain the origin of these metaphors during each interview in detail.
3	Scoring of the Chaos Attractor Variance Models	The respondents were able to do a Likert scoring of all the variance models. The researcher had to explain each of the elements of each variance model. This helped the respondents to understand the origin of the variance model elements that allowed them to map and transfer these concepts to the capital project domain.

The observations and lessons learned as were recorded during the pilot interview (refer to paragraph 4.5.2.6) were generally the same for the 14 Round 2 interviews.

4.6.3 Round 2 Data Analysis

4.6.3.1 Round 2 Conversion of Verbal Responses to Transcripts

Data collected during the Round 2 interviews using the in-depth interview technique was done by voice recording and Likert scale scoring of the variance models. Some notes on the conversion of the recorded voice data to transcribed texts are listed in Table 4-23.

Table 4-23: Notes on the Data Transcription of the Conversion of Voice Recordings to Typed Transcripts for the Round 2 Interviews

No.	Aspect	Notes
1	Quality of Voice Recording	Some portions of some of the voice recordings were difficult to transcribe as respondents spoke softly or were not speaking into the microphone. In some cases, the written responses of such respondents proved helpful to recognise phrases of the voice recording.
2	Non-Recognition of Voice Recording	In a few cases specific words or phrases could not be recognised by the researcher either by replay of the voice recording or by reading the associated handwritten response from the respondent. In such cases the text was marked with the symbol [?].
3	Atlas.ti Software	The voice recording transcription function of the Atlas.ti software was employed to convert voice recordings to typed transcriptions. It was found that a number of transcriptions had to be redone due to software malfunction. The researcher was not able to use the same software for voice recording transcription and content analysis. These two actions were then separated, and all transcribed data was recorded in a Word file as an intermediate step to avoid data loss due to software crashes.

The notes on the conversion of voice recorded data to transcribed data for the Round 1 and 2 interviews were similar (refer to Table 4-14 and Table 4-23). These results indicate that it could be assumed that a similar “systematic error” may have been present during the voice transcription of both rounds of interviews.

4.6.3.2 Round 2 Code Book for Content Analysis

The same code book was used for the Round 2 content analysis as was used for the Round 1 content analysis. Only a few new keywords were added during the analysis as indicated in Appendix D, paragraph D.8. The use of the same code book for both rounds enforced consistent content analysis to enhance the rigor of this qualitative research as was desired for triangulation (refer to paragraph 4.3.2.9).

4.6.3.3 Round 2 Content Analysis and Scoring of Variance Models

It was only realised during the content analysis of Round 2 that the respondents of both round 1 and 2 were describing and emergent form of capital projects. During Round 1 interviews respondents were commenting on converging and diverging project types but then also added a third type that contained both converging and diverging characteristics. When these capital project types were shown to the Round 2 respondents, they recognised these types and added more detail and more types. It was decided to refer to these capital project types that were formed using chaos theory concepts as “archetypes”. This term was borrowed form Peter Senge who defined ”system archetypes” to describe “nature’s templates” i.e. the repetitive types of structures that “recur again and again” (Senge, 2006:92-93).

The responses obtained from respondents on chaos metaphors and during the scoring of the variance models were transcribed and analysed using three methods as shown in Figure 4-9.

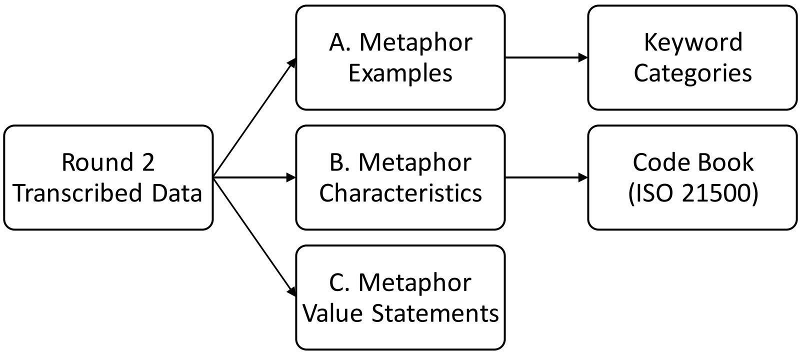

Figure 4-9: Content Analysis Methodologies used for Round 2 Transcribed Data

Evidence of examples of chaos metaphors in the capital project environment were marked using the Atlas.ti software and categorised separately as “examples” for each type of chaos metaphor as shown in Figure 4-9(A). The same transcribed text was analysed using predominantly the direct content analysis method (refer to Table 4-7) and the code book (refer to Appendix D, paragraph D.8) to further categorise the characteristics of each metaphor as shown in Figure 4-9(B). The transcribed text for each recorded interview was then searched again for metaphor value statements. These were statements from respondents that indicated that these metaphors provided either positive or negative value of thinking about capital projects to them (Figure 4-9(C)). The analysis was done using the functionalities of the Atlas.ti software, while post-processing of results was done using Microsoft Excel software.

4.6.3.4 Round 2 Observations and Lessons Learned

Two observations and lessons learned were made during the Round 2 content analysis as shown in Table 4-24.

Table 4-24: Observations and Limitations for the Round 2 Data Analysis

No.	Aspect	Observation and/or Lesson Learned
1	Iterative Content Analysis	It was found that direct content analysis was iterative in nature. Using the code book and keyword assignments (Atlas.ti) a number of transcribed texts were analysed before the results could be consistently extracted. Once this

No.	Aspect	Observation and/or Lesson Learned
		"methodology" was identified, the content analysis was redone completely to ensure consistent application of the "methodology".
2	Code Book for Consistent Keyword Categorisation	The code book was found to be an important anchor to ensure maximum consistency during content analysis. Each respondent used both similar but also sometimes completely different terminology in their responses. Keywords were searched in the international standard (ISO, 2012) and added if they could not be identified.
3	Delayed Grasping of the Metaphor Concepts	One respondent had difficulty in grasping and applying some of the metaphors to the capital project environment. However, when the landscape of chaos attractors was presented, as well as the presumed overall convergence effect, the respondent was able to identify the metaphors which were unrecognisable to him earlier during the interview. It was realised that the in-depth interviews had both an exploratory but also educational nature and that respondents needed time and perhaps a different viewpoint of the same concept to enable understanding of the metaphors in the capital project environment.

4.6.3.5 Round 2 Limitations

A summary of the limitations for the Round 2 data collection and data analysis is given in Table 4-25.

Table 4-25: Limitations of Results for the Data Collection and Data Analysis for the Round 2 Interviews

No.	Aspect	Limitations
1	Sample	The selected sample of 14 experienced project managers had an average exposure of 17.5 years to capital projects and on average worked in 67% successful and 33% failed projects. For this sample 53% of the respondents occupied project manager positions, 19% program managers, 20% portfolio managers and 9% project directors. This means that the results obtained originate not only from capital projects but are also applicable to programs and portfolios. Also, 44% of the respondents managed capital projects with a maximum value less than R1,4bn ($10's million), 34% managed major projects R1,5bn – R14bn (100's million USD) and 23% managed mega projects R15bn – R740bn (1bn USD). This means that the results of this sample originate not from a homogenous sample but to capital projects, program and portfolios with various sizes. The results will therefore not be limited only to the capital project as the unit of analysis as desired in paragraph 4.3.2.3.
2	Sample Size	A total of 14 experienced project managers were interviewed during Round 2. The cumulative experience of these respondents span successful (67%) and failed projects (33%), exposure to four different types of project complexities, exposure to various management aspects, various industries (power generation, infrastructure, mining, and metallurgical) in both public (50%) and private (49%) companies as shown for the selected sample in paragraph 4.6.2.2. Although the representation of the 14 respondents seems to cover a wide range of desired criteria, a larger sample size would have better confirmed all of these dimensions.
3	Data Collection	During the interview of the first respondents for Round 2 (respondent code KS), an error occurred with the voice recording of the first two questions.

No.	Aspect	Limitations
		After the interview the researcher wrote down as many of the interview content for these two questions as he could remember. The results were sent back to the respondent for verification. The data for these two questions might have limited validity. The voice recording of all other interviews were completely captured.
4	Data Analysis	The limitations in terms of converting the hand-written responses as well as the voice recorded responses to transcribed text were shown in Table 4-23. Therefore, not all the collected data could be transcribed with absolute accuracy. Furthermore, the direct content analysis method was used together with the code book for some questions and for others the summative content analysis method was used (keywords). Although care has been taken to be consistent in the categorisation of keywords and codes some errors may have occurred as all the data analysis was done by the researcher without the help or checks from an additional content analyst or by using computerised analysis.

The results for the Round 2 interviews are presented in Chapters 6 and 7.

4.7 Summary

The objective of the qualitative research methodology was to craft a strategy and design a research method that would enable answering the two main research questions in a valid and rigorous manner. Rigor in this qualitative research is enhanced for this study by transparency of method and identification of limitations during the execution of the chosen research design.

The scope of this research was confined to the exploratory testing of the Randomness-Chaos-Complexity-Order (RCCO) continuum concept, the local convergence ability of six individual chaos attractors and the overall convergence ability of a group of six chaos attractors in the capital project domain.

The research strategy constitutes a qualitative research strategy for an applied research type in which both theory building and model building were done. The variance models that were built for the chaos attractor metaphors were tested using exploratory testing techniques. Data was collected using interviews and data analysis was done by employing qualitative analysis.

The research design comprised of two rounds of interviews with two different groups of experienced capital project managers. Each round of interviews was preceded with a pilot interview. The research design was done in such a manner as to test and link three model types in different manners during both rounds of interviews, in order to enhance the rigor of the results and to incorporate a form of triangulation. The three model types comprised the continuum and chaos attractor landscape, chaos attractor metaphors and variance models and capital project archetypes.

The Round 1 interviews were executed using 12 capital project managers with an average capital project experience of 21.3 years and 55% exposure to successful and 45% exposure to failed projects. This selected sample consisted predominantly of capital project managers (71%) that have managed capital projects with a size of less than R1,4bn (84%). These project managers had experience of four complexity types and managed different aspects of capital projects. They predominantly represented the power generation, infrastructure and mining industries in both the public and private sectors. The Nominal Group Technique (NGT) was used during the interviews to record both written and voice recorded data. The data was analysed using the summative content analysis method with the assistance of Atlas.ti software. A self-assessment indicated that respondents were able to understand and transfer the chaos attractor metaphor concept to the capital project environment.

The Round 2 interviews were done with a different group of 14 experienced capital project managers. This group had an average capital project experience of 17.5 years and 67% exposure to successful and 33% exposure to failed projects. This selected sample had not only project management experience (53%), but also program management (19%), portfolio management (20%) and project director experience (9%). Similar to the Round 1 respondents, these project managers had experience of four complexity types and managed different aspects of capital projects. They predominantly represented the power generation, infrastructure and mining industries in both the public and private sectors. Data collection was done using in depth interviews and employing the Mixed Methods Research (MMR) methodology. A qualitative methodology was employed to obtain responses from respondents on recognising and indicating examples of chaos attractor metaphors in the capital project environment. A quantitative methodology was employed to obtain Likert scores for each of the elements of the various variance models for the chaos attractors. The data was analysed using the direct content analysis method with the assistance of Atlas.ti software. A self-assessment indicated that respondents were able to understand and transfer the chaos attractor metaphor concept to the capital project environment.

It was found that although two different groups of project managers were interviewed in two rounds, using different methodologies, that both groups were able to understand and transfer the chaos metaphor concept to the capital project environment. Furthermore, it was also found that the research design intended for the scope of this research to enable the answering of the research questions proved to be a viable design strategy.

The research results obtained during the two rounds of data collection and data analysis using the research methodology as described in this chapter, are presented in Chapters 5, 6 and 7.

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CHAPTER 5: RESULTS FOR THE RANDOMNESS-CHAOS-COMPLEXITY-ORDER CONTINUUM IN CAPITAL PROJECTS

5.1 Introduction

After completion of the literature survey in Chapter 2, theories and models were developed for chaos attractors in Chapter 3. The research methodology employed for the data collection and data analysis for the two rounds of interviews was explained in Chapter 4. The empirical results of this research are given in Chapters 5, 6 and 7. This chapter presents the research results for the grounded definition of the Randomness-Chaos-Complexity-Order (RCCO) continuum domains and the initial understanding of the chaos attractor concept as given by capital project managers during the Round 1 interviews. Research results on the capital project archetypes is given in Chapter 6 and chaos attractor metaphors and variance models in Chapters 7.

5.2 Origin of Results and Scope of Reporting

This chapter covers the research results that originate from the Round 1 interviews with experienced capital project managers. Refer to Chapter 4, paragraph 4.5 for the data capturing and data collection methodologies employed. Results reporting for this chapter is confined to data collected and analysed for the Randomness-Chaos-Complexity-Order (RCCO) continuum and on chaos attractors as shown in Figure 5-1.

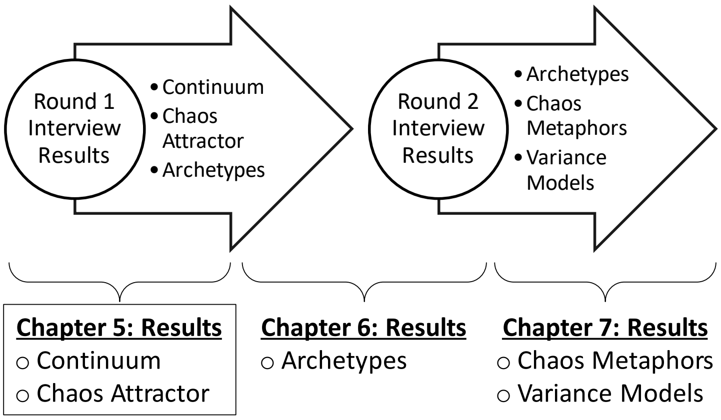
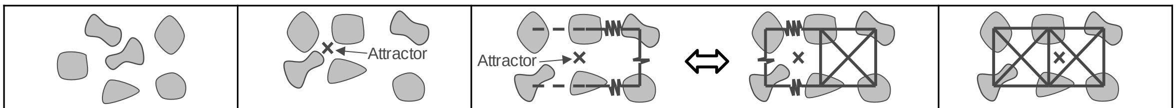


Figure 5-1: Origin and Scope of Results Reporting for Chapter 5

Chapter 6 will cover the results on archetypes for capital projects that originated from both the Round 1 and Round 2 interviews. Chapter 7 will only report on the results for the chaos metaphors and the variance models.

5.3 Grounded Definitions for Randomness, Chaos, Complexity and Order in Capital Projects

This section covers the definition of order, complexity, chaos and randomness by capital project managers during the Round 1 interviews. The interview questionnaire design was constructed to first ask for the definition of order by capital project managers and then for the definition of complexity, chaos and randomness. This was done deliberately as it was assumed that a capital project manager would be able to describe the desired project state of order more easily compared to states that represent an increase in disorder. The objective of this section was to obtain grounded definitions from experienced capital project managers on the model that was defined in Chapter 3 (Figure 3-6) for the Randomness-Chaos-Complexity-Order (RCCO) continuum as shown in Figure 5-2. However, this model was not shown or explained to the capital project managers during the interviews to ensure that they formulate their own grounded definitions for the continuum elements of order, complexity, chaos and randomness.



RANDOMNESS		CHAOS		COMPLEXITY				ORDER	
Completely Random	Not Deterministic	Full Chaos	Limited Chaos	Self-organising Complexity & Edge of Chaos	Evolving Complexity	Dynamic Complexity	Static Complexity	Complicated	Simple

Figure 5-2: Model for the Randomness-Chaos-Complexity-Order Continuum as Defined in Chapter 3

5.3.1 Definition of Order in Capital Projects

Capital project managers that were interviewed during Round 1 were asked to define the concept of order in capital projects using the following interview question:

IQ1.1) Provide your own definition of <u>order</u> in capital projects? Generic example?

The results for the definition of order in capital projects are given in Table 5-1 in terms of unique 1st order terms by respondents that were allocated to 2nd order concepts for the aggregate construct of order. The ISO 21500 subject groups (ISO, 2012) were chosen as the 2nd order concepts during the data analysis process. This grounded process of allocation

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of respondent terms to concepts that culminate in aggregate concepts is described fully by Gioia et al. (2013).

Table 5-1: Definition of Order in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:20	Steady project execution	Integration	Definition of Order
2	2:11	Planning is done		
3	2:18	Proper plan		
4	2:76	Processes do not change in-situ		
5	3:12	Project elements well defined		
6	3:20	Project runs smoothly		
7	4:10	Project is planned		
8	4:20	Properly defined		
9	4:31	Planning, control and assurance		
10	4:33	All project elements addressed		
11				
12	2:13	Timelines are achieved	Time	
13	2:17	Everything happens as it was planned		
14	2:29	Timelines established		
15	3:14	Logical order of proceedings		
16	3:15	Execution follows plan		
17	3:16	Logical execution order		
18	3:21	A logical flow of procedures		
19	4:16	All elements can be modelled		
20	4:19	Project on schedule		
21	4:23	Project can be planned		
22				
23	1:14	Clearly defined roles and responsibilities	Resource	
24	1:16	Organisation structure		
25	1:18	Competent team		
26	2:12	Responsibilities are known		
27	2:28	Responsibilities are		

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
		executed		
28	3:11	Team focussed on outcomes		
29	4:24	Experienced people		
30	4:30	Understand role		
31	4:35	Resources are allocated		
32	4:83	Disciplined resources		
33				
34	3:26	Not a volatile scope	Scope	
35	1:12	Clear scope		
36	3:27	Few scope changes		
37	3:17	Defined requirements are known		
38	4:13	Requirements known		
39	2:16	Stable goals		
40	4:22	Project requirements known		
41	3:25	Stable scope		
42	4:27	Logical work packages		
43				
44	1:11	Few unforeseen requirements	Risk	
45	1:22	Few unforeseen events		
46	1:23	Few events requiring extra intervention		
47	2:10	All risks mitigated		
48	2:15	Effective management of unknowns		
49	2:23	Management to prevent surprises		
50	2:24	Effective risk management		
51	4:11	Known technology		
52	4:14	Risk mitigated		
53				
54	3:23	Stakeholder buy-in	Stakeholder	
55	4:12	Few stakeholders		
56	4:17	Few disciplines involved		
57	4:21	Not too many stakeholders		
58				
59	2:14	Effective communication	Communication	

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
60	1:15	Clear communication channels		
61	3:19	Project team understands		
62				
63	1:13	Appropriate contacting model	Procurement	
64	4:34	Effective contract management		
65				
66	3:24	Stable budget	Cost	

Table 5-1 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups) for the Definition of Order (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 58

The number (z) of unique 1st order terms per subject group, as shown in Table 5-1, varied per 2nd order concept for integration (z = 10), time (z = 10), resource (z = 10), scope (z = 9), risk (z = 9), stakeholders (z = 4), communication (z = 3), procurement (z = 2) and cost (z = 1). No unique 1st order terms from the responses could be assigned to the ISO 21500 subject group quality. Unique 1st order terms for the definition of order were reported by participants of all four groups for the ISO 21500 subject groups of integration, resource and scope. This can be seen in Table 5-1 as the Atlas.ti software transcription reference (Round 1 - Ref.) of 1:xx for responses from group 1 respondents, 2:xx for group two, 3:xx for group three and 4:xx for group four. Rows were left empty in all tables to enhance visibility of 1st order terms that were allocated to the ISO 21500 subject groups.

The frequency of 1st order terms that were assigned to the ISO 21500 subject groups across the four interview groups is shown in Figure 5-3 for the definition of order by capital project managers. The Spider Diagram shows the ranking from the highest cumulative frequency achieved (e.g. integration) per ISO 21500 subject group across the four interview groups clockwise towards the lowest cumulative frequency achieved (e.g. quality).

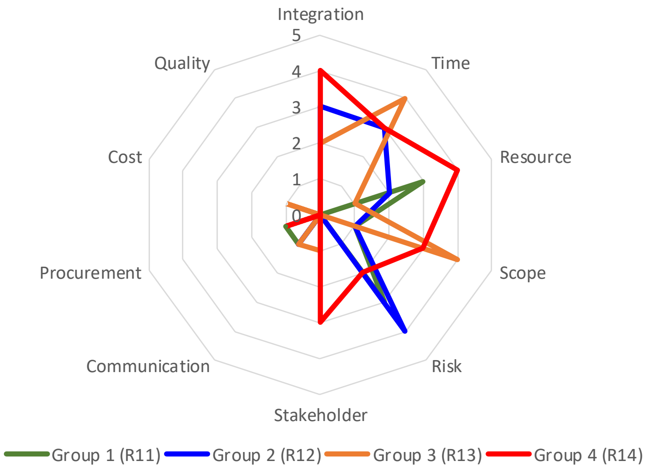

Figure 5-3: Frequency of ISO 21500 Subject Groups Related the Definition of Order in Capital Projects

Most of the responses from capital project managers across the four interview groups with a frequency (f) ranging between f = 0 and f_{max} = 4 were related to for the ISO 21500 subject groups of integration, time, resource, scope, risk and stakeholder as shown on the right side of the Spider Diagram in Figure 5-3. Limited responses with f = 0 and f_{max} =1 were reported across all four interview groups for the ISO 21500 subject groups of communication, procurement, cost and none for quality.

This result indicates that capital project managers seemed to believe that the concept of order in capital projects is more strongly related to integration, time, resource, scope, risk and stakeholder ISO 21500 subject groups and weakly related to communication, procurement, cost and not at all related to quality. This result is portrayed from an ISO 21500 point of view as shown in Table 5-1.

5.3.2 Definition of Complexity in Capital Projects

Capital project managers that were interviewed during Round 1 were asked to define the concept of complexity in capital projects using the following interview question:

IQ1.2) Provide your own definition of complexity in capital projects? Generic example?

The results for the definition of complexity in capital projects is given in Table 5-2 in terms of unique 1st order terms by respondents that were allocated to 2nd order concepts for the aggregate construct of complexity. The ISO 21500 subject groups (ISO, 2012) were chosen as the 2nd order concepts during the data analysis process.

Table 5-2: Definition of Complexity in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:29	New technology	Risk	Definition of Complexity
2	2:32	First of a kind technology		
3	2:34	Different factors		
4	3:34	Unfamiliar factors		
5	3:60	Uncertainty		
6	4:39	New technology		
7	4:49	Risk to meet time and scope		
8	4:50	Lack of risk mitigation		
9	4:51	Inability to identify risk		
10	3:30	Technical complexity		
11				
12	1:26	Multiple stakeholders	Stakeholder	
13	1:27	Unstable political environment		
14	2:38	More stakeholders		
15	3:33	Many stakeholders		
16	4:44	Increased number of disciplines		
17	4:48	Several stakeholders		
18	1:24	Multiple disciplines		
19	2:37	Stakeholder alignment to common goals		
20	3:32	Multidisciplinary roles		
21				
22	1:28	Multiple interfaces	Integration	
23	2:39	Increase number of processes		
24	2:44	More interface points		
25	3:57	Many interfaces		
26	3:58	Undefined &and misaligned interfaces		
27	4:47	Systems engineering not defined		
28	3:59	Planning uncertainty		
29	3:35	Planning &and management uncertainty		
30				
31	3:28	Individuals &and teams own focus	Resource	
32	4:52	Low levels of experience		

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
33	2:36	Different people		
34	2:42	Increased number of people		
35	2:45	People induced complexity		
36				
37	4:53	Incomplete communication	Communication	
38	4:55	Lack of common terminology		
39	4:42	Low levels of communication		
40				
41	4:46	Huge effort for requirements management	Scope	
42	4:43	Outstanding requirements		
43	4:54	Unknown unknown requirements		
44				
45	4:45	Some project elements cannot be modelled	Time	

Table 5-2 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that are Allocated to 2nd Order Concepts (ISO 21500 Subject Groups) for the Definition of Complexity (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 39

The number of unique 1st order terms per subject group, as shown in Table 5-2, varied per 2nd order concept for risk (z = 11), stakeholder (z = 10), integration (z = 8), resource (z = 5), communication (z = 3), scope (z = 3) and time (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject groups of procurement, cost and quality. Unique 1st order terms for the definition of order were reported by participants of all four groups for the ISO 21500 subject groups of risk, stakeholder and integration. This can be seen in Table 5-2 as the Atlas.ti software transcription reference (Round 1 - Ref.) of 1:xx for responses from group 1 respondents, 2:xx for group two, 3:xx for group three and 4:xx for group four.

The frequency of unique 1st order terms that were assigned to the ISO 21500 subject groups across the four interview groups is shown in Figure 5-4 for the definition of complexity by capital project managers. The Spider Diagram shows the ranking from the highest cumulative frequency achieved (e.g. risk) per ISO 21500 subject group across the four interview groups clockwise towards the lowest cumulative frequencies achieved (e.g. procurement, cost and quality).

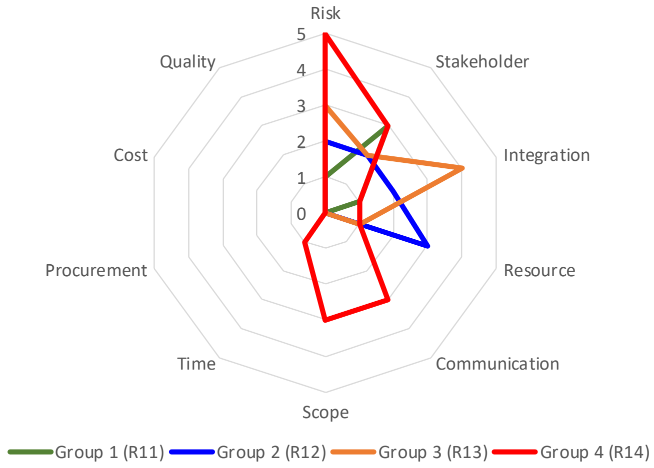

Figure 5-4: Frequency of ISO 21500 Subject Groups Related the Definition of Complexity in Capital Projects

Most of the responses from capital project managers across the four interview groups with a frequency ranging between f = 0 and f_{max} = 5 were related to for the ISO 21500 subject groups of risk, stakeholder, integration, resource, communication and scope as shown on the right side of the Spider Diagram in Figure 5-4. A single response (f = 1) was recorded for the time subject group while no responses were recorded for the ISO 21500 subject groups of procurement, cost and quality.

This result indicates that capital project managers seem to believe that the concept of complexity in capital projects is more strongly related to the risk, stakeholder, integration, resource, communication and scope ISO 21500 subject groups and weakly related to time and not at all related to procurement, cost and quality. This result is portrayed from an ISO 21500 point of view as shown in Table 5-2.

5.3.3 Definition of Chaos in Capital Projects

Capital project managers that were interviewed during Round 1 were asked to define the concept of chaos in capital projects using the following interview question:

IQ1.3) Provide your own definition of <u>chaos</u> in capital projects? Generic example?

The results for the definition of chaos in capital projects is given in Table 5-3 in terms of 1st unique order terms by respondents that were allocated to 2nd order concepts that comprise the aggregate construct of chaos. The ISO 21500 subject groups (ISO, 2012) were chosen as the 2nd order concepts during the data analysis process.

Table 5-3: Definition of Chaos in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:35	Poorly defined reporting	Integration	Definition of Chaos
2	2:54	Poor processes		
3	2:55	No cause effect relationship		
4	2:57	Not knowing what to do next		
5	2:58	No plan		
6	3:39	Multiple project changes		
7	3:48	Things are not synchronised		
8	4:63	Functions are not clear and integrated		
9	4:65	No clear project or program strategy		
10				
11	1:31	No clear direction	Resource	
12	1:34	Unclear responsibilities		
13	1:40	Lack of leadership		
14	2:46	Poor leadership		
15	2:52	Poor project management		
16	2:53	Lack of project manager competence		
17	2:61	Lack of accountability		
18	2:62	Lack of roles and responsibility		
19	3:40	Varying focus		
20				
21	1:38	Risk mitigation capacity limit reached	Risk	
22	2:50	Many surprises and unplanned events		
23	2:51	Increase in unknowns		
24	3:36	Changing technology		
25	3:46	Definitely unexpected change		
26	4:58	Risk realising, no mitigation		
27	4:62	Uncertainty in terms of planning		
28	4:64	Risks are not managed		
29	4:66	Lack of risk mitigation		
30				
31	2:47	Poor project progress	Time	
32	2:59	No project progress		

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
33	3:42	Out of sequence project mobilisation		
34	3:44	Unapproved schedule		
35	3:45	Disturbed logic		
36	4:57	Schedule overruns		
37	4:61	Most elements cannot be modelled		
38				
39	1:36	Poorly defined reporting structures	Communication	
40	4:60	Unknown communications		
41	1:39	Poorly defined reporting channels		
42	2:60	Lack of communication		
43				
44	4:84	Cost overruns	Cost	
45	3:43	Unapproved budgets		
46	3:37	Changing financials		
47				
48	4:59	Unknown requirements	Scope	
49	1:41	Unclear scope of work		
50	3:41	Unrealistic expectation		
51				
52	3:47	Lack of stakeholder buy-in	Stakeholder	
53	1:37	Poorly defined stakeholder structures		
54				
55	1:42	Inappropriate contracting models	Procurement	

Table 5-3 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that are Allocated to 2nd Order Concepts (ISO 21500 Subject Groups) for the Definition of Chaos (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 47

The number of unique 1st order terms per subject group, as shown in Table 5-3, varied per 2nd order concept as shown for integration (z = 9), resource (z = 9), risk (z = 9), time (z = 7), communication (z = 4), cost (z = 3), scope (z = 3), stakeholder (z = 2) and procurement (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject group quality. Unique 1st order terms for the definition of chaos were reported by participants of all four groups for the ISO 21500 subject groups of integration and risk. This can be seen in Table 5-3 as the Atlas.ti software transcription reference (Round 1 - Ref.) of 1:xx for responses from group 1 respondents, 2:xx for group two, 3:xx for group three and 4:xx for group four.

The frequency of unique 1st order terms that were assigned to the ISO 21500 subject groups across the four interview groups is shown in Figure 5-5 for the definition of chaos by capital project managers. The Spider Diagram shows the ranking from the highest cumulative frequency achieved (e.g. integration) per ISO 21500 subject group across the four interview groups clockwise towards the lowest cumulative frequencies achieved (e.g. quality).

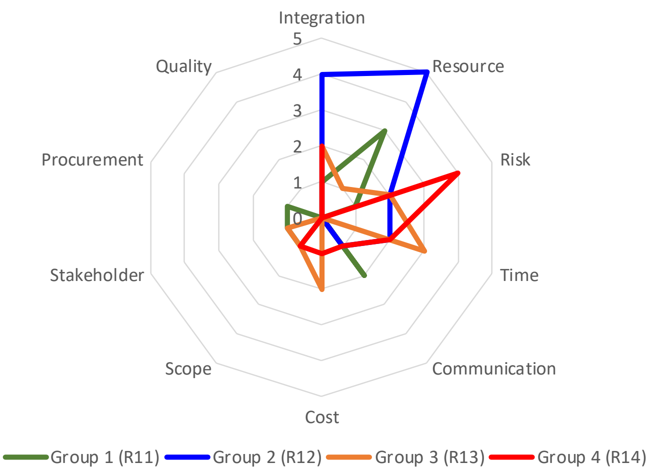

Figure 5-5: Frequency of ISO 21500 Subject Groups Related the Definition of Chaos in Capital Projects

Most of the responses from capital project managers across the four interview groups with a frequency ranging between f = 0 and f_{max} = 5 were related to the ISO 21500 subject groups of integration, resource, risk and time as shown on the top right side of the Spider Diagram in Figure 5-5. Frequencies between f = 0 and f_{max} =2 were obtained for the subject groups communication, cost, scope, stakeholder and procurement at the bottom and left side of the Spider Diagram. No response was recorded for quality (f = 0).

This result indicates that capital project managers seem to believe that the concept of chaos in capital projects is more strongly related to the integration, resource, risk and time ISO 21500 subject groups and weakly related to communication, cost, scope, stakeholder and procurement and not at all related to quality. This result is portrayed from an ISO 21500 point of view as shown in Table 5-3.

5.3.4 Definition of Randomness in Capital Projects

Capital project managers that were interviewed during Round 1 were asked to define the concept of randomness in capital projects using the following interview question:

IQ1.4) Provide your own definition of randomness in capital projects? Generic example?

The results for the definition of randomness in capital projects is given in Table 5-4 in terms of unique 1st order terms by respondents that were allocated to 2nd order concepts that formed the aggregate construct of randomness. The ISO 21500 subject groups (ISO, 2012) were chosen as the 2nd order concepts during the data analysis process.

Table 5-4: Definition of Randomness in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:43	Multiple unforeseen events	Risk	Definition of Randomness
2	1:46	Unknown unknowns		
3	1:51	Could not have predicted		
4	2:65	Unexpected events or actions		
5	2:66	Sudden events with no pre-determined action		
6	3:52	Unforeseen things with low priority		
7	3:53	Unpredictable event		
8	4:70	No risk mitigation		
9				
10	2:68	Everyone is working but it is not integrated	Integration	
11	2:70	Something outside of your control		
12	4:69	No control		
13	1:59	Unstructured		
14	1:48	Uncontrolled		
15	4:74	Project plan does not exist		
16	1:45	Higher levels of uncertainty in forecasting and planning		
17				
18	1:49	Stakeholder political intervention	Stakeholder	
19	1:50	New ideas from new stakeholder		
20	3:50	Political intervention		
21	3:51	Change in stakeholders		
22	4:72	No common goal from many stakeholders		
23	4:78	A lot of stakeholders		
24	4:85	No common goal between the stakeholders		

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
25				
26	4:75	Lack of roles and responsibilities	Resource	
27	4:77	Project manager management inability		
28	2:67	Uncoordinated resources		
29	2:72	Lack of a wider focus		
30				
31	2:69	Not working towards a goal	Scope	
32	3:49	Unexpected shift in objectives		
33				
34	4:73	No elements of the project can be modelled	Time	
35	2:64	Poor understanding of interlinking activities		
36				
37	4:71	No communication	Communication	
38				
39	4:76	No assurance	Quality	

Table 5-4 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that are Allocated to 2nd Order Concepts (ISO 21500 Subject Groups) for the Definition of Randomness (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 32

The number of unique 1st order terms per subject group, as shown in Table 5-4, varied per 2nd order concept as shown for risk (z = 8), integration (z = 7), stakeholder (z = 7), resource (z = 4), scope (z = 2), time (z = 2), communication (z = 1), quality (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject groups cost and procurement. Unique 1st order terms for the definition of order were reported by participants of all four groups for the ISO 21500 subject group of risk. This can be seen in Table 5-4 as the Atlas.ti software transcription reference (Round 1 - Ref.) of 1:xx for responses from group 1 respondents, 2:xx for group two, 3:xx for group three and 4:xx for group four.

The frequency of unique 1st order terms that were assigned to the ISO 21500 subject groups across the four interview groups is shown in Figure 5-6 for the definition of randomness by capital project managers. The Spider Diagram shows the ranking from the highest cumulative frequency achieved (e.g. risk) per ISO 21500 subject group across the four interview groups clockwise towards the lowest cumulative frequency (e.g. cost and procurement).

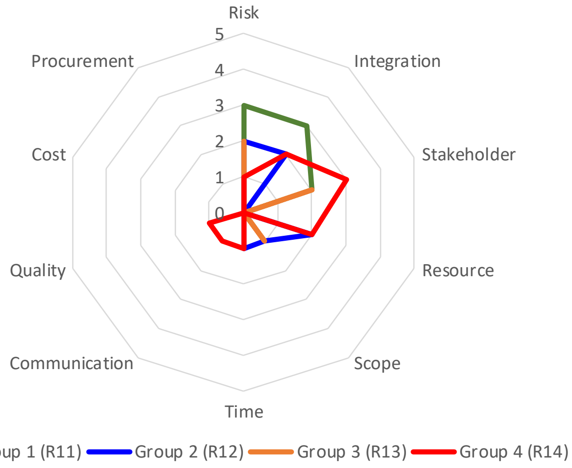

Figure 5-6: Frequency of ISO 21500 Subject Groups Related the Definition of Randomness in Capital Projects

Most of the responses from capital project managers across the four interview groups with a frequency ranging between f = 0 and f_{max}= 3 were related to for the ISO 21500 subject groups of risk, integration, stakeholder and resource as shown on the top right side of the Spider Diagram in Figure 5-6. Frequencies between f = 0 and f_{max} =1 were obtained for the subject groups scope, time, communication and quality at the bottom side of the Spider Diagram. No responses were recorded for cost and procurement (f = 0).

This result indicates that capital project managers seem to believe that the concept of randomness in capital projects is more strongly related to the risk, integration, stakeholder and resource ISO 21500 subject groups and weakly related to scope, time, communication and quality and not at all related to cost and procurement. This result is portrayed from an ISO 21500 point of view as shown in Table 5-4.

5.3.5 Summary of Grounded Definitions from Capital Project Managers on Randomness, Chaos, Complexity and Order

All the responses from all the capital project managers for Round 1 across the four interview groups for their definitions of randomness, chaos, complexity and order is shown in Figure 5-7.

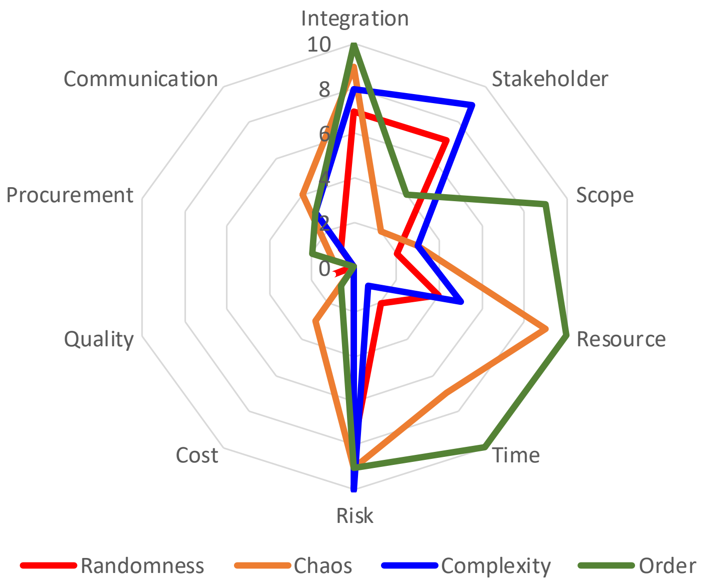

Figure 5-7: Frequency of ISO 21500 Subject Groups Related to the Randomness-Chaos-Complexity-Order Continuum Domains in Capital Projects

Most of the responses from capital project managers across the four interview groups with a frequency ranging between f = 0 and f_{max} = 10 are related to for the ISO 21500 subject groups of integration, stakeholder, scope, resource, time and risk as shown on the right side of the Spider Diagram in Figure 5-7. Frequencies between f = 0 and f_{max} =4 were obtained for the subject groups cost, quality, procurement and communication at the left side of the Spider Diagram.

This result indicates that capital project managers seemed to agree that the continuum domains of randomness, chaos, complexity and order are strongly related to the ISO 21500 subject groups of integration, stakeholder, scope, resource, time and risk and weakly related to cost, quality, procurement and communication.

5.4 Ranking of Continuum Domains for Capital Projects

Capital project managers that were interviewed during Round 1 were asked to rank the continuum domains of order, complexity, chaos and randomness with the following interview question:

IQ1.5) Rank the above categories in order of increased disorder

The responses for the ranking of the continuum domains as obtained from the capital project managers across the four interview groups are shown in Table 5-5.

Table 5-5: Ranking of Continuum Domains towards Increased Disorder in Capital Projects

No.	Round 1 - Ref	Group ID	Resp. No.	Ranking Towards Increased Disorder ➔			
1	1:58	Group 1 (R11)	Resp.3	Order	Complexity	Chaos	Randomness
2	2:75	Group 2 (R12)	Resp.6	Order	Complexity	Chaos	Randomness
3	3:61	Group 3 (R13)	Resp.7	Order	Complexity	Chaos	Randomness
4	4:79	Group 4 (R14)	Resp.10	Order	Complexity	Chaos	Randomness
5	4:80	Group 4 (R14)	Resp.11	Order	Complexity	Chaos	Randomness
6	4:81	Group 4 (R14)	Resp.12	Order	Complexity	Chaos	Randomness
7							
8	1:57	Group 1 (R11)	Resp.2	Order	Complexity	Randomness	Chaos
9	1:56	Group 1 (R11)	Resp.1	Order	Complexity	Randomness	Chaos
10	2:74	Group 2 (R12)	Resp.5	Order	Complexity	Randomness	Chaos
11	3:63	Group 3 (R13)	Resp.9	Order	Complexity	Randomness	Chaos
12	3:62	Group 3 (R13)	Resp.8	Order	Complexity	Randomness	Chaos
13							
14	2:73	Group 2 (R12)	Resp.4	Order	Randomness	Complexity	Chaos

Table 5-5 Notes: Round 1 Interviews, Sample Size: n = 12

Six of the twelve (50%) capital project managers intuitively ranked the order of the domains towards increased disorder as was found in the literature survey and derived model as order, complexity, chaos and randomness (refer to Chapter 3, paragraph 3.5.1) as shown in Table 5-5(1-6). A further five of the twelve (42%) respondents were of the opinion that the chaos domain was more disordered than the randomness domain as shown in Table 5-5(8-12). One respondent was of the opinion that the ranking of the continuum domains towards increased order should be order, randomness, complexity and chaos as shown in Table 5-5(14).Bearing in mind that no prior information on the continuum definitions was given to the capital project managers before the group interviews, it seems that 92% of the respondents agreed that the first two domains towards increased disorder should be the order and complexity domains.

The results indicate that most of the capital project managers were able to provide a ranking of the continuum domains towards increased disorder as either chaos followed by randomness; or randomness followed by chaos; and then complexity and order domains.

5.5 Movement of Successful and Failed Capital Projects in the Continuum

Once the capital project managers generated their own definitions for the continuum domains of randomness, chaos, complexity and order and did their own ranking of these domains, they were informed of the results from the literature survey on the domain ranking order. The respondents were informed that they should assume a continuum domain ranking towards increased order of randomness, chaos, complexity and order when answering the following two interview questions:

> ***IQ1.6) Provide your opinion and comment on the following statement: "A successful capital project ultimately moves from a state of randomness and chaos towards order"***
>
> ***IQ1.7) Provide your opinion and comment on the following statement: "A failed capital project ultimately moves from a state of order towards chaos and randomness (maximum disorder)"***

During the data analysis of the responses to this question by respondents it was realised that capital project managers are describing archetypes. The archetypes for the Round 1 interviews were shown to the respondents of the Round 2 interviews.

It was found that the respondents of the Round 2 interviews were not only able to recognise these archetypes but to identify additional archetypes. Therefore, the results for these interview questions (IQ1.6 and IQ1.7 for Round 1) as well as the results for the first research question for the Round 2 interviews were analysed together to extract all the archetypes as shown in Chapter 6.

5.6 Definition of Chaos Attractors in Capital Projects

This section covers the grounded definition of a chaos attractor by capital project managers during the Round 1 interviews.

5.6.1 Definition of Chaos Attractors in Capital Projects

Three interview questions were used to obtain grounded information and responses from capital project managers on their understanding of the phenomenon of a chaos attractor in capital projects. These interview questions were:

IQ2.1) What is your intuitive definition of a chaos attractor in capital projects?

IQ2.2) How is chaos converted into order?

IQ2.3) When is chaos converted into order

The results for the definition of a chaos attractor in capital projects are given in Table 5-6 in terms of unique 1st order terms by respondents that were allocated to 2nd order concepts comprise the aggregate construct of a chaos attractor. The ISO 21500 subject groups (ISO, 2012) were chosen as the 2nd order concepts during the data analysis process.

Table 5-6: Definition of a Chaos Attractor in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:82	Roles and responsibilities definition	Resource	Definition of a Chaos Attractor
2	1:87	Sufficiently qualified and experienced team		
3	2:95	Experience		
4	2:96	Personality		
5	2:99	People		
6	3:77	Remove misfit team member		
7	4:104	Experience - what worked before		
8	4:105	Skilled and experienced resources		
9	4:106	To motivate people can perform miracles		
10	4:107	Celebrating of small successes		
11	4:109	Sometimes you need to replace a person		
12				
13	1:44	Order and structure should ultimately minimise randomness	Integration	
14	1:83	Timeous and effective management of random events		
15	1:86	Daily project management against a plan		
16	2:105	Control		
17	2:94	Planning for unknowns before they happen		
18	3:78	Multi-level intervention		
19	3:79	Continuous intervention, monitoring and actions		
20	4:101	You have to act timeous		

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
21	4:98	Understand what causes the randomness		
22	4:99	Remove the reason for the chaos		
23				
24	2:102	Communication help to identify unknowns	Communication	
25	3:73	Common goal detected and understood		
26	3:74	Informed client		
27	3:75	Informed management		
28				
29	1:81	Formally agreed and singed-off scope	Scope	
30	1:85	Clarification of scope		
31	3:76	Clear, concise outcome definition		
32				
33	4:108	Fair contracting strategy	Procurement	
34				
35	1:84	PMBOK knowledge areas and processes	Quality	
36				
37	2:104	Measurement where you are in the project	Time	

Table 5-6 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups) for the Definition of a Chaos Attractor (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 31

The number of unique 1st order terms per subject group, as shown in Table 5-6, varied per 2nd order concept as shown for resource (z = 11), integration (z = 10), communication (z = 4), scope (z = 3), procurement (z = 1), quality (z = 1) and time (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 stakeholder, risk and cost subject groups.

The cumulative frequency of unique 1st order terms that were assigned to the ISO 21500 subject groups across the four interview groups is shown in Figure 5-8 for the definition of a chaos attractor by capital project managers. The Spider Diagram shows the ranking from the highest cumulative frequency achieved (e.g. resource) per ISO 21500 subject group across the four interview groups clockwise towards the lowest cumulative frequency (e.g. stakeholder, risk and cost).

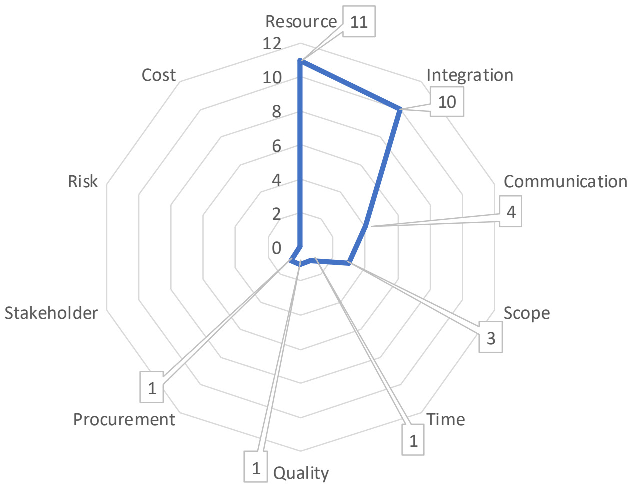

Figure 5-8 Number of ISO 21500 Subject Groups Related to the Definition of a Chaos Attractor in Capital Projects

The results in Figure 5-8 shows the total number of responses for the ISO 21500 subject groups of for resource (n = 11) and integration (n = 10) were reported by respondents from all four interview groups. This can be seen in Table 5-6 where the Altas.ti references (Round 1 - Ref.) for the integration 2nd order concept indicated as R1-Ref. 1:82 and 1:87 for respondents from group one, R1-Ref. 2:95, 2:96, 2:99 for respondents from group two, R1-Ref. 3:77 for a respondent from group three and R1-Ref. 4:104, 4:105, 4:106, 4:107 and 4:109 for respondents from group four. It is concluded that it appears if the capital project managers across all four interview groups agreed that the ISO 21500 subject groups of resources and integration are associated with the definition of a chaos attractor in a capital project.

During the content analysis for the definition of a chaos attractor in capital projects, some of the respondents of group four (R1-Ref. 4:100, 4:102, 4:103) indicated their views on what a chaos attractor is not, as shown in Table 5-7.

Table 5-7: The Antithesis of a Chaos Attractor

No.	Round 1 - Ref.	Definition - Not a Chaos Attractor
1	4:100	New stakeholder generates chaos
2	4:102	Micromanagement will not create convergence and order
3	4:103	Reactive people create chaos

Table 5-7 Notes: Round 1 Interviews, Sample Size: n = 12, Number of Selected Quotations = 3

The result in Table 5-7 shows that a new stakeholder and people (team members) that behave reactively generate chaos while micromanagement will not create conversion and order. These terms could perhaps be viewed as the antithesis of a chaos attractor or a chaos repeller.

5.6.2 Multi-Dimensional Nature of Chaos Attractors in Capital Projects

The final interview question that was asked to capital project managers during the Round 1 interviews pertains to the dual nature of a chaos attractor as follows:

> ***IQ2.4) What is your view on the statement that chaos attraction is a multidimensional concept i.e. it has to do with both project management, systems engineering management etc. (hard aspects) as well as psychology, sociology (soft aspects)?***

All twelve capital project managers agreed that a chaos attractor in a capital project is a multi-dimensional concept that involves both hard and soft aspects as shown in Figure 5-9.

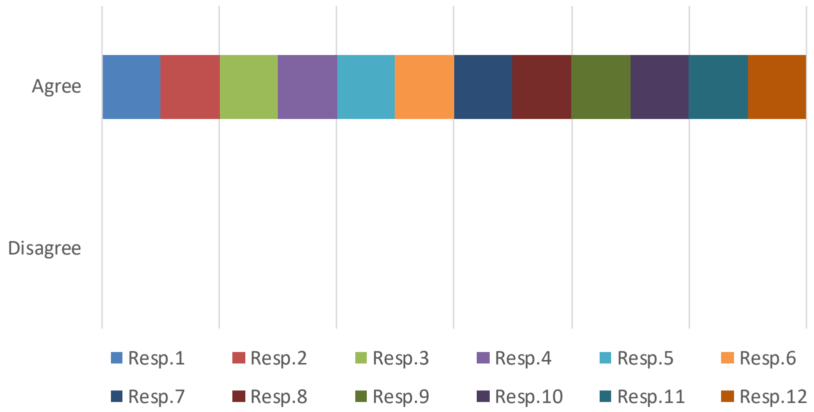

Figure 5-9: Agreement by Respondents that Chaos Attractors Contain both Hard and Soft Aspects in Capital Projects

The results of the content analysis and further elaboration on the research question by respondents is shown in Table 5-8.

Table 5-8: Multi-Dimensional Nature of Chaos Attractors in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	3:81	Systems support processes	Hard	Nature of a chaos attractor
2				
3	3:80	Leadership to mobilise resources	Soft	
4	3:83	The social impact		
5	4:110	The soft aspects include personalities, relationships		
6	1:88	PMBOK etc. devote far too little attention to soft issues		
7	1:89	Integration and communication are often where the project struggle		
8	1:91	Individual personalities can go some way to shaping success through commitment, collaboration etc.		
9	1:92	Soft skills		
10				
11	3:82	It is normally the attention to the soft aspects that streamline and give effect to the hard aspects	Both Hard and Soft	
12	3:84	You are working with people and therefore you need to take both into account		
13	3:85	The hard stuff is just to help the soft stuff. The hard stuff you can actually do - the soft stuff makes it happen		
14	2:106	The above aspects are all inter-related and interactive		

Table 5-8 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups) on the Multi-Dimensional Nature of a Chaos Attractor (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 12

The results in Table 5-8 indicate responses from all four interview groups (e.g. R1-Ref. 1:88, 2:106, 3:81 and 4:110). System support processes are indicated as a "hard aspect" while leadership, social impact, relationships, integration, communication and personalities were indicated as "soft" aspects of chaos attractors. Finally, a number of capital project managers (R1-Ref. 3:82, 3:84, 3:85 and 2:106) indicated that both the hard and soft aspects are important characteristics of chaos attractors.

One respondent (R1-Ref. 1:90) indicated that "people can contribute greatly to decrease chaos" as shown in Table 5-9. This statement is not taken as a definition of a chaos attractor but seems as an important contributor (independent variable) to help understand how chaos attractors work in capital projects.

Table 5-9: Single Statement by a Respondent on People and Chaos

No.	Round 1 - Ref.	Multi-Dimensional Effect of a Chaos Attractor
1	1:90	People can contribute greatly to decrease chaos

The results on the definition of chaos attractors in capital projects indicate that capital project managers interviewed during Round 1 agree that a chaos attractor is a multi-dimensional concept and that it consists of both hard and soft elements.

5.7 Discussion of Results - Chaos Concepts in Capital Projects

The concept of the Randomness-Chaos-Complexity-Order (RCCO) continuum was revealed during the literature review in Chapter 3 and a model was defined in Chapter 4. During the Round 1 interviews, capital project managers were requested to provide their own definition of these domains (the continuum model was not shown to them during the interviews). Combining the results for the continuum model and capital project manager responses, reveals the characteristics of these domains in the capital project environment as shown in Figure 5-10.

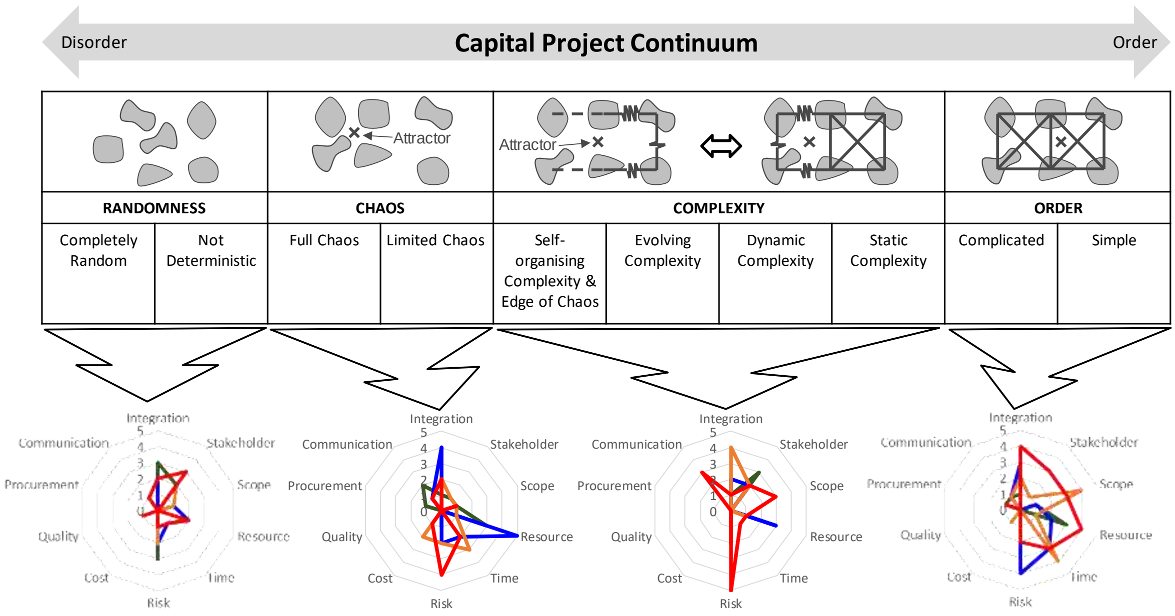

Figure 5-10: Comparison of the Capital Project Continuum Domains and Frequencies of ISO 21500 Subject Groups for Each Continuum Domain

It is shown in Figure 5-10 that most of the definitions of the capital project continuum domains as defined by capital project managers were related to the ISO 21500 subject groups of integration, stakeholder, scope, resource, time and risk. This is indicated as the right-hand side of the Spider Diagrams of all domains. Similarly, it appears as if the ISO 21500 subject groups of cost, quality, procurement and communication played a minor role in the definition of these continuum domains. The only exception is perhaps the definition of the complexity domain where it seems the ISO 21500 subject group communication appears to be relevant.

The results in Table 5-6 indicated that Capital project managers of all four interview groups seemed to relate the ISO 21500 subject groups of resources and integration as relevant to the definition of a chaos attractor in a capital project. Also, the results in Table 5-8 indicated that both hard and soft aspects are important characteristics of a chaos attractor in capital projects. By combining these results, the chaos attractor convergence effect in a capital project could perhaps be schematically presented as shown in Figure 5-11.

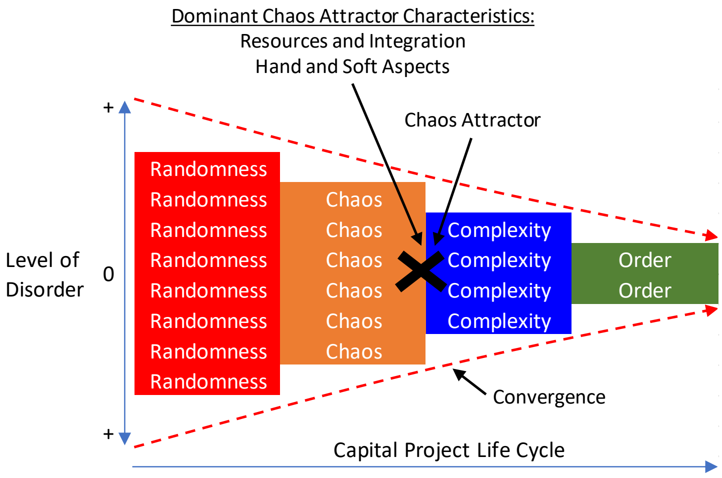

Figure 5-11: Definition and Characteristics of a Chaos Attractors in Capital Projects

Note that the chaos attractor in Figure 5-11 (indicated by an X) has been positioned between the chaos and complexity domains for illustrative purposes only. It was found during the literature survey in Chapter 2 that chaos attractors were identified in the chaos, complexity and ordered domains. This aspect warrants further investigation.

5.8 Summary

The research results for the Round 1 interviews with experienced capital project managers provided initial grounded information (Gioia et al., 2013) on the mapping of chaos theory concepts from their source domains to the capital project environment. The following results regarding the Randomness-Chaos-Complexity-Order (RCCO) continuum and the chaos attractor concept were recorded:

a) Definition of Continuum Domains:

i. Capital project managers were able to define the concept of order

- The concept of order in capital projects seems more strongly related to integration, time, resource, scope, risk and stakeholder and weakly related to communication, procurement, cost and not at all related to quality, when analysed using the ISO 21500 subject groups.

ii. Capital project managers were able to define the concept of complexity

- The concept of complexity in capital projects seems more strongly related to risk, stakeholder, integration, resource, communication and scope and weakly related to time and not at all related to procurement, cost and quality.

iii. Capital project managers were able to define the concept of chaos

- The concept of chaos in capital projects seems more strongly related to integration, resource, risk and time and weakly related to communication, cost, scope, stakeholder and procurement and not at all related to quality.

iv. Capital project managers were able to define the concept of randomness

- The concept of randomness in capital projects seems more strongly related to risk, integration, stakeholder and resource and weakly related to scope, time, communication and quality and not at all related to cost and procurement.

v. Comparison of definitions provided by capital projects managers for the Randomness-Chaos-Complexity-Order (RCCO) continuum domains

- The continuum domains of randomness, chaos, complexity and order seem strongly related to the ISO 21500 subject groups of integration, stakeholder, scope, resource, time and risk and weakly related to cost, quality, procurement and communication.

b) Ranking of Continuum Domains

i. Most of the capital project managers were able to provide a ranking of the continuum domains towards increased disorder as: order, complexity, chaos and randomness.

c) Definition of Chaos Attractors

i. Capital project managers across all four interview groups agreed that the ISO 21500 subject groups of resources and integration are associated with the definition of a chaos attractor in a capital project

ii. Capital project managers agreed that a chaos attractor is a multi-dimensional concept that consists of both hard and soft elements.

These results are followed in Chapter 6 by analysed data on archetypes that originated from both the Round 1 and 2 interviews.

5.9 References

Gioia, D. A., Corley, K. G. & Hamilton, A. L. 2013. Seeking Qualitative Rigor in Inductive Research. *Organizational Research Methods,* 16(1)**,** pp 15-31.

ISO. 2012. Guidance on Project Management. *BS ISO 21500:2012.* Geneva: International Standards Organisation.

CHAPTER 6: RESULTS FOR ARCHETYPES IN CAPITAL PROJECTS

6.1 Introduction

This Chapter is a continuation of the reporting on the empirical research results of the effect of chaos attractors which is believed to cause capital project convergence from chaos to order. In Chapter 5 the research results were presented for the definition of continuum domains and the understanding of the chaos attractor concept by experienced capital project managers. This chapter reports on nine capital project archetypes that emerged from descriptions by capital project managers during two rounds of interviews. The contents of this chapter cover the origin of the research results on archetypes. The Round 1 interview results are provided for five archetypes followed by the Round 2 interview results for the descriptions of a further four archetypes. The results are discussed and conclusions on archetypes for capital projects are made. Chapter 7 will cover the final set of research results that report on the chaos attractor metaphors and variance models.

6.2 Origin of Results

The research results for archetypes originate from responses from two different groups of capital project managers that participated in the research interviews. The data capturing and data collection methodologies that were employed to extract the empirical results for capital project archetypes were described in Chapter 4, paragraph 4.5. Results reporting for this chapter will therefore be confined to the archetypes for capital projects that were identified during the Round 1 and Round 2 interviews as shown in Figure 6-1.

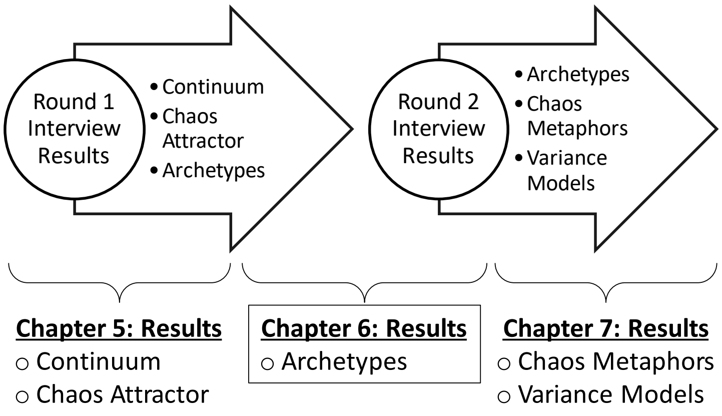

Figure 6-1: Origin and Scope of Research Results for Chapter 6

Results on the chaos attractor metaphors and variance models will be covered in Chapter 7.

6.3 Round 1 Results for Archetypes in Capital Projects

This section provides information on the research results that originate from the Round 1 interviews with 12 capital project managers and the emergence of five types of capital project archetypes.

6.3.1 Interview Question for the Movement of Capital Projects in the Continuum

After capital project managers provided their own definitions for the continuum domains of randomness, chaos, complexity and order (refer to the interview questionnaire in Appendix D, paragraph D2 as well as results in Chapter 5), they were asked to rank these domains in increased disorder. The respondents were then informed that they should assume a continuum domain ranking towards increased order to have domains of randomness, chaos, complexity and order when answering the following two questions:

> ***IQ1.6) Provide your opinion and comment on the following statement: "A successful capital project ultimately moves from a state of randomness and chaos towards order"***
>
> ***IQ1.7) Provide your opinion and comment on the following statement: "A failed capital project ultimately moves from a state of order towards chaos and randomness (maximum disorder)"***

During the data analysis of the responses to these interview questions by respondents it was realised by the researcher that capital project managers are describing archetypes as described by Senge (2006). The data analysis was then repeated to focus on the description of the emerging archetypes as shown in the following sections. The results were organised to assign recorded quotation terms to ISO 21500 subject groups (using the code books as shown in Appendix D, paragraphs D2 and D8) as well as creating new 2nd order concepts where applicable.

6.3.2 Archetype C1 – Converging Cone

Responses from capital project managers during the Round 1 interviews that resembled a converging cone archetype for a capital project are shown in Table 6-1. These responses were selected out of a total of 49 responses that described various capital project archetypes.

Table 6-1: Description of Characteristics for Archetype C1 – Converging Cone in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:67	Continuous managerial effort lessens chaos	Integration	Archetype C1 - Converging Cone
2	1:78	As we complete work, goals are clearer and order increases		
3	3:65	Intervention results in convergence		
4	2:89	Planning, responsibilities and communication improve order		
5	1:66	Shape and input (of the project) causes order		
6				
7	1:76	Unknowns at the start are assessed and planned for	Risk	
8	2:80	Dealing with unknowns reduces chance of unknown's disruptions		
9				
10	3:72	Outcome fit for purpose (even) with budget overrun	Scope	
11	4:88	Requirements clarity causes stable management		
12				
13	4:90	Maturity of project team	Resource	
14				
15	1:68	Learning to structure lessens chaos	Knowledge Management	
16	4:89	Knowledge and understanding creates order and success		
17				
18	1:64	Effective management of random events	Random Events	
19	1:63	Few random events		

Table 6-1 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetypes C1 (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 49

The transcribed text was analysed and unique quotation terms were identified as 1st order terms (Gioia et al., 2013). These 1st order terms were then matched with the code book descriptions (refer to Appendix D, paragraph D2) and assigned to 2nd order ISO 21500 concepts or new 2nd order concepts were generated as shown in Table 6-1. The 2nd order terms comprised the aggregate concept for the archetype C1 – converging cone.

The archetype C1 – converging cone characteristics (Table 6-1) could be allocated to the ISO 21500 subject groups of integration, risk, scope and resource but also portrays characteristics of knowledge management and random events. The schematic representation of the archetype across the life cycle of a capital project may be represented as shown schematically in Figure 6-2.

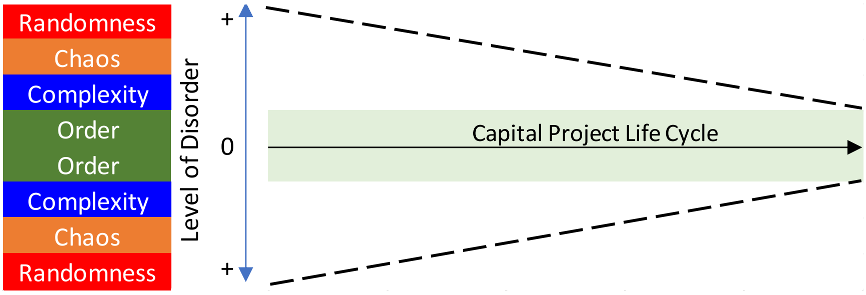

Figure 6-2: Suggested Schematic Representation for Archetype C1 – Converging Cone in Capital Projects

The converging cone archetype in Figure 6-2 suggests that a capital project is started at a maximum level of disorder (randomness) and converges continually during its life cycle through the domains of chaos and complexity towards order at the end of the capital project life cycle. Support for this archetype was obtained from capital project managers in all four interview groups as can be seen in by the Atlas.ti software reference numbers (Round 1 - Ref.): 1:xx, 2:xx, 3:xx and 4:xx in Table 6-1. For the remainder of this chapter the abbreviation “R1-Ref.” will be used to represent the Atlas.ti software reference numbers used for Round 1 research results.

6.3.3 Archetype C2 – Continuous Order

Some of the capital project managers believes that certain types of projects converge quickly to a state of order at the beginning of the capital project life cycle. Their impression is that these types of projects start ordered and stay ordered (R1-Ref. 4:86) and that there is sufficient knowledge and understanding (R1-Ref. 4:91) at the beginning of the capital project to cause quick convergence from randomness to order as shown by their responses in Table 6-2.

Table 6-2: Description of Characteristics for Archetype C2 – Continuous Order in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	4:86	A successful project start ordered and stay ordered	Integration	Archetype C2 - Continuous
2				

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
3	4:91	Enough knowledge and understanding at beginning	Knowledge Management	Order

Table 6-2 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetypes C2 (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 49

The archetype form for these types of capital projects is suggested to resemble a short converging cone from randomness to order and then continuous order up to the end of the capital project life cycle as shown schematically in Figure 6-3.

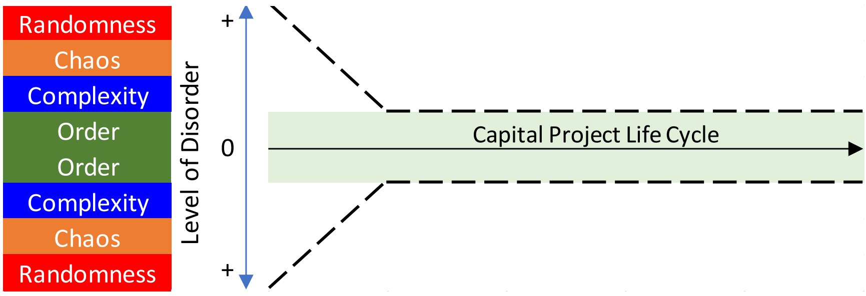

Figure 6-3: Suggested Schematic Representation for Archetype C2 – Continuous Order in Capital Projects

Based on the two responses in Table 6-2, the ISO 21500 subject group of integration as well as knowledge management may be important 2nd order concepts for Archetype C2. This archetype was also further investigated during the Round 2 interviews as discussed in paragraph 6.4.

6.3.4 Archetype C3 – Order-Bubble-Order

A number of capital project managers from interview groups 2, 3 and 4 (R1-Ref. 2:xx, 3:xx, 3:xx and 4:xx) were of the opinion that certain capital projects may quickly converge from randomness to order as shown in Figure 6-3 but just before the end of the project, typically at commissioning, chaos erupts (Table 6-3, R1-Ref. 2:81). This chaos must be brought under control towards order before the close-out of the capital project. The responses of capital project managers for the Order-Bubble-Order Archetype C3 are shown in Table 6-3.

Table 6-3: Description of Characteristics for Archetype C3 – Order-Bubble-Order in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	4:92	Order project from time to time	Integration	Archetype C3 - Order-Bubble-Order
2				
3	4:93	Unknown elements discovered in the middle of project	Risk	
4				
5	2:77	Order, construction chaos but order at the end	General characteristics	
6	2:81	Chaos at commissioning stage		
7	2:88	Successful project in order from beginning, randomness and chaos dealt with as it occurs		
8	3:66	Suddenly backward in funnel but order at end		
9	3:68	Last minute chaos and then desired outcome		
10	2:82	No more chaos after commissioning and project closure		

Table 6-3 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetypes C3 (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 49

The suggested graphical representation of this capital project archetype is shown schematically in Figure 6-4.

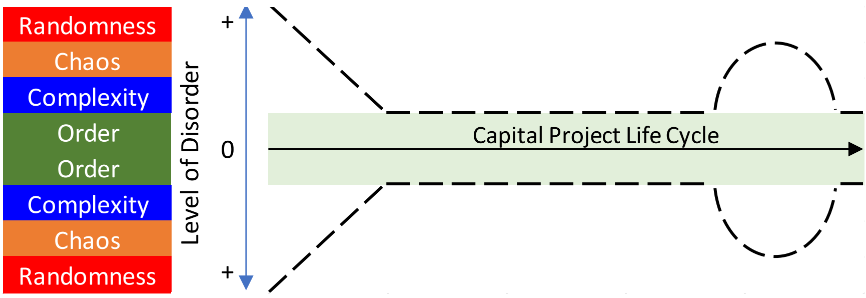

Figure 6-4: Suggested Schematic Representation for Archetype C3 – Order-Bubble-Order in Capital Projects

Based on the responses by capital project managers as indicated in Table 6-3, the onset of the 'chaos bubble' as shown in Figure 6-4 may be triggered by unknown elements in the middle of the project (R1-Ref. 4:93), the construction phase (R1-Ref. 2:77), the commissioning stage (R1-Ref. 2:81) or last minute chaos (R1-Ref. 3:68). However, the responses for this archetype suggests that order is finally achieved at the end of the capital project life cycle irrespective of the type of chaos trigger.

6.3.5 Archetype D1 – Diverging Cone

The responses from capital project managers that relate to the divergence of a capital project from order to chaos is shown in Table 6-4.

Table 6-4: Description of Characteristics for Archetype D1 – Diverging Cone in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	4:95	Chaos and disorder created by lack of planning, control, scope creep and risk management	Integration	Archetype D1 - Diverging Cone
2				
3	4:94	When risk management fails	Risk	
4				
5	1:73	Much higher potential of (project) failure	General Characteristics	
6	3:71	Randomness trigger chaos to cause divergence		
7	4:96	Something happens and it opens up (diverges)		
8	2:93	Start in order end in chaos		

Table 6-4 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetypes D1 (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 49

It appears as if this archetype could be characterised by the ISO 21500 subject groups integration and risk as shown in Table 6-4. Also, it seems that the trigger for divergence could be related to a lack of planning, project controls, scope creep (R1-Ref. 4:95), inadequate risk management (R1-Ref. 4:94 and 4:95) as well as chaos activated and / or triggered by randomness (R1-Ref. 3:71). The sketch for the divergent archetype D1 was inspired by the quotation terms such as cause divergence (R1-Ref. 3:71), it opens up (R1-Ref. 4:96) and end in chaos (R1-Ref. 2:93) as shown schematically in Figure 6-5.

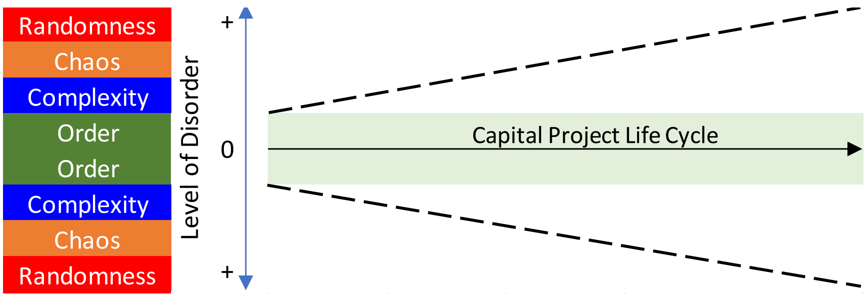

Figure 6-5: Suggested Schematic Representation for Archetype D1 – Diverging Cone in Capital Projects

6.3.6 Archetype D2 – Continuous Chaos

Capital project managers from three different interview groups (R1-Ref. 1:xx, 2:xx and 3:xx) described a type of capital project that never converges as shown in Table 6-5. This archetype D2 is named Continuous Chaos.

Table 6-5: Description of Characteristics for Archetype D2 – Continuous Chaos in Capital Projects

No.	Round 1 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:69	Failed capital projects start off in chaos and continues	General Characteristics	Archetype D2 - Continuous Chaos
2	2:91	Failed project identification by early stage level of chaos and disorder		
3	2:90	Projects never converges		
4	2:86	Start and end in chaos		
5	3:69	Start and stay in chaos		
6	1:74	Start in chaos and continuous		
7	2:87	Start in chaos and incompetence and continue		

Table 6-5 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that were Allocated to the 2nd Order Concept (General Characteristics) for Archetype D2 (Aggregate Construct). Round 1 Interviews, Sample Size: n = 12, Number of Responses Analysed for Interview Question = 49

The responses from capital project managers as shown in Table 6-5 for this archetype seem to indicate that this type of project starts and stays in chaos (R1-Ref. 1:69, 2:86, 3:69 and 1:74). The proposed sketch for archetype D2 is shown in Figure 6-6 and represents a capital project that start in the randomness domain and at most converges to a chaotic state for the duration of the project life cycle.

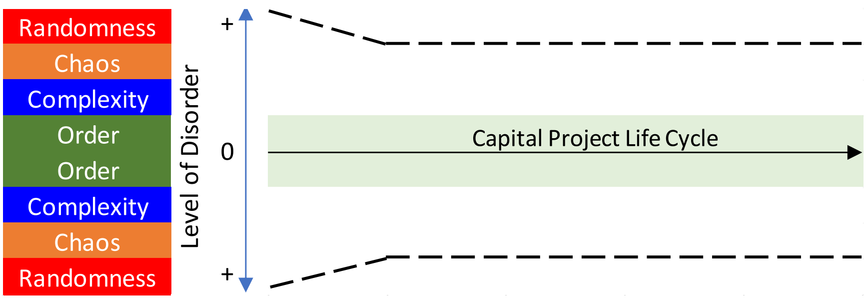

Figure 6-6: Suggested Schematic Representation for Archetype D2 – Continuous Chaos in Capital Projects

6.3.7 Other Comments on Archetypes from Respondents

A number of general comments on capital project archetypes were made by capital project managers that relate to project success, randomness and chaos as well as other characteristics as shown in Table 6-6.

Table 6-6: General Description of Characteristics for Archetypes C1, C2, C3, D1 and D2 in Capital Projects

No.	Round 1 - Ref.	Quotation Terms for Other Insights
1		**Project could be in ordered state but failure in terms of success criteria**
2	2:84	An over budget project can end in order
3	1:80	Failed projects still move to order but miss the goal
4	2:92	Failed project eventually goes to order when completed
5	1:79	Late and over budget but goal is clear
6	1:77	Late and over budget but resources can be aligned
7	1:70	Project move to order but can still fail
8		**Project point of no return and new beginning**
9	1:71	Capital project in state of randomness and chaos has little chance of success
10	4:97	Point of no-return - chaos and randomness so much no order possible
11	3:67	Randomness and chaos might produce a new goal
12		**Other Characteristics**
13	1:75	Perceived order but in reality, very little order
14	2:85	After certain deliverables nothing can disrupt project anymore
15	3:70	Last minute randomness creates chaos

Table 6-6 Notes: Round 1 Interviews, Sample Size: n = 12, Number of Quotations Analysed for Interview Question = 49

The first insight as portrayed by respondents is that a capital project could end in an ordered state but may be over budget and late (R1-Ref. 2:84, 1:79, 1:77), missed its goal (R1-Ref. 1:80) and still fail (R1-Ref. 1:70) as shown in Table 6-6. This evidence seems to support a conclusion that a capital project in an ordered state does not cause a successful project i.e. the capital project can still fail.

The second insight from respondents is that if the magnitude of randomness and chaos is high then no order is possible (R1-Ref. 4:97) and the capital project has little chance of success (R1-Ref. 1:71). These responses could be understood to indicate that order and project success may not be possible as envisaged by the project stakeholders at the start of the project. However, chaos theory states that order can be produced from chaos using the four chaos attractors as was discussed in Chapter 2 and 3. Therefore, it seems possible to redefine such a chaotic project and set new goals (R1-Ref. 3:67).

The third insight into the general characteristics of capital project archetypes is that there might be a perceived order in a capital project (R1-Ref. 1:75) or perhaps a false sense of order. Such a situation may be followed by a 'chaos bubble' – however, the trigger event may not always be activated. Respondents have also expressed the view that when sufficient deliverables have been achieved that the capital project will reach closure (R1-Ref. 2:85) and that the last-minute randomness in capital projects could be the trigger to cause chaos (R1-Ref. 3:70).

The descriptions of five capital project archetypes and their general characteristics allows for a summary of the research results for the Round 1 interviews.

6.3.8 Summary of Archetypes in Capital Projects During Round 1 Interviews

The results of the Round 1 interviews pertaining to the description of capital project archetypes revealed that capital project managers were able to describe five types of archetypes as shown in Figure 6-7.

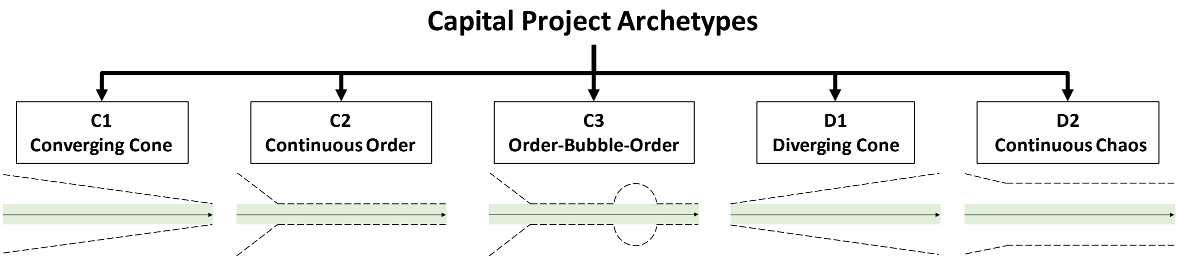

Figure 6-7: Summary of Capital Project Archetypes Described by Capital Project Mangers during Round 1 Interviews

Three of the archetypes shown in Figure 6-7 represent typical overall capital project behaviour for the convergence from randomness to chaos to complexity and finally to an ordered state at the end of the project life cycle (archetypes C1, C2 and C3). Two archetypes represent overall capital project behaviour that does not end in order but diverged from order to randomness (archetype D1) and never converged and remained in a state of chaos (archetype D2).

Respondents also indicated that a capital project that has achieved an ordered state might not be a successful project as it might have achieved this ordered state by overspending, being late and missing its original goals. Therefore, it can be concluded that a capital project that has reached an ordered state does not necessarily represent a successful capital project.

During the Round 1 interviews on what emerged as descriptions of archetypes, the comments made by capital project managers for the different archetypes were allocated to ISO 21500 subject groups or to other general categories. The number of allocated archetype descriptions for archetype C1 in Table 6-1, C2 in Table 6-2, C3 in Table 6-3, D1 in Table 6-4 and D2 in Table 6-5 are summarised in Table 6-7.

Table 6-7: Number of Capital Project Archetype Descriptions Allocated to ISO 21500 Subject Groups

No.	Dimensions	Archetype				
		C1	C2	C3	D1	D2
1	Integration	5	1	1	1	
2	Stakeholder					
3	Scope	2				
4	Resource					
5	Time					
6	Cost					
7	Risk	2		1	1	
8	Quality					
9	Procurement					
10	Communication					
11	General	5		6	4	7

<u>Table 6-7 Notes:</u> Round 1, General Category (11) Added to ISO 21500 Subject Groups

It is interesting to note that no allocations of any archetype description could be made to the ISO 21500 subject groups of resource, time, cost, quality, procurement or communication. For the purpose of this initial analysis, the categories of knowledge management as indicated in Table 6-1 and Table 6-2 and random events as indicated in Table 6-1 were counted in Table 6-7 as part of the general category. This analysis was repeated after the Round 2 interviews as will be shown in Table 6-27.

In order to verify these initial results as identified by the Round 1 capital project managers, it was decided to start the second round of interviews with a different group of capital project managers and test their agreement or disagreement with these five capital project archetypes as shown in Figure 6-7.

6.4 Round 2 Results for Archetypes in Capital Projects

This section provides information on the research results that originate from the Round 2 interviews with 14 capital project managers, the recognition of the five archetypes that were identified during the Round 1 interviews and the further description of four new archetypes.

6.4.1 Interview Questions

The in-depth interviews of Round 2 were commenced by showing the archetypes as defined by the Round 1 capital project managers to the Round 2 respondents. This was done in order to establish if these archetypes, as defined during the Round 1 interviews, were also recognised by the Round 2 respondents and thereby linking the concept of capital project archetypes between two rounds of interviews with different groups of capital project managers.

The Round 2 interview question pertaining to capital project archetypes as found during the Round 1 interviews, was:

The results of Round 1 of this research indicated that the capital project life-cycle may be characterised by stages of a randomness-chaos-complexity-order continuum as shown in Figure 6-8.

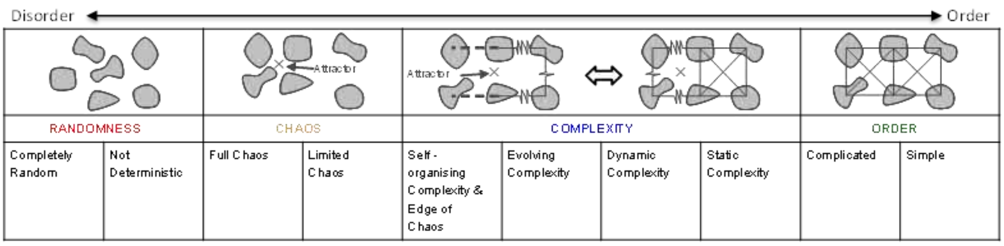

Figure 6-8: The Randomness-Chaos-Complexity-Order Continuum for Capital Projects based on a Literature Survey

The research explored the convergence and divergence in capital projects as indicated in Figure 6-9.

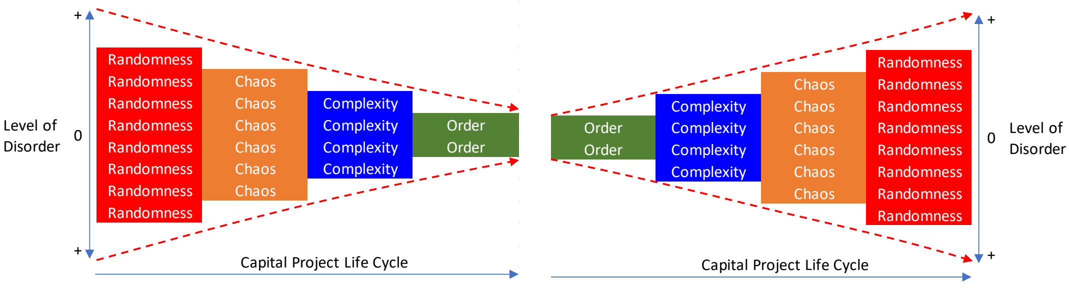

Figure 6-9: Theoretical Convergence and Divergence Suggested to Take Place in the Execution of Capital Projects

The interview results based on responses from 12 experienced capital project managers indicated that at least three archetypes seem possible to represent project overall convergence towards order and two for project divergence as indicated in Figure 6-10.

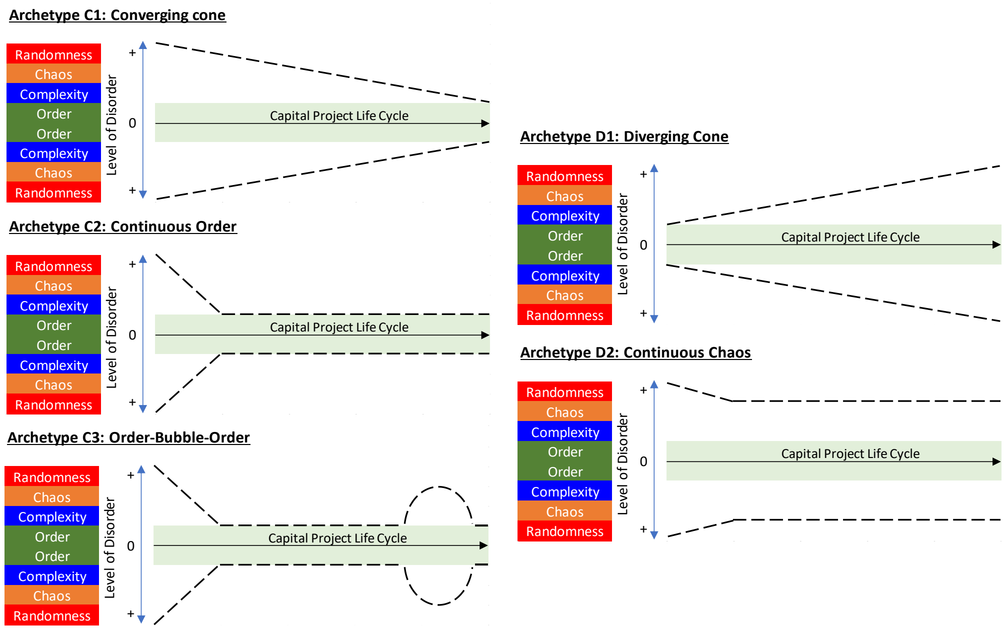

Figure 6-10: Previous Research Results Showing Archetypes for Capital Project Convergence Towards Order and Project Divergence / Not Reaching Order

IQ0.1) Please comment on your agreement / disagreement with the previous research results?

Before posing the above question to Round 2 capital project managers, chaos theory concepts were explained by the researcher. The responses of the Round 2 respondents were therefore obtained with some understanding of the concepts of randomness, chaos, complexity and order, movement of a capital project along a continuum as well as capital project convergence and divergence.

6.4.2 Recognition of Archetypes by Round 2 Respondents

The first set of interview responses obtained from capital project managers were on their recognition of the Round 1 archetypes, agreement or disagreement with these four achetypes and examples of such archetypes in their capital projects. The responses were analysed to calculate the number of project managers who recognised each of the archetypes in the capital projects that they were involved in.

6.4.2.1 Archetype C1 - Converging Cone

The capital project archetype C1 – converging cone that was identified during the Round 1 interviews, was shown to the Round 2 capital project managers and their response requested according to the interview question as indicated in paragraph 6.4.1. The schematic representation of archetype C1 is shown in Figure 6-11.

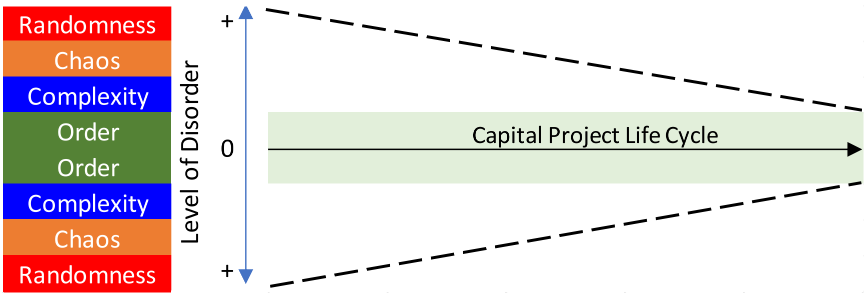

Figure 6-11: Schematic Diagram for Archetype C1 – Converging Cone for Capital Projects

Capital project managers provided examples of the archetype C1 – converging cone as shown in Table 6-8. The capital project examples that represent capital project convergence during the capital project life cycle were indicated as megaprojects in the power generation industry (R2-Ref. 1:13 and 10:12), mining projects (R2-Ref. 2:13 and 3:10) as well as a nuclear power plant project (R2-Ref. 13:17). For the remainder of this chapter the abbreviation “R2-Ref.” will be used to represent the Atlas.ti software reference numbers used for Round 2 research results as “Round 2 – Ref.”.

Table 6-8: Examples for Archetype C1 – Converging Cone in Capital Projects

No.	Round 2 - Ref.	Quotation Terms for Examples of Archetype C1
1	1:13	Megaprojects Power Stations M & K on overall level

No.	Round 2 - Ref.	Quotation Terms for Examples of Archetype C1
2	2:13	Mine project development project
3	3:10	Mining Project
4	10:12	Megaproject M
5	13:17	Nuclear power plant

Table 6-8 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for Interview Question = 131

The characteristics of archetype C1 – converging cone in capital projects were described by the Round 2 capital project managers as shown in Table 6-9. Quotation terms (1st order terms) were identified and assigned to ISO 21500 (ISO, 2012) subject groups using a code book (refer to Appendix D, paragraph D.8) or new 2nd order concepts were generated. The 2nd order concepts formed part of the aggregate concepts – archetype C1 in this case. This methodology employed is described in detail in Gioia et al. (2013).

Table 6-9: Description of Characteristics for Archetype C1 – Converging Cone in Capital Projects

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	2:17	Increased project structure from pre-feasibility to feasibility study with way forward becoming clear	Integration	Archetype C1 - Converging Cone
2	2:19	Proper execution plan will cause convergence and better chance of successful project		
3	2:21	Governance and procedures are important		
4	2:22	Have to obtain permission to investigate changes during execution		
5				
6	1:30	Exceeding specifications	Scope	
7	7:13	Proper requirements management		
8				
9	1:29	Multiple Units are commissioned one after another	Time	
10				
11	1:33	Availability of timeous geological info caused project convergence	General Characteristics	
12	2:14	Uncomfortable for an engineer at project start because of randomness		
13	2:15	Very random at the start of a capital project		
14	2:16	Multiple options at project start		
15	2:18	Project start is a mess ("deurmekaar") with no fixed relationships		
16	2:20	Strict stage gate governance		
17	3:15	Intended outcome of a project (not realised)		

Table 6-9 Notes: Unique 1st Order Terms that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetype C1 (Aggregate Construct). Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

The number of unique 1st order terms per subject group (z), as shown in Table 6-9, varied per 2nd order concept as shown for integration (z = 4), scope (z = 2) and time (z = 1). It appears that capital project convergence is caused by a re-definition of the project structure as the project is developed (R2-Ref. 2:17), 'proper' project execution (R2-Ref. 2:19), definition and implementation of project governance and project procedures (R2-Ref. 2:21) and to avoid uncontrolled and unauthorised project changes (R2-Ref. 2:22). According to respondent's, convergence will also be brought about by scope related matters such as requirements management (R2-Ref. 7:13) and exceeding project specifications during execution (R2-Ref. 1:30). Capital project convergence also seems to be aided when capital projects consist of multiple similar units (R2-Ref. 1:29) that have to be completed one after another. It is assumed that the ability to learn from the first units aid overall project convergence when later similar units have to be commissioned. Capital project managers seems to agree that the beginning of a capital project could be characterised as random (R2-Ref. 2:14), uncertainty in terms of multiple options (R2-Ref. 2:16) and as a mess (R2-Ref. 2:18). However, the availability of timeous information (R2-Ref. 1:33) and adherence to a strict project governance framework (R2-Ref. 2:20) seems to cause overall capital project convergence. One respondent noted that the archetype C1 – converging cone might be seen as the desired or intended outcome of a capital project but that it is not realised (R2-Ref. 3:15) in an exact straight converging line as shown in Figure 6-11. Another interesting comment is that the project relationships are not fixed at the start of a capital project (R2-Ref. 2:18). This comment agrees well with the loose relationships between project elements in the randomness domain (start of capital project) that are developed continually towards perhaps fixed, steady and strong relationships in the ordered domain as shown schematically in Figure 6-8.

This result indicates that the archetype C1 – converging cone, that was first described by the Round 1 capital project managers, was recognised and further described by a different group of capital project managers during the Round 2 interviews. Megaprojects in the power generation industry, mining projects and nuclear projects were indicated by respondents as examples of this capital project archetype. Is also seems that the ISO 21500 subject groups of integration, scope and time may have an influence on the creation of this capital project archetype. Capital projects that represent this archetype seem to start with a state of randomness but with the implementation of strict governance is seems possible to cause overall capital project convergence during the project life cycle towards a start of order at the end of the project life cycle.

6.4.2.2 Archetype C2 - Continuous Order

The capital project archetype C2 – continuous order that was described during the Round 1 interviews was shown to capital project managers and their response requested according to the interview question as indicated in paragraph 6.4.1. The schematic representation of archetype C2 is shown in Figure 6-12.

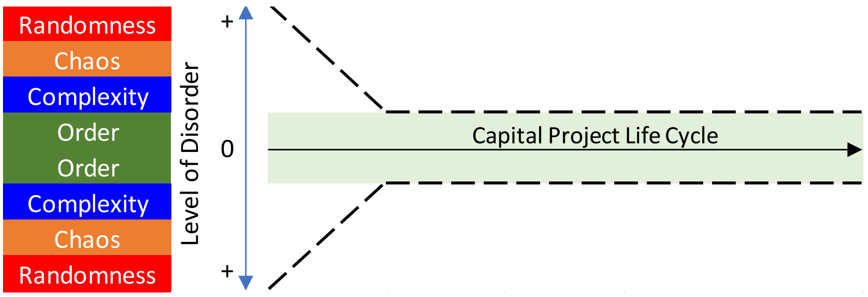

Figure 6-12: Schematic Diagram for Archetype C2 – Continuous Order for Capital Projects

Capital project managers provided examples of the archetype C2 – continuous order as shown in Table 6-10.

Table 6-10: Examples for Archetype C2 – Continuous Order in Capital Projects

No.	Round 2 - Ref.	Quotation Terms for Examples of Archetype C2
1	1:11	Wind Farm
2	1:20	Transmission line and Sub-Station
3	8:11	Power Station Project M - Multiple Units from Unit 2 onwards
4	10:13	Wind Farm project once the first or second units were completed
5	13:17	Nuclear power plant

Table 6-10 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for Interview Question = 131

The capital project examples that represent a capital project that converges quickly from a state of randomness to a state of order during the capital project life cycle were given as a wind farm project (R2-Ref. 1:11 and R2-Ref. 10:13), transmission line and sub-station projects (R2-Ref. 1:20), power station project with multiple units (R2-Ref. 8:11) and a nuclear power plant project (R2-Ref. 13:17). Wind farm, transmission line and sub-stations may be seen as simple, standard and repeatable projects (Wysocki, 2010). In such types of projects the technology risks are low and both the goals and the solutions of these projects are well known at project commencement requiring only a traditional project management approach (Wysocki, 2010).

The characteristics of the archetype C2 – continuous order that emerged during the Round 2 interviews are shown in Table 6-11.

Table 6-11: Description of Characteristics for Archetype C2 – Continuous Order in Capital Projects

No.	Round 2 – Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:18	Scope is clear and fixed	Scope	Archetype C2 - Continuous Order
2				
3	8:19	Quick convergence and order due to forced learning on a multi-unit project	Knowledge Management	
4				
5	1:17	Mature technology	General Characteristics	
6	1:19	Very little chaos is experienced		
7	1:21	Relatively simple standard and repeatable projects		
8	8:20	Quick convergence as relationships are now in place		

Table 6-11 Notes: Unique 1st Order Terms that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetype C2 (Aggregate Construct). Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

Capital project managers were of the opinion that a clear and fixed scope at the commencement of a capital project (R2-Ref. 1:18), mature technology (R2-Ref. 1:17) and simple, standard and repeatable projects (R2-Ref. 1:21) resemble archetype C2 as shown in Table 6-11. This type of capital project also experiences very little chaos (R2-Ref. 1:19) and converge quickly from a state of randomness to a state of order at the onset of the project (R2-Ref. 8:19 and 8:20). It is interesting to note that once quick capital project convergence has occurred towards an ordered state, the project relationships are in place (R2-Ref. 8:20). This response may indicate that, similar to the response in Table 6-9 (R2-Ref. 2:18), that the relationships between the project elements evolved perhaps from 'loose' at the project start to 'fixed' when the project reaches an ordered state. This idea is also portrayed schematically in the capital project randomness-chaos-complexity-order continuum as shown in Figure 6-8.

6.4.2.3 Archetype C3 - Order-Bubble-Order

The capital project archetype C3 – order-bubble-order that was identified during the Round 1 interviews was shown to capital project managers and their response requested according to the interview question as indicated in paragraph 6.4.1. The schematic representation of archetype C3 is shown in Figure 6-13.

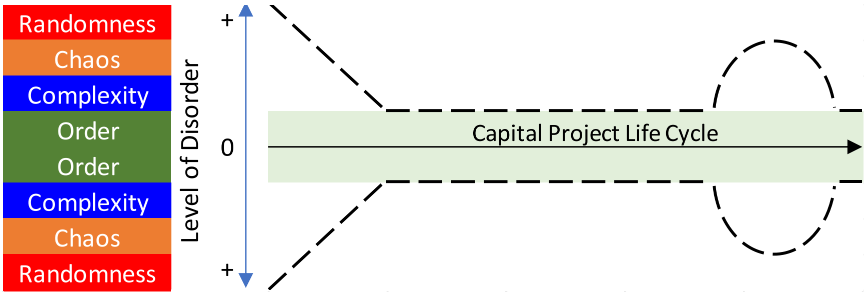

Figure 6-13: Schematic Diagram for Archetype C3 – Order-Bubble-Order for Capital Projects

Capital project examples for archetype C3 were provided by capital project managers during the Round 2 interviews as shown in Table 6-12.

Table 6-12: Examples for Archetype C3 – Order-Bubble-Order in Capital Projects

No.	Round 2 - Ref.	Quotation Terms for Examples of Archetype C3
1	2:10	Company S Lost Time Injury incident
2	3:10	Mining project
3	8:11	Power Station Project M - First Unit
4	13:14	Mining projects
5	14:10	Project G train refurbishment
6	14:13	Bubble caused by water in the train tunnel event, but order was restored
7	14:14	Bubble caused by incorrect anticipated bus routes, but order was restored

Table 6-12 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for Interview Question = 131

The examples from respondents on archetype C3 as shown in Table 6-12 seem to apply to capital projects that converge at project inception but then an event occurs that creates a chaotic condition towards the end of the capital project life cycle. Such trigger events seem to originate from a safety incident (R2-Ref. 2:10), unforeseen flooding (R2-Ref. 14:13) or incorrect scenario planning (R2-Ref. 14:14). Examples of capital projects that experience this type of archetype behaviour may be a mining project (R2-Ref. 3:10), construction of the first Unit of a power station megaproject (R2-Ref. 8:11) and a train railway project (R2-Ref. 14:10).

Capital project managers provided a description of the archetype C3 during the Round 2 in-depth interviews as shown in Table 6-13. The unique 1st order terms were assigned to ISO 21500 subject groups where possible and the remainder of the responses pertaining to archetype C3 were allocated to general characteristics.

Table 6-13: Description of Characteristics for Archetype C3 – Order-Bubble-Order in Capital Projects

No.	Round 2 – Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	2:26	Unpreparedness for a safety incident during project execution caused chaos	Risk	Archetype C3 - Order-Bubble-Order
2				
3	8:18	Chaos bubble due to lack of up-front planning	Integration	
4				
5	9:21	Divergence and chaos caused by government appointed people and contractors there are not qualified	Resource	
6				
7	13:15	Timelines between bubbles may differ for different projects	Time	
8				
9	2:27	Establishment of safety procedures after incident created order	General Characteristics	
10	3:13	Concept design stage is completely random		
11	3:14	Concept design study is to generate order from randomness		
12	3:16	Actual outcome of a project (not intended)		
13	10:15	Bubble gets created if something goes wrong on project		
14	10:16	A fatality could cause a chaos bubble		

Table 6-13 Notes: Unique 1st Order Terms that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetype C3 (Aggregate Construct). Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

Unique first order terms for the archetype C3 – order-bubble-order were assigned to the ISO 21500 subject groups of risk (z = 1), integration (z = 1), resource (z = 1) and time (z = 1) as shown in Table 6-13.

Similar to the trigger events example shown in Table 6-12, the chaos bubble of this archetype C3 seems to be caused by unpreparedness for a safety incident (R2-Ref. 2:26), a fatality (R2-Ref. 10:16), a lack of upfront project planning (R2-Ref. 8:18), unqualified resources (R2-Ref. 9:21) and if something goes wrong on a capital project (R2-Ref. 10:15).

Other characteristics of this archetype C3 seems to be that the position of the bubble during the capital project life cycle may differ (R2-Ref. 13:15). Also, during the concept design phase at the start of the capital project there seems to be a definite decrease in the level of disorder from randomness to order (R2-Ref. 3:13 and 3:14). This archetype seems to be the actual outcome of capital project examples mentioned in Table 6-12 but this was perhaps not the intended outcome when the project was planned. Perhaps it could be assumed that the intended outcome of the capital project was more like archetypes C1 and C2 although the realised capital project is more like archetype C3.

6.4.2.4 Archetype D1 - Diverging Cone

The capital project archetype D1 – diverging cone, identified during the Round 1 interviews, was shown to the capital project managers and their response requested according to the interview question as indicated in paragraph 6.4.1. The schematic representation of archetype D1 is shown in Figure 6-14.

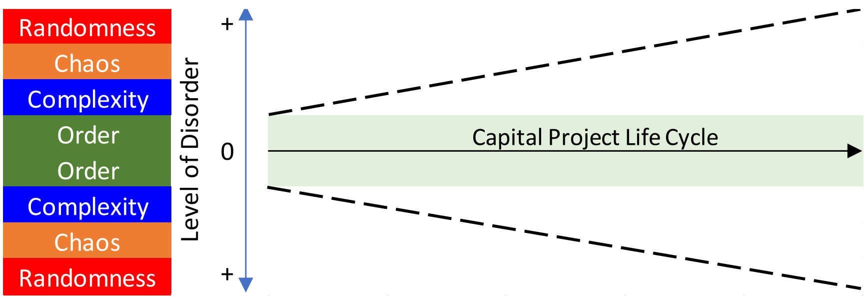

Figure 6-14: Schematic Diagram for Archetype D1 – Diverging Cone for Capital Projects

No examples of capital projects were identified by respondents for this archetype. However, capital project managers were able to describe this capital project archetype as given in Table 6-14.

Table 6-14: Description of Characteristics for Archetype D1 – Diverging Cone in Capital Projects

No.	Round 2-Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	9:18	Divergence caused by government appointed people that "do not know what to do"	Resource	Archetype D1 - Diverging Cone
2	9:19	Divergence caused by lack of qualified, registered and professional engineers		
3	9:21	Divergence and chaos caused by government appointed people and contractors there are not qualified		

No.	Round 2-Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
4	9:23	Divergence and chaos caused by lack of training		
5	9:24	Divergence and chaos caused by people without right experience and know-how		
6				
7	2:23	Execution planning was not done well	Integration	
8	2:24	If you do not stick to the execution plan		
9	2:25	Project manager not enforcing change procedure causes chaos		
10	13:12	Result of poor management		
11				
12	7:14	Outside forces cause the loss of project control	General Characteristics	

Table 6-14 Notes: Unique 1st Order Terms that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetype D1 (Aggregate Construct). Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

Five of the responses from capital project managers for describing the diverging cone archetype (D1) were assigned to the ISO 21500 subject group of resources as shown in Table 6-14. According to the respondents, capital project divergence as a result of resources is caused by a lack of trained people (R2-Ref. 9:23), unskilled people (R2-Ref. 9:18 and 9:24), unqualified engineers, people and contractors (R2-Ref. 9:19 and 9:21). It further seems that capital project divergence occurs when project execution planning is not done (R2-Ref. 2:23), not followed-through (R2-Ref. 2:24) and change management is not enforced (R2-Ref. 2:25). Capital project divergence seems to be caused by poor management (R2-Ref. 13:12). All of these characteristics seems to point to internal capital project failures. One respondent indicated that capital project divergence may also be caused by outside forces that result in the loss of project control (R2-Ref. 7:14).

6.4.2.5 Archetype D2 - Continuous Chaos

The capital project archetype D2 – continuous chaos that was identified during the Round 1 interviews, was shown to capital project managers and their response requested according to the interview questions as indicated in paragraph 6.4.1. The schematic representation of archetype D2 is shown in Figure 6-15.

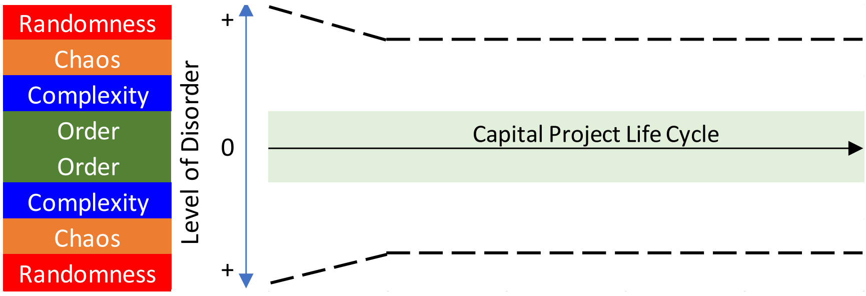

Figure 6-15: Schematic Diagram for Archetype D2 – Continuous Chaos for Capital Projects

Capital project managers cited three examples of capital projects that could be characterised as the archetype D2 namely a pumped-storage megaproject (R2-Ref. 1:14), another megaproject during the hand-over stage (R2-Ref. 8:14) and a project in West Africa (R2-Ref. 10:11) as shown in Table 6-15.

Table 6-15: Examples for Archetype D2 – Continuous Chaos in Capital Projects

No.	Round 2 - Ref.	Quotation Terms for Examples of Archetype D2
1	1:14	Megaproject Pump-Storage Scheme I for a long time
2	8:14	Megaproject M - Hand-over
3	10:11	West Africa project

Table 6-15 Notes: Unique 1st Order Terms that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetype D1 (Aggregate Construct). Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

Three descriptions were given by capital project managers during the Round 2 interviews on this archetype D2 as shown in Table 6-16 related to the ISO 21500 subject group of scope as well as two general characteristics.

Table 6-16: Description of Characteristics for Archetype D2 – Continuous Chaos in Capital Projects

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:32	Lack of early geological info caused chaos, cost and schedule overruns	Scope	Archetype D2 - Continuous Chaos
2				
3	5:11	Stay in chaos as no time to get to order - there is no time to get order	General Characteristics	
4	11:14	Chaotic thing that continues		

Table 6-16 Notes: Unique 1st Order Terms that were allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetype D2 (Aggregate Construct). Round 2 Interviews,

Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

It seems that the lack of early critical data such as geological information (R2-Ref. 1:32) may have caused chaos, cost and schedule overruns presumably because incorrect or no decisions were made based on the absence of this vital project information. A general characteristic of archetype D2 – continuous chaos seems to be that there is no time or drive to call for order (R2-Ref. 5:11) that results in the capital project remaining in the state of chaos (R2-Ref. 11:14).

6.4.2.6 Summary on the Recognition of Round 1 Archetypes

The transcribed text of all Round 2 responses from 14 experienced capital project managers to the interview question as shown in paragraph 6.4.1 were analysed and all occurrences were marked with the Atlas.ti software program where a respondent recognised any of the archetypes C1, C2, C3, D1 or D2. The number of recognitions per archetype were counted (total = 58) for the 14 respondents and expressed as a percentage as shown in Figure 6-16.

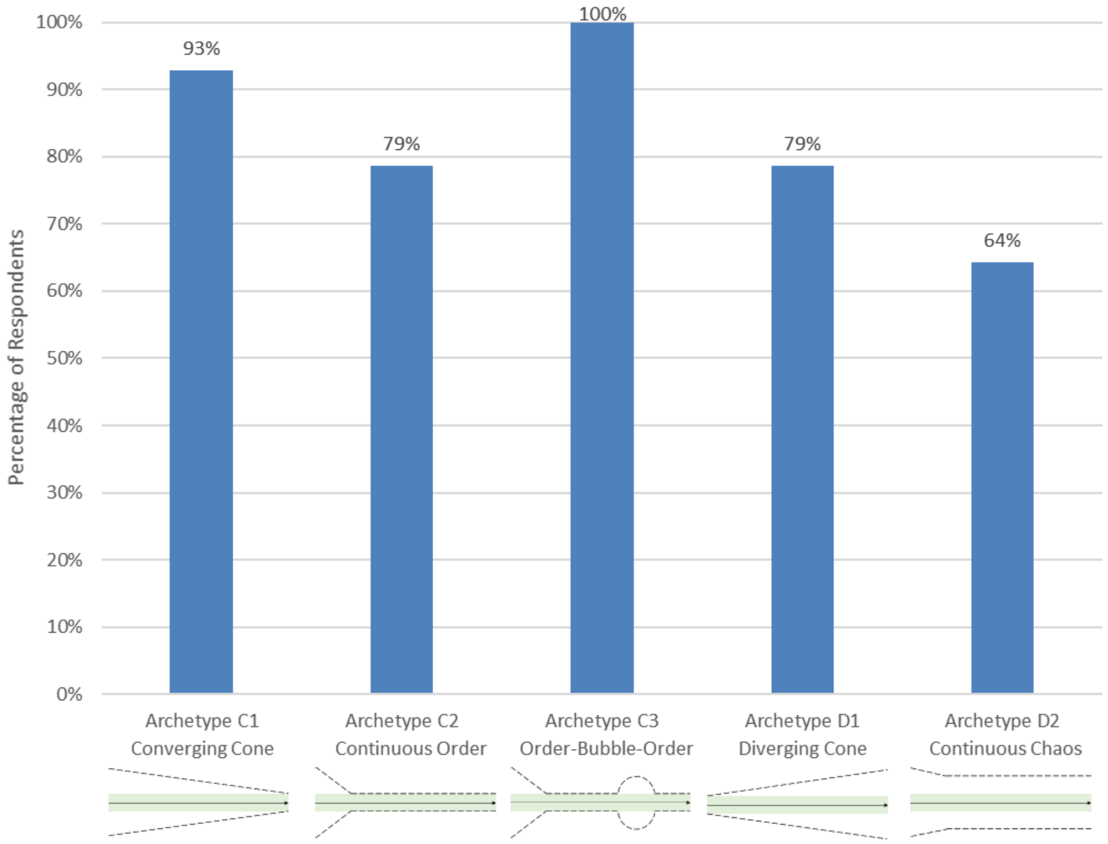

Figure 6-16: Percentage of Capital Project Managers from the Round 2 Interviews that Recognised the Archetypes that were Described by the Round 1 Capital Project Managers

It is interesting to note that all capital project managers that were interviewed during Round 2 recognised the archetype C3 – order-bubble-order (100%) followed by archetype C1 – converging cone (93%). Archetype C2 – continuous order and archetype D1 – diverging cone were recognised by 79% of the respondents. Only 64% of the 14 capital project managers recognised archetype D2 – continuous chaos as representative of capital projects that they were exposed to during their careers.

6.4.3 Newly Defined Archetypes

Archetype C3 – order-bubble-order was not only recognised by all capital project managers during the Round 2 interviews, but they were able to further elaborate and define four new variants of this archetype.

6.4.3.1 Archetype C3a - Order-Multiple-Bubbles-Order

Respondents indicated that one variant of the archetype C3 – order-bubble-order could be a capital project that had not only one but multiple 'chaos bubbles'. The descriptions for a new archetype C3a – order-multiple-bubbles-order is given in Table 6-17.

Table 6-17: Description of Characteristics for Archetype C3a – Order-Multiple-Bubbles-Order in Capital Projects

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:23	Any new technology	Risk	Archetype C3a - Order-Multiple-Bubble-Order
2	1:27	New materials		
3				
4	1:24	New methodology	Integration	
5	1:26	New way of working on site		
6				
7	1:25	New contractors	Resource	
8	1:28	Experienced people converge chaos into order		
9				
10	1:22	Starting construction work without completed designs	Time	

Table 6-17 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetype C3a (Aggregate Construct). Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

The descriptions for this multiple-bubble archetype was allocated to the ISO 21500 subject groups of risk (z = 2), integration (z = 2), resource (z = 2) and time (z = 1) as shown in Table

6-17. It seems that the trigger events for the formation of the multiple bubbles of this archetype could be contributed to various forms of novelty and newness such as new technology (R2-Ref. 1:23), new materials (R2-Ref. 1:27), new methodology (R2-Ref. 1:24), new way of working (R2-Ref. 1:26) or new contractors (R2-Ref. 1:25). The concept of project “fast tracking” (Steyn et al., 2008:33) where project phases overlap and where work is started on the next phase before completion of the preceding phase, could perhaps also serve to trigger a bubble behaviour for this archetype (R2-Ref. 1:22). An example of two megaprojects for the construction of power stations were cited as examples of capital projects that represent the archetype C3a – order-multiple-bubbles-order as shown in Table 6-18.

Table 6-18: Examples for Archetype C3a – Order-Multiple-Bubbles-Order in Capital Projects

No.	Round 2 - Ref.	Quotation Terms for Examples of Archetype C3a
1	1:12	Megaprojects Power Stations M & K

Table 6-18 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for Interview Question = 131

Taking the original archetype C3 – order-bubble-order and the responses from capital project managers in Table 6-17 and Table 6-18 into consideration, the schematic layout of the new archetype C3a – order-multiple-bubble-order is suggested as shown in Figure 6-17. Once the capital project has converged from a initial state of randomness toward order, a number of chaos-bubbles may be formed during the remainder of the capital project life cycle.

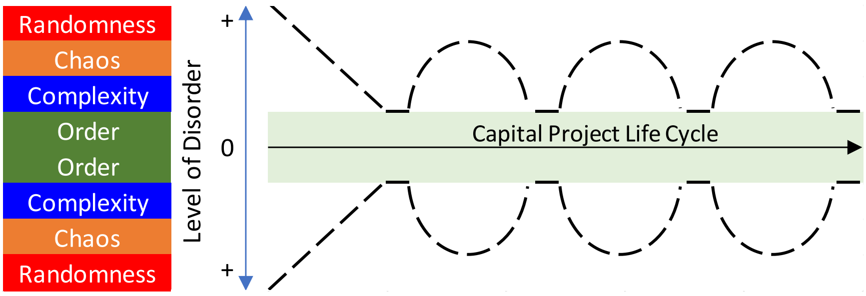

Figure 6-17: Suggested Schematic Representation for Archetype C3a – Order-Multiple-Bubbles-Order in Capital Projects

6.4.3.2 Archetype C3b - Order-Bubble-Complexity

Capital project managers indicated that another variant of the archetype C3 – order-bubble-order could be a capital project where one project manager and team is responsible for project development and another for project execution. This transition may lead to unique capital project characteristics as shown in the responses from respondents in Table 6-19.

Table 6-19: Description of Characteristics for Archetype C3b – Order-Bubble-Complexity in Capital Projects

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	12:15	At start of project execution new contractors enter the project and at start of project execution new disruptive stakeholders enter the project	Stakeholders	Archetype C3b - Order-Bubble-Complexity
2	12:17	At start of project execution new contractors and disruptive stakeholders cause divergence		
3	12:19	At start of project execution new contractors provide different budgets and schedules		
4	12:23	At start of project execution new suppliers cause divergence and it "stays very wide open"		
5				
6	12:14	There is a change in the project for the transition from project development to execution	Integration	
7	12:18	Project development front-end-planning cause an ordered state and alignment among structures		
8	12:25	Project development is the "honeymoon phase" and controls are not necessarily yet effective		
9				
10	12:16	Realisation at start of project execution of discrepancy between plan and reality	Time	
11	12:22	Harsh realities of project execution reveal optimistic assumptions at project development		
12				
13	12:12	Project starts with a number of unknowns i.e. perfect chaos	Risk	
14				
15	12:13	Project has a known deliverable	Scope	
16				
17	12:20	The CII toolsets are used during front-end-gates to reduce and unknown world to a known understanding	Quality	
18				
19	12:21	Anchoring of cost and schedule at start of project development leads to underestimations	Cost	
20				
21	12:24	The reduction of divergence after the project transition is dependent on the type of project manager	Resource	

Table 6-19 Notes: Unique 1st Order Terms that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetype C3b (Aggregate Construct). Round 2 Interviews,

Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

The unique 1st order terms were allocated to ISO 21500 subject groups of resource (z = 4), integration (z = 3), time (z = 2), risk (z = 1), scope (z = 1), quality (z = 1) and resource (z = 1). It seems that at the start of project execution there is a change or transition (R2-Ref. 12:14) that could be described as divergent (R2-Ref. 12:17), disruptive (R2-Ref. 12:15) that could be caused by new stakeholders (R2-Ref. 12:15) and new contractors (R2-Ref. 12:17). It also seems that although the Construction Industry Institute (CII) toolsets may have been used during project development to obtain a known understanding of the project (R2-Ref. 12:20) and anchoring of cost and schedules (R2-Ref. 12:21), new contractors that enter the capital project during execution provide different budgets and schedules (R2-Ref. 12:19). Project controls do not seem to be effective yet during the project development phase (R2-Ref. 12:25). Although the capital project has a known deliverable (R2-Ref. 12:13), project execution seems to start with a number of unknowns (R2-Ref. 12:12) and new suppliers cause the project to stay “wide open” i.e. not in an ordered state (R2-Ref. 12:23). However, the magnitude of the divergence that occurs after the start of project execution seems to be dependent on the type of project manager (R2-Ref. 12:24). An example was given by the respondents of a company E that execute its project development and project execution with different project managers and teams as shown in Table 6-20.

Table 6-20: Examples for Archetype C3b – Order-Bubble-Complexity in Capital Projects

No.	Round 2 - Ref.	Quotation Terms for Examples of Archetype C3b
1	12:11	Company E project development and project execution

Table 6-20 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for Interview Question = 131

A variant of the archetype C3 – order-bubble-order where the capital project enters the project execution phase with a chaos bubble as described in Table 6-19 and then converges at most to a complexity state is thought to represent this archetypical description as shown schematically in Figure 6-18. This archetype is called C3b – order-bubble-complexity.

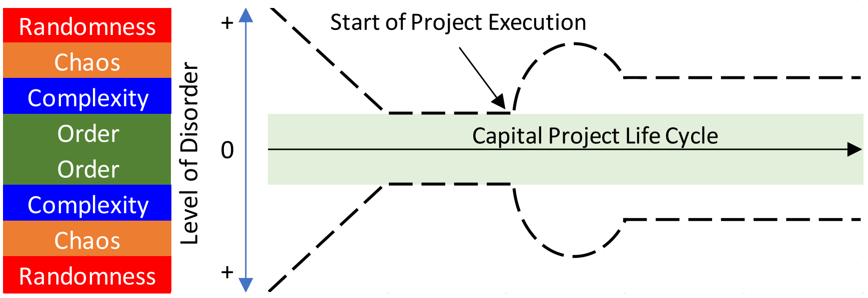

Figure 6-18: Suggested Schematic Representation for Archetype C3b – Order-Bubble-Complexity in Capital Projects

6.4.3.3 Archetype C3c - Order-Bubble-Divergence

Respondents indicated that another variant of the archetype C3 – order-bubble-order could be a capital project where divergence follow the chaos bubble. The descriptions for archetype C3c – order-bubble-divergence are given in Table 6-21.

Table 6-21: Description of Characteristics for Archetype C3c – Order-Bubble-Divergence in Capital Projects

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	6:15	Technology does not work	Risk	Archetype C3c - Order-Bubble-Divergence
2				
3	7:10	Divergence if stakeholders cannot bring project back	Stakeholders	
4				
5	7:10	Divergence if project requirements are not fulfilled	Scope	
6				
7	6:16	Chaos bubble does not converge but diverge at commissioning	General Characteristics	

Table 6-21 Notes: Unique 1st Order Terms that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetype C3c (Aggregate Construct). Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

The responses that were obtained from capital project managers for this archetype relates to a capital project that diverges at the end of the life cycle due to technology that does not work (R2-Ref. 6:15), project requirements could not be met or fulfilled (R2-Ref. 7:10(5)) or unsuccessful commissioning (R2-Ref. 6:16) as shown in Table 6-21. This capital project archetype diverges even with the involvement of project stakeholders (R2-Ref. 7:10(3)). The associated ISO 21500 subject groups are risk (z = 1), stakeholders (z = 1) and scope (z = 1). An example of a capital project of the archetype C3c – order-bubble-divergence was mentioned as the South African Nuclear Pebble Bed Modular Reactor (PBMR) project as shown in Table 6-22.

Table 6-22: Examples for Archetype C3c – Order-Bubble-Divergence in Capital Projects

No	Round 2 – Ref.	Quotation Terms for Examples of Archetype C3c
1	6:12	PBMR project

Table 6-22 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for Interview Question = 131

The schematic for this archetype is derived from the archetype C3 – order-bubble-order but blended with descriptions as given by capital project managers in Table 6-21 and is given schematically in Figure 6-19.

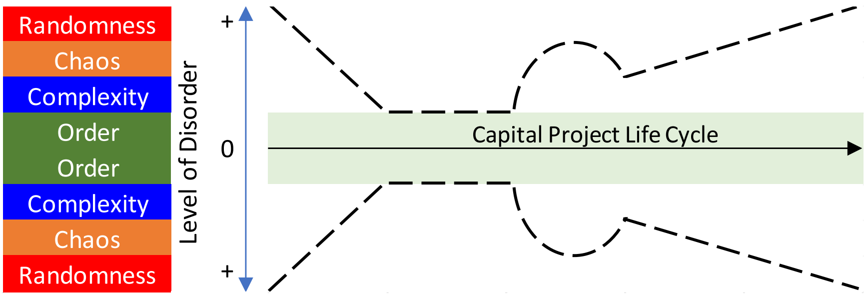

Figure 6-19: Suggested Schematic Representation for Archetype C3c – Order-Bubble-Divergence in Capital Projects

6.4.3.4 Archetype C3d - Order-Bubble-Order-Operational-Bubble

The final derivative of the archetype C3 – order-bubble-order was indicated by interviewed capital project managers as the characteristics possible at capital project hand-over and directly after project hand-over. The respondents indicated that poor hand-over could create a chaos bubble at the start of operations as described by the archetype C3d – order-bubble-order-operational-bubble as shown in Table 6-23.

Table 6-23 Description of Characteristics for Archetype C3d – Order-Bubble-Order-Operational-Bubble in Capital Projects

No.	Round 2 -Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	8:16	Commissioning and Hand-Over are separate project activities	Integration	Archetype C3d - Order-Bubble-Order-Operational-Bubble
2	8:17	Both commissioning and Hand-Over contain chaos		

3	8:21	After Hand-Over chaos remains for a long time similar to Archetype D2		
4	8:24	Short term operation info in place but not life-time records		
5	8:25	Liability type of info is handed over but not all as-build info		
6	8:26	Hand-Over is not well defined and not instantaneous		
7	8:27	Hand-Over chaos is created by the plant data available as a range between document-centric and data-centric		
8	8:28	Hand-Over plant data is received by the owner in different formats		
9	8:29	Information digitisation difficult due to different platforms, lack of people and contractor maturity		
10	8:30	Limited contractors cause defragmented contractor base and incomplete plant data		
11	8:31	Hand-Over data in different formats, duplication and partially digitised		
12	8:32	Chaos is created by being in the middle between document and data centric information sets		
13	8:33	Incompatible data formats lead to re-work		
14				
15	8:22	Project information not configured to achieve the operational baseline	General Characteristics	
16	8:23	Value leakage between project and operations		

Table 6-23 Notes: Unique 1st Order Terms Captured Across the Four Groups of Respondents that were Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for Archetype C3d (Aggregate Construct). Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

Most of the responses from capital project managers for the archetype C3d – order-bubble-order-operational-bubble were assigned to the ISO 21500 subject group of integration (z = 13) as shown in Table 6-23. Project commissioning and hand-over are described as two separate project activities (R2-Ref. 8:16) that both contain chaos (R2-Ref. 8:17) and the hand-over chaos period could have a long duration (R2-Ref. 8:21). A contributor to the hand-over chaos seems to be relating to the plant data that is handed over from various sub and main contractors (R2-Ref. 8:30) to the client (R2-Ref. 8:28) in incompatible formats that range from a document centric to data centric (R2-Ref. 8:27 and 8:31). However, important data related to plant liability is handed over (R2-Ref. 8:25) but the hand-over of all other data seem not to be well defined or instantaneous (R2-Ref. 8:26). Hand-over of incomplete data from the sub and main contractor to the owner seems to create unplanned re-work (R2-Ref. 8:33). It seems therefore that the project information that is not configured for operational purposes (R2-Ref. 8:22) leads to the value leakage between the project and operations (R2-Ref. 8:23) and the formation of the operational chaos bubble. The example of a mega power station build project was cited by respondents as an example of this archetype C3d as shown in Table 6-24.

Table 6-24: Examples for Archetype C3d – Order-Bubble-Order-Operational-Bubble in Capital Projects

No.	Round 2 - Ref.	Quotation Terms for Examples of Archetype C3d
1	8:34	Power Station projects of Company E

Table 6-24 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for Interview Question = 131

Based on the original archetype C3 – order-bubble-order and the description by capital project managers of the archetype C3d variant as given in Table 6-23, the schematic of this archetype has been created as shown in Figure 6-20.

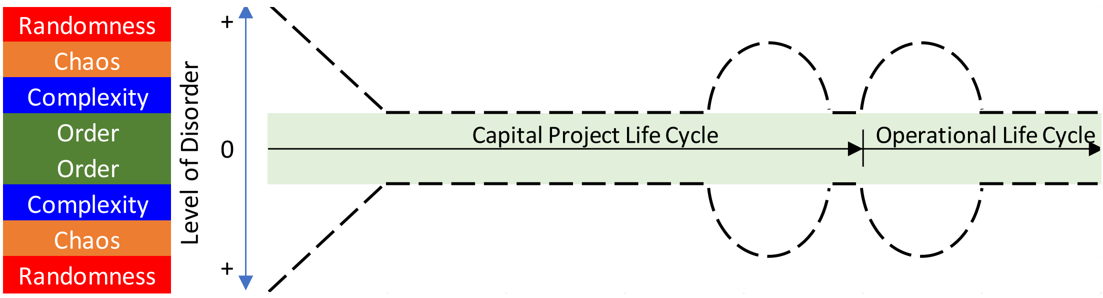

Figure 6-20: Suggested Schematic Representation for Archetype C3d – Order-Bubble-Order-Operational-Bubble in Capital Projects

6.4.4 General Characteristics of all Archetypes

Responses from capital project managers during the Round 2 interviews that could not be assigned to the description of a specific archetype were grouped in Table 6-25.

Table 6-25: Responses from Capital Project Managers that were not Allocated to a Specific Archetype

No.	Round 2 – Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:34	A competent team will create convergence and order from chaos	Resource	General Archetype Characteristics
2				
3	14:16	There must be an intervention to bring a project back to order	Integration	
4				

5	8:13	Transformation from Archetype C3 to C2 is caused by development of interrelationships	Multi-Dimensional Relationship Development	
6	13:13	Interrelationship building creates order form chaos		
7	13:19	Interrelationships actually determine the ability to create order		
8	13:21	Interrelationships develop from loose too rigid during project life cycle		
9	13:22	Definition of interrelationships as more information, battery limits, boundaries and performance targets become available		
10	13:23	Interrelationships are non-existing at project start		
11				
12	13:16	Archetypes are applicable at different scales and different teams	General Characteristics	
13	1:15	Archetypes D1 and D2 are valid for project phase / stage but are followed by other Archetypes		
14	7:11	Archetypes C1 and D1 are found in combination in a project		
15	8:13	Multi-unit type of projects causes a transformation from Archetype C3 (first units) to C2 (later units)		
16	8:13	Transformation from Archetype C3 to C2 caused by forced learning		
17	11:15	The durations of Archetype formations differ for each project		
18	13:19	Some of the initial convergence is due to a chaos attractor		
19	13:20	An attractor represents the intend of a project		

Table 6-25 Notes: Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

The responses as shown in Table 6-25 seems to relate to the ISO 21500 subject groups of resource (z = 1), integration (z = 1), multi-dimensional relationship development (z = 6) and general characteristics (z = 9). It seems that the creation of order from chaos has to do with an active intervention (R2-Ref. 14:16) and a competent team (R2-Ref. 1:34). Relationships between project elements seems to be non-existent at the start of a capital project (R2-Ref. 13:23) but the building of these relationships creates order from chaos (R2-Ref. 13:13 and 13:19). These relationships appear to develop as more project information becomes available (R2-Ref. 13:22) and progressively develop from loose to rigid (R2-Ref. 13:21) during the project life cycle. These responses from capital project managers confirm the notion of progressive relationship development as shown in Figure 6-8 of the proposed capital project continuum. The comment from a respondent that archetypes are applicable at different scales, different teams and different times (R2-Ref. 13:16 and 11:15) relates to the concept of fractals as discovered by Mandelbrot (Fractal Foundation, 2009) and may indicate that these capital project archetypes are present at different project levels, different project phases and for different project teams. The notion that a capital project exhibits both divergence and convergence (R2-Ref. 7:11 and 1:15) not only during the project life cycle but also per project phase may indicate that archetypes also capture individual project behaviour. Archetype also seem to follow-on to each other or transform from one type to another (R2-Ref. 1:15, 8:13 and 8:15). Multi-unit type of capital projects and forced learning (R2-Ref. 8:13) may cause transformation from one archetype into another. Two remarks were made on chaos attractors in terms of the initial convergence effect (R2-Ref. 13:19) and the intent of a capital project (R2-Ref. 13:20). These remarks are interesting as the concept of a chaos attractor metaphor was not yet explained to respondents when this review question was posed.

These responses indicate that the formation and development of relationships in capital projects contribute to convergence. Also, that one archetype is not only found across the entire capital project life cycle but that archetypes seems to transform from one type to another and that they occur at different project phases and at different levels of capital projects. Capital project convergence seems to be brought about by an active intervention by the project management team that have to consist of competent resources.

6.4.5 Value Statements from Capital Project Managers

Statements made by capital project managers during the Round 2 interviews that expressed the value of the capital project archetypes were identified using the Atlas.ti software and are given in Table 6-26.

Table 6-26: Summary of Unique Value Statements on Archetypes

No.	Round 2 - Ref.	Quotation Terms for the value statements of Archetypes
1	4:11	Definitely. A lot of them (the global project I have been on) can be applied to each one of these (archetypes as shown in Figure 6-10)
2	5:13	Yes, I think it (these chaos concepts and archetypes) makes sense
3	6:17	It makes sense
4	8:35	It makes a lot of sense
5	10:17	So, I can identify with the models (archetypes)
6	11:13	[Q] So, you think there is some things (value) for us there (for capital projects)? [A] Without a question.

No.	Round 2 - Ref.	Quotation Terms for the value statements of Archetypes
7	11:16	Each of them (the archetypes) makes kind of sense
8	12:10	One can definitely relate to this

Table 6-26 Notes: Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for Interview Question = 131

The statements on archetypes from respondents as indicated in Table 6-26 relates to recognition of the archetypes in capital projects (R2-Ref. 4:11 and 10:17), that the archetypes makes sense (R2-Ref. 5:13, 6:17, 8:35 and 11:16), relation to archetypes (R2-Ref. 12:10) and potential value for capital project managers (R2-Ref. 11:13).

6.4.6 Summary of Results for Round 2 Interviews on Archetypes in Capital Projects

Capital project managers that were interviewed during Round 2 were able to recognise and further describe the five archetypes C1, C2, C3, D1 and D2 that were identified during the Round 1 interviews. These project managers also elaborated and defined four new variants for archetype C3 as C3a, C3b, C3c and C3d as shown schematically in Figure 6-21.

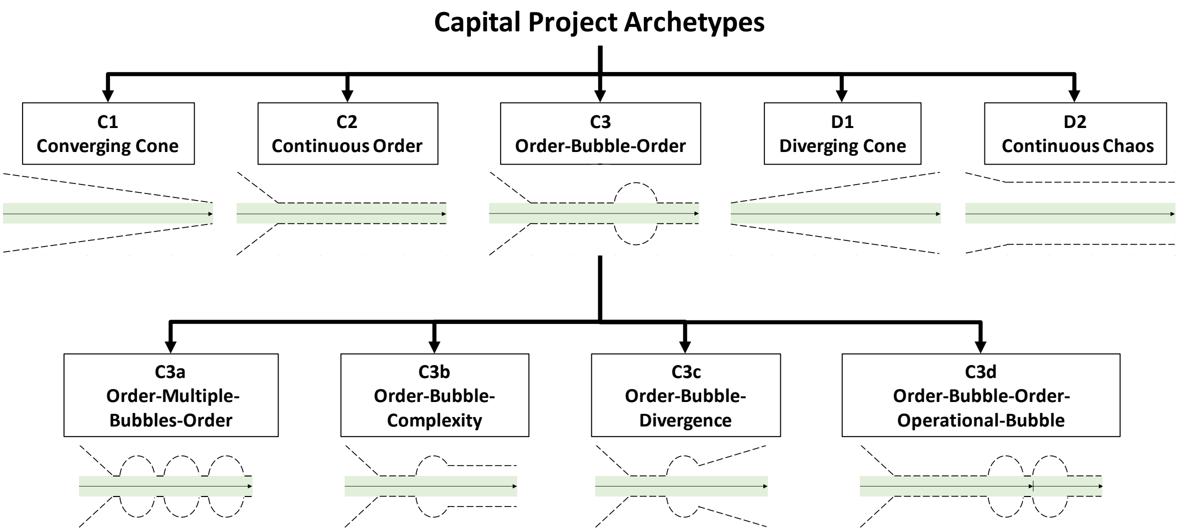

Figure 6-21: Summary of Capital Project Archetypes Described by Capital Project Mangers during Round 2 Interviews

All 14 capital project managers that were interviewed during Round 2 were able to recognise archetype C3 – order-bubble-order in their capital projects i.e. 100% (similar to Figure 6-16). This was followed by the recognition of archetype C1 – converging cone (93%). Archetype C2 – continuous order and archetype D1 – diverging cone were recognised by 79% of the respondents. Only 64% of the capital project managers recognised archetype D2 –

continuous chaos as representative of capital projects that they were exposed to during their careers. Examples were given for all of the archetypes except for archetype D1 – diverging cone.

Capital project managers provided characteristics and examples for newly defined archetypes C3 as C3a, C3b, C3c and C3d. From this response it seems that the 'chaos-bubble' appealed to capital project managers with >15 years' experience and they were able to recognise such behaviour in their capital projects.

In all the descriptions of the nine archetypes as given by capital project managers, their responses could only be allocated to the ISO 21500 subject groups of integration, stakeholder, scope, resource, time, cost, risk and quality as shown in Table 6-27. The number of descriptions per archetype was obtained for archetype C1 from Table 6-9, archetype C2 from Table 6-11, archetype C3 from Table 6-13, for archetype D1 from Table 6-14, for archetype D2 from Table 6-16, for archetype C3a from Table 6-17, for archetype C3b from Table 6-19, for archetype C3c from Table 6-21 and for archetype C3d from Table 6-23. No descriptions were given by capital project managers that could be assigned to the ISO 21500 subject groups of procurement or communication as shown in Table 6-27.

Table 6-27: Number of Archetype Descriptions Allocated to ISO 21500 Subject Groups During Round 2 Interviews

No.	Dimension	C1	C2	C3	D1	D2	C3a	C3b	C3c	C3d
1	Integration	4		1	3		2	3		13
2	Stakeholder					1		4	1	
3	Scope	2	1					1	1	
4	Resource			1	5		2	1		
5	Time	1		1				2		
6	Cost							1		
7	Risk			1			2	1	1	
8	Quality							1		
9	Procurement									
10	Communication									
11	General	7	5		1	2			1	2

A greater number of responses on archetypes C1, C2, C3, D1 and D2 by capital project managers were allocated by the Round 2 respondents compared to the Round 1 respondents when comparing Table 6-7 (z = 36) with Table 6-27 (z = 75). This could perhaps be attributed to the fact that archetypes emerged during the Round 1 interviews, while capital project managers were explicitly asked to describe these archetypes during the Round 2 interviews.

6.5 Discussion of Results and Conclusions

The results of capital project archetypes are discussed in this section with reference to the emergence of these archetypes, the movement of a capital project within the randomness-chaos-complexity-order continuum, the relevance of ISO 21500 subject groups in the descriptions of capital project archetypes and the confirmation of the importance of capital project relationships contribution towards the creation of order from chaos.

6.5.1 Emergence of Capital Project Archetypes

The descriptions of capital project forms and types across their life cycles by the Round 1 capital project managers during the interviews emerged as archetypes – a term borrowed from Senge (2006).

The Round 1 interview questions and discussions only focused on the concept of capital project convergence and divergence but respondents further elaborated and indicated that other types and forms of capital projects such as fast convergence, divergence and convergence at commissioning as well as a state of no-convergence at the end of the project life cycle, are sometime seen in capital projects.

After studying the responses form the Round 1 project managers on the capital project forms and types, sketches were generated, and names were assigned to these emerging archetypes. Five archetypes emerged from descriptions by 12 capital project managers during the Round 1 interviews as shown in Figure 6-7. These were named and numbered as follows: a) archetype C1 – converging cone; b) archetype C2 – continuous order; c) archetype C3 – order-bubble-order; d) archetype D1 – diverging cone; and e) archetype D2 – continuous order.

In order to confirm the existence of these five archetypes, it was decided to start the Round 2 interviews by asking another group of 14 experienced capital project managers if they could recognise the five archetypes that were identified during Round 1. The results for the Round 2 interviews indicated that capital project managers were able to recognise all archetypes C1, C2, C3, D1 and D2. All 14 experienced capital project managers were able to recognise archetypes C3 as well as describing another four variants based on archetype C3 as C3a, C3b, C3c and C3d as shown in Figure 6-21. The short description of these newly described archetypes is: a) archetype C3a – order-multiple-bubbles-order; b) archetype C3b – order-bubble-complexity; c) archetype C3c – order-bubble-divergence; and d) archetype C3d – order-bubble-order-operational-bubble.

Archetypes C1, C2, C3, D1 and D2 were described by 12 capital project managers during the Round 1 interviews. These archetypes were recognised by a second group of 14 capital project managers during the Round 2 interviews and in addition, archetypes C3a, C3b, C3c and C3d were described. It is concluded that capital project archetypes may be used to describe types or forms of capital projects that occur and may perhaps be used to distinguish between different types of capital projects.

All identified archetypes changes in level of disorder during the capital project life cycle and describe the progression of a capital project between stages of randomness, chaos, complexity and order. Capital project managers that were interviewed were able to associate with the chaos theory concepts of randomness, chaos, complexity and order. It is therefore concluded that it seems that chaos theory concepts can be applied in capital projects to aid the description of some of the characteristics of these types of projects.

6.5.2 Movement of Capital Project along the Randomness-Chaos-Complexity-Order Continuum

The research result was that two different groups of capital project managers were able to describe, recognise and further develop capital project archetypes based on chaos theory concepts such as randomness, chaos, complexity and order. Furthermore, the results suggest that capital projects transition from one domain in the Randomness-Chaos-Complexity-Order (RCCO) capital project continuum towards another during its life cycle (Figure 6-8).

From the results on archetypes that were defined, it appears that it is possible that capital projects transition from high levels of disorder towards lower levels of disorder. This behaviour is evident for archetype C1 – converging cone, archetype C2 – continuous order and the initial portions of archetypes C3 – order-bubble-order, archetype C3a – order-multiple-bubbles-order, archetype C3b – order-bubble-complexity, archetype C3c – order-bubble-divergence and archetype C3d – order-bubble-order-operational-bubble. These archetypes suggest that capital project movement may occur from the randomness domain through the chaos and complexity domains towards the ordered domain.

The results on capital project archetypes also seem to indicate that a project transition or movement is possible from an ordered state towards levels of disorder (complexity, chaos and randomness) as given by the archetype D1 – diverging cone and archetype C3c – order-bubble-divergence.

The results also indicated a third type of capital project movement in the RCCO capital project continuum. This is the temporary increase in the level of disorder to form a chaos bubble and the containment and reduction of that disorder back to lower levels of disorder. This behaviour is evident from the archetype C3 – order-bubble-order, archetype C3a – order-multiple-bubbles-order, archetype C3b – order-bubble-complexity and archetype C3d – order-bubble-order-operational-bubble.

An important insight was gained when some of the capital project managers noted that a capital project in an ordered state is not necessarily a successful project. Similarly, that a failed capital project is not necessarily a capital project that is in a non-ordered state. This is firstly because active intervention may transition a project from a higher level of disorder towards a lower level of disorder as was seen in the responses from respondents. Secondly, by overspending the capital project budget and exceeding the schedule, many capital projects could ultimately be transitioned into a state of order. However, a state of order that is obtained in this manner by exceeding the set project budget and schedule should not be considered a successful project. Thirdly, the definition of project success is subjective and different for different companies and institutions and evolves over time (Jugdev and Müller, 2005). It is therefore concluded that it seems that capital project success cannot necessarily be associated with a project being in the ordered state and capital project failure cannot necessarily be associated with a project not being in the ordered state of the randomness-chaos-complexity-order capital project continuum.

6.5.3 The Relevance of ISO 21500 Subject Groups in the description of Capital Project Archetypes

The responses from capital project managers in both Round 1 and Round 2 interviews were allocated, using a code book, to the ISO 21500 subject groups of integration, stakeholder, scope, resource, time, cost, risk, quality, procurement and communication. It was noticed that for most of the descriptions of archetypes by capital project managers it was not possible to assign all their descriptions to ISO 21500 subject groups and those descriptions that could not be assigned were categorised as “general”. Further, that no descriptions could be assigned during the Round 2 data analysis to the ISO 21500 subject groups of procurement and communication (see Table 6-27).

It is concluded from these results that the ISO 21500 International Standard on the guidance on project management does not seem to contain the vocabulary and subject groups to describe chaos theory concepts in capital projects. Secondly, that it seems that the two ISO 21500 subject groups of procurement and communication do not seem to be relevant in the description of chaos theory related concepts when defining archetypes for capital projects. This result seems to agree with the Spider Diagrams drawn for the definitions provided by the Round 1 respondents for the concepts of order, complexity, chaos and randomness as shown in Chapter 5, Figure 5-6. In these diagrams it was shown that the definitions of order, complexity, chaos and randomness are weakly associated with the ISO 21500 concepts of cost, quality, procurement and communication.

6.5.4 Confirmation on the Importance of Relationship Building for Capital Project Convergence

Another interesting result is the reference made, specifically by the capital project managers interviewed during Round 2, on the importance of relationships in capital projects. It was shown in the analysed comments from capital project managers in Table 6-9, Table 6-11 and Table 6-25 that project relationships are non-existent and not fixed at the start of a capital project, building these relationships creates order from chaos. Relationships seem to develop as more project information becomes available and they progressively develop from loose too rigid during the project life cycle, and quick project convergence happens when relationships are in place. This result agrees well with the notion of relationship development from randomness through chaos and complexity toward order as displayed in the randomness-chaos-complexity-order continuum model (top part of the model) in Figure 6-8.

It is therefore concluded that relationships between elements in capital projects seem to play an important role in the creation of capital project convergence from a state of higher disorder towards a state of lower disorder. When looking at the defined capital project archetypes it also seems possible to conclude that relationships between elements play a role in the creation of order from chaos in capital projects during its life cycle. It is assumed that the term relationships include both non-physical human being relationships as well as physical system relationships.

6.6 Summary

The results on the capital project archetypes that emerged from the Round 1 and Round 2 interviews with two groups of 12 and 14 experienced capital project managers is summarised as follows:

a) Emergence and Definition of Nine Archetypes for Capital Projects

   i. Five archetypes emerged from descriptions obtained and analysed from capital project managers during the Round 1 interviews. These were named and numbered as follows: a) archetype C1 – converging cone; b) archetype C2 – continuous order; c) archetype C3 – order-bubble-order; d) archetype D1 – diverging cone; and e) archetype D2 – continuous order.

   ii. These five archetypes were recognised and confirmed during the second round of interviews with a further 14 capital project managers. In addition, the analysis of descriptions from the Round 2 interviews revealed another four variants of the archetype C3 that was initially identified during the Round 1 interviews. These four variants were named and numbered as: a) archetype C3a – order-multiple-bubbles-order; b) archetype C3b – order-bubble-complexity; c) archetype C3c – order-bubble-divergence; and d) archetype C3d – order-bubble-order-operational-bubble.

   iii. Sketches were generated to describe all nine archetypes (see Table 6-21).

b) Movement of Capital Projects within the Randomness-Chaos-Complexity-Order (RCCO) Continuum

   i. During the Round 1 interviews, capital project managers were requested to define the concepts of randomness, chaos, complexity and order and to rank these concepts as part of a continuum for increased disorder. They were then requested to provide their opinion on the movement of successful and failed projects within this continuum.

   ii. During the Round 2 interviews, the results of the Round 1 interviews were explained and the archetypes that emerged from the Round 1 interviews shown to the capital project managers to request their responses.

   iii. Capital project managers therefore either defined or were exposed to the concepts of randomness, chaos, complexity and order. The archetypes that were described by both groups of capital project managers across the capital project life cycle function and move within the domains of randomness, chaos, complexity and order.

iv. It is therefore concluded that chaos theory concepts can be applied in capital projects to aid the description of some of the characteristics of these types of projects using archetypes.

v. It is further concluded from the description of all nine archetypes that it appears that capital projects move within the domains for randomness, chaos, complexity and order. Sometimes the movement is towards levels of increased order i.e. from randomness through chaos and complexity towards order. However, movement also seems to be possible from a low level of disorder towards higher levels of disorder i.e. from order through complexity and chaos towards randomness.

c) Scalability of Archetypes

i. The comment from a respondent that archetypes are applicable at different scales, different teams and different times relates to the concept of fractals as discovered by Mandelbrot (Fractal Foundation, 2009) and may indicate that these capital project archetypes are present at different project levels, different project phases and for different project teams.

d) Project Success and Order; Project Failure and Disorder

i. An important insight was gained when some of the capital project managers noted that a capital project in an ordered state is not necessarily a successful project. Similarly, that a failed capital project is not necessarily a capital project that is in a non-ordered state.

ii. The explanation for this response by capital project managers may be that it is possible to manage a capital project in an ordered state by overspending and exceeding the schedule. However, such actions may not be seen by the project sponsors as a successful project. Also, the definition of project success and failure appear from the literature survey to be subjective and confined to different definitions by institutions and corporations.

e) The Importance of Relationships to Cause Capital Project Convergence Towards Order

i. During the analysis of the interview data for Round 2 responses a number of comments were made by capital project managers on the importance of relationships in capital projects.

ii. It appeared that project relationships are non-existent and not fixed at the start of a capital project, building these relationships creates order from chaos, relationships seems to develop as more project information becomes available and they progressively develop from loose to rigid during the project life cycle and that quick project convergence happens when relationships are in place.

iii. This result agrees well with the notion of relationship development from randomness through chaos and complexity toward order as displayed in the randomness-chaos-complexity-order continuum model.

f) Capital Project Archetypes as a New Way of Describing Project Dynamics

i. The results from this chapter on the responses on the nine capital project archetypes perhaps provide a new way of describing the overall and deeper level project dynamics using chaos theory concepts.

The next chapter will provide results on the chaos attractor metaphor descriptions as well as for variance models for chaos attractors.

6.7 References

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CHAPTER 7: RESULTS FOR CHAOS METAPHORS AND VARIANCE MODELS IN CAPITAL PROJECTS

7.1 Introduction

This chapter is the final of three chapters portraying the exploratory research results on chaos attractors and their local and overall convergence effect from chaos to order in capital projects. Chapter 5 summarised research results that was obtained from the first group of capital project managers that was interviewed (Round 1) on the Randomness-Chaos-Complexity-Order (RCCO) continuum concept and their interpretation of the convergence nature of chaos attractors in capital projects. Chapter 6 covered nine archetypes that were defined by two groups of experienced capital project managers during the Round 1 and Round 2 interviews. This chapter covers the exploratory research results on the local convergence effect of six individual chaos attractors, as well as the overall convergence effect of a landscape of six chaos attractors in capital projects. The results for this chapter was obtained during the Round 2 interviews from experienced capital project managers. This chapter is concluded with a summary of the research findings.

7.2 Origin of Results

The research results on chaos attractor metaphors and variance models for this chapter originate from responses obtained during the Round 2 individual interviews with capital project managers. Exploratory research results reporting for this Chapter 7 is confined to chaos metaphors and variance models for capital projects, as shown in Figure 7-1. The data capturing and data collection methodologies that were employed to extract the results were described in Chapter 4, paragraph 4.5.

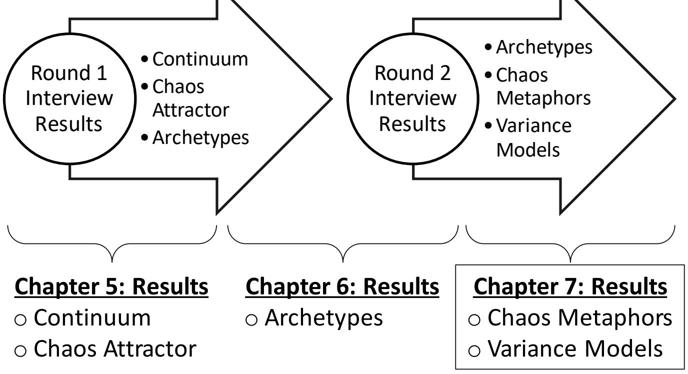

Figure 7-1: Origin of Research Results and Scope of Results Reporting for Chapter 7

The results reporting in the remainder of this chapter is divided into three sections. The first section (paragraph 7.3) covers the research results on the local converging effect of each chaos attractor metaphor, on its own, in a capital project. The second section (paragraph 7.4) covers the exploratory research results on the overall converging effect of a landscape of chaos attractors in a capital project. The third section (paragraph 7.5) covers results on the recognition of the chaos attractors and landscapes of chaos attractors by capital project managers, as well as the allocation of chaos attractor characteristics to ISO 21500 (ISO, 2012) subject groups. The chapter is concluded with a summary of all the exploratory results covered in the three sections. It should be noted that when reference is made in this research to chaos attractors, it also includes the fixed-point chaos repeller as is commonly done in the literature on chaos attractors.

7.3 Results for Local Converging Effect of Individual Chaos Attractors in Capital Projects

Five chaos attractor types were evaluated individually to gain and understanding from the responses of experienced capital project managers on their local converging effect from chaos to order when used in capital projects. One chaos repeller was also evaluated to better understand the repulsion effect on capital project elements and their trajectories as a result of the presence of this repeller in a capital project. Respondents were also exposed to sketches that represent the chaos attractors and repeller metaphors and were asked to provide examples and characteristics of these metaphors in capital projects. Finally, a variance model was presented to respondents on each of these chaos attractors and repeller. They were requested to score the relevance of the independent variables as well as the local convergence effect of the dependent variable in a capital project environment. Statements made by respondents about the recognition and contribution to convergence from chaos order were recorded as value statements.

This research approach attempted to determine if the respondents were able to understand the chaos attractor and chaos repeller metaphors as found in the literature (source domain) and transfer the meaning of the metaphors to the capital project domain (target domain). Conclusions are drawn at the end of this section on all chaos attractors and their individual convergence effect from chaos to order in capital projects.

7.3.1 Results for the Fixed-Point Chaos Attractor in Capital Projects

7.3.1.1 Interview Question for Fixed-Point Chaos Attractor Metaphor

A few different schematic representations of the fixed-point chaos attractor metaphor are shown in Figure 7-2. These chaos attractor metaphors were shown and explained by the researcher to capital project managers who were individually interviewed during the Round 2 interviews.

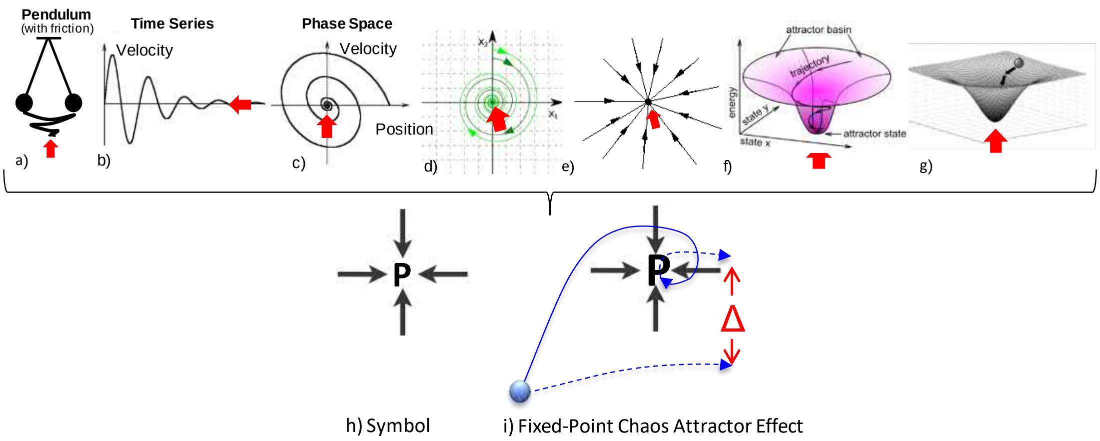

Figure 7-2: Sketches of Fixed-Point Chaos Attractor Metaphors

The verbal explanations by the researcher on the fixed-point chaos attractor metaphor as shown in Figure 7-2 were based on the chaos attractor metaphor models that were developed in Chapter 3, paragraph 3.5. Respondents were requested to provide examples and characteristics of such metaphors in the capital project environment. The verbal responses from respondents were captured, transcribed and analysed using the Atlas.ti software as explained in Chapter 4. The results of the analysed data for examples of fixed-point chaos attractors are given in paragraph 7.3.1.2 while the characteristics are given in paragraph 7.3.1.3. Value statements about this metaphor were captured in paragraph 7.3.1.4 and the results for the scoring of the variance model in paragraph 7.3.1.5. Conclusions for this section are provided in paragraph 7.3.1.6.

7.3.1.2 Examples of the Fixed-Point Chaos Attractors in Capital Projects

Examples of fixed-point chaos attractors in capital projects as described by capital project managers during the Round 2 interviews are given in Table 7-1.

Table 7-1: Examples of Fixed-Point Chaos Attractors in Capital Projects

No.	Round 2 - Ref.	Examples of Fixed-Point Chaos Attractor Metaphors
1		**Schedule Target**
2	5:14	Project deadline
3	6:18	Project deadline
4	6:20	The Y2K project - Fixed point for everybody
5	7:16	Time critical project or project deliverables
6	8:38	Time critical project
7	10:20	Project P50 & P80 schedule dates
8	13:30	The Life-Of-Mine (LOM) end date
9	14:17	Megaproject G - A lot of elements need to be fed in to meet the target dates
10		**First Event / Deliverable / Milestone**
11	3:18	First-coal on a mining project
12	3:19	First-arc on a smelter project
13	7:15	Project scope or requirements
14	8:39	Project Milestone
15	9:25	Project Milestone
16	11:18	Hyperloop First-Of-A-Kind project - Arranging the necessary project elements
17	13:25	Project stage gate approvals
18		**Financial Target**
19	5:15	Empty project bank account
20	14:20	Megaproject G - Milestone payments
21		**Project Objective**
22	6:19	Project objectives
23	12:27	Megaprojects with a well-defined ultimate objective
24		**Specific Meetings**
25	1:36	Power Station Project M - Weekly 4D meetings
26		**Leadership**
27	2:29	Mine project B - Strong leadership recovered a failed project

Table 7-1 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for this Research Question = 71

It seems from Table 7-1 that a scheduled target could resemble a fixed-point chaos attractor in capital projects. Examples given by respondents inlude: a project deadline (R2-Ref. 5:14 and 6:18); mine and megaproject targets dates (R2-Ref. 10:20, 13:30 and 14:17) as well as time critical projects (R2-Ref. 8:38 and 7:16) such as the Y2K project (R2-Ref. 6:20). The Atlas.ti reference “Round 2 – Ref.” as shown in Table 7-1 is abbreviated as "R2-Ref." and indicates the respondent number as well as the transcribed text line number in the format: "xx:yy".

Another type of fixed-point chaos attractor was given by respondents as a first event on a capital project such as: a) first coal on a mining project (R2-Ref. 3:18) or b) the first arc on a smelter project (R2-Ref. 3:19). A First-Of-A-Kind (FOAKE) project seems to require arrangement of all the necessary project elements in order to get fixed-point convergence (R2-Ref. 11:18). A project milestone is also seen by interviewed capital project managers as a fixed-point chaos attractor (R2-Ref. 8:39 and 9:25). Project scope and requirements also seem to be acting as fixed-point chaos attractors (R2-Ref. 7:15), as well as obtaining stage-gate approvals during the review of capital project life cycles (R2-Ref. 13:25).

Financial targets in terms of an empty project bank account (R2-Ref. 5:15); payment milestones (R2-Ref. 14:20); project objectives (R2-Ref. 6:19 and 12:27); specific meetings (R2-Ref. 1:36); and strong leadership (R2-Ref. 2:29) were also mentioned by respondents as examples of fixed-point chaos attractors in capital projects.

One of the respondents (Respondent 4) provided a sketch of a Fishbone Diagram (Schalken et al., 2004), as shown in Figure 7-3, as an example of a fixed-point chaos attractor for commissioning activities on a megaproject in the power generation industry.

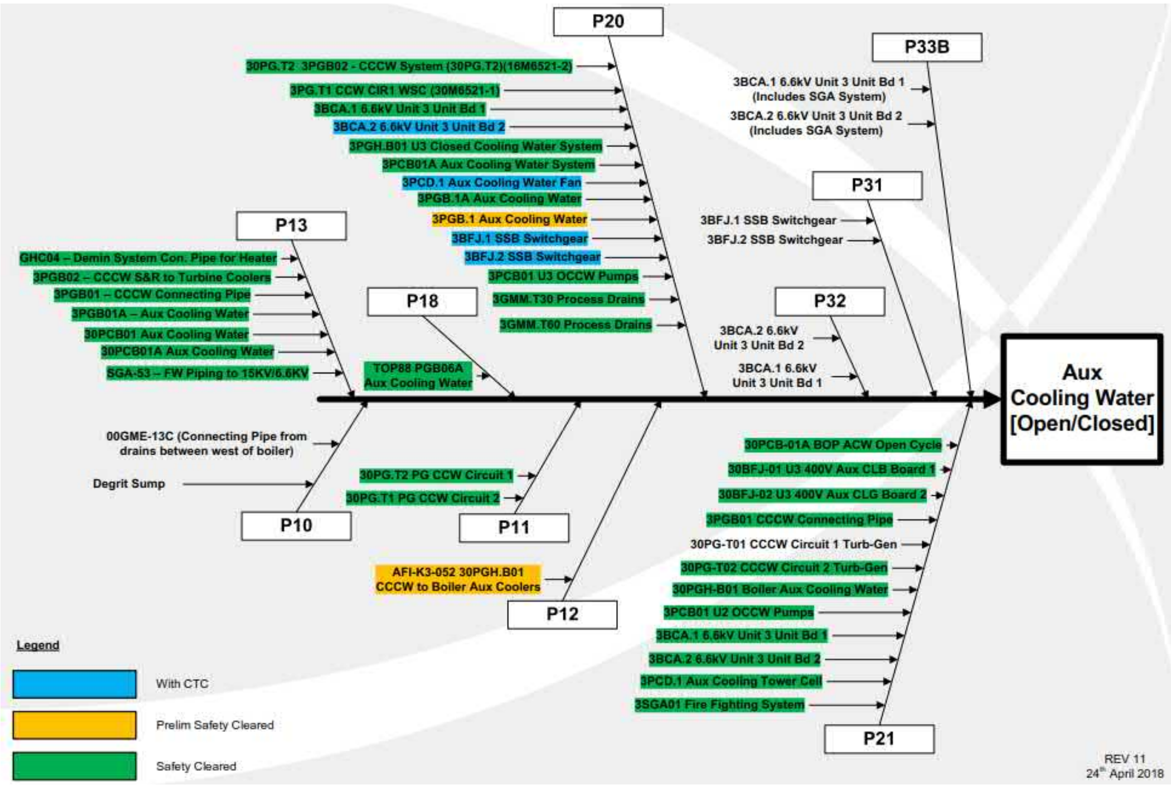

Figure 7-3: Example of a Fixed-Point Chaos Attractor in the Power Generation Industry

This fixed-point chaos attractor for the auxiliary cooling water system is composed of multiple lower-level fixed-point chaos attractors at sub-system level (for example P21, P12, P11, P10, P13, P18, P20, P32, P31 and P33B), which in turn are made up of more fixed-point chaos attractors at unit-level as shown in Figure 7-3. Each unit that is safety cleared is marked green and is comprised of a number of activities. When all the units in a sub-system are marked green, the sub-system will be marked green. This implies that resources, effort, strategy and planning are employed in order to safety clear (green marking) activities, sub-systems and finally the auxiliary cooling water system. The fixed-point chaos attractors in the form of the system, sub-systems and their units guide or influence resources, effort, strategy and planning towards fixed points. Also, lower level fixed-point chaos attractors resemble the format of higher level fixed-point chaos attractors – this phenomena was explained by Benoit Mandelbrot as fractals (Fractal Foundation, 2009). Another interesting feature of the Fishbone Diagram resembling multiple layers of fixed-point chaos attractors, is that the highest system level chaos attractor can only achieve the green status when all the different chaos attractors at the lower levels have achieved their green status. However, the overall chaos attractor seems to continue to have a convergence effect on resources, planning and activities, regardless of the current safety status anywhere in the fixed-point chaos attractor multi-layer network.

7.3.1.3 Characteristics of the Fixed-Point Chaos Attractor in Capital Projects

The results for the characteristics of fixed-point chaos attractors as given by capital project managers who were interviewed during the Round 2 interviews are given in Table 7-2.

Table 7-2: Description of the Characteristics of a Fixed-Point Chaos Attractor in Capital Projects

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:35	A competent team causes convergence towards an ordered situation	Resource	Fixed-Point Chaos Attractor
2	1:40	Experienced people are one of the strongest fixed-point attractors		
3	2:28	People and strong leadership		
4	2:33	In my mind there is a people aspect involved		
5	2:35	You must have the right people in the right place		
6	2:36	Industry specific project management experience is required		
7	2:37	Experienced coaching		

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
8	3:23	Team alignment (as used by CII) is very important otherwise nobody knows what is going on		
9	4:13	Shared goal facilitation of contractors to make money through productivity and savings		
10	4:18	It's not technology but people who do the work - you have to understand people and their motivation		
11	6:21	Project ownership, intelligence, drive, commitment and "maak 'n plan" (make-a-plan attitude)		
12	8:41	If the team believes in the deliverables - they will deliver		
13	11:21	Group dynamic phases are necessary to achieve convergence		
14	2:38	Correctly aligned incentives		
15	4:17	If we all go for the shared common goal you also achieve your own individual goal along the way		
16	13:29	Everybody on a project work towards a fixed point but short-term contractors have built-in incentive to prolong fixed-point		
17	14:19	Special team alignment sessions helped to get team cohesion in multi-nationality teams		
18				
19	1:39	Weekly laser scans of construction environment and interface meetings reduces quantity of interface problems	Integration	
20	2:31	Project procedures are not sufficient to cause fixed-point convergence		
21	2:32	You must understand project procedures to manoeuvre towards fixed-point convergence		
22	3:21	Everything must be in place to make your first product		
23	4:15	Once the tipping point is reached (roll, team motion) convergence takes care of itself		
24	4:16	However, if you do nothing and everybody does their own thing then divergence		
25	11:19	Necessary conditions for delivery such as a concept and timing of manufacturing companies		
26	11:22	Verify that the necessary items such as technology etc. are available		
27	12:26	Some project has three fixed points (Triple constraints theory) and the attraction goes to all of them and therefore no convergence to a particular point		
28	12:28	Project triple constraint cause competition and trade-offs between two of the three objectives		
29				
30	5:16	Having finality on the project scope	Scope	
31	5:17	You need to know what the end product is		
32	11:17	Translation of ideas into workable designs on paper		
33	3:22	Common team goal		

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
34	8:40	Unbelievable milestone dates do not work as fixed-point chaos attractors		
35	9:26	Finishing a number of related milestones cause the completion of a major milestone		
36	4:12	Everyone has a common goal towards which they are driving		
37	12:31	Project triple constraints are secondary to the project ultimate objective		
38	13:27	Stage-gate has built-in objective		
39				
40	8:42	Team defined design & integrated schedule cause delivery	Time	
41	10:18	Unrealistic political target date milestones do not materialise		
42	12:30	An ill-conceived milestone has the opposite effect of a fixed-point chaos attractor		
43	14:18	Fixed-point chaos attractors could be time and/or money		
44				
45	10:22	Stakeholders must understand their input and obtain support from politicians	Stakeholder	
46	11:20	Helpful owner intervention cause convergence		
47				
48	4:14	Get everybody on the same page through communication	Communication	
49				
50	2:34	Company maturity (understanding the project environment, change management and procedures) will cause attraction	General	
51	1:38	Good design, integrated CAD aid interface management aid reduction of chaos and creation of order		
52	14:21	A design brings focus		
53	13:28	Too much energy of person, team or project will cause trajectory to be flung out of basin		
54	13:24	Starting trajectory with specific requirements will not converge to basin bottom but be flung out		
55	12:29	Individual fixed-point attractors are subordinated to the overall fixed-point project objective		

Table 7-2 Notes: Unique 1st Order Terms Captured and Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for the Fixed-Point Chaos Attractor Aggregate Construct. Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 71

The number of unique 1st order terms per ISO 21500 subject group, as shown in Table 7-2, varied per 2nd order concept for: resource (z = 17); integration (z = 10); scope (z = 9); time (z = 4); stakeholder (z = 2) and communication (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject groups cost; risk; quality and procurement.

Resource related characteristics of a fixed-point chaos attractor seem to be related to competence, leadership, goal alignment, motivation and group dynamics. A competent team seems to cause convergence towards an ordered situation (R2-Ref. 1:35) in capital projects. Experienced people (R2-Ref. 1:40), implying the right people in the right places (R2-Ref. 2:35), could cause the fixed-point chaos attraction. However, it seems that the experience of the project team members must be industry specific (R2-Ref. 2:36). Strong leadership (R2-Ref. 2:28), shared goal facilitation (R2-Ref. 4:13 and 4:17), team alignment (R2-Ref. 3:23 and 14:19) and realistic deliverables (R2-Ref. 8:41) seem to be important to ensure clear roles and responsibilities. However, although everybody on a project may work towards a fixed-point, short-term contractors may have an incentive to prolong the fixed-point (R2-Ref. 13:29) and remain on the project as long as possible.

Understanding what motivates team members (R2-Ref. 4:18) and correctly aligned incentives (R2-Ref. 2:38) seem to be important in order to create project ownership, commitment and drive (R2-Ref. 6:21). The understanding and development of the group dynamic for various project phases seems to be necessary to achieve capital project convergence (R2-Ref. 11:21).

Respondents also mentioned characteristics related to integration. The accurate status of a project site construction environment, on a weekly basis, as reported during the interface meetings, seems to provide a fixed-point attraction that could reduce interface problems (R2-Ref. 1:39). An understanding of the project procedures seems to be important to enable movement towards fixed-point convergence (R2-Ref. 2:32). However, it seems that project procedures alone are not sufficient to cause fixed-point convergence (R2-Ref. 2:31). Project convergence seems to be brought about when the correct technology is available (R2-Ref. 11:22) and a multitude of activities (R2-Ref. 3:21) are performed timeously (R2-Ref. 11:19). It seems that there could be a build-up towards a tipping point (R2-Ref. 4:15) (fixed-point) after which convergence could happen automatically. But, if managerial effort is not invested and team alignment is missing, it seems that integration may not take place - rather divergence (R2-Ref. 4:16) could take place in a capital project. Project triple constraint (time, cost and scope) could cause competition and trade-offs between two of the three objectives (R2-Ref. 12:28). It may also appear that some projects have three fixed points (triple constraints theory (Van Wyngaard et al., 2012)) and the attraction could be directed towards all of them with the result that no convergence may take place at a particular point (R2-Ref. 12:26) or project constraint.

Fixed point attraction characteristics related to capital project scope seems to involve common goals, milestones and common objectives. A capital project scope seems to have finality (R2-Ref. 5:16) and the end product must be known (R2-Ref. 5:17). A clear scope would require the translation of ideas into workable designs on paper (R2-Ref. 11:17). A stage-gate process could have a built-in objective (R2-Ref. 13:27) that could cause attraction towards a fixed-point. Common project goals (R2-Ref. 3:22 and 4:12) and project objectives (R2-Ref. 12:31) could help to create a fixed-point of attraction. To achieve these goals, a number of related milestones need to be completed as they could cause the completion of a major milestone (R2-Ref. 9:26). However, unrealistic milestone dates may not work to form fixed-point chaos attractors (R2-Ref. 8:40).

A fixed-point chaos attractor could be time related (R2-Ref. 14:18). Yet, if the milestone date is ill-conceived (R2-Ref. 12:30) or unrealistic (R2-Ref. 10:18) it may have the opposite effect of a fixed-point chaos attractor and could cause capital project diversion. The best time related schedule seems to occur when it is designed by the project team (R2-Ref. 8:42) and not influenced by unrealistic target dates (R2-Ref. 10:18).

Stakeholder associated characteristics related to a fixed-point chaos attractor seem to indicate that a situation needs to be created in a capital project where stakeholders understand their input and the required support is obtained from politicians (R2-Ref. 10:22). In addition, supportive and helpful intervention from the project champion or owner could cause capital project convergence (R2-Ref. 11:20). Good and effective communication in a capital project seems to contribute to convergence (R2-Ref. 4:14).

A few general comments were made by respondents on the fixed-point chaos attractor characteristics in capital projects. Respondent 2 suggested that company maturity (understanding the project environment, change management and procedures) could cause fixed-point chaos attraction (R2-Ref. 2:34). Another respondent was of the opinion that a good design, integrated CAD (Computer Aided Design) could aid interface management and thereby aid the reduction of chaos and creation of order (R2-Ref. 1:38) because a design could bring focus (R2-Ref. 14:21). Respondent 13 agreed with the description that was given by the researcher in Figure 7-2 that too much energy of person, team or project could cause the project trajectory to be flung out of the basin (R2-Ref. 13:28). It also seems that fixed-point chaos attractors could function as a fractal structure (Fractal Foundation, 2009) in the sense that individual fixed-point attractors could be subordinated to the overall fixed-point project objective or attractor (R2-Ref. 12:29). The comments made by Respondent 13, that the starting trajectory of a capital project with specific requirements may not converge to the fixed-point chaos attractor basin bottom but could be flung out (R2-Ref. 13:24) is not understood by the researcher and perhaps should be investigated further in follow-up research.

7.3.1.4 Value Statements for the Fixed-Point Chaos Attractor in Capital Projects

One of the capital project managers expressed a value statement in terms of a fixed-point chaos attractor during the Round 2 interview, as shown in Table 7-3.

Table 7-3: Value Statements for the Fixed-Point Chaos Attractor Metaphor in Capital Projects

No.	Round 2 - Ref.	Value Statement for Fixed-Point Chaos Attractors
1	10:21	"Yes, definitely. No, totally. It was the changing point in the project using that (fixed point attractors) and a lot of the noise disappeared, and everybody focused this way."

Table 7-3 Notes: Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 71

The quotation of Respondent 10 as shown in Table 7-3 originates from his response that the introduction of only two new schedules (P50 for 50% and P80 for 80% probability of the new schedules materialising (Department of Energy, 2016)) for each of the power generation megaprojects were sufficient to create project convergence and instil stakeholder confidence. Both power station megaprojects were suffering from cost and time overruns. This value statement indicates that the respondent was able to understand the fixed-point chaos attractor concept, was able to identify such a chaos attractor in two mega capital projects and was convinced about the converging effect from chaos towards order.

7.3.1.5 Variance Model for Fixed-Point Chaos Attractor in Capital Projects

Capital project managers that were interviewed individually, during the Round 2 interviews, were exposed to a variance model for a fixed-point chaos attractor as shown in Figure 7-4. This model was derived from various literature references, from various fields of science, on the conceptualisation and application of fixed-point chaos attractors as was discussed in Chapter 3, paragraph 3.5. Each element of this model in terms of independent variables, dependent variables and outcomes was explained verbally to each respondent by the researcher and questions of clarification were answered. Each respondent was asked to apply a Likert scale score with a range between 1 (strongly disagree) – 5 (strongly agree), to each of the elements of the variance model as they apply to the capital project environment, based on their experience in capital projects. The minimum (min.), mode and maximum (max.) values were recorded for the independent variables and the chaos attractor outcomes as shown in Figure 7-4. Mode values of 4 (agree) and 5 (strongly agree) were marked in green as shown.

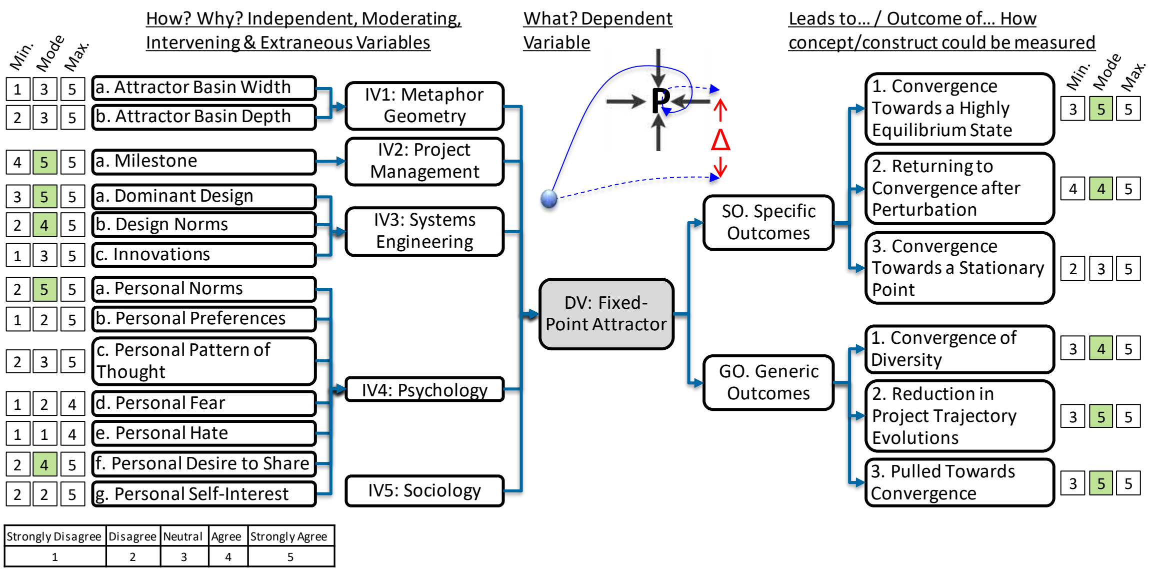

Figure 7-4: Likert Scale Scoring the Fixed-Point Chaos Attractor Variance Model for Capital Projects

The results in Figure 7-4 indicate that most (mode = 4 or 5) of the 14 capital project managers believe that a project management milestone (IV2:a), systems engineering aspects related to a dominant design (IV3:a) design norms (IV3:b), as well as the psychological aspect of a personal desire to share (IV4:f) contribute as independent variables, to determine the magnitude of the fixed-point chaos attractor as dependent variable. Note that psychological aspects, as used in this research, refers to the "studying and attempting to understand individual behaviour" (Robbins, 2005:13), in comparison to sociology that "studies people in relation to their fellow human beings... [and] group behaviour " (Robbins, 2005:13). No new aspects related to sociology were identified by respondents.

The metaphorical descriptions in terms of the fixed-point chaos attractor basin width (IV1:a) and the depth (IV1:b) were scored with a mode value of 3 (neutral). This may indicate that the details of the graphical geometry of the fixed-point chaos attractor, as displayed in the metaphorical sketches in Figure 7-2, are perhaps not so important when defining this chaos attractor.

Most (mode = 4 or 5) of the interviewed capital project managers agreed the specific outcomes of the presence of a fixed-point chaos attractor in a capital project were: convergence towards a highly equilibrium state (SO.1) and returning to convergence after perturbation (disruption) (SO.2). Most of the respondents also agreed that the generic outcomes or effect of the presence of a fixed-point chaos attractor in a capital project would be: the convergence of diversity (GO.1); reduction in project trajectory evolutions (GO.2) and that the chaos attractor would cause a pull towards convergence (GO.3). These results indicate that most capital project managers interviewed agreed that a fixed-point chaos attractor creates a converging effect in projects.

7.3.1.6 Conclusions on the Fixed-Point Chaos Attractor Metaphor for Capital Projects

The results obtained from 14 experienced capital project managers, that were individually interviewed, on various aspects of the fixed-point chaos attractor in the capital project environment indicate the following:

a) Respondents were able to provide examples of this metaphor in capital projects as shown in Table 7-1
b) Respondents were able to provide characteristics of this metaphor in capital projects as shown in Table 7-2
c) One respondent provided a value statement on this metaphor as shown in Table 7-3
d) Respondents mostly agreed (mode = 4 or 5) on relevant independent variables of the fixed-point chaos attractor (dependent variable) as shown in Figure 7-4
e) Respondents mostly agreed on the local converging effect of a fixed-point chaos attractor in a capital project for the specific and generic outcomes as shown in Figure 7-4.

Based on these observations for the current exploratory research it is concluded that:

a) Respondents were able to <u>understand</u> the fixed-point chaos attractor metaphor, as displayed and explained in Figure 7-2

b) Respondents were able to transfer the fixed-point chaos attractor metaphor, as displayed and explained in Figure 7-2, to the capital project environment

c) Respondents indicated that the presence of a fixed-point chaos attractor in a capital project environment as evaluated in the variance model shown in Figure 7-4 could lead to local convergence.

It is recommended that for future research, in-depth interviews be conducted with experienced capital project managers, using these exploratory research results as a starting point, to gain a better understanding of the fixed-point chaos attractor phenomena to enable the formulation of an updated variance model.

7.3.2 Results for the Fixed-Point Chaos Repeller in Capital Projects

7.3.2.1 Interview Question for Fixed-Point Chaos Repeller Metaphor

Several different schematic representations of the fixed-point chaos repeller metaphor are shown in Figure 7-5. These chaos repeller metaphors were shown and explained by the researcher to the capital project managers who were individually interviewed during the Round 2 interviews.

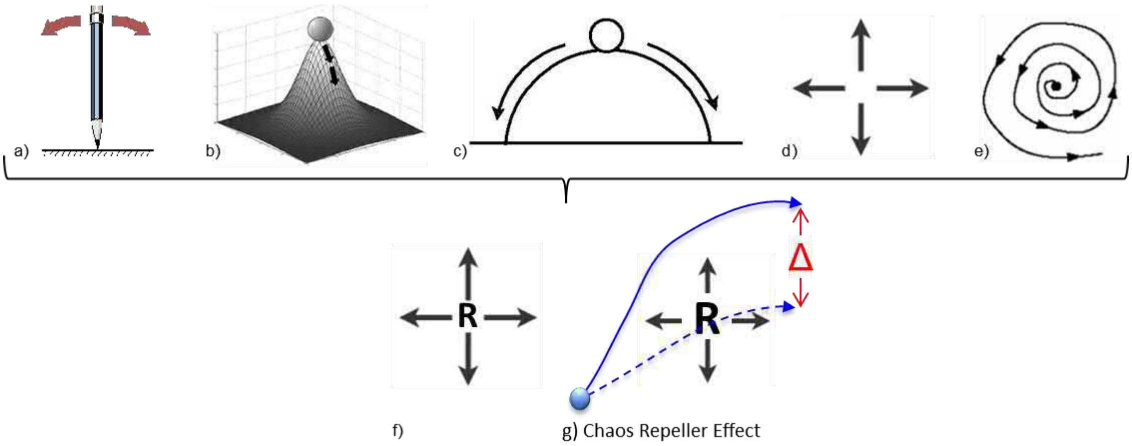

Figure 7-5: Sketches for Fixed-Point Chaos Repeller Metaphors

The verbal explanations by the researcher of the fixed-point chaos repeller metaphor as shown in Figure 7-5 were based on the chaos repeller metaphor models that were developed in Chapter 3, paragraph 3.5. Respondents were requested to provide examples and characteristics of such metaphors in the capital project environment. The verbal responses from respondents were captured, transcribed and analysed using the Atlas.ti software as explained in Chapter 4. The results of the analysed data for examples of fixed-point chaos repellers are given in paragraph 7.3.2.2, while the characteristics are given in paragraph 7.3.2.3. Value statements about this metaphor were captured in paragraph 7.3.2.4 and the results for the scoring of the variance model in paragraph 7.3.2.5. Conclusions for this section are provided in paragraph 7.3.2.6.

7.3.2.2 Examples of the Fixed-Point Chaos Repellers in Capital Projects

Examples of fixed-point chaos repellers in capital projects, as described by capital project managers during the Round 2 interviews, are given in Figure 7-4.

Table 7-4: Examples of Fixed-Point Chaos Repellers in Capital Projects

No.	Round 2 - Ref.	Examples of Fixed-Point Chaos Repeller Metaphors
1		**Financial Disincentive**
2	1:44	Company E Megaprojects M & K using of performance bonds for both international and local companies
3	2:41	Contractor will be repelled from causing a strike or have unhappy people as he might not get paid
4	2:44	Company S mining project not following site instruction caused non-payment
5	3:24	Project contractual penalties
6	3:25	Retention money on a project
7		**Safety Related Incidents / Events**
8	5:19	The potential of a safety incident (LTI) will force you to change the way you operate
9	6:23	Safety targets
10	11:24	Accident on site such as a fatality
11	11:27	USA 9/11 event caused projects far away to be affected
12	14:23	A fatal safety incident could cause a stop work condition
13		**Client /Contractor / Stakeholder Attitude**
14	10:24	Company S had to win at all cost, did not want to compromise and drove contractors out of business
15	10:25	Aggressive and militant labour drives everybody away from a project
16	11:25	Industrial labour action
17	12:37	Leadership attitude and ownership attitude can be a repeller or an attractor
18		**Cost Related Targets**
19	2:40	Client will be repelled from requesting project changes due to the additional cost
20	6:24	Cost targets
21	7:18	Cash flow problems
22		**Political Interference**
23	8:3	Politics & ignorance
24	11:26	Political interference
25		**Disciplinary Consequences**

No.	Round 2 - Ref.	Examples of Fixed-Point Chaos Repeller Metaphors
26	2:42	Disciplinary consequences will repel employees from not following delegation of authority rules
27		**Not Understanding what Motivates People**
28	4:23	Trying to understand why people behave in a certain manner and work with them to correction is the best repeller of unwanted future behaviour
29		**Any Type of Project Change**
30	7:3	Any type of project change such as standards, scope etc.
31		**Other**
32	9:28	Clear, unambiguous contract repels contractor to look for loopholes
33	12:33	Project performance measures could create a culture of avoiding being seen as not performing

Table 7-4 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for this Research Question = 44

The first group of examples of a fixed-point chaos repeller as understood by experienced capital project managers who were individually interviewed, seems to be related to financial disincentives in capital projects, as shown in Table 7-4. Examples were given for: potential financial losses due to performance bonds being called up (R2-Ref. 1:44); potential payment delays due to strike action (R2-Ref. 2:41); not following a site instruction that may lead to contractor non-payment (R2-Ref. 2:44); as well as contractual penalties (R2-Ref. 3:24). These examples seem to indicate that behaviour by contractors on a capital project will be repelled away from triggers that could cause these financial disincentives to materialise.

The second group of examples of fixed-point chaos repellers related to safety events or incidents. It appears that stakeholders on a capital project will rather change the way they operate (behaviour) than incur a Lost Time Injury (LTI) (R2-Ref. 5:19) because a fatality (R2-Ref. 11:24) could lead to stop work conditions (R2-Ref. 14:23). Similarly, it seems that stringent safety targets (R2-Ref. 6:23) could change stakeholder behaviour away from non-safe practices. One respondent (R2-Ref. 11:27) mentioned that the USA 9/11 events affected projects far away from the scene, implying that governments would try to avoid such occurrences due to the negative effect on capital projects.

The next group of chaos repeller examples related to specific behaviour. The behaviour of a specific primary contracting company drove or repelled contracting companies out of business (R2-Ref. 10:24), while aggressive and militant labour force behaviour (R2-Ref. 10:25) or industrial action (R2-Ref. 11:25) drove or repelled potential stakeholders away from a capital project (R2-Ref. 10:25). It is further suggested that poor leadership could be an example of a chaos repeller (R2-Ref. 12:37).

Cost related targets may also be fixed-point repellers. Respondents provided examples such as: the avoidance of clients to request further project scope changes (R2-Ref. 2:40); avoidance of not achieving cost targets (R2-Ref. 6:24); and changing project behaviour to avoid running into cash flow problems (R2-Ref. 7:18). Political ignorance (R2-Ref. 8:3) and inferences (R2-Ref. 11:26) may repel stakeholders from doing the right things on projects. Disciplinary consequences may repel employees from not following delegation of authority rules (R2-Ref. 2:42). If a project manager expends the effort to try and understand why people on a project behave in a certain manner and work with them to solve such issues, it could repel people from behaving in an unwanted manner (R2-Ref. 4:23). It therefore seems that trying to understand what motivates people and work with them is a good form of chaos repeller.

An example was also given by respondents that any type of project change could act as a chaos repeller because people generally do not want to change (R2-Ref. 7:3). If the project scope and requirements are clearly stated and contracted, it seems to repel contractors from spending time looking for loopholes in the contract (R2-Ref. 9:28) and perhaps avoid project claims.

The final example of a fixed-point chaos repeller, as given by Respondent 12, is related to project performance measures and metrics. Project team members would not like to be seen as not performing and could therefore report false measures or metrics (R2-Ref. 12:33). Project performance measures or metrics could therefore repel project team members from honestly reporting problems and failures.

7.3.2.3 Characteristics of the Fixed-Point Chaos Repeller in Capital Projects

The results for the characteristics of fixed-point chaos repellers as given by capital project managers that were interviewed during the Round 2 interviews, are given in Table 7-5.

Table 7-5: Description of the Characteristics a Fixed-Point Chaos Repeller in Capital Projects

No.	Round 2 – Ref.	1st Order Terms	2nd Order Terms	Aggregate Construct
1	1:45	Contractor penalties are limited to the contract value (maximum effect)	Procurement	Fixed-Point Chaos Repeller

No.	Round 2 – Ref.	1st Order Terms	2nd Order Terms	Aggregate Construct
2	3:26	Project penalties and retention money drives behaviour		
3	4:21	Using contractual remedies as a first option causes a negative force		
4	4:22	Using contractual remedies as a first option creates defensive behaviour		
5	4:24	Using contractual remedies as a first option may cause bad feelings		
6	5:21	Lots of smaller penalties may not be as effective as one big penalty at the project end		
7	9:29	A penalty clause is only effective if the contactor values it as worthwhile		
8	10:26	Ineffective penalty clause if you have penalised the contactor to the point where there is nothing more to penalise		
9	13:32	We use penalties all the time, but they are not effective		
10				
11	5:20	Fear of losing your job on a failing project causes you to change	Resource	
12	11:28	Unexpected events impact the human psyche and creates a repeller		
13	12:35	A culture of "I do not want to hear bad news" cause people to hide the truth and repels form doing the right things		
14	12:36	Management attitude could lead to the creation of a fake project		
15	14:25	Lack of a good project manager will cause automatic repelling between project elements		
16				
17	1:41	Potential reputational damage when a performance bond is called	Stakeholder	
18	1:43	Called performance bond news spreads immediately in the international construction industry causing reputational damage		
19	1:46	Reputational damage (calling up a performance bond) is a much stronger repeller than money (penalties)		
20	1:42	Called performance bond will cause higher bond costs in future for the contractor		
21				
22	2:43	Project governance prevent unwanted behaviour and chaos	Integration	
23				
24	13:33	Quality may be a repeller to get convergence, but the effectiveness is questionable	Quality	

Table 7-5 Notes: Unique 1st Order Terms Captured and Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for the Fixed-Point Chaos Repeller Aggregate Construct. Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 44

The number of unique 1st order terms per ISO 21500 subject group, as shown in Table 7-5, varied per 2nd order concept for: procurement (z = 9); resource (z = 5); stakeholder (z = 4); integration (z = 1) and quality (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject groups: integration; scope; time; cost; risk and communication.

The procurement related characteristics of a fixed-point chaos repeller in capital projects seems to be related to penalties. It seems that project penalties and retentions could drive contractor behaviour (R2-Ref. 3:26). However, the repelling effect towards desired behaviour by contractors on a capital project, as a result of penalties, may have a maximum and limiting effect (R2-Ref. 1:45) and only seems to work if the contractor also values the penalties as worthwhile (R2-Ref. 9:29) otherwise they may be ineffective (R2-Ref. 13:32). One penalty at the end of the capital project may be more effective than several smaller penalties during the project (R2-Ref. 5:21) provided that the contractor is able to pay such a penalty (R2-Ref. 10:26). The unwanted behaviour by contractors if penalties are used as a first option of resolve, might be that contractors are negative (R2-Ref. 4:21), it creates bad feeling (R2-Ref. 4:24) or defensive behaviour (R2-Ref. 4:22).

Resource related characteristics of a fixed-point chaos repeller could be poor project management and management attitude (R2-Ref. 12:36), such as project managers who do not want to hear bad news (R2-Ref. 12:35). Poor project management seems to cause project stakeholders to hide the truth (R2-Ref. 12:35), repels people from doing the right things on projects (R2-Ref. 12:35) and may lead to automatic repelling between project elements (R2-Ref. 14:25). The tragic 9/11 events in the USA were an unexpected incident that created an impact on the human psyche of project teams far away from the event and repelled people for a period of time from focusing on their project activities (R2-Ref. 11:28). Fear could also act as a repeller (R2-Ref. 5:20) on a failing project as it might cause project team members to change their behaviour, perhaps to secure their own survival, to the detriment of the project.

Stakeholder characteristics of a fixed-point chaos repeller may be conceptualised in the form of contractor reputational damage (R2-Ref. 1:41). The possibility of a contractor incurring local and international reputational damage (R2-Ref. 1:43) and higher future bond costs (R2-Ref. 1:42) when a performance bond is called (R2-Ref. 1:41), may repel his intended behaviour to different behaviour. The loss of reputational damage may even be a stronger repeller than a monetary penalty (R2-Ref. 1:46). The implementation of proper project governance may repel stakeholder behaviour to prevent unwanted behaviour and chaos (R2-Ref. 2:43). The implementation of quality assurance and quality control may also act to repel unwanted behaviour in a capital project (R2-Ref. 13:33) but may not on its own be effective enough.

A fixed-point chaos repeller in capital projects therefore seems to have the ability to repel unwanted behaviour and cause the deliberate choice for different behaviour.

7.3.2.4 Value Statements for the Fixed-Point Chaos Repeller in Capital Projects

No value statements were extracted from the transcribed text for the fixed-point chaos repeller in capital projects.

7.3.2.5 Variance Model for a Fixed-Point Chaos Repeller in Capital Projects

Capital project managers that were interviewed individually during the Round 2 interviews were exposed to a variance model for a fixed-point chaos repeller, as shown in Figure 7-6. This model was derived from various literature references, from various fields of science, on the conceptualisation and application of fixed-point chaos repellers as was discussed in Chapter 3, paragraph 3.5. Each element of this model in terms of independent variables, dependent variables and outcomes was verbally explained to each respondent and questions of clarification were answered. Each respondent was asked to apply a Likert scale score with a range between 1 (strongly disagree) – 5 (strongly agree) to each of the elements of the variance model, as they apply to the capital project environment based on their experience in capital projects. The minimum (min.), mode and maximum (max.) values were recorded for the independent variables and the chaos repeller outcomes as shown in Figure 7-6. Mode values of 4 (agree) and 5 (strongly agree) were marked in green as shown.

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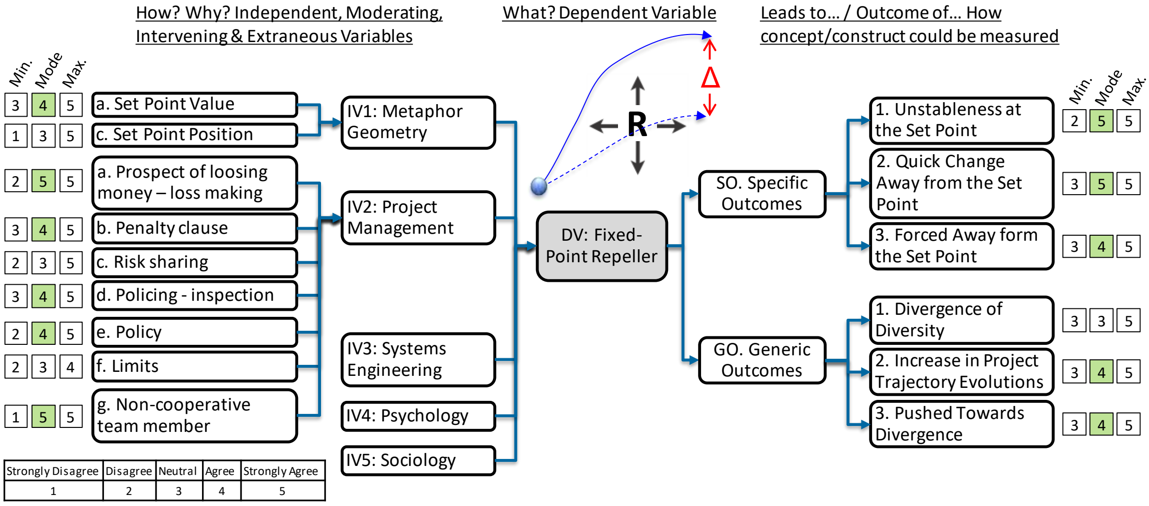

Figure 7-6: Likert Scale Scoring of the Fixed-Point Chaos Repeller Variance Model for Capital Projects

Most of the 14 individually interviewed experienced capital project managers concurred that a set point value for the metaphor geometry, as was displayed in Figure 7-6, causes the formation of an independent variable of the fixed-point chaos repeller (mode = 4). This set point value may perhaps be a penalty with an associated monetary value or the value of reputational damage as was shown in Table 7-5. Respondents also seemed to agree that: the prospect of losing money; a penalty clause; scheduled project inspections; project policies and an uncooperative project team member were all independent variables that could cause the formation of a fixed-point chaos repeller in capital projects. No responses were obtained for independent variables that are related to systems engineering, psychology or sociology.

All respondents accepted the specific outcomes of a fixed-point chaos repeller in a capital project. These were: the creation of unstableness at a set point (SO.1); quick change away from the set point (SO.2); and an acting force to create movement away from the set point (SO.3). There was also agreement on the generic effects of a fixed-point repeller to increase the project trajectory evolutions (GO.1) and a push towards divergence (GO.2).

7.3.2.6 Conclusions on the Fixed-Point Chaos Repeller Metaphor for Capital Projects

The results obtained from the 14 experienced capital project managers who were individually interviewed on various aspects of the fixed-point chaos repeller in the capital project environment indicate the following:

a) Respondents were able to provide examples of this metaphor in capital projects as shown in Table 7-4
b) Respondents were able to provide characteristics of this metaphor in capital projects as shown in Table 7-5
c) No value statement for this metaphor was obtained from the results
d) Respondents were able to mostly agree (mode = 4 or 5) on relevant independent variables of the fixed-point chaos repeller (dependent variable) as shown in Figure 7-6
e) Respondents mostly agree on the local diverging effect of a fixed-point chaos repeller in a capital project for the specific and generic outcomes as shown in Figure 7-6.

Based on these observations for the current exploratory research it is accepted that:

a) Respondents were able to understand the fixed-point chaos repeller metaphor, as displayed and explained in Figure 7-5
b) Respondents were able to transfer the fixed-point chaos repeller metaphor, as displayed and explained in Figure 7-5, to the capital project environment
c) Respondents indicated that the presence of a fixed-point chaos repeller in a capital project environment, as evaluated in the variance model shown in Figure 7-6, could lead to local divergence.

It is recommended that for future research in-depth interviews be conducted with experienced capital project managers, using these exploratory research results as a starting point, to gain a better understanding of the fixed-point chaos repeller phenomena to enable the formulation of an updated variance model.

7.3.3 Results for the Limit-Cycle Chaos Attractor in Capital Projects

7.3.3.1 Interview Question for Limit-Cycle Chaos Attractor Metaphor

A number of different schematic representations of the limit-cycle chaos attractor metaphor are shown in Figure 7-7. These chaos attractor metaphors were shown and explained to capital project managers by the researcher during the individual Round 2 interviews.

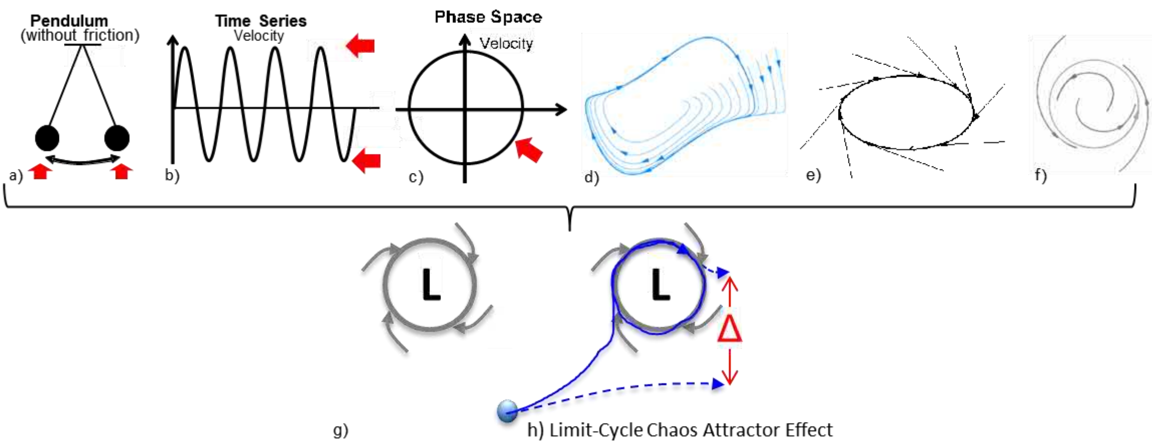

Figure 7-7: Sketches for Limit-Cycle Chaos Attractor Metaphors

The verbal explanations by the researcher of the limit-cycle chaos attractor metaphor as shown in Figure 7-7 were based on the chaos attractor metaphor models that were developed in Chapter 3, paragraph 3.5. Respondents were requested to provide examples and characteristics of such metaphors in the capital project environment. The verbal responses from respondents were captured, transcribed and analysed using the Atlas.ti software as explained in Chapter 4. The results of the analysed data for examples of limit-cycle chaos attractors are given in paragraph 7.3.3.2, while the characteristics are given in paragraph 7.3.3.3. Value statements about this metaphor were captured in paragraph 7.3.3.4 and the results for the scoring of the variance model in paragraph 7.3.3.5. Conclusions for this section are provided in paragraph 7.3.3.6.

7.3.3.2 Examples of the Limit-Cycle Chaos Attractors in Capital Projects

Examples of limit-cycle chaos attractors in capital projects as described by capital project managers during the Round 2 interviews are given in Table 7-6.

Table 7-6: Examples of Limit-Cycle Chaos Attractors in Capital Projects

No.	Round 2 - Ref.	Examples of Limit-Cycle Chaos Attractor Metaphors
1		**Regular Meetings**
2	1:48	Company E megaproject weekly 4D construction meetings
3	2:46	Design & engineering reviews
4	2:48	HAZOP 1, 2, 3, 4, & 5 cycles during project development and execution
5	3:28	Progress meeting
6	3:29	Technical evaluation meeting
7	3:30	Steering committee meetings

No.	Round 2 - Ref.	Examples of Limit-Cycle Chaos Attractor Metaphors
8	4:26	Steering group meetings
9	4:28	Monthly project claims meetings to close-out all claims
10	6:25	Weekly feedback meetings
11	6:27	Monthly project reconciliation reporting
12	7:20	Project feedback reporting
13	10:29	Daily commissioning meetings in the morning
14	11:30	Yearly megaproject budged approvals
15	11:34	Weekly safety meetings
16	12:39	Integrated project review meetings
17	14:29	Progress meeting - if it is sensible and decisions are taken
18		**Repetitive Processes**
19	2:49	Recruitment of project staff
20	3:35	Project management procedures and templates will give you that pattern
21	7:19	Project reviews
22	8:47	Structured project life cycle model (PLCM)
23	8:48	Company E - 8 x Engineering review cycles
24	9:31	Project G - Design-review-approve cycles
25	13:34	Any iterative process such as engineering design
26		**Repetitive Work Packages**
27	8:45	Company E - Building multiple Power Generation Units
28	11:31	Megaprojects M & K - cyclical tasks before synchronisation on each Unit
29	11:35	Project with repetitive nature - Cooling towers, railway lines & mass housing projects
30		**Other**
31	4:27	Team building events outside of work that are done efficiently and that makes sense
32	4:30	Company M's Aspire Leadership Principles - consistently say this is the way we do things
33	5:23	Learning cycles as part of a learning curve
34	14:26	Train schedule
35	10:28	Contractors cycling between project location and family location far away

Table 7-6 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for this Research Question = 59

The examples given by capital project managers of limit-cycle chaos attractors in capital projects are related to: regular meetings; repetitive processes and repetitive work packages, as shown in Table 7-6.

Regular meetings appear to be an example of a limit-cycle chaos attractor irrespective of whether the meetings are scheduled daily (R2-Ref. 10:29), weekly (R2-Ref. 6:25), monthly (R2-Ref. 4:28) or yearly (R2-Ref. 11:30). Different types of meetings seem to be able to form this type of chaos attractor, such as: design meetings (R2-Ref. 2:46); HAZOP meetings (R2-Ref. 2:48); technical meetings (R2-Ref. 3:29); progress meetings (R2-Ref. 14:29); steering committee meetings (R2-Ref. 3:30); claims meetings (R2-Ref. 4:28). However, it appears that progress meetings would only attract and cause local convergence if it is a sensible meeting and decisions are taken (R2-Ref. 14:29).

Different types of repetitive processes also seem able to form a limit-cycle chaos attractor in capital projects. These processes could include: recruitment processes (R2-Ref. 2:49); project management procedures (R2-Ref. 3:35); project reviews (R2-Ref. 7:19); and engineering and design reviews (R2-Ref. 8:48, 9:31 and 13:34). A well-structured project life cycle model (PLCM) with stage-gates and the required repetitive processes (R2-Ref. 8:47) appear to aid the formation of a limit-cycle chaos attractor in capital projects. Similarly, repetitive work packages as found during the construction of multiple power generation units (R2-Ref. 8:45) with the same type of systems (R2-Ref. 11:35) and the same cyclical tasks (R2-Ref. 11:31).

Other examples of cyclical events were mentioned such as team building (R2-Ref. 4:27), training cycles (R2-Ref. 14:26) and learning cycles (R2-Ref. 5:23). The consistent repetition of company M's Aspire Leadership Principles (R2-Ref. 4:30) may be another example of a limit-cycle chaos attractor as exercised in a capital project. The final example is the repetitive cycling of contractors between the project location and their homes during project construction (R2-Ref. 10:28).

7.3.3.3 Characteristics of the Limit-Cycle Chaos Attractors in Capital Projects

The results for the characteristics of limit-cycle chaos attractors as given by capital project managers that were interviewed during the Round 2 interviews are given in Table 7-7.

Table 7-7: Description of the Characteristics of a Limit-Cycle Chaos Attractor in Capital Projects

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:49	Regular meetings cause coordination of modelling, planning & scheduling	Integration	Limit-Cycle Chaos Attractor
2	2:47	Cycles of drawings, client review, comments, updating etc. converges to client approval		
3	2:51	These types of design and engineering review cycles help to create convergence and order		
4	3:33	You can overdo it when you have too many meetings		

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
		and feedback sessions		
5	3:34	Meetings need to be well defined and directed to be effective		
6	6:28	Regularly reporting cause people to actually do activities that will form part of the report		
7	8:50	It is all part of the exercise of integration		
8	8:51	If you differentiate without integration - you are doomed		
9	12:40	Regular integrated project review meetings cause the same view of thinking		
10	12:44	Repetition creates momentum		
11	13:35	Ensures incorporation of all disciplines and suppliers		
12	14:28	Creation of a pattern of activities		
13				
14	1:50	Revisiting the installation sequence and bringing parties in line cause convergence, progress and delivery	Time	
15	2:50	Cycles have a logical sequence of their own e.g. completion before commissioning		
16	3:31	You have to have a drumbeat of meetings with a specific theme		
17	3:32	Meetings have to happen at a certain frequency		
18	3:36	There is a certain rhythm on how to do things		
19	8:46	Repetition causes learning and ease of doing		
20	11:32	Repeated logical construction sequence		
21	14:27	Trying to keep to the (train) schedule caused less chaos and order		
22				
23	4:31	Consistently repeating the same leadership message cause employee initiative within those guidelines	Resource	
24	6:26	Staff payments on Friday midday creates divergence as no more work gets done		
25	12:41	Change from individual performance to project performance		
26	12:42	Change from individuals to teams		
27	12:45	Poor performing people are likely to change as they start to see themselves with reference to what is happening		
28	12:46	Weekly planning session changed polarised and silo type individual behaviour to harmonious team mode behaviour		
29				
30	12:43	Create a space where everybody can have their say	Communication	
31				
32	4:29	Monthly claims meetings caused realistic claims by contactors without delays	Procurement	

Table 7-7 Notes: Unique 1st Order Terms Captured and Allocated to 2nd Order Concepts (ISO 21500

Subject Groups and New Concepts) for the Limit-Cycle Chaos Attractor Aggregate Construct. Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 59

The number of unique 1st order terms per ISO 21500 subject group, as shown in Table 7-7, varied per 2nd order concept for: integration (z = 12); time (z = 8); resource (z = 6); communication (z = 1) and procurement (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject groups: stakeholder; scope; cost; risk and quality.

A limit-cycle chaos attractor in a capital project seems to be able to: cause coordination of modelling, planning and scheduling (R2-Ref. 1:49); convergence towards client approval using drawings, client reviews and updating towards final client approval (R2-Ref. 2:47) as part of design and engineering review cycles (R2-Ref. 2:51). These activities form part of the exercise of integration (R2-Ref. 8:50) in capital projects. Regular integrated project review meetings may cause cyclical convergence in terms of: fostering the same view or paradigm of thinking (R2-Ref. 12:40); creation of momentum (R2-Ref. 12:44); incorporation of all disciplines and suppliers (R2-Ref. 13:35) and a pattern of activities (R2-Ref. 14:28) on capital projects. Limit-cycles may cause project stakeholders to actually do the work that will form part of the deliverables (R2-Ref. 6:28). However, to form an effective limit-cycle chaos attractor, meetings need to be effective, well defined and well run (R2-Ref. 3:34) as too much repetition may not lead to convergence (R2-Ref. 3:33). Also, after generating new ideas on a project (differentiation) integration activities need to take place (R2-Ref. 8:51) otherwise divergence may occur.

The time related aspects of a limit-cycle chaos attractor for capital projects as shown in Table 7-7 seem to relate to a repetitive drum beat (R2-Ref. 3:31), rhythm (3:36) and a certain frequency (R2-Ref. 3:32). Timeous repetition seems to cause learning convergence and ease of doing (R2-Ref. 8:46) and keeping to a schedule causes less chaos (R2-Ref. 14:27). A repeated logical construction and installation sequence (R2-Ref. 2:50) could bring stakeholders in line (R2-Ref. 11:32) and cause convergence, progress and delivery (R2-Ref. 1:50).

A limit-cycle chaos attractor in capital projects seems to cause the focus to move away from an individual toward teams (R2-Ref. 12:42 and 12:42) and from individual performance towards project performance (R2-Ref. 12:41). The attracting effect of a limit-cycle chaos attractor may be to move poor performing team members towards performance as they see themselves in comparison to the performance of other performing team members (R2-Ref. 12:45). Repetitive weekly meetings appear to have an integration function as there is a change from polarised and silo type of individual behaviour towards harmonious team mode behaviour (R2-Ref. 12:46). Also, by consistently repeating the same leadership message in a capital project may cause the activation of project team member initiative (R2-Ref. 4:31). All these repetitions seem to contribute towards limit-cycle convergence. However, some limit-cycles could have a diverging effect. For example, when staff payments are done on midday on a Friday - this could cause no more work to be done (R2-Ref. 6:26).

The communication aspect of a limit-cycle chaos attractor may be related to the creation of a regular opportunity for project team members to voice themselves (R2-Ref. 12:43). This could lead to the early detection of problems but may also serve to identify project opportunities. The implementing of regular monthly claim meetings (R2-Ref. 4:29) could cause realistic claims by contractors and could reduce invalid claims and project delays.

7.3.3.4 Value Statements for the Limit-Cycle Chaos Attractor in Capital Projects

No value statements were extracted from the transcribed text for the limit-cycle chaos attractor in capital projects.

7.3.3.5 Variance Model for Limit-Cycle Chaos Attractor in Capital Projects

Capital project managers that were interviewed individually during the Round 2 interviews were exposed to a variance model for a limit-cycle chaos attractor, as shown in Figure 7-8. This model was derived from various literature references, from various fields of science, on the conceptualisation and application of limit-cycle chaos attractors as was discussed in Chapter 3, paragraph 3.5. Each element of this model in terms of independent variables, dependent variables and outcomes was verbally explained to each respondent and questions of clarification were answered. Each respondent was asked to apply a Likert scale score with a range between 1 (strongly disagree) – 5 (strongly agree) to each of the elements of the variance model, as they apply to the capital project environment based on their experience in capital projects. The minimum (min.), mode and maximum (max.) values were recorded for the independent variables and the chaos attractor outcomes as shown in Figure 7-8. Mode values of 4 (agree) and 5 (strongly agree) were marked in green as shown.

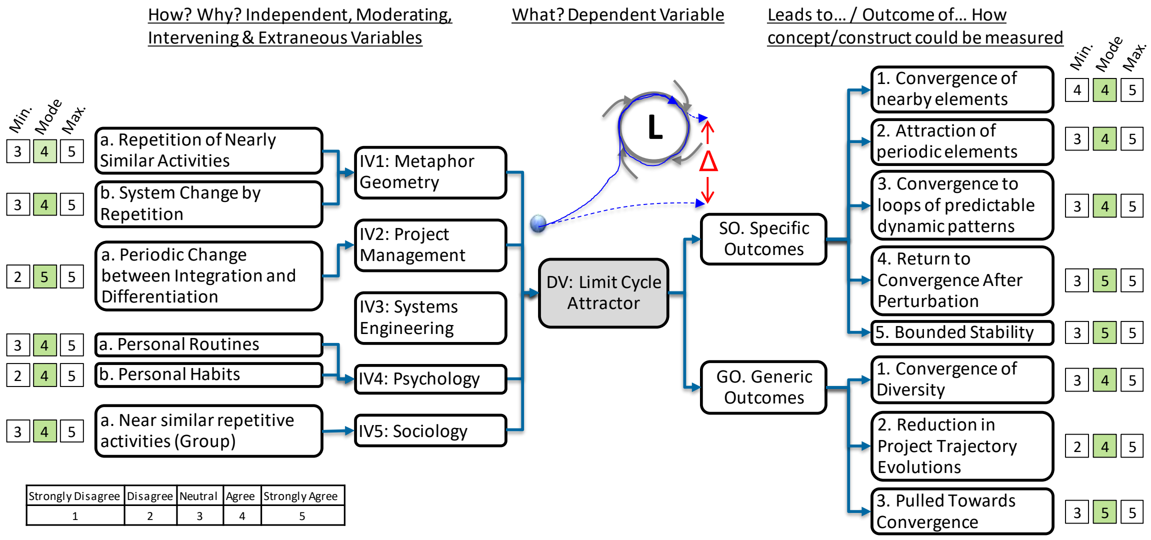

Figure 7-8: Likert Scale Scoring of the Limit-Cycle Chaos Attractor Variance Model for Capital Projects

Most of the capital project managers agreed with the limit-cycle chaos attractor model elements for independent variables and outcomes as seen in the scoring of mode = 4 (agreed) and mode = 5 (strongly agree) in Figure 7-8. Respondents added no new elements to this model.

7.3.3.6 Conclusions on the Limit-Cycle Chaos Attractor Metaphor for Capital Projects

The results obtained from 14 experienced capital project managers that were individually interviewed on various aspects of the limit-cycle chaos attractor in the capital project environment indicate the following:

a) Respondents were able to provide examples of this metaphor in capital projects as shown in Table 7-6
b) Respondents were able to provide characteristics of this metaphor in capital projects as shown in Table 7-7
c) No results were obtained for value statements on this metaphor
d) Respondents were able to mostly agree (mode = 4 or 5) on relevant independent variables of limit-cycle chaos attractors (dependent variable) as shown in Figure 7-8
e) Respondents mostly agree on the local converging effect of a limit-cycle chaos attractor in a capital project for the specific and generic outcomes as shown in Figure 7-8.

Based on these observations for the current exploratory research it can be concluded that:

a) Respondents were able to understand the limit-cycle chaos attractor metaphor, as displayed and explained in Figure 7-7
b) Respondents were able to transfer the limit-cycle chaos attractor metaphor, as displayed and explained in Figure 7-7, to the capital project environment
c) Respondents indicated that the presence of a limit-cycle chaos attractor in a capital project environment as evaluated in the variance model shown in Figure 7-8 could lead to local convergence.

It is recommended that for future research in-depth interviews be conducted with experienced capital project managers, using these exploratory research results as a starting point, to gain a better understanding of the limit-cycle chaos attractor phenomena to enable the formulation of an updated variance model.

7.3.4 Results for the Torus Chaos Attractor in Capital Projects

7.3.4.1 Interview Question for Torus Chaos Attractor Metaphor

Several different schematic representations for the torus chaos attractor metaphor are shown in Figure 7-9. These chaos attractor metaphors were shown and explained by the researcher to the capital project managers who were individually interviewed during the Round 2 interviews.

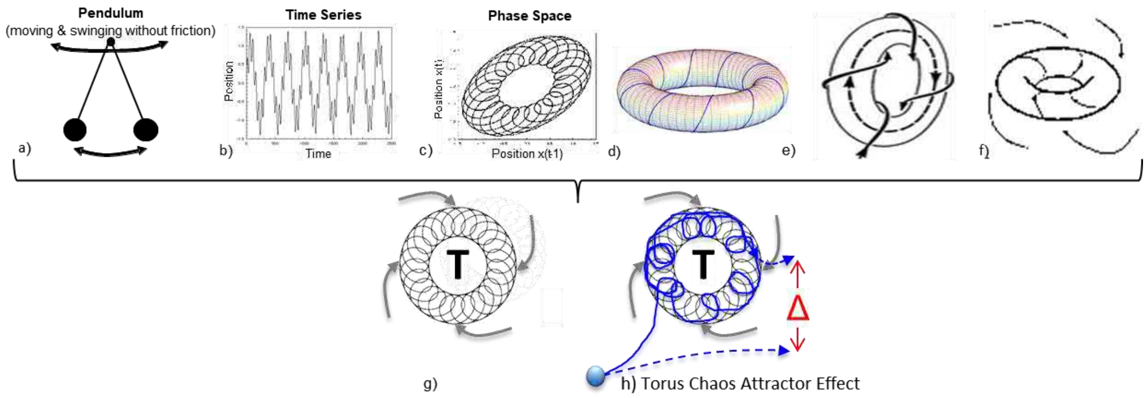

Figure 7-9: Sketches for Torus Chaos Attractor Metaphors

The verbal explanations by the researcher of the torus chaos attractor metaphor as shown in Figure 7-9 were based on the chaos attractor metaphor models that were developed in Chapter 3, paragraph 3.5. Respondents were requested to provide examples and characteristics of such metaphors in the capital project environment. The verbal responses from respondents were captured, transcribed and analysed using the Atlas.ti software as explained in Chapter 4. The results of the analysed data for examples of torus chaos attractors are given in paragraph 7.3.4.2 while the characteristics are given in paragraph 7.3.4.3. Value statements about this metaphor were captured in paragraph 7.3.4.4 and the results for the scoring of the variance model in paragraph 7.3.4.5. Conclusions for this section are provided in paragraph 7.3.4.6.

7.3.4.2 Examples of the Torus Chaos Attractors in Capital Projects

Examples of torus chaos attractors in capital projects as described by capital project managers during the Round 2 interviews are given in Table 7-8.

Table 7-8: Examples of Torus Chaos Attractors in Capital Projects

No.	Round 2 - Ref.	Examples of Torus Chaos Attractor Metaphors
1		**Project Containing Inner Cycle Construction Activities**
2	5:26	Concrete works - Different inner cycle activities required to complete the works
3	6:31	Company E - Megaproject M - Construction of each Unit as a torus attractor for 6 Units
4	10:31	Multiple inner construction cycles during the construction of a turbine
5	11:37	Project M & K - Each Unit of a Power Station being built
6	14:32	Project G as outer cycle with multiple inner cycles (land expropriation, earthworks, structures & track)
7		**Project Containing Various Other Inner Cycles Activities**
8	1:53	Company E - Megaprojects M & K - Cyclical local and government elections during single project
9	1:54	Company E - Very long transmission line project - Successive mobilisation & demobilisation of local contractors in one project
10	1:55	Company E - Megaproject M - Learning cycles from successive Units in one project
11	2:56	Outer project development cycle with inner phases / stages
12	3:38	Mining company E - One project with multiple inner project life-cycle processes per phase
13	3:39	Mining licence to operate process requires multiple legislative inner cycles
14		**Engineering Design Process Containing Inner Cycles**
15	2:53	Engineering design process - Multi-discipline activities within one outer design cycle
16	8:53	The final design consists of concept, basic and detail design processes
17	7:22	One design (outer cycle) with different disciplines / areas / processes (inner cycles)
18	14:31	Project daily train schedule design containing two peaks and off-peaks in-between
19		**Project Methodologies**
20	2:54	Mining company A - One project methodology covering each project life cycle phase
21	12:48	Megaproject (outer cycle) with project management groups planning, execution, monitoring & controlling (inner cycles)

No.	Round 2 - Ref.	Examples of Torus Chaos Attractor Metaphors
22	12:49	Project phase (outer cycle) with routines and cycles (inner cycles)
23		**New Product Development Project**
24	1:52	Gas turbine development - Improved efficiency of every successive new version
25	11:36	R&D project - Technology development cycles

Table 7-8 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for this Research Question = 38

All the examples of torus chaos attractors that were identified by capital project managers, as shown in Table 7-8, have multiple inner cycles that are repeated and form part of an outer cycle (R2-Ref. 2:56). These examples are related to: types of projects; project methodologies; engineering design; and construction activities of capital projects.

Project types that resemble torus chaos attractor behaviour include: power generation megaprojects with multiple similar units (R2-Ref. 1:55); mining development projects (R2-Ref. 3:38); transmission line projects (R2-Ref. 1:54); and new system development projects such as a gas turbine development projects (R2-Ref. 1:52). Research and development projects also contain multiple inner development cycles (R2-Ref. 11:36).

Respondents specifically mentioned project construction activities such as: multiple-units (R2-Ref. 6:31, 10:31 and 11:37) that may contain concrete works (R2-Ref. 5:26); land expropriation; earthworks; structures and track (R2-Ref. 14:32); and mining licence acquiring processes (R2-Ref. 3:39).

Engineering design processes may also contain multiple inner torus-cycles such as the multi-discipline individual activities (R2-Ref. 7:22) that form part of the overall engineering design process (R2-Ref. 2:53). When viewing the capital project life cycle it may consist of repetitive design processes that repeat during concept, basic and detail design phases (R2-Ref. 8:53). Another example was given for the daily train schedule design that contains two peaks with off-peaks in-between (R2-Ref. 14:31).

Project methodologies contain an outer cycle with multiple inner cycles (R2-Ref. 2:54) per phase (R2-Ref. 12:49). Similarly, the typical PMBOK cycles (PMI's Project Management Body of Knowledge) applied to a mega capital project in the form of planning, execution, monitoring and controlling (R2-Ref. 12:48) (PMI, 2017).

7.3.4.3 Characteristics of the Torus Chaos Attractor in Capital Projects

The results for the characteristics of torus chaos attractors as given by capital project managers that were interviewed during the Round 2 interviews are given in Table 7-9.

Table 7-9: Description of Torus Chaos Attractor Characteristics in Capital Projects

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	2:55	Procedures for each internal cycle are well defined	Integration	Torus Chaos Attractor
2	5:27	The efficiency of inner cycles influences the outer cycle outcome		
3	5:28	The outcome of an outer cycle is a higher level of maturity or completeness		
4	6:30	The torus attractor becomes stronger with more repetitions in a project		
5	7:23	The solutions of each inner cycle form part of the overall result / outcome		
6	9:33	Maturing of a project through different stages		
7	11:38	Multiple torus chaos attractors are connected to each other as successive R&D developmental steps		
8	12:50	Increase in project maturity caused by inner cycles during each project phase		
9	12:51	Fractal structure of Torus at different project levels from project to task level		
10	14:33	Self-similar projects but not similar due to differences in project types and complexity		
11				
12	3:40	One license follows on the other - there is a specific sequence	Time	
13	6:32	The first torus attractor is more difficult than the last one in multi-unit projects		
14	10:32	Quicker and faster construction due to learning cycles		
15	13:5	Torus chaos attractor (incestuous knowledge base) could lead to stagnation		
16				
17	12:52	Successive build-up of deliverables from task to work package to phase to project level	Scope	
18				
19	5:25	The torus chaos attractor is not as strong as the fixed-point chaos attractor	General	

Table 7-9 Notes: Unique 1st Order Terms Captured and Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for the Torus Chaos Attractor Aggregate Construct. Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 38

The number of unique 1st order terms per ISO 21500 subject group, as shown in Table 7-9, varied per 2nd order concept for integration (z = 10), time (z = 4) and scope (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject groups: stakeholder; resource; cost; risk; quality; procurement and communication.

The torus chaos attractor in capital projects that relate to the ISO 21500 subject group of integration could be represented by project procedures for each internal project cycle that are well defined (R2-Ref. 2:55), as shown in Table 7-9. The efficiency of the inner cycles may influence the outer cycle outcome (R2-Ref. 5:27) and the solutions of each inner cycle seem to form part of the overall outer cycle result (R2-Ref. 7:23). The result or outcome of the outer torus cycle could be at a higher level of maturity or completeness compared to before entering the torus cycle (R2-Ref. 5:28). The torus chaos attractor could become stronger with each repetition in a capital project (R2-Ref. 6:30) and could help to mature a capital project through its different stages (R2-Ref. 9:33 and 12:50). This can be seen in a research and development project where multiple torus chaos attractors are connected to each other as successive developmental steps (R2-Ref. 11:38). The self-similar (R2-Ref. 14:33) torus structure could be found at different project levels (R2-Ref. 12:51) for different projects types and complexity.

The torus like characteristics related to the ISO 21500 subject group of time seem to follow a specific sequence for the inner cycles (R2-Ref. 3:40). The first torus chaos attractor in a multi-unit project seems to be more difficult to compared to the last ones (R2-Ref. 6:32). Due to the learning effect the cycle time of the inner torus cycles could become quicker and faster (R2-Ref. 10:32). However, following the same torus chaos attractor in capital projects could lead to stagnation due to the use of an incestuous knowledge base (R2-Ref. 13:5).

Successive and multi-layered work packages from task to work package to phase and deliverables at project level, could form a torus chaos attractor related to the ISO 21500 subject group scope (R2-Ref. 12:52). Respondent 5 postulated that in his opinion, a torus chaos attractor in a capital project is not as strong as a fixed-point chaos attractor (R2-Ref. 5:25).

7.3.4.4 Value Statements for the Torus Chaos Attractor in Capital Projects

Two of the capital project managers (Respondent 9 and 10) expressed value statements in terms of a torus chaos attractor during the Round 2 interviews as shown in Table 7-10.

Table 7-10: Value Statements for the Torus Chaos Attractor Metaphor in Capital Projects

No.	Round 2 - Ref.	Value Statements for Torus Chaos Attractors
1	9:35	It becomes very complex now
2	10:34	This is a bit difficult

Table 7-10 Notes: Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 38

Although respondents were able to provide examples of the torus chaos attractor metaphor (Table 7-8), describe the characteristics (Table 7-9) and were able to score and rate the variance model (Figure 7-10), these two responses indicated that the conceptual understanding of this metaphor becomes complex (R2-Ref. 9:35) and difficult (R2-Ref. 10:34). These two statements might also imply that the metaphors for the fixed-point chaos attractor, fixed-point chaos repeller and limit-cycle chaos attractors were conceptually easier to understand compared to the torus chaos attractor metaphor.

7.3.4.5 Variance Model for Torus Chaos Attractor in Capital Projects

Capital project managers that were interviewed individually during the Round 2 interviews were exposed to a variance model for a torus chaos attractor as shown in Figure 7-10. This model was derived from various literature references, from various fields of science, on the conceptualisation and application of torus chaos attractors as was discussed in Chapter 3, paragraph 3.5. Each element of this model in terms of independent variables, dependent variables and outcomes was verbally explained to each respondent and questions of clarification were answered. Each respondent was asked to apply a Likert scale score with a range between 1 (strongly disagree) – 5 (strongly agree) to each of the elements of the variance model as they apply to the capital project environment, based on their experience in capital projects. The minimum (min.), mode and maximum (max.) values were recorded for the independent variables and the chaos attractor outcomes as shown in Figure 7-10. Mode values of 4 (agree) and 5 (strongly agree) were marked in green as shown.

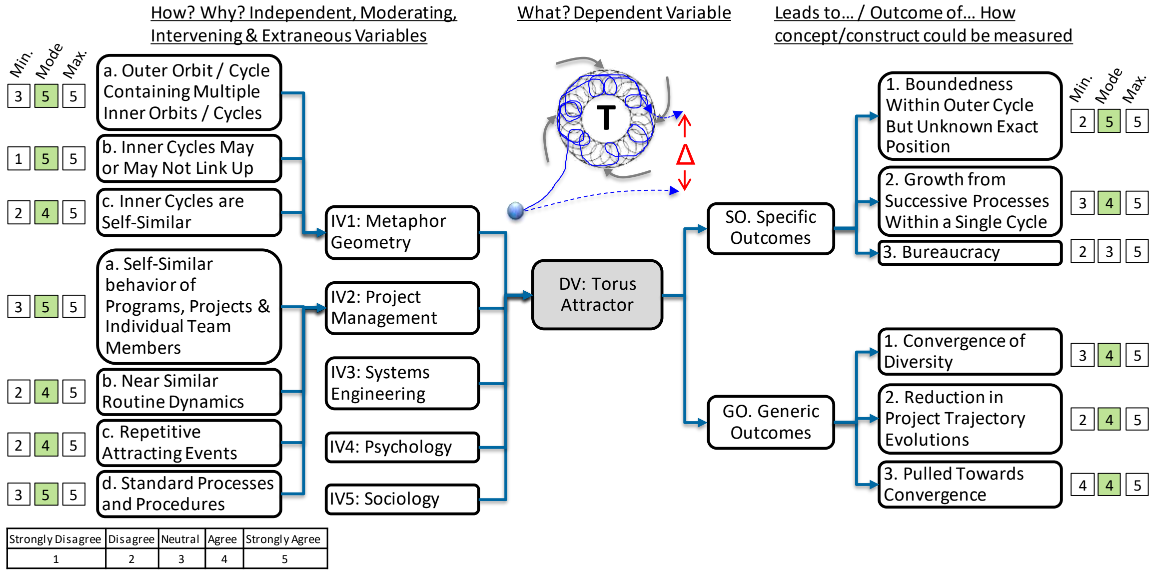

Figure 7-10: Likert Scale Scoring of the Torus Chaos Attractor Variance Model for Capital Projects

Most of the 14 capital project managers that were interviewed agreed with all the elements of the proposed torus chaos attractor variance model, except for the specific outcome of bureaucracy (SO.3), as shown in Figure 7-10. Some of the respondents indicated that they do not want bureaucracy as a specific outcome of a torus chaos attractor in their capital projects.

7.3.4.6 Conclusions on the Torus Chaos Attractor Metaphor for Capital Projects

The results obtained from 14 experienced capital project managers that were individually interviewed on various aspects of the torus chaos attractor, in the capital project environment indicate the following:

a) Respondents were able to provide examples of this metaphor in capital projects as shown in Table 7-8
b) Respondents were able to provide characteristics of this metaphor in capital projects as shown in Table 7-9
c) Two respondents provided value statements for this metaphor as shown in Table 7-10
d) Respondents were able to mostly agree (mode = 4 or 5) on relevant independent variables of torus chaos attractor (dependent variable) as shown in Figure 7-10
e) Respondents mostly agree on the local converging effect of a torus chaos attractor in a capital project for the specific and generic outcomes as shown in Figure 7-10.

Based on these observations for the current exploratory research it is concluded that:

a) Respondents were able to understand the torus chaos attractor metaphor, as displayed and explained in Figure 7-9
b) Respondents were able to transfer the torus chaos attractor metaphor, as displayed and explained in Figure 7-9, to the capital project environment
c) Respondents indicated that the presence of a torus chaos attractor in a capital project environment as evaluated in the variance model shown in Figure 7-10 could lead to local convergence.

It is recommended for future research that in-depth interviews be conducted with experienced capital project managers, using these exploratory research results as a starting point, to gain a better understanding of the torus chaos attractor phenomena to enable the formulation of an updated variance model.

7.3.5 Results for the Butterfly Chaos Attractor in Capital Projects

7.3.5.1 Interview Question for Butterfly Chaos Attractor Metaphor

A few different schematic representations of the butterfly chaos attractor metaphor are shown in Figure 7-11. These chaos attractor metaphors were shown and explained by the researcher to the capital project managers who were individually interviewed during the Round 2 interviews.

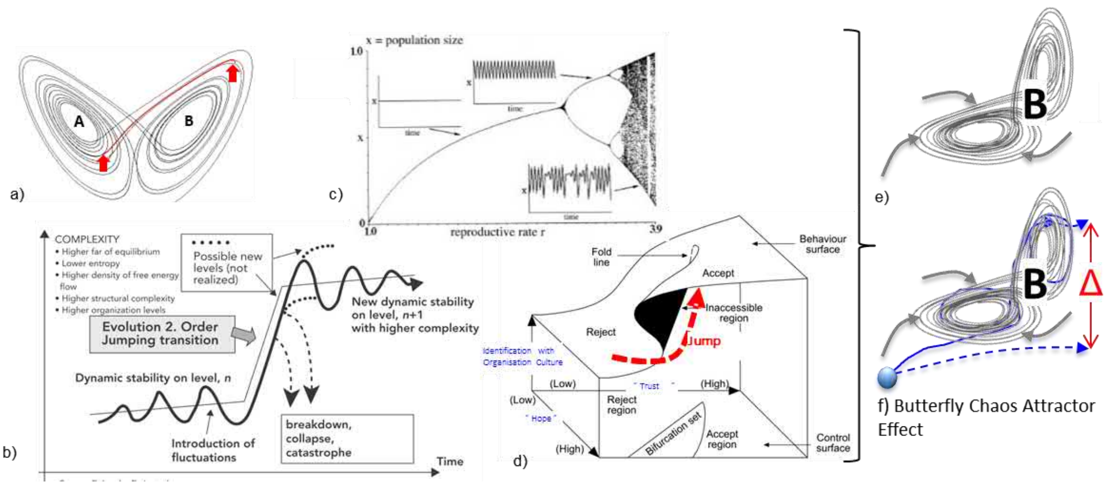

Figure 7-11: Sketches for Butterfly Chaos Attractor Metaphors

The verbal explanations by the researcher of the butterfly chaos attractor metaphors as shown in Figure 7-11 were based on the chaos attractor metaphor models that were developed in Chapter 3, paragraph 3.5. Respondents were requested to provide examples and characteristics of such metaphors in the capital project environment. The verbal responses from respondents were captured, transcribed and analysed using the Atlas.ti software as explained in Chapter 4. The results of the analysed data for examples of butterfly chaos attractors are given in paragraph 7.3.5.2, while the characteristics are given in paragraph 7.3.5.3. Value statements about this metaphor were captured in paragraph 7.3.5.4 and the results for the scoring of the variance model in paragraph 7.3.5.5. Conclusions for this section are provided in paragraph 7.3.5.6.

7.3.5.2 Examples of the Butterfly Chaos Attractors in Capital Projects

Examples of butterfly chaos attractors in capital projects as described by capital project managers during the Round 2 interviews are given in Table 7-11.

Table 7-11: Examples of Butterfly Chaos Attractors in Capital Projects

No.	Round 2 - Ref.	Examples of Butterfly Chaos Attractor Metaphors
1		**Outcome of Events**
2	1:57	Company E - Megaprojects M & K - Failure of FATs (trigger event) for Boiler Protection System caused sudden loss of hope & trust for performance
3	5:31	Change of technique, people or systems could lead to a sudden fall
4	10:36	Project I (Power Generation) - Multiple fatalities caused a drop-off
5	11:40	A jump occurs after obtaining financial close (things take off)
6	12:58	Missing ill-conceived milestone dates cause a fall
7	13:39	After reaching a trigger point in losing hope & trust, there is an immediate step down (fall)
8		**Project Stage-Gates**
9	3:48	Mine development project that transition between pre-concept and concept design phases
10	7:25	Project stage-gate jumps (agree with Saynisch)
11	9:37	Only one jump at the very beginning of a project
12	12:54	Jumps at each project stage-gate
13	12:55	A go-ahead decision / green light at a stage gate represents a jump
14		**Group Dynamics**
15	4:33	About 25% into a project the team and leadership issues are sorted, and you can go up (jump)
16	4:34	After celebration of achievable but stretched milestones, it takes off (jump)
17	13:04	The jump occurs when you get the team dynamics correct

No.	Round 2 - Ref.	Examples of Butterfly Chaos Attractor Metaphors
18	13:05	Required megaproject fall during the storming phase
19		**Stakeholders**
20	1:58	On a failed project, company MHE entered with both finances and competence and caused a sudden jump in hope and trust that performance will happen
21	7:27	Direction change from a (key) stakeholder could lead to a fall
22	7:28	Agreement among stakeholders could lead to a jump
23		**Decisions**
24	2:58	Alter a long time of project uncertainty clarity on a decision and direction caused a sudden jump and traction
25	8:54	A firm management decision gives direction and a jump
26	8:56	Shareholder decision or lack thereof cause jump or fall
27		**Leadership**
28	2:59	Mediocre project suddenly gets traction with appointment of a strong leader (trigger)
29	5:30	Someone (important) that leaves the project could lead to a sudden fall
30		**Preparation for a Trigger Event**
31	6:34	Difficulties in commissioning C&I system and suddenly they get it working
32		**Project Reset**
33	10:35	Project I (Power Generation) - Settling all claims and a new agreement caused a jump
34		**Other**
35	14:35	Project G (train infrastructure) - Sudden jump by people between different transportation systems

Table 7-11 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for this Research Question = 55

Examples of the butterfly chaos attractor metaphor, as explained in Figure 7-11, were given by capital project managers, that were individually interviewed, related to: outcome of events; project stage-gates; group dynamics; stakeholders; decisions; preparation for a trigger event; project reset and others as shown in Table 7-11. Note that the details of the characteristic jump or fall of the butterfly chaos attractor need to be better defined in follow-up research. Respondents only provided examples of jumps and falls that could happen when certain trigger events occurred.

The examples given by respondents for the outcome of events in capital projects covered both the characteristic jump and fall of a butterfly chaos attractor. A jump in capital project activities, enthusiasm or momentum may occur after achieving financial closure and things take off (R2-Ref. 11:40). The respondent may have referred to various project activities as “things”. The other examples were for the characteristic sudden fall that seems to occur after: losing hope and trust with the occurrence of a specific event (R2-Ref. 1:57 and 13:39);

missing ill-conceived deadlines (R2-Ref. 12:58); multiple fatalities (R2-Ref. 10:36) or a change in technique, people or systems (R2-Ref. 5:31).

Respondents seem to agree with the sudden jumps (R2-Ref. 7:25) that occur at a project stage-gate, as described by Saynisch (2010) and shown in Figure 7-11(b) (R2-Ref. 12:54). The go-ahead decision in a capital project could represent a sudden jump (R2-Ref. 12:55) but jumps also seem to occur in mine development projects between the pre-concept and concept design phases (R2-Ref. 3:48). Respondent 9 believed only one jump occurs at the very beginning of a capital project (R2-Ref. 9:37).

Examples were also given for the seemingly required falls and jumps related to group dynamics in a capital project. During the initial stages of a capital project a storming phase might cause a fall in motivation (R2-Ref. 13:05), but by skilful management of the group dynamics (R2-Ref. 13:04) it seems that after reaching an achievable but stretched target, a jump may occur (R2-Ref. 4:34). According to the experience of Respondent 4, this jump may occur after about 25% of the schedule of a capital project (R2-Ref. 4:33).

On a recovery project low levels of hope and trust seemed to jump to higher levels and were triggered by another company (MHE) that provided finances and competence to the project (R2-Ref. 1:58). Similarly, agreement among stakeholders could lead to a jump in a capital project (R2-Ref. 7:28). However, a directional change in a capital project by stakeholders could lead to a fall (R2-Ref. 7:27).

Decisions could also cause either a jump or a fall in a capital project as suggested by the butterfly chaos attractor. Clarity on a decision and direction (R2-Ref. 2:58) and a firm management decision (R2-Ref. 8:54) could cause a jump in a capital project. However, a lack of shareholder decisions could lead to a fall (R2-Ref. 8:56). When a strong leader is appointed to a struggling capital project, the project gets traction and there appears to be a sudden jump (R2-Ref. 2:58). A firm management decision also seems to cause a sudden jump (R2-Ref. 8:54). Similarly, a shareholder decision could cause a jump (R2-Ref. 8:56) in a capital project or the lack of a decision may cause a fall (R2-Ref. 8:56). Appointing a strong leader in a capital project could cause a jump (R2-Ref. 2:59) while the departure of an important stakeholder could cause a sudden fall in a capital project (R2-Ref. 5:30).

A capital project re-set situation, where all the claims are settled, and a new management team is appointed could cause a jump (R2-Ref. 10:35). The behaviour of train riders could suddenly change from one transportation system to another and could be seen as a sudden jump (R2-Ref. 14:35).

7.3.5.3 Characteristics of the Butterfly Chaos Attractor in Capital Projects

The results for the characteristics of butterfly chaos attractors as given by capital project managers that were interviewed during the Round 2 interviews are given in Table 7-12.

Table 7-12: Description of the Characteristics a Butterfly Chaos Attractor in Capital Projects

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:59	The trust started to fade - first the trust and later on the hope that the event can be fixed	Resource	Butterfly Chaos Attractor
2	4:35	Norming group dynamics phase (team, leadership, goals, responsibilities) contributes to jump trigger		
3	7:29	Close to the jump / bifurcation point people get excited and start to interact		
4	12:56	After project stage-gate jump there is a different energy in the team and a different starting platform		
5	12:57	A project going to a stage-gate gives confidence		
6	12:61	Team recognition-based approach uplift team spirit and contribute to a trigger event		
7	12:63	Unconsciously everybody moves from a state of distress to an excitement stage (jump)		
8	12:66	A fall during the forming stage is necessary in order to have a jump at the performance stage		
9				
10	2:60	Preparation, procedures and the right people contributed to the trigger event	Integration	
11	3:44	A decision based on multiple options creates a trigger to transition from concept to higher level of design		
12	3:45	A lot of churning in one spot to find a viable solution that acts as a jump to take you forward		
13	7:26	Considering different concepts or options leads to agreement on preferred option at stage-gate and then jump to implement single option		
14	8:55	Your single biggest jump is coming with decision making		
15				
16	11:41	After the jump, the project becomes fruitful	Scope	
17	12:59	Missing ill-conceived milestones cause a sudden realisation of a loss of things that was never there		
18	12:62	Achieving small milestone and full team recognition contribute to a jump event		
19				

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
20	6:35	Just give me one more day in my project and it can cause a major positive effect	Time	
21	10:37	A jump happens in a short space of time		
22				
23	12:60	Not acknowledging of technocrat advice cause questioning of leadership and a loss of trust and hope	Stakeholders	
24				
25	3:43	A critical mass needs to be reached	General	
26	3:46	Triggered jumps at different levels also occur within a single phase (such as concept design)		
27	9:38	Never a sudden jump in projects - only gradual development		
28	13:37	I do not see an upward jump only going up slowly		
29	13:38	This attractor is only able to generate a fall not a jump		
30	13:40	Jumps and falls are almost like hysteresis in personal behaviour (up and down paths differ)		

Table 7-12 Notes: Managers. Unique 1st Order Terms Captured and Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for the Butterfly Chaos Attractor Aggregate Construct. Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 55

The number of unique 1st order terms per ISO 21500 subject group, as shown in Table 7-12, varied per 2nd order concept for: resource (z = 8); integration (5); scope (z = 3); time (z = 2) and stakeholders (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject groups: cost; risk; quality; procurement and communication. The remainder of the 1st order terms were assigned to the general 2nd order concept category.

Respondents provided some characteristics related to the resources ISO 21500 subject group related to team dynamics. Team process dynamics are described by forming, storming, norming and performing (Robbins, 2005). A 'fall' during the forming stage seems necessary in order to have a butterfly chaos attractor jump at the performance stage (R2-Ref. 12:66). The norming process is believed to contribute to a jump trigger event (R2-Ref. 4:35). There could be early warning signs close to the occurrence of a jump in a capital project as project team members get excited and start to interact more than before (R2-Ref. 7:29). Recognising team member efforts in a capital project may uplift team spirit and may contribute to a trigger event (R2-Ref. 12:61). These processes may also happen unconsciously when the whole project team jumps from a state of distress to a state of excitement (R2-Ref. 12:63). A project that reaches the stage-gate review may give confidence to the project team and a jump may occur (R2-Ref. 12:57). After a butterfly chaos attractor jump in a capital project there is a different energy in the team as well as a different starting platform (R2-Ref. 12:56). The fading of first the trust followed by hope that the project event can be fixed (R2-Ref. 1:59) could describe the conditions before a potential trigger event in a capital project.

Another characteristic of a butterfly chaos attractor is the sensitive dependence on initial conditions (Lorenz, 1995; Lorenz, 2000). Respondent 6 hinted toward this characteristic by stating that being given another day in a capital project could cause a major positive effect (R2-Ref. 6:35). Such butterfly chaos attractor jumps could happen in a short space of time (R2-Ref. 10:37). When the project leadership does not heed sound technical advice from technocrats, they may start questioning the leadership with a resulting loss of trust and hope (R2-Ref. 12:60), that eventually may lead to a sudden fall in confidence.

A few unique 1st order quotation terms related to the general characteristics of butterfly chaos attractors in capital projects could not be allocated to any ISO 21500 subject groups. One respondent believed a critical mass needs to be reached before the butterfly jump or fall would occur (R2-Ref. 3:43). Butterfly chaos attractor jumps are not constrained to the overall project level but may also occur at different levels within a single phase (R2-Ref. 3:46). This remark seems to resemble a fractal nature of butterfly chaos attractors (Fractal Foundation, 2009). Another interesting comment was made by Respondent 13 who noted that the parts of jumps and falls within capital projects differ i.e. they resemble the principle of hysteresis (R2-Ref. 13:40) (Rao, 1990). Two respondents noted that the butterfly jumps are never sudden but only occur slowly (R2-Ref. 9:38 and 13:37) while one respondent noted that the butterfly chaos attractor is only able to fall and not jump (R2-Ref. 13:38).

7.3.5.4 Value Statements for the Butterfly Chaos Attractor in Capital Projects

Four of the capital project managers (Respondents 3, 5, 9 and 13) expressed value statements in terms of a butterfly chaos attractor during the Round 2 interview as shown in Table 7-13.

Table 7-13: Value Statements for the Butterfly Chaos Attractor Metaphor in Capital Projects

No.	Round 2 - Ref.	Value Statements for Butterfly Chaos Attractors
1	3:42	"Yes, this (butterfly chaos attractor) is definitely more abstract"
2	5:32	"This (the butterfly chaos attractor) makes more sense that a whirlybird (torus

No.	Round 2 - Ref.	Value Statements for Butterfly Chaos Attractors
		chaos attractor)."
3	9:36	"I do not agree that the butterfly attractor exists."
4	13:41	"Development through a series of bifurcation jumps. No, I do not want jumps in my projects."

Table 7-13 Notes: made by Capital Project Managers. Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 55

Two value statements were obtained on the possible existence of the butterfly chaos attractor (R2-Ref. 3:42 and 5:32) in capital projects and two that doubt the existence of this chaos attractor (R2-Ref. 9:36 and 13:41). Respondent 3 indicated that for him the butterfly chaos attractor is more abstract compared to the previous chaos attractors that were discussed in the interview i.e. fixed-point, limit-cycle and torus. Respondent 5 indicated that the butterfly chaos attractor made more sense to him compared to the torus chaos attractor (R2-Ref. 5:32).

7.3.5.5 Variance Model for Butterfly Chaos Attractor in Capital Projects

Capital project managers who were interviewed individually during the Round 2 interviews were exposed to a variance model for a butterfly chaos attractor as shown in Figure 7-12. This model was derived from various literature references, from various fields of science, on the conceptualisation and application of butterfly chaos attractors as was discussed in Chapter 3, paragraph 3.5. Each element of this model in terms of independent variables, dependent variables and outcomes was verbally explained to each respondent and questions of clarification were answered. Each respondent was asked to apply a Likert scale score with a range between 1 (strongly disagree) – 5 (strongly agree) to each of the elements of the variance model as they apply to the capital project environment based, on their experience in capital projects. The minimum (min.), mode and maximum (max.) values were recorded for the independent variables and the chaos attractor outcomes as shown in Figure 7-12. Mode values of 4 (agree) and 5 (strongly agree) were marked in green as shown.

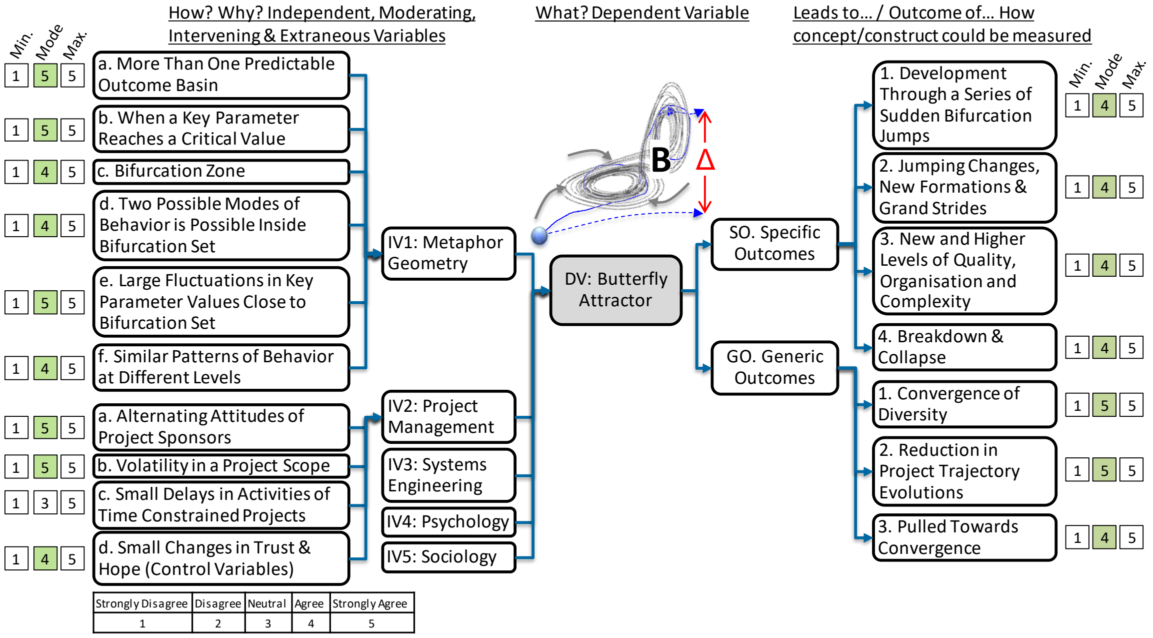

Figure 7-12: Likert Scale Scoring of the Butterfly Chaos Attractor Variance Model for Capital Projects

Most of the capital project managers that rated and scored the butterfly chaos attractor variance model agreed with the elements that were displayed for this model in Figure 7-12 (mode 4 = agree or mode 5 = strongly agree). One exception was that small delays in the activities of a time constrained capital project could have a huge effect on the project outcome (IV2:c). No new independent variables were defined by respondents for systems engineering, psychology or the sociology dimensions.

7.3.5.6 Conclusions on the Butterfly Chaos Attractor Metaphor for Capital Projects

The results obtained from 14 experienced capital project managers that were individually interviewed on various aspects of the butterfly chaos attractor in the capital project environment indicate the following:

a) Respondents were able to provide examples of this metaphor in capital projects as shown in Table 7-11
b) Respondents were able to provide characteristics of this metaphor in capital projects as shown in Table 7-12
c) Four respondents provided value statements for this metaphor as shown in Table 7-13
d) Respondents were able to mostly agree (mode = 4 or 5) on relevant independent variables of butterfly chaos attractor (dependent variable) as shown in Figure 7-12

e) Respondents mostly agree on the local converging effect of a butterfly chaos attractor in a capital project for the specific and generic outcomes as shown in Figure 7-12.

Based on these observations for the current exploratory research it is concluded that:

a) Respondents were able to understand the butterfly chaos attractor metaphor, as displayed and explained in Figure 7-11
b) Respondents were able to transfer the butterfly chaos attractor metaphor, as displayed and explained in Figure 7-11, to the capital project environment
c) Respondents indicated that the presence of a butterfly chaos attractor in a capital project environment as evaluated in the variance model shown in Figure 7-12 could lead to local convergence.

It is recommended that for future research in-depth interviews be conducted with experienced capital project managers, using these exploratory research results as a starting point, to gain a better understanding of the butterfly chaos attractor phenomena to enable the formulation of an updated variance model.

7.3.6 Results for the Strange Chaos Attractor in Capital Projects

7.3.6.1 Interview Question for Strange Chaos Attractor Metaphor

A number of different schematic representations of the strange chaos attractor metaphor are shown in Figure 7-13. These chaos attractor metaphors were shown and explained by the researcher to capital project managers that were individually interviewed during the Round 2 interviews.

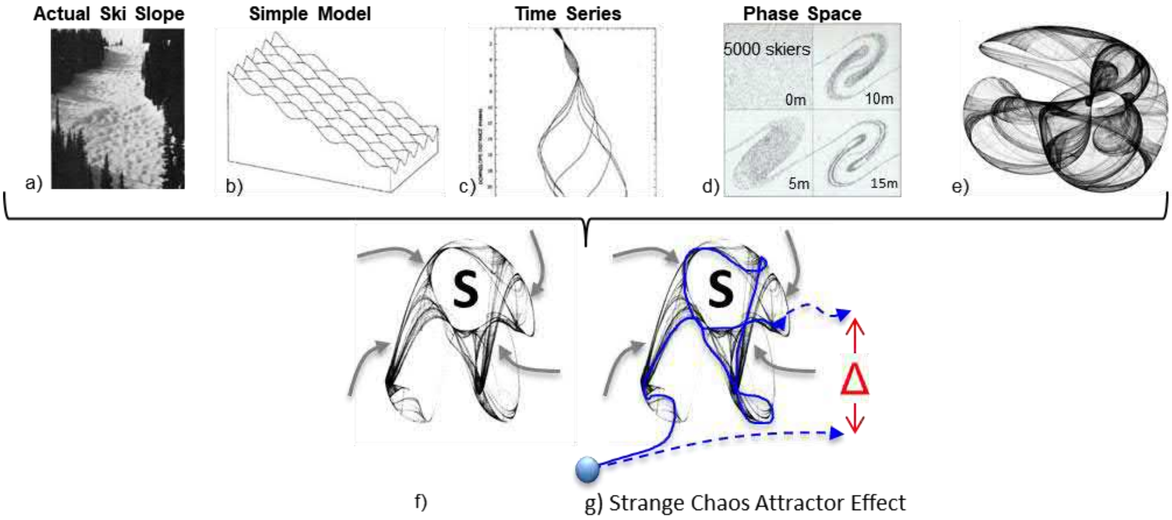

Figure 7-13: Sketches of Strange Chaos Attractor Metaphors

The verbal explanations given by the researcher to the respondents of the strange chaos attractor metaphor as shown in Figure 7-13 were based on the chaos attractor metaphor models that were developed in Chapter 3, paragraph 3.5. Respondents were requested to provide examples and characteristics of such metaphors in the capital project environment. The verbal responses from respondents were captured, transcribed and analysed using the Atlas.ti software as explained in Chapter 4. The results of the analysed data for examples of strange chaos attractors are given in paragraph 7.3.6.2 while the characteristics are given in paragraph 7.3.6.3. Value statements about this metaphor were captured in paragraph 7.3.6.4 and the results for the scoring of the variance model in paragraph 7.3.6.5. Conclusions for this section are provided in paragraph 7.3.6.6.

7.3.6.2 Examples of the Strange Chaos Attractors in Capital Projects

Examples of strange chaos attractors in capital projects as described by capital project managers during the Round 2 interviews are given in Table 7-14.

Table 7-14: Examples of Strange Chaos Attractors in Capital Project Mangers

No.	Round 2 - Ref.	Examples of Strange Chaos Attractor Metaphors
1		**Leadership**
2	2:62	Leadership
3	3:51	The same leader strangely cause attraction in small projects but not in a megaproject
4	4:37	Good leadership cause people to pull in the same direction
5	5:34	A stronger person will attract more people to a specific cause

No.	Round 2 - Ref.	Examples of Strange Chaos Attractor Metaphors
6	7:31	Paths of least resistance pattern could explain project leadership style
7	9:41	A leader with good track record
8	11:43	Plant start-up manager taking a chaotic project towards in-time completion
9	12:68	Leaders with balanced task/technical and human dynamics skills strangely cause project convergence
10		**Culture**
11	3:49	Culture
12	6:37	Strange gathering of people at 9h45 to talk about work
13	7:33	Celebrating small successes strangely helps convergence
14	8:58	Routine strangely attracts
15		**Policy & Procedure**
16	1:62	Company E - Employers agent leniency on contractual payment advances caused strange contractor behaviour
17	1:66	Changing the delegation of authority of the employer's agent caused a reduction in unsubstantiated claims from distressed contractors
18		**Other**
19	10:40	All my management experience that worked in one department did not work in another

Table 7-14 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for this Research Question = 40

Eight respondents mentioned leadership (R2-Ref. 2:62) as an example of a strange chaos attractor in capital projects as shown in Table 7-14, based on the explanation provided by the researcher for the various representations of strange chaos attractors in Figure 7-13. Respondent 11 mentioned that a plant start-up and commissioning manager was somehow able to take a chaotic project toward in-time completion (R2-Ref. 11:43) and he could attribute this event to a strange chaos attractor. Good (R2-Ref. 4:37) and strong (Ref. 5:34) leaders who are able to strangely cause capital project convergence (pull in the same direction) seem to have a number of qualities such as a balanced technical and human dynamics skill (R2-Ref. 12:68) and a good track record (R2-Ref. 9:41). However, the same leader who strangely caused chaos attraction and convergence in small projects was not able to do the same in a megaproject (R2-Ref. 3:51). Similarly, the project management experience that seemed to work in one department did not work in another (R2-Ref. 10:40).

Project culture (R2-Ref. 3:49) was also seen by capital project managers as a strange chaos attractor in capital projects. Respondent 6 has seen a strange gathering of project team members at a specific time to talk about project related issues (R2-Ref. 6:37). The celebration of small successes in capital projects seems to strangely help for project convergence (R2-Ref. 7:33). Routine in a capital project is believed to cause strange chaos attraction (R2-Ref. 8:58). Routine in this context could perhaps point to "the way we do things in this capital project" and may not be the same as the repetitive cycles as found in the limit-cycle chaos attractor (Figure 7-7) and the torus chaos attractor (Figure 7-9).

The lenient manner in which an employer's agent executed payment advances caused strange contractor behaviour (R2-Ref. 1:62). When the delegation of authority was changed it strangely caused a reduction in unsubstantiated claims from distressed contractors (R2-Ref. 1:66).

7.3.6.3 Characteristics of the Strange Chaos Attractor in Capital Projects

The results for the characteristics of strange chaos attractors as given by capital project managers that were interviewed during the Round 2 interviews are given in Table 7-15.

Table 7-15: Description of the Characteristics a Strange Chaos Attractor in Capital Projects

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	2:63	Leadership is a funny form of authenticity and trust	Resource	Strange Chaos Attractor
2	2:64	Genuine qualities in leaders cause people to follow them		
3	2:65	A team bond and network of relationships		
4	11:47	Project vision, yes, that is where congruency happened		
5	11:48	A lack of adaptability of team members cause projects to fail		
6	12:69	Recognition of local talent (acknowledgement) and ownership contributed to project success		
7	14:39	For me it is focus that help to convergence and project success		
8				
9	11:44	Not following the classical sequential approach	Time	
10	11:45	Time critical schedule contributed to successful project outcome		
11	14:38	Project start with a plan - you have to continuously re-plan to ensure convergence		
12				
13	11:46	Duplication of start-up approach in one project did not work in another	Integration	
14	11:50	Team processes not rigidly followed		
15				
16	1:64	Contractors under financial pressure follow the same pattern as those who got successful advance payments	Procurement	
17				

No.	Round 2 - Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
18	1:65	Information sharing among distressed contractors caused a multitude of requests for payment advances to the employer's agent	Communication	
19				
20	4:39	It is all of these other little things that you do not plan but they have an impact on the overall convergence	General	
21	5:35	A strange attractor incorrectly constituted may become a dangerous repeller		
22	5:36	The presence of a strange chaos attractor will cause or prevent convergence to occur		
23	9:42	I do not understand how the leader gets it right (the project)		
24	10:39	Yes, things work but you do not know how		
25	11:49	From the outside you would think it is chaos but not! There is method in the madness		

Table 7-15 Notes: Unique 1st Order Terms Captured and Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for the Strange Chaos Attractor Aggregate Construct. Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 40

The number of unique 1st order terms per ISO 21500 subject group, as shown in Table 7-15, varied per 2nd order concept for: resource (z = 7); time (z = 3); integration (z = 2); procurement (z = 1) and communication (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject groups: stakeholder; scope; time; cost; risk and quality. The remainder of the 1st order terms were assigned to the general 2nd order concept category.

A few resource related characteristics of a strange chaos attractor in capital projects were given by capital project managers that were interviewed as shown in Table 7-15. It is the genuine qualities in project leaders that cause project team members to follow them (R2-Ref. 2:64), as leadership may be perceived as a form of authority and trust (R2-Ref. 2:63). When there is recognition of local talent and project ownership, it seems to contribute to strange attraction and project success (R2-Ref. 12:69). A project vision (R2-Ref. 11:47) and focus (R2-Ref. 14:39) could also act as a strange chaos attractor as this is where congruency could happen (R2-Ref. 11:47). However, a lack of adaptability of team members could cause capital projects to fail (R2-Ref. 11:48). This could imply that a lack of adaptability could prevent the formation of a strange chaos attractor.

Strange chaos attractor behaviour in capital projects related to time were explained by respondents as not following a classical sequential approach (R2-Ref. 11:44). By having a time critical schedule, it was as if project activities were strangely drawn to it (R2-Ref. 11:45) and the project plan that is continually updated throughout the life-cycle of the capital project strangely attract all activities to ensure convergence (R2-Ref. 14:38).

Strange chaos attractors do not seem to follow a checklist logic as the duplication of a project start-up approach that was applied in one capital project did not work in another (R2-Ref. 11:46). Team processes that are not rigidly followed may also represent a strange chaos attractor in capital projects (R2-Ref. 11:50). A strange chaos attractor also seems to cause patterns of behaviour as contractors under financial pressure followed the same pattern as those who got successful advance payments (R2-Ref. 1:64). The communication related aspect of a strange chaos attractor may also be evident when the information sharing among distressed contractors caused a multitude of requests for payment advances to the employer's agent (R2-Ref. 1:65).

The effect of a strange chaos attractor in capital projects is perhaps explained by all of these other little things that do not get planned but they have an impact on the overall project convergence (R2-Ref. 4:39). The working of a strange chaos attractor is difficult to understand (R2-Ref. 10:39) for example how a leader causes project convergence (R2-Ref. 9:42). Chaos attractors at work in capital projects may seem chaotic from the outside but their effect is the opposite (R2-Ref. 11:49). However, a strange attractor incorrectly constituted in a capital project may become a dangerous repeller (R2-Ref. 5:35) therefore the presence of a strange chaos attractor could either cause or prevent project convergence to occur (R2-Ref. 5:36).

7.3.6.4 Value Statements for the Strange Chaos Attractor in Capital Projects

Four of the capital project managers (Respondents 1, 3, 4 and 9) expressed value statements in terms of a strange chaos attractor during the Round 2 interview as shown in Table 7-16.

Table 7-16: Value Statements for the Strange Chaos Attractor Metaphor in Capital Projects

No.	Round 2 - Ref.	Value Statements for Strange Chaos Attractors
1	1:61	"Was this the attractor for this behaviour? Yes. And this is also not in PMBOK."
2	3:50	"There is definitely an association with capital projects"
3	4:38	"PMBOK would also not talk about this stuff"
4	9:39	"So, again the term strange attractor is a difficult term for me if you understand what I getting to in the sense that I would like have order and I would not like to see it as

No.	Round 2 - Ref.	Value Statements for Strange Chaos Attractors
		a strange attractor but as a attractor that I planned and I appointed, in this case, the particular person for that purpose to react in a certain way."
5	9:40	"I do not think we can afford to do things that way and appointing people in the hope that, without understanding, that he would be able to get it right and make a success of the (that failed) project"

Table 7-16 Notes: Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 40

Respondents 1, 3 and 4 expressed a value for the concept of strange chaos attractors in capital projects as it contributes to the understanding (R2-Ref. 3:50) of how capital projects work and noted that this concept is not discussed in the PMBOK (ISO, 2012) (R2-Ref. 1:61 and 4:38) as shown in Table 7-16. Respondent 9 disagrees and felt that the strange chaos attractor concept is difficult for him to understand and only subscribes to the linear world for cause-and-effect (R2-Ref. 9:39 and 9:40).

7.3.6.5 Variance Model for Strange Chaos Attractors in Capital Projects

Capital project managers who were interviewed individually during the Round 2 interviews were exposed to a variance model for a strange chaos attractor as shown in Figure 7-14. This model was derived from various literature references, from various fields of science, on the conceptualisation and application of strange chaos attractors as was discussed in Chapter 3, paragraph 3.5. Each element of this model in terms of independent variables, dependent variables and outcomes was verbally explained to each respondent and questions of clarification were answered. Each respondent was asked to apply a Likert scale score with a range between 1 (strongly disagree) – 5 (strongly agree) to each of the elements of the variance model, as they apply to the capital project environment based on their experience in capital projects. The minimum (min.), mode and maximum (max.) values were recorded for the independent variables and the chaos attractor outcomes as shown in Figure 7-14. Mode values of 4 (agree) and 5 (strongly agree) were marked in green as shown.

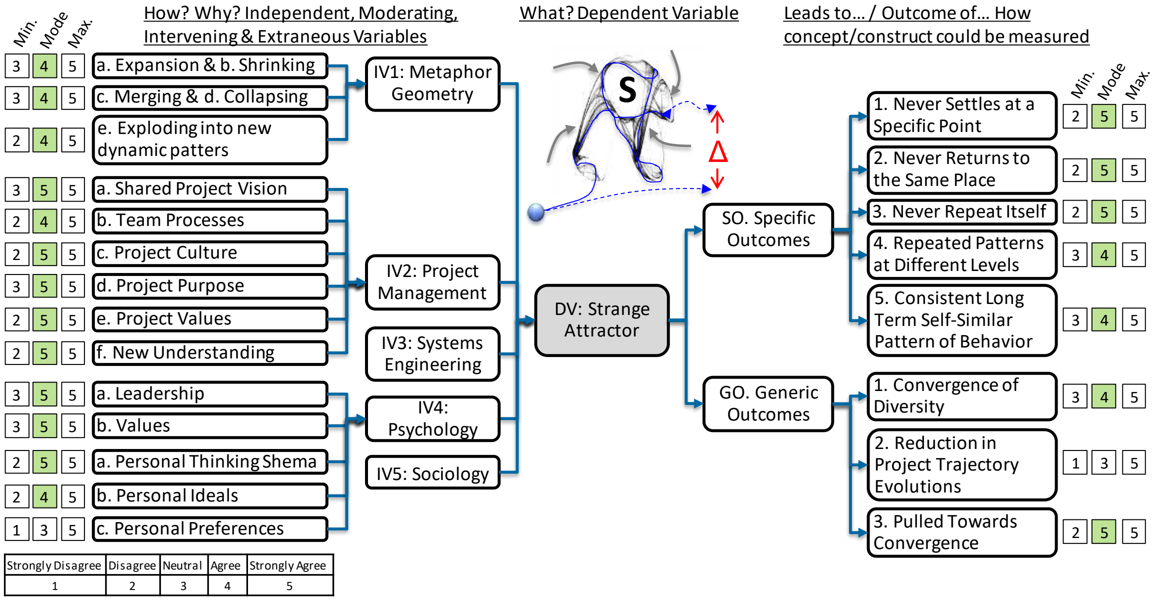

Figure 7-14: Likert Scale Scoring of the Strange Chaos Attractor Variance Model for Capital Projects

Most of the capital project managers that rated and scored the strange chaos attractor variance model agreed with the elements that were displayed for this model as shown in Figure 7-14 (mode 4 = agree or mode 5 = strongly agree). The two exceptions were for the independent variable personal preferences (IV4:c) and the generic outcome that a strange chaos attractor causes a reduction in project trajectory evolutions (GO.2).

7.3.6.6 Conclusions on the Strange Chaos Attractor Metaphor for Capital Projects

The results obtained from 14 experienced capital project managers who were individually interviewed on various aspects of the strange chaos attractor in the capital project environment indicate the following:

a) Respondents were able to provide examples of this metaphor in capital projects as shown in Table 7-14
b) Respondents were able to provide characteristics of this metaphor in capital projects as shown in Table 7-15
c) Four respondents provided value statements for this metaphor as shown in Table 7-16
d) Respondents were able to mostly agree (mode = 4 or 5) on relevant independent variables of strange chaos attractor (dependent variable) as shown in Figure 7-14
e) Respondents mostly agree on the local converging effect of a strange chaos attractor in a capital project for the specific and generic outcomes as shown in Figure 7-14.

Based on these observations for the current exploratory research it is concluded that:

a) Respondents were able to understand the strange chaos attractor metaphor, as displayed and explained in Figure 7-13
b) Respondents were able to transfer the strange chaos attractor metaphor, as displayed and explained in Figure 7-13, to the capital project environment
c) Respondents indicated that the presence of a strange chaos attractor in a capital project environment as evaluated in the variance model shown in Figure 7-14 could lead to local convergence.

It is recommended that for future research in-depth interviews be conducted with experienced capital project managers, using these exploratory research results as a starting point to gain a better understanding of the strange chaos attractor phenomena to enable the formulation of an updated variance model.

7.3.7 Conclusions on the Local Converging Effect of Individual Chaos Attractors in Capital Projects

The objective of this section was to determine if individual chaos attractors are able to cause local convergence in a capital project as is stated in the first main research question in Chapter 1, paragraph 1.9.1 as:

> ***Does the use of individual chaos attractors lead to local convergence from chaos to order of capital project elements and their trajectories?***

However, before attempting to answer this question, respondents were first introduced to the separate metaphor concepts for: a fixed-point chaos attractor; fixed-point chaos repeller; limit-cycle chaos attractor; torus chaos attractor; butterfly chaos attractor and strange attractor. These metaphors were explained to respondents and they were requested to provide examples and characteristics of each metaphor in the capital project environment. Finally, respondents were asked to score a variance model for each of the chaos attractors separately. The variance models consisted of independent variables as well as outcomes of the dependent variables (the chaos attractors). The outcomes contained statements about the local convergence effect of each chaos attractor. Value statements were recorded during the interview discussions on each chaos attractor separately.

Responses obtained from 14 respondents for capital project examples, characteristics, value statements, independent variables and local convergence effect, are shown in Table 7-17.

Table 7-17: Responses Obtained from Capital Project Managers During Individual Interviews on Various Aspects of each Type of Chaos Attractor

No.	Description of Chaos Attractor and Reference	Examples Related to Capital Projects	Characteristics Related to Capital Projects	Value Statements Related to Capital Projects	Independent Variables Related to Capital Projects	Local Convergence Effect Related to Capital Projects
1	Fixed-point chaos attractor (paragraph 7.3.1)	✓	✓	✓	✓	✓
2	Fixed-point chaos repeller (paragraph 7.3.2)	✓	✓	✗	✓	✓
3	Limit-cycle chaos attractor (paragraph 7.3.3)	✓	✓	✗	✓	✓
4	Torus chaos attractor (paragraph 7.3.4)	✓	✓	✓	✓	✓
5	Butterfly chaos attractor (paragraph 7.3.5)	✓	✓	✓	✓	✓
6	Strange chaos attractor (paragraph 7.3.6)	✓	✓	✓	✓	✓

Legend: ✓ = Results Recorded, ✗ = No Results Recorded

The following conclusions are made for each of the chaos attractors based on the overall responses, as contained in Table 7-17, as well as the results for each individual chaos attractor that were covered in each sub-section of paragraph 7.3:

a) Conclusions on the fixed-point chaos attractor:

i. Respondents were able to provide examples of this metaphor in capital projects

ii. Respondents were able to provide characteristics of this metaphor in capital projects

iii. Respondents provided value statements for this metaphor

iv. Respondents were able to identify relevant independent variables for the variance model related to capital projects

v. Respondents were able to identify local convergence outcomes for the variance model related to capital projects
vi. Respondents were to be able to understand the metaphor
vii. Respondents were able to transfer the metaphor to the capital project environment

b) Conclusions on the fixed-point chaos repeller:

i. Respondents were able to provide examples of this metaphor in capital projects
ii. Respondents were able to provide characteristics of this metaphor in capital projects
iii. Respondents were not able to provide value statements for this metaphor
iv. Respondents were able to identify relevant independent variables for the variance model related to capital projects
v. Respondents were able to identify local convergence outcomes for the variance model related to capital projects
vi. Respondents were to be able to understand the metaphor
vii. Respondents were able to transfer the metaphor to the capital project environment

c) Conclusions on the limit-cycle chaos attractor:

i. Respondents were able to provide examples of this metaphor in capital projects
ii. Respondents were able to provide characteristics of this metaphor in capital projects
iii. Respondents were not able to provide value statements for this metaphor
iv. Respondents were able to identify relevant independent variables for the variance model related to capital projects
v. Respondents were able to identify local convergence outcomes for the variance model related to capital projects
vi. Respondents were to be able to understand the metaphor
vii. Respondents were able to transfer the metaphor to the capital project environment

d) Conclusions on the torus chaos attractor:

i. Respondents were able to provide examples of this metaphor in capital projects

ii. Respondents were able to provide characteristics of this metaphor in capital projects
iii. Respondents were able to provide value statements for this metaphor
iv. Respondents were able to identify relevant independent variables for the variance model related to capital projects
v. Respondents were able to identify local convergence outcomes for the variance model related to capital projects
vi. Respondents were to be able to understand the metaphor
vii. Respondents were able to transfer the metaphor to the capital project environment

e) Conclusions on the butterfly chaos attractor:

i. Respondents were able to provide examples of this metaphor in capital projects
ii. Respondents were able to provide characteristics of this metaphor in capital projects
iii. Respondents provided value statements for this metaphor
iv. Respondents were able to identify relevant independent variables for the variance model related to capital projects
v. Respondents were able to identify local convergence outcomes for the variance model related to capital projects
vi. Respondents were to be able to understand the metaphor
vii. Respondents were able to transfer the metaphor to the capital project environment

f) Conclusions on the strange chaos attractor:

i. Respondents were able to provide examples of this metaphor in capital projects
ii. Respondents were able to provide characteristics of this metaphor in capital projects
iii. Respondents provided value statements for this metaphor
iv. Respondents were able to identify relevant independent variables for the variance model related to capital projects
v. Respondents were able to identify local convergence outcomes for the variance model related to capital projects
vi. Respondents were to be able to understand the metaphor
vii. Respondents were able to transfer the metaphor to the capital project

environment.

Based on the responses in this section, that were obtained from experienced capital project managers, it is concluded that it is possible that each chaos attractor, given the right circumstances, could cause local convergence in a capital project.

7.4 Results for the Overall Converging Effect of a Group of Chaos Attractors in Capital Projects

A two-stage process was followed to obtain exploratory research results from capital project managers on the overall converging effect of a group of chaos attractors that are arranged in a specific configuration in a capital project landscape. The first stage was to expose respondents to different landscapes of chaos attractors with an overall converging effect that were found in literature and to ask the respondents to provide examples and characteristics for these metaphors in capital projects. The second stage was to expose respondents to a specifically designed landscape of chaos attractors and chaos repeller (as was designed by the researcher) for a capital project across its life cycle and obtain the views of respondents on the overall converging effect in an actual capital project.

This two-step approach firstly tried to determine if the respondents were able to understand the landscape of chaos attractor metaphors, as found in literature for various sciences and transfer them to the capital project domain. The second objective was to determine if respondents were able to understand a specifically designed landscape of chaos attractors and chaos repeller metaphor for a capital project and were able to provide examples, characteristics and value statements.

7.4.1 Results for a Metaphor for a Landscape of Chaos Attractors

7.4.1.1 Interview Question for the Landscape of Chaos Attractors Metaphor

During the first part of the individual interviews, capital project managers were exposed to the individual chaos attractors (fixed-point chaos attractor and repeller, limit-cycle chaos attractor, torus chaos attractor, butterfly chaos attractor and strange chaos attractor) to try and determine the local converging effect of each chaos attractor on its own in a capital project. The results were given in paragraph 7.3. The objective of the final part of the individual interviews was to determine the overall converging effect of a group of chaos attractors arranged in a specific format in a landscape. Respondents were exposed to the various landscapes of chaos attractors, as found in the literature from various sciences and shown in Figure 7-15.

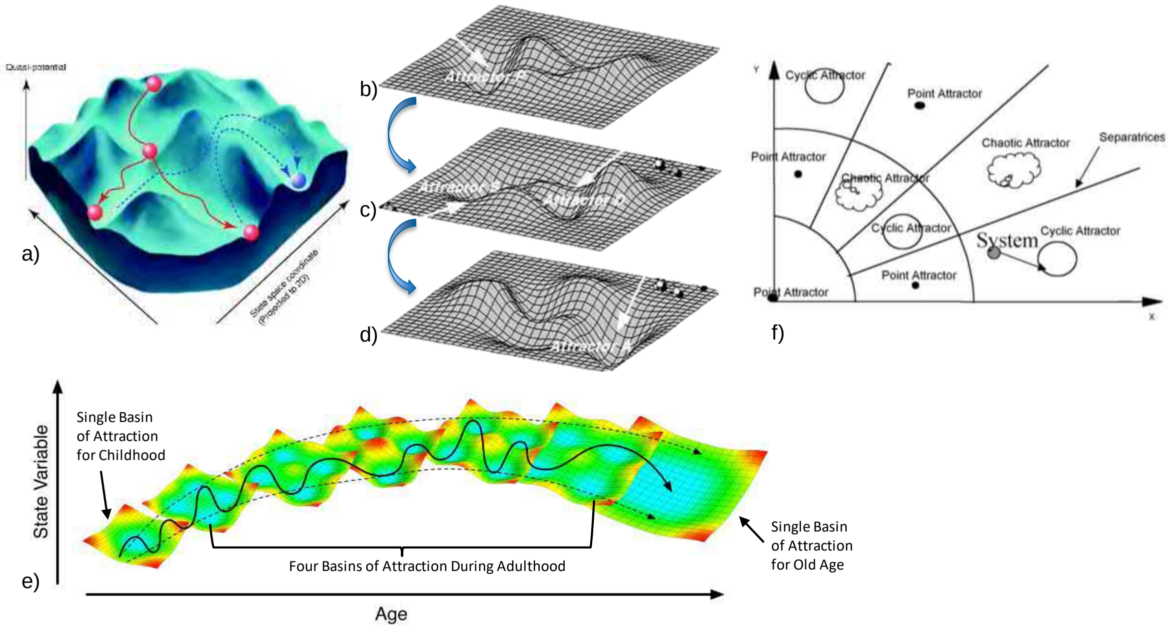

Figure 7-15: Sketches for Landscapes of Chaos Attractors

A verbal explanation for each landscape of chaos attractors was given by the researcher, based on the descriptions found in the literature and as was given in Chapter 3, paragraph 3.5. Respondents were then asked to provide examples and characteristics for a landscape of chaos attractors and their overall converging effect in their capital projects. The verbal responses from respondents were captured, transcribed and analysed using the Atlas.ti software as explained in Chapter 4. The results of the analysed data for examples of a landscape of chaos attractors are given in paragraph 7.4.1.2 while the characteristics are given in paragraph 7.4.1.3. Conclusions on the landscapes of chaos attractors and their overall convergence effect are given in paragraph 7.4.1.4.

7.4.1.2 Examples of the Landscape of Chaos Attractors in Capital Projects

Examples of the landscape of chaos attractors metaphor in capital projects, as described by capital project managers during the Round 2 interviews, that were based on the sketches in Figure 7-15, are given in Table 7-18.

Table 7-18: Examples of a Landscape of Chaos Attractors in Capital Projects

No.	R2-Ref.	Examples of Landscapes of Chaos Attractors
1		**<u>Cost Savings</u>**
2	1:68	Company E - Project I - We could have saved between 10% - 20% on the

No.	R2-Ref.	Examples of Landscapes of Chaos Attractors
		megaproject cost if we had the elements of an attractor landscape in place
3		**Boundedness**
4	1:69	Company E - Gas turbine replacement project - Project trajectory, attractors and boundedness clearly laid out to the contractor
5	12:72	Megaprojects - More than one route exists in the landscape of chaos attractors
6		**Recognition**
7	4:43	I have seen them (landscapes with chaos attractors) in lots of projects
8	12:76	Megaproject represents a landscape of multiple kinds of chaos attractors

Table 7-18 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for this Research Question = 17

Examples of the overall converging effect of a landscape of chaos attractors in a capital project seem to relate to cost savings, boundedness and recognition, as shown in Table 7-18. Respondent 1 noted that if they had an appropriate landscape of chaos attractors in place for their project, they could have realised a cost saving of between 10% and 20% (R2-Ref. 1:68). Examples of the boundedness characteristic of a landscape of chaos attractors were noted for a gas turbine project (R2-Ref. 1:69) and in various megaprojects (R2-Ref. 12:72). More than one capital project trajectory exists in the landscape of chaos attractors (R2-Ref. 12:76) based on the position and anticipated effect of the chaos attractor configurations (R2-Ref. 1:69) but the final capital project trajectory is bounded to this landscape. Respondent 4 acknowledged that he has seen this landscape of chaos attractors in many capital projects (R2-Ref. 4:43) while Respondent 12 noted that a megaproject represents a landscape of multiple kinds of chaos attractors (R2-Ref. 12:76).

7.4.1.3 Characteristics of a Landscape of Chaos Attractors in Capital Projects

The results for the characteristics of a landscape of chaos attractors as given by capital project managers that were interviewed during the Round 2 interviews and for the metaphor sketches in Figure 7-15, are given in Table 7-19.

Table 7-19: Description of the Characteristics for a Landscape of Chaos Attractors in Capital Projects

No.	R2-Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	1:70	Up-front positioning of attractor landscape, attractors & repellers provided a clear route for the contactor to follow	Integration	Landscape of Chaos Attractors
2	1:72	Project trajectory can definitely be influenced by landscape of chaos attractors		
3	2:67	Experience will indicate what attractors to put in place in order to guide project behaviour		

No.	R2-Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
4	3:54	An understanding of project management, the industry and the lay of the land is required to apply the landscape of chaos attractors		
5	3:55	The chaos attractor landscape will have to be tailored for each industry		
6	5:38	Something that is good in one landscape is not good in another landscape		
7	5:39	A landscape of chaos attractors requires fluidness - there is no fixed answer to anything		
8				
9	5:40	A good leader in one role is not necessarily a good leader in another role	Resource	
10	8:63	If you know what the different chaos attractors are doing - you can use them in capital projects		
11				
12	12:73	All stakeholders have seen different landscapes and different possibilities	Stakeholder	
13	12:74	You want to contain stakeholders to 3 - 4 trajectories		
14				
15	1:78	New technology and disruptors cause you to be more in a chaotic than ordered mode	Risk	

Table 7-19 Notes: Unique 1st Order Terms Captured and Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for the Landscape of Chaos Attractors Aggregate Construct. Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 17

The number of unique 1st order terms per ISO 21500 subject group, as shown in Table 7-19, varied per 2nd order concept for: integration (z = 7); resource (z = 2); stakeholder (z = 2) and risk (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject group: scope; time; cost; quality; procurement and communication.

The first statement from Respondent 1 (R2-Ref. 1:70) that was allocated to the ISO 21500 subject group of integration in Table 7-19 perhaps captures the suspected essence of a landscape of chaos attractors. That is to guide overall capital project behaviour towards convergence. Respondent 1 noted that the up-front positioning of a chaos attractor landscape that contains attractors and repellers, could provide a clear route for a contactor to follow (R2-Ref. 1:72) during the life cycle of a capital project. The overall capital project trajectory could be influenced by a landscape of chaos attractors (R2-Ref. 1:72). How to design this landscape of chaos attractors to have the desired overall convergence effect seems to be dependent on experience (R2-Ref. 2:67). An understanding of capital project management, the capital project industry (R2-Ref. 3:55) and the lay of the land seems to be required to apply the landscape of chaos attractors (R2-Ref. 3:54). However, a landscape of chaos attractors requires fluidness - there is no fixed answer to anything (R2-Ref. 5:39) because a chaos attractor configuration that is good in one landscape is not necessarily good in another landscape (R2-Ref. 5:38).

Resource related characteristics contains leadership and desired behaviour. A good leader in one role is not necessarily a good leader in another role (R2-Ref. 5:40). This comment could apply to the non-linearity of capital projects and perhaps indicate that if a strange chaos attractor has been planned in both a small and megaproject, the same project leader may be successful in one project but fail in the other. It seems that a specific leader needs to be matched to a specific chaos attractor to have the desired overall convergence effect. Furthermore, a fundamental understanding of each chaos attractor seems like a prerequisite for using them effectively to create overall convergence in capital projects (R2-Ref. 8:63).

It also appears that it may be possible for stakeholders to see different landscapes and different possibilities (R2-Ref. 12:73) and therefore you have to contain their behaviour to 3 - 4 possible trajectories (R2-Ref. 12:74), by the suitable placement of chaos attractors in the capital project life-cycle landscape. However, when dealing with new and disruptive technology the chaos attractor landscape may be more in a chaotic than ordered mode (R2-Ref. 1:78) and awareness is required that the landscape of chaos attractors could be dynamic and changing, as shown in Figure 7-15(b-d).

7.4.1.4 Conclusions on the Landscape of Chaos Attractors Metaphor for Capital Projects

The results obtained from 14 experienced capital project managers who were individually interviewed on various aspects of a landscape of chaos attractors in the capital project environment indicate the following:

a) Respondents were able to provide examples of this metaphor in capital projects as shown in Table 7-18
b) Respondents were able to provide characteristics of this metaphor in capital projects as shown in Table 7-19
c) No value statements were recorded.

Based on these observations for the current exploratory research it is concluded that:

a) Respondents were able to understand the landscape of chaos attractors metaphor, as displayed and explained in Figure 7-15
b) Respondents were able to transfer landscape of chaos attractors metaphor, as displayed and explained in Figure 7-15, to the capital project environment.

These results allowed for the further exploratory testing on the overall convergence effect of a specifically designed landscape of chaos attractors for a capital project.

7.4.2 Results for a Metaphor for a Specifically Designed Landscape of Chaos Attractors for Capital Projects

7.4.2.1 Interview Question for a Specifically Designed Landscape of Chaos Attractors for Capital Projects Metaphor

An attempt was made by the researcher to generate a specifically designed landscape of chaos attractors across two stage-gates of a capital project, as shown in Figure 7-16. Note that the term 'landscape of chaos attractors' implies the presence of both chaos attractors and repellers. Their combined effect is presumed to be chaos attraction as well as local and overall convergence. Due to the presence of this pre-designed landscape of chaos attractors, the suggested trajectory of the capital project towards overall project convergence is suggested by the blue line in Figure 7-16. Capital project managers that were individually interviewed were exposed to this specifically designed landscape of chaos attractors and an explanation of the functioning of the landscape was given by the researcher based on the descriptions provided in Chapter 3, paragraph 3.5.

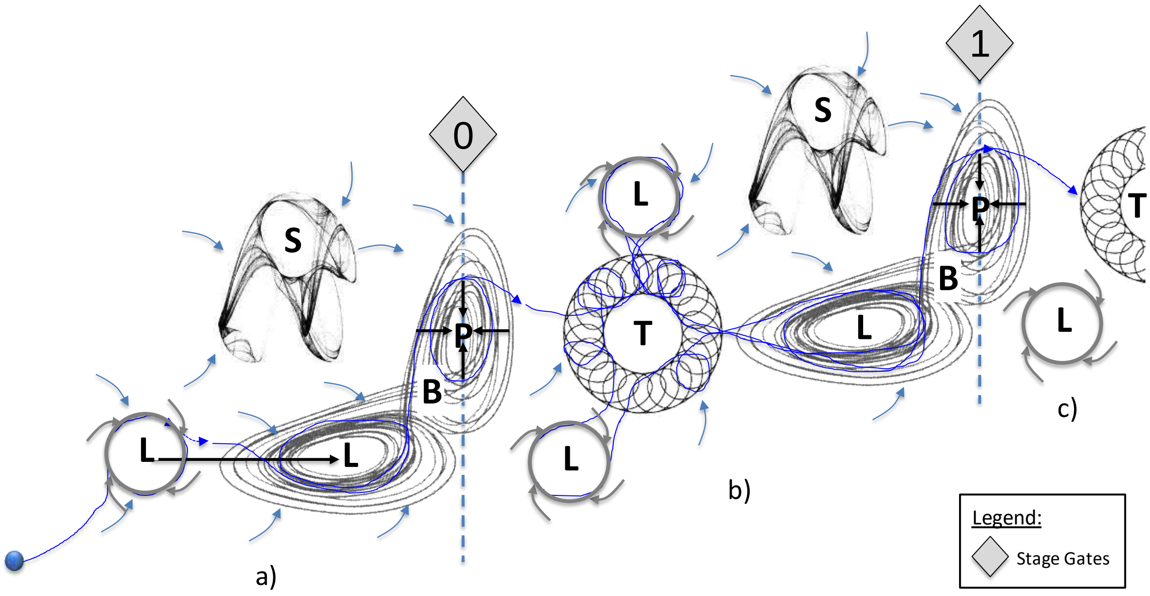

Figure 7-16: Researcher's Sketch for a Specifically Designed Landscape of Five Types of Chaos Attractors (Fixed-Point, Limit-Cycle, Torus, Butterfly and Strange) that are Configured Across (a - c) Two Stage-Gates (0 and 1) of a Capital Project

Respondents were then informed that the landscape of chaos attractors that was specifically designed for capital projects, as shown in Figure 7-16, was duplicated across all stage-gates of a capital project as a fractal structure (Fractal Foundation, 2009), as shown in Figure 7-17. Fixed-point chaos repellers were positioned at the boundary of the project as shown. The suggested effect of such a landscape of chaos attractors was to cause overall capital project convergence (blue dotted line) and a guided and bounded trajectory of the capital project (thick green line) towards the project goals as shown in Figure 7-17. Verbal explanations were given by the researcher, based on the descriptions of Figure 7-16 and Figure 7-17, as was described in detail in Chapter 3, paragraph 3.5.

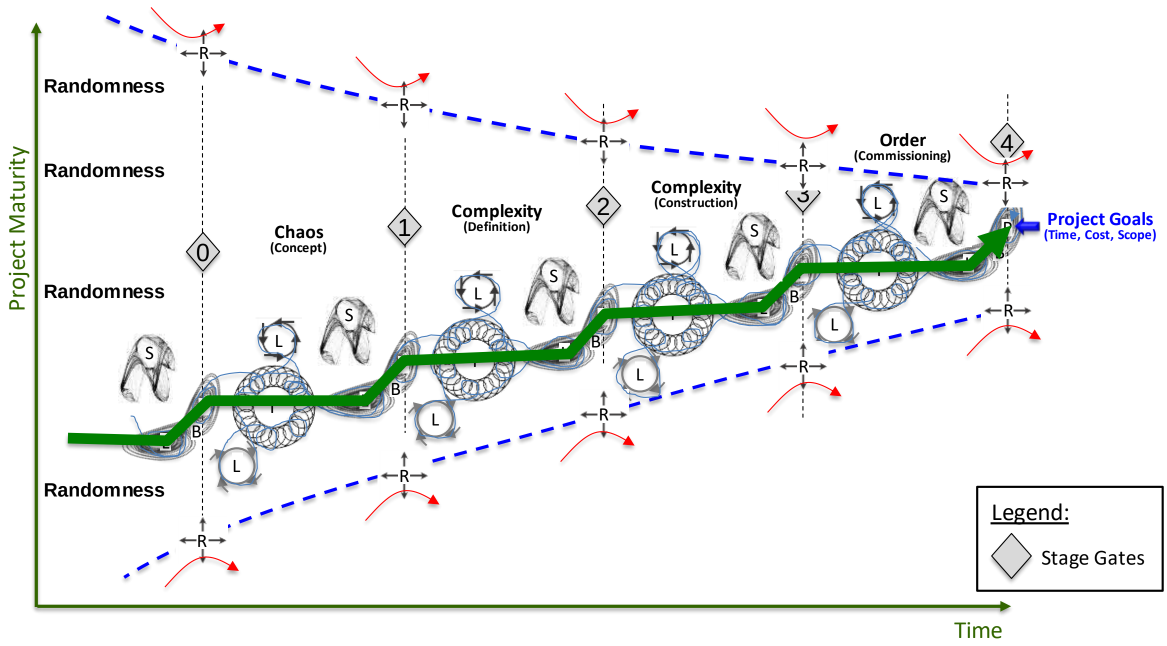

Figure 7-17: Researcher's Sketch for a Specifically Designed Landscape of Six Chaos Attractors that are Configured Across the Life Cycle of a Capital Project to Cause Local and Overall Convergence from Chaos to Order

Each of the respondents was asked during the individual interview if: a) such a landscape could be generated with to cause an overall converging effect and b) to provide capital project examples and characteristics of such landscapes of chaos attractors. The verbal responses from respondents were captured, transcribed and analysed using the Atlas.ti software as explained in Chapter 4. The results of the analysed data for examples of a landscape of chaos attractors are given in paragraph 7.4.2.2 while the characteristics are given in paragraph 7.4.2.3. Value statements were made by the respondents on the metaphor as shown in Figure 7-16 and Figure 7-17. The results of the value statements were captured in paragraph 7.4.2.5 and conclusions in paragraph 7.4.2.6.

7.4.2.2 Examples of a Specifically Designed Landscape of Chaos Attractors in Capital Projects

The results for examples in capital projects of a specifically designed landscape of chaos attractors, as given by capital project managers that were interviewed during the Round 2 interviews, for the metaphor sketches in Figure 7-16 and Figure 7-17, are given in Table 7-20.

Table 7-20: Examples of a Specifically Designed Landscape of Chaos Attractors for Capital Projects

No.	R2-Ref.	Examples of a Specific Designed Landscape of Chaos Attractors for Capital Projects
1	1:74	Company E - Megaproject M - Multiple iterations to achieve the project go-ahead decision
2	1:75	Company E - Wind Farm project
3	6:41	The strange attractor could create disorder - people at work at 8h00 but only start to work at 10h00
4	7:34	My current project looks like this landscape if you look backwards
5	9:45	Government water affairs department - In chaos and in need of a quantum jump at the beginning of the project
6	11:56	In every project start-up and commissioning is chaos therefore map Archetype C3 onto this landscape
7	13:48	During commissioning you get this step-up (jump) and then you get hand-over and a step-down

Table 7-20 Notes: Round 2, Sample Size n = 14, Number of Quotations Analysed for this Research Question = 63

Respondent 1 mentioned that a megaproject followed multiple iterations during project development, as indicated in Figure 7-16 and Figure 7-17 and converged to achieve the project go-ahead decision (R2-Ref. 1:74). Similarly, a wind farm project (R2-Ref. 1:75) and the current capital project of Respondent 7 resembles the proposed landscape of chaos attractors when viewed in retrospect (R2-Ref. 7:34). Respondent 11 noted that during commissioning there was a similar stage-gate jump as indicated in the specifically designed landscape of chaos attractors, but when you get to hand-over there is a step down (R2-Ref. 13:48). This step down may be a reference to the value leakage that could take place because of improper hand-over from the project team to the operational team (Deloitte, 2013). This value leakage was also noted by capital project managers who described the archetype C3d – order-bubble-order-operational-bubble as was shown in Chapter 6, paragraph 6.4.3.4.

Respondent 11 recommended that during capital project start-up and commissioning there is a situation of chaos and that archetype C3 should be mapped onto this landscape (R2-Ref. 11:56). Respondent 9 referred to the government Water Affairs department that is in chaos and in need of a quantum jump at the beginning of the project (R2-Ref. 9:45). It is accepted that these two respondents could identify with the specifically designed landscape of chaos attractors that were shown in Figure 7-16 and Figure 7-17 but that they suggest an improvement of the specific positioning of the chaos attractor configurations.

However, Respondent 6 noted that a strange chaos attractor does not only create convergence and order. The strange attractor could create disorder; for example, people that arrive at work at 8h00 but only start to work at 10h00 (R2-Ref. 6:41). Perhaps the suggestion is that the landscape of chaos attractors could only create overall project convergence if the individual chaos attractors function in a convergence mode otherwise local divergence might occur that could inhibit overall capital project convergence.

7.4.2.3 Characteristics of a Specifically Designed Landscape of Chaos Attractors in Capital Projects

The results for the characteristics of a specifically designed landscape of chaos attractors, as given by capital project managers that were interviewed during the Round 2 interviews, and for the metaphor sketches in Figure 7-16 and Figure 7-17, are given in Table 7-21.

Table 7-21: Description of the Characteristics of a Specifically Designed Chaos Attractor Landscape in Capital Projects

No.	R2-Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
1	3:58	Projects needs to be managed to ensure jumps at stage-gates and not gradually evolve	Integration	Specifically Designed Landscape of Chaos Attractors
2	3:59	When you do not have enough churning or the correct trigger you may have a fall (failure) of an immature project		
3	3:60	The effect of the butterfly chaos attractor at the project stage-gate is what is supposed to happen		
4	5:41	The landscape of chaos attractors represents the perfect world - the real world is more dynamic that this		
5	8:64	If you are missing either leadership or processes overall convergence is not going to happen		
6	11:53	Convergence occurs for each project phase		
7	11:54	Each project phase starts at a higher level of maturity		
8	11:55	You have both overall converging cone and a converging cone for each project phase		
9				
10	4:44	People start to form bonds as you move through the project	Resource	
11	5:43	You need to continuously apply management energy to obtain convergence		
12	7:36	The strange chaos attractor creates organisational culture		
13	13:18	I think leadership will be quite important		
14	13:19	Trust has to be built throughout the project to avoid a trust deficit		
15				
16	2:71	A torus chaos attractor in a capital project helps to reduce scope uncertainty	Scope	
17	5:47	You can go through a milestone without a huge jump such as		

No.	R2-Ref.	1st Order Terms	2nd Order Concepts	Aggregate Construct
		at the end of concrete works you are going to steel works		
18				
19	5:44	Government intervention in the middle of the project might require an additional aggressive fixed-point chaos attractor to get to an ordered state again	Stakeholder	
20				
21	2:69	At the start of a capital project the limit cycle chaos attractors are bigger than later on	General	
22	2:70	From the middle of the capital project life cycle the torus chaos attractors are much bigger and the limit cycle chaos attractors much smaller		
23	2:73	I think the strange chaos attractor is often underestimated		
24	2:74	The applicability, importance & impact of these chaos attractors differs for each project phase		
25	3:57	The butterfly chaos attractor is actually more dominant in explaining how a project progresses compared to the other chaos attractors in the landscape		
26	3:61	The torus and butterfly chaos attractors should be in parallel or overlap		
27	5:42	A different set of chaos attractors may be required to keep a project in an ordered state		
28	5:46	Maybe you need a different configuration of chaos attractors to deal with different issues		
29	6:40	Agree with the landscape without the two strange attractors		
30	9:44	The landscape configuration depends on the type of project and on the government organisation responsible for the project		
31	10:43	You need to understand the chaos attractors and what they can do and where to place them in the landscape		
32	11:57	You need a much stronger strange attractor during start-up and commissioning		
33	13:43	There are significant differences between project phases and the associated chaos attractor landscapes		
34	13:44	The different chaos attractors might have different effectiveness and influence on the project outcome		
35	13:45	A torus chaos attractor is good for improving and refining but bad for execution		
36	13:46	The torus chaos attractor is pivotal during the detail design phase		
37	13:47	Is the landscape perspective the same from the owner and contractors' point of view?		
38	13:49	Value leakage after hand-over		
39	13:50	The ability of the strange attractor to be a predictor is limited - it is rather supporting		
40	14:42	The landscape schema is repeatable over the whole project		

Table 7-21 Notes: Unique 1st Order Terms Captured and Allocated to 2nd Order Concepts (ISO 21500 Subject Groups and New Concepts) for the Specifically Designed Landscape of Chaos Attractors Aggregate Construct. Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for

this Research Question = 63

The number of unique 1st order terms per ISO 21500 subject group, as shown in Table 7-21, varied per 2nd order concept for: integration (z = 8); resource (z = 5); scope (z = 2) and stakeholder (z = 1). No 1st order terms from the responses could be assigned to the ISO 21500 subject groups of stakeholder, time, cost, risk, quality, procurement and communication.

A comment was made by Respondent 5 relating to the ISO 21500 integration subject group. He stated that the specifically designed landscape of chaos attractors for capital projects as shown in Figure 7-16 and Figure 7-17 represents the perfect world and that the real world is more dynamic (R2-Ref. 5:41). This comment seems to indicate that the landscape of chaos attractors is not static as for example in Figure 7-15(a) but dynamic with changes and evolutions of chaos attractors as was shown in Figure 7-15(b-d).

A further interesting comment relates to convergence. It seems that without either leadership or processes, overall convergence is not going to happen (R2-Ref. 8:64). Convergence also seems to occur for each capital project phase (R2-Ref. 11:53) and therefore an overall converging cone as well as a converging cone for each project phase (R2-Ref. 11:55) seems to exist. Each project phase seems to start at a higher level of project maturity (R2-Ref. 11:54).

The third comment relating to the ISO 21500 integration subject group relates to the butterfly chaos attractor jumps at the capital project stage gates. Respondent 3 was of the opinion that projects need to be actively managed to ensure jumps at stage-gates and that they do not gradually evolve (R2-Ref. 3:58) as this is what is supposed to happen at a stage-gate (R2-Ref. 3:60). A butterfly chaos attractor jump at a capital project stage-gate requires sufficient effort or churning to activate the trigger event otherwise a fall might occur that could result in an immature project and possibly project failure (R2-Ref. 3:59).

The resource related characteristics of a specifically designed chaos attractor landscape seem to be related to management and leadership aspects. External energy in the form of continuous management energy, needs to be expended in a capital project in order to obtain convergence (R2-Ref. 5:43). This leadership energy (R2-Ref. 13:18) may be used to: form and strengthen bonds between project team members during the project life cycle (R2-Ref. 4:44); create a desired organisational culture using a strange chaos attractor (R2-Ref. 7:36);

and trust (R2-Ref. 13:19).

Two comments were made that relate to capital project scope. A torus chaos attractor in capital projects seems to help reduce scope uncertainty (R2-Ref. 2:71). This is probably because the many internal torus cycles would revisit the scope of work to be done. Respondent 5 noted that it is possible to go through a milestone where the scope of concrete works is completed and move on to steelworks without a noticeable butterfly chaos attractor jump (R2-Ref. 5:47). Perhaps not all milestones should be associated with butterfly chaos attractor jumps.

A stakeholder related comment was made by Respondent 5. After government intervention in the middle of a capital project, an additional aggressive fixed-point chaos attractor might be required to get the project to an ordered state again (R2-Ref. 5:44).

The remainder of this discussion pertains to the general characteristics of a specifically designed landscape of chaos attractors for a capital project as given in Table 7-21. It is suggested by Respondent 2 that at the start of a capital project the limit cycle chaos attractors are bigger than later on in the project life cycle (R2-Ref. 2:69). From the middle of the capital project life cycle, it is suggested that the torus chaos attractors are much bigger and the limit-cycle chaos attractors much smaller (R2-Ref. 2:70). The torus and butterfly chaos attractors should be in parallel or overlap (R2-Ref. 3:61) and a much stronger strange attractor may be needed during capital project start-up and commissioning (R2-Ref. 11:57). A torus chaos attractor is good for improving and refining capital project developmental processes but bad for execution (R2-Ref. 13:45). The torus chaos attractor could be pivotal during the detail design phase (R2-Ref. 13:46). The ability of the strange attractor to be a predictor is suggested to be limited - it could rather be supporting (R2-Ref. 13:50). The landscape schema is suggested to be repeatable over the whole project (R2-Ref. 14:42).

A different set of chaos attractors may be required to keep a project in an ordered state (R2-Ref. 5:42). Perhaps a different configuration of chaos attractors is needed to deal with different issues (R2-Ref. 5:46). Respondent 6 noted that he agreed with the suggested capital project landscape of chaos attractors, but the two strange chaos attractors should be excluded (R2-Ref. 6:40). The landscape configuration seems to depend on the type of project and on the government organisation responsible for the project (R2-Ref. 9:44).

The converging effect of the strange chaos attractor may often be underestimated (R2-Ref. 2:73). The butterfly chaos attractor is suggested to be more dominant in explaining how a project progresses compared to the other chaos attractors in the landscape (R2-Ref. 3:57).

The applicability, importance and impact of these chaos attractors may differ for each project phase (R2-Ref. 2:74). Therefore, in order to design a landscape of chaos attractors for capital projects it seems that an understanding is required of the chaos attractors and what they can do and where to place them in such as landscape (R2-Ref. 10:43). This is because there are significant differences between project phases and the associated chaos attractor landscapes (R2-Ref. 13:43). Also, the different chaos attractors might have different effectiveness and influences on the project outcome (R2-Ref. 13:44).

One respondent raised the interesting question when he asked if a landscape of chaos attractors is the same from the owner and contractors' point of view (R2-Ref. 13:47)? Respondent 13 noted the phenomenon of value leakage at capital project hand-over (R13:49).

7.4.2.4 Value Statements for a Specifically Designed Landscape of Chaos Attractors in Capital Projects

Value statements were captured from a total of 10 capital project managers who were individually interviewed during the Round 2 interviews as shown in Table 7-22.

Table 7-22: Value Statements for a Specifically Designed Landscape of Chaos Attractors Metaphor in Capital Projects

No.	R2-Ref.	Value Statements for a Specifically Designed Landscape of Chaos Attractors
1	1:73	"I think you can definitely, to some extent, influence this trajectory by being proactive on these types of things that are not in the books"
2	1:76	"You have put a totally different line of thinking in my head today around this now and how one would utilise this chaos theory in our environment (capital projects) - it is the first time - I need to reflect on it a bit but I can definitely see a place for it"
3	1:77	"Maybe there is more value to understand that there is chaos continuously and you have to create order out of chaos than trying to think you going to read the PMBOK book and you are going to setup a project and that is going to be successful"
4	2:72	"Absolutely. These things are all applicable"
5	3:53	"I think the PMBOK try to do some of that... to guide you in a certain way"
6	4:40	"Definitely you could portray the capital project landscape like this"
7	4:42	"I think this is something that you could definitely apply to capital project"
8	4:45	"I can definitely see that this can get you to the point where you know what button to push to get what reaction"

No.	R2-Ref.	Value Statements for a Specifically Designed Landscape of Chaos Attractors
9	7:35	"That is perfect (to explain) how you get going and the moment you do that step-up (butterfly chaos attractor jump) that is when you start getting your internal sprints much more - I am seeing it now. I can see that"
10	8:60	"To me this is very valid"
11	8:61	"There is definitely potential"
12	8:65	"Yes. It is worth further exploring"
13	8:66	"I think what it is saying is that to have your structured way of the project is one side of the coin. The other side of the coin is the reality in terms of the dynamics within the project and how that either benefit the project or derail it"
14	9:46	"I mean it is like left brain and right brain... but we as engineers try and be orderly... I mean coming back to your chaos and order.... we try to manage that right from the beginning that it (the project) is as orderly as possible and we do not like it to be chaotic"
15	10:44	"Previously you did not understand what was happening in the project - this gives you more of an understanding of what are those things that influence this (attractors) convergence or not. Or if a project just fails like that - why does it fail like that? I think it makes sense to me, I think you will need much more time on it like you have done to get it to a point where you can apply this. But as a concept I think - I agree. I think this has value for capital projects"
16	11:8	"Yes. I agree. I personally feel that the concepts that you have brought in together and trying to get all these things together - is doable. It requires some work, but it is doable. The aspects of attractor and repeller are wonderful because those are the things that you want to do more often (in projects). So, yes, it is doable. The way you have tried to put it (the chaos attractor landscape) into a form of a picture is fascinating! You are even going to this depth. The thing that is going to come out (of this research) is going to be revolutionary. This is new. This has not been thought off and I like the fact that you are even applying something that is outside of the normal (project paradigm). I like it!"
17	11:58	"It means that there is a lot of work that you have to do after this! Is the metaphor transferable? Yes, the answer is yes"
18	11:59	"Does the metaphor create new insight, a new understanding of where we are working? Yes, it does."
19	12:77	"Definitely there is something else that needs to be investigated beyond the current what is called: "Structured approach" as defined by PMBOK (Project Management Body of Knowledge) and various standards and which go beyond the project scientific formulas."
20	12:80	"I will say from the path (chaos attractor landscape) looks for me to talk to the key dynamics."

Table 7-22 Notes: Round 2 Interviews, Sample Size: n = 14, Number of Quotations Analysed for this Research Question = 63

It appears that the trajectory of a capital project could be influenced to some extent (R2-Ref. 1:73) by a specifically designed landscape of chaos attractors. The Project Management Body of Knowledge (PMBOK) is limited and only provides a partial explanation of how capital projects work and should work (R2-Ref. 1:77 and 3:53). Chaos theory and the landscape of chaos attractors may represent a new paradigm in thinking about capital projects (R2-Ref. 1:76, 4:40, 4:42, 7:35, 8:60, 8:66, 9:46, 10:44, 11:8, 11:59, 12:77 and 12:80) and the concepts portrayed may be applicable (R2-Ref. 2:72). This theory may help to better understand cause-and-effect in a complex capital project (R2-Ref. 4:45) and could be worthwhile to explore further (R2-Ref. 8:65 and 11:58).

7.4.2.5 Variance Model for a Specifically Designed Landscape of Chaos Attractors in Capital Projects

Capital project managers who were interviewed individually during the Round 2 interviews were exposed to a variance model for a specifically designed landscape of chaos attractors as shown in Figure 7-18. This model was derived from various literature references, from various fields of science, on the conceptualisation and application of strange chaos attractors as was discussed in Chapter 3, paragraph 3.5. Each element of this model in terms of independent variables, dependent variables and outcomes was verbally explained to each respondent and questions of clarification were answered. Each respondent was asked to apply a Likert scale score that ranged between 1 (strongly disagree) – 5 (strongly agree) to each of the elements of the variance model as they apply to the capital project environment, based on their experience in capital projects. The minimum (min.), mode and maximum (max.) values were recorded for the independent variables and the chaos attractor outcomes as shown in Figure 7-18. Mode values of 4 (agree) and 5 (strongly agree) were marked in green as shown.

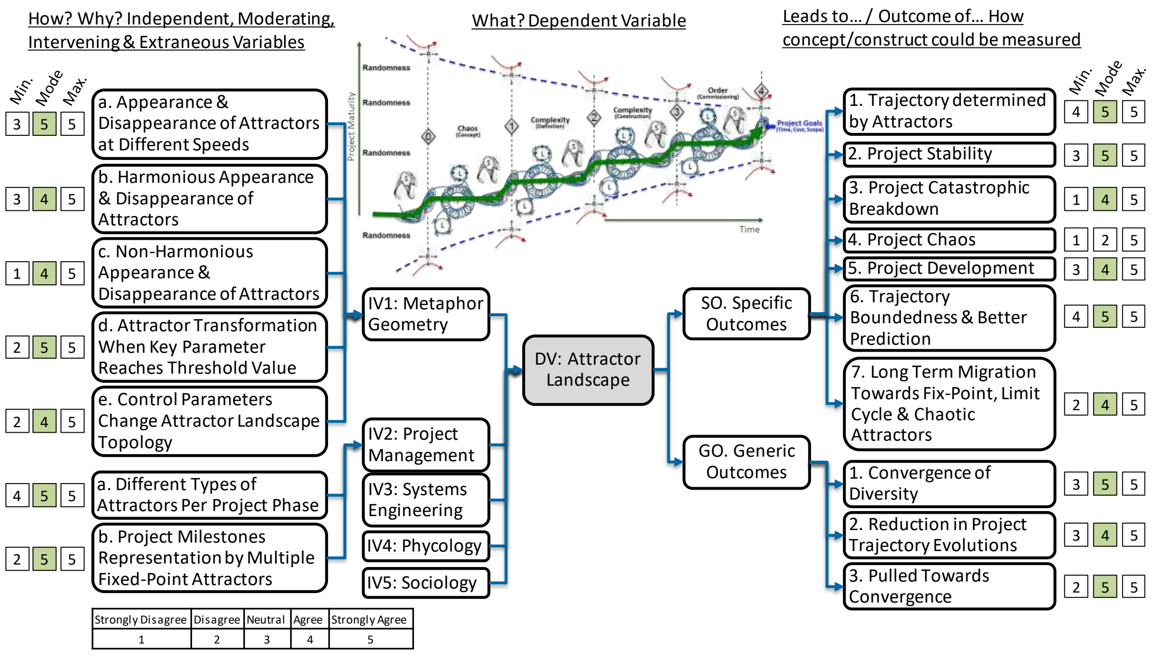

Figure 7-18: Likert Scale Scoring of the Landscape of Chaos Attractor Variance Model Specifically Designed for Capital Projects

Most of the capital project managers that rated and scored the specifically designed landscape of chaos attractor variance model agreed with the elements that were displayed as shown in Figure 7-18 (mode 4 = agree or mode 5 = strongly agree). The only exception was for the specific outcome SO.4. Most respondents agreed that a landscape of chaos attractors for a capital project that is inadequately designed would lead to project chaos.

7.4.2.6 Conclusions on a Specifically Designed Landscape of Chaos Attractors Metaphor for Capital Projects

The results obtained from 14 experienced capital project managers that were individually interviewed on various aspects of a specifically designed landscape of chaos attractors in the capital project environment indicate the following:

a) Respondents were able to provide examples of this metaphor in capital projects as shown in Table 7-20
b) Respondents were able to provide characteristics of this metaphor in capital projects as shown in Table 7-21
c) Ten of the 14 respondents provided value statements for this metaphor as shown in Table 7-22
d) Respondents were able to mostly agree (mode = 4 or 5) on relevant independent variables of a specifically designed landscape of chaos attractors (dependent variable) as shown in Figure 7-18
e) Respondents mostly agree on the overall converging effect of a specifically designed landscape of chaos attractors in a capital project for the specific and generic outcomes as shown in Figure 7-18.

Based on these observations for the current exploratory research it is concluded that:

a) Respondents were able to <u>understand</u> the landscape of chaos attractors metaphor, as displayed and explained in Figure 7-16 and Figure 7-17
b) Respondents were able to <u>transfer</u> the landscape of strange chaos attractors metaphor, as displayed and explained in Figure 7-16 and Figure 7-17, to the capital project environment
c) Respondents indicated that the presence of a landscape of strange chaos attractors in a capital project environment as evaluated in the variance model shown in Figure 7-18 could lead to <u>overall convergence</u>.

It is recommended that for future research in-depth interviews be conducted with experienced capital project managers, using these exploratory research results as a starting point, to gain a better understanding of a specifically designed landscape of chaos attractors phenomena to enable the formulation of an updated variance model.

7.4.3 Conclusions on the Overall Converging Effect of a Landscape of Chaos Attractors in Capital Projects

The objective of this section was to determine if a landscape of chaos attractors is able to cause overall convergence in a capital project as stated in the second main research question in Chapter 1, paragraph 1.9.1 as:

Does the use of combinations of different types of chaos attractors lead to overall convergence from chaos to order of capital projects?

The first configuration of a landscape of fixed-point chaos attractors, fixed-point chaos repellers, limit-cycle chaos attractors, torus chaos attractors, butterfly chaos attractors and strange attractors, as was found in the literature, that originated from various sciences, were presented to individually interviewed capital project managers. Their responses in terms of examples and characteristics of such landscapes in capital projects were recorded and analysed. The second configuration of chaos attractors was specifically designed by the researcher and mapped onto the life cycle of a capital project. Responses and scores were obtained from the capital project managers for examples, characteristics and value statements

Responses for these two research questions on a landscape of chaos attractors and a specifically designed landscape of chaos attractors for capital projects in terms of examples, characteristics, value statements, independent variables and the overall convergence effect, are shown in Table 7-23.

Table 7-23: Responses Obtained from Capital Project Managers During Individual Interviews on Various Aspects of Landscapes of Chaos Attractors

No.	Description of Chaos Attractor and Reference	Examples Related to Capital Projects	Characteristics Related to Capital Projects	Value Statements Related to Capital Projects	Independent Variables Related to Capital Projects	Overall Convergence Effect Related to Capital Projects
1	Landscape of chaos attractors	✓	✓	✗	N/A	N/A

No.	Description of Chaos Attractor and Reference	Examples Related to Capital Projects	Characteristics Related to Capital Projects	Value Statements Related to Capital Projects	Independent Variables Related to Capital Projects	Overall Convergence Effect Related to Capital Projects
	(paragraph 7.4.1)					
2	Specifically designed landscape of chaos attractors (paragraph 7.4.2)	✓	✓	✓	✓	✓

Legend: N/A = Not Applicable

The following conclusions are made for the two landscapes of chaos attractors based on the overall responses as contained in Table 7-23, as well as the results for each landscape of chaos attractors that was covered in each sub-section of paragraph 7.4:

a) Conclusions on the landscape of chaos attractors:
   i. Respondents were able to provide examples of this metaphor in capital projects
   ii. Respondents were able to provide characteristics of this metaphor in capital projects
   iii. Respondents did not provide value statements for this metaphor
   iv. Respondents were able to understand the metaphor
   v. Respondents were able to transfer the metaphor to the capital project environment

b) Conclusions on the specifically designed landscape of chaos attractors for a capital project:
   i. Respondents were able to provide examples of this metaphor in capital projects
   ii. Respondents were able to provide characteristics of this metaphor in capital projects
   iii. Respondents were able to provide value statements for this metaphor
   iv. Respondents were able to identify relevant independent variables for the variance model related to capital projects
   v. Respondents were able to identify overall convergence outcomes for the variance model related to capital projects
   vi. Respondents were able to understand the metaphor
   vii. Respondents were able to transfer the metaphor to the capital project environment.

Based on the evidence provided, by experienced capital project managers, on the specifically designed landscape of chaos attractors for a capital project it seems possible, given the right circumstances, this metaphor could cause overall convergence in a capital project.

7.5 Chaos Metaphor Recognition and ISO 21500 Subject Group Associations

Two additional sets of results were extracted from the responses obtained from capital project managers on chaos attractors. The first set of results relate to evidence that was obtained from the individual interviews that suggest that respondents recognised and understood the chaos attractor, repeller and landscape of chaos attractor metaphors. The second set of results relates to the allocation of descriptions of the characteristics of these metaphors to ISO 21500 subject groups. This was done to try and understand the similarity in terminology and concepts of chaos theory and the current project management paradigm.

7.5.1 Recognition of Chaos Attractor Metaphors by Capital Project Managers

The transcribed text of all 14 capital project mangers' responses to the research questions on the local convergence effect of individual chaos attractors as given in paragraph 7.3 and their responses for the overall capital project convergence as a result of a landscape of chaos attractors as given in paragraph 7.4, were analysed. All occurrences in the transcribed text were marked with the Atlas.ti software program where a respondent recognised any of the individual chaos attractors (fixed-point attractor, fixed-point repeller, limit-cycle, torus, butterfly or strange) or recognition of the landscape of chaos attractors. The numbers of recognitions per individual chaos attractor and for the landscape of chaos attractors were counted and expressed as a percentage, as shown in Figure 7-19.

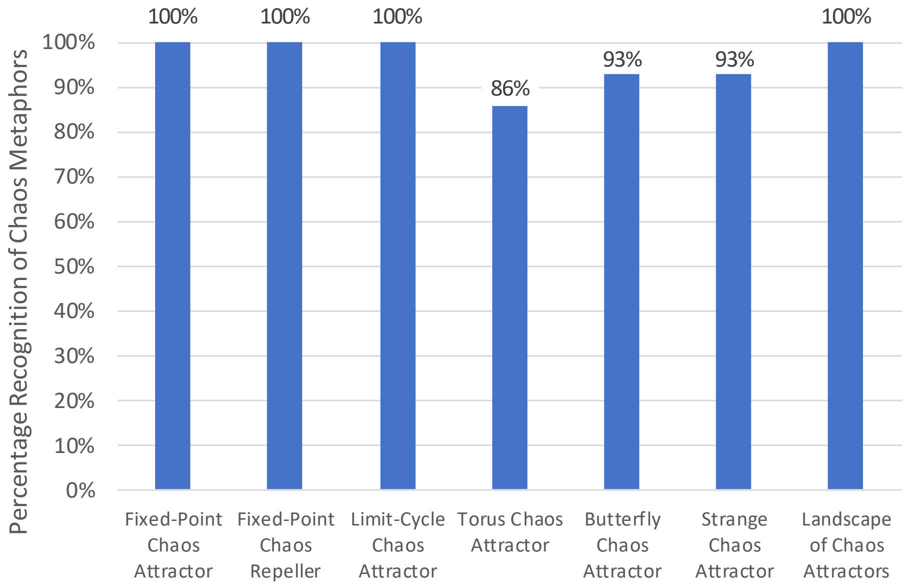

Figure 7-19: Percentage of Capital Project Managers that Recognised the Individual Chaos Attractors and the Landscape of Chaos Attractor Metaphors

All 14 capital project managers that were individually interviewed (14/14=100%) recognised the fixed-point chaos attractor, fixed-point chaos repeller, limit-cycle chaos attractor as well as the landscape of chaos attractor metaphors as indicated in Figure 7-19. The butterfly and strange chaos attractor metaphors were recognised by 93% (13/14) of the capital project managers while 86% (12/14) recognised the torus chaos attractor metaphor. An average of 96% (94/98) of capital project managers that were individually interviewed during the Round 2 interviews was able to recognise chaos attractor metaphors for this research.

7.5.2 Allocation of Interview Quotation Terms to ISO 21500 Subject Groups

The number of characteristics descriptions that were allocated to ISO 21500 subject groups for the six individual chaos attractors and for the two landscapes of chaos attractors were added. The total number of characteristics descriptions for the: fixed-point chaos attractor from Table 7-2; fixed-point chaos repeller from Table 7-5; limit-cycle chaos attractor from Table 7-7; torus chaos attractor from Table 7-9; butterfly chaos attractor from Table 7-12; strange chaos attractor from Table 7-15; a landscape of chaos attractors from Table 7-19 and for a specifically designed landscape of chaos attractors from Table 7-21 is shown in Table 7-24.

Table 7-24: Number of Chaos Attractor Metaphor Characteristics Allocated to ISO 21500 Subject Groups

No.	Dimension	Fixed-Point Chaos Attractor	Fixed-Point Chaos Repeller	Limit-Cycle Chaos Attractor	Torus Chaos Attractor	Butterfly Chaos Attractor	Strange Chaos Attractor	Landscape of Chaos Attractors
1	Integration	10	1	12	10	5	2	15
2	Stakeholder	2	4			1		3
3	Scope	9			1	3		2
4	Resource	17	5	6		8	7	7
5	Time	4		8	4	2	3	
6	Cost							
7	Risk							1
8	Quality		1					
9	Procurement		9	1			1	
10	Communication	1		1			1	
11	General	6			1	6	6	20

From all the characteristics descriptions of the six individual chaos attractors and two landscapes of chaos attractors by capital project managers, their responses could mostly be allocated to the ISO 21500 subject groups of: integration; stakeholder; scope; resource and time as shown in Table 7-24. A total of nine responses for the fixed-point chaos repeller was assigned to the ISO 21500 subject group of procurement while only a few responses for the chaos attractors and landscape of chaos attractors. This result may be further investigated in future research. It is interesting to note that only a few allocations could be made to the ISO21500 subject groups of risk ($z = 1$), quality ($z = 1$) and communication ($z = 3$). No allocations could be made for cost ($z = 0$).

These results may indicate that the nature of chaos theory, chaos attractors, local and overall convergence in capital projects relates more to the ISO 21500 subject groups of integration, stakeholder, scope, resource and time, and less to the ISO 21500 subject groups of risk, quality, communication and cost.

7.6 Summary

The objective of this final chapter on exploratory research results was to report on the chaos attractor metaphors and variance models that were developed from the literature, originating in various fields of science, for applicability to the capital project domain. A prerequisite for the use and potential value of these metaphors is that the experienced capital project managers that participated in the individual interviews, understood the metaphors and could transfer these metaphors to the capital project domain. The two main research questions that this research aims to answer are the local convergence effect of individual chaos attractors on their own and the overall convergence effect of a landscape of chaos attractors.

To assist in answering the main research questions, the results in this chapter is summarised as follows:

a) Results for Local convergence of Individual Chaos Attractors in Capital Projects

i. Results for fixed-point chaos attractors

- Respondents were able to provide examples of this metaphor in capital projects
- Respondents were able to provide characteristics of this metaphor in capital projects
- Respondents provided value statements for this metaphor
- Respondents were able to identify relevant independent variables for the variance model related to capital projects
- Respondents were able to identify local convergence outcomes for the variance model related to capital projects
- Respondents were to be able to understand the metaphor
- Respondents were able to transfer the metaphor to the capital project environment
- Respondents indicated that this metaphor could cause local convergence in a capital project environment

ii. Results for fixed-point chaos repellers

- Respondents were able to provide examples of this metaphor in capital projects
- Respondents were able to provide characteristics of this metaphor in capital projects
- Respondents were not able to provide value statements for this metaphor
- Respondents were able to identify relevant independent variables for the variance model related to capital projects

- Respondents were able to identify local convergence outcomes for the variance model related to capital projects
- Respondents were to be able to understand the metaphor
- Respondents were able to transfer the metaphor to the capital project environment
- Respondents indicated that this metaphor could cause local convergence in a capital project environment

iii. Results for limit-cycle chaos attractors

- Respondents were able to provide examples of this metaphor in capital projects
- Respondents were able to provide characteristics of this metaphor in capital projects
- Respondents were not able to provide value statements for this metaphor
- Respondents were able to identify relevant independent variables for the variance model related to capital projects
- Respondents were able to identify local convergence outcomes for the variance model related to capital projects
- Respondents were to be able to understand the metaphor
- Respondents were able to transfer the metaphor to the capital project environment
- Respondents indicated that this metaphor could cause local convergence in a capital project environment

iv. Results for torus chaos attractors

- Respondents were able to provide examples of this metaphor in capital projects
- Respondents were able to provide characteristics of this metaphor in capital projects
- Respondents were able to provide value statements for this metaphor
- Respondents were able to identify relevant independent variables for the variance model related to capital projects
- Respondents were able to identify local convergence outcomes for the variance model related to capital projects
- Respondents were to be able to understand the metaphor

- Respondents were able to transfer the metaphor to the capital project environment
- Respondents indicated that this metaphor could cause local convergence in a capital project environment

v. Results for butterfly chaos attractors

- Respondents were able to provide examples of this metaphor in capital projects
- Respondents were able to provide characteristics of this metaphor in capital projects
- Respondents provided value statements for this metaphor
- Respondents were able to identify relevant independent variables for the variance model related to capital projects
- Respondents were able to identify local convergence outcomes for the variance model related to capital projects
- Respondents were to be able to understand the metaphor
- Respondents were able to transfer the metaphor to the capital project environment
- Respondents indicated that this metaphor could cause local convergence in a capital project environment

vi. Results for the strange chaos attractor

- Respondents were able to provide examples of this metaphor in capital projects
- Respondents were able to provide characteristics of this metaphor in capital projects
- Respondents provided value statements for this metaphor
- Respondents were able to identify relevant independent variables for the variance model related to capital projects
- Respondents were able to identify local convergence outcomes for the variance model related to capital projects
- Respondents were to be able to understand the metaphor
- Respondents were able to transfer the metaphor to the capital project environment
- Respondents indicated that this metaphor could cause local convergence in a

capital project environment

b) Results for Overall Convergence of a Landscape of Chaos Attractors in Capital Projects

i. Results for a Landscape of Chaos Attractors

- Respondents were able to provide examples of this metaphor in capital projects
- Respondents were able to provide characteristics of this metaphor in capital projects
- Respondents did not provide value statements for this metaphor
- Respondents were to be able to understand the metaphor
- Respondents were able to transfer the metaphor to the capital project environment

ii. Results for a Specifically Designed Landscape of Chaos Attractors

- Respondents were able to provide examples of this metaphor in capital projects
- Respondents were able to provide characteristics of this metaphor in capital projects
- Respondents were able to provide value statements for this metaphor
- Respondents were able to identify relevant independent variables for the variance model related to capital projects
- Respondents were able to identify overall convergence outcomes for the variance model related to capital projects
- Respondents were to be able to understand the metaphor
- Respondents were able to transfer the metaphor to the capital project environment
- Respondents indicated that this metaphor could cause overall convergence in a capital project environment

c) Results for the Recognition of Chaos Attractor Metaphors by Capital Project Managers

i. 100% recognition of the fixed-point chaos attractor metaphor
ii. 100% recognition of the fixed-point chaos repeller metaphor
iii. 100% recognition of the limit-cycle chaos attractor metaphor
iv. 86% recognition of the torus chaos attractor metaphor
v. 93% recognition of the butterfly chaos attractor metaphor

vi. 93% recognition of the strange chaos attractor metaphor
vii. 100% recognition of a landscape of chaos attractors metaphor
viii. An average of 96% recognition of all chaos attractor metaphors

d) Results for the Allocation of Interview Quotation Terms to ISO 21500 Subject Groups
i. Responses for all chaos attractor metaphors were mostly allocated to the ISO 21500 subject groups integration, stakeholder, scope, resource and time
ii. Responses for the fixed-point chaos repeller were mostly allocated to the ISO 21500 subject group of procurement
iii. Responses for all chaos attractor metaphors were weakly allocated to the ISO 21500 subject groups of risk, quality and communication
iv. No responses on all chaos attractor metaphors could be allocated to the ISO 21500 subject group of cost.

The research results revealed many detailed aspects for each of the six individual chaos attractors and the landscape of chaos attractors (consisting of the fixed-point chaos attractor, fixed-point chaos repeller, limit-cycle chaos attractor, torus chaos attractor, butterfly chaos attractor and strange chaos attractor). The analysis and synthesis of these detailed aspects could lead to the formulation of an updated variance models and follow-on research.

The next chapter will aim to combine the research results for the capital project continuum and chaos attractors (Chapter 5), archetypes (Chapter 6) and chaos attractor metaphors and variance models (this chapter) to provide answers to the major and sub-research questions.

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CHAPTER 8: DISCUSSION OF RESULTS

Chaos theories and models were derived for capital projects in Chapter 3 based on the literature survey in Chapter 2 in order to answer the main and sub-research questions formulated in Chapter 1. Research results were obtained through questions posed during deep interviews with experienced capital project managers, using the research methodology described in Chapter 4. Empirical results supporting the existence of a capital project randomness-chaos-complexity-order (RCCO) continuum, archetypes and chaos attractor metaphors and variance models were presented in Chapters 5, 6, and 7. The objective of this chapter is to compare and discuss the empirically obtained exploratory results, as a means of providing evidence for the validity of the derived chaos theories and models for capital projects. An attempt is made to provide answers to the main and sub research questions as well as to indicate the limitations of this research.

8.1 Introduction

The approach employed in this Chapter is to demonstrate that the research results support the existence of chaos theory in capital projects. Initially the main and sub-research questions are restated. Then the conceptual model used for this research, in terms of local and overall convergence as a result of chaos attractors in capital projects, is portrayed as this formed the overall chaos attractor for this research.

This is followed by two sets of derived theories and empirical research results. The first set of results provide supporting evidence for the existence of the randomness-chaos-complexity-order continuum (RCCO), while the second set of results provide supporting evidence for the local and overall converging effect of individual and a landscape of chaos attractors.

Evidence is then provided to demonstrate the applicability of the international project management standard (ISO, 2012) subject groups in describing the reported characteristics of chaos theory concepts in capital projects. An attempt is made to provide answers to the main and sub-research questions based on the derived theories and empirical results of this research.

Finally, the limitations and suggested improvements for the research methodology are presented.

8.2 Main and Sub-Research Questions

The main and sub-research questions, as formulated in Chapter 1, paragraph 1.9 are:

Main Research Question 1:

Does the use of individual chaos attractors lead to local convergence from chaos to order of capital project elements and their trajectories?

Main Research Question 2:

Does the use of combinations of different types of chaos attractors lead to overall convergence from chaos to order of capital projects?

Sub-Research Questions:

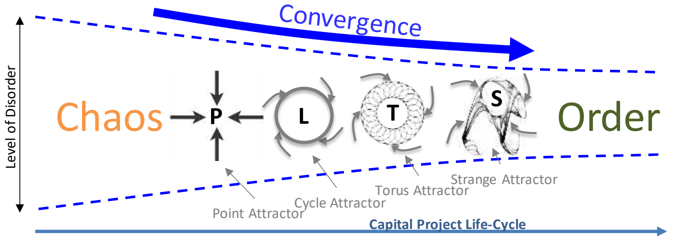
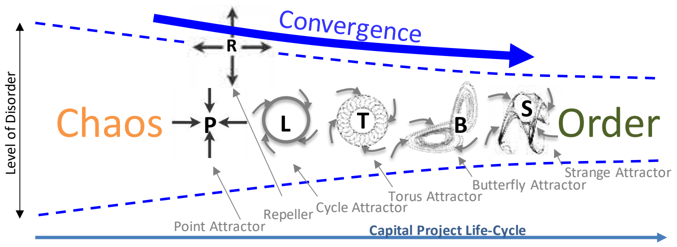
a) Which attractor types and classes could be identified from the literature?
b) What are the characteristics and functions of each attractor based on the literature?
c) What empirical studies have been done to demonstrate the effect of attractors?
d) Do attractors only appear in chaotic types of systems, or also in random, complex and ordered system types?
e) Do attractors appear simultaneously in systems, and what are the effects of attractors on each other and on the overall system behaviour?
f) Do attractors only appear naturally in systems or could they be pre-designed?
g) Are there strong and weak attractors?
h) Where in the project life cycle do attractors occur naturally?
i) What is the effect of naturally occurring attractors on overall project behaviour and as part of the project life cycle?
j) Could attractors be designed and positioned as part of the pre-project architecture to have an overall project convergence effect?

8.3 Chaos Theory Derived for Capital Projects

Chaos theory was used as the theoretical paradigm for this research to study the convergence from chaos to order in capital projects, as explained in Chapter 1. It is believed that the creation of order from chaos in a capital project, that is immersed in a faster changing VUCA world (Gandhi, 2017; Bennett and Lemoine, 2014), would contribute to addressing the current and future capital cost overruns and therefore the delayed or total destruction of the ‘multiplication-of-value-effect’ to society that capital projects hold.

An overall conceptual model, based on chaos theory, that represents the convergence from chaos to order for capital projects was derived in Chapter 1. This conceptual model, together with chaos theory served as an addition to the literature survey on chaos theory concepts and chaos attractors in Chapter 2, culminating in the derivation of various levels of chaos theories and different variance models for capital projects in Chapter 3. The original and refined overall conceptual model and chaos theory applied to the capital project domain for this research is shown in Table 8-1.

Table 8-1: The Original and Refined Overall Conceptual Model Employing Chaos Theory for the Convergence from Chaos to Order in Capital Projects

No.	Conceptual Model for Capital Projects	Grand Chaos Theories Derived for Capital Projects
a	Original Overall Conceptual Model for Capital Projects 	"Chaos theory considers the convergence from chaos to order a natural phenomenon in social systems that is brought about by point, cycle, torus and strange chaos attractors" (Chapter 3, paragraph 3.4.9.1) ↓ "Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by point, cycle, torus and strange chaos attractors" (Chapter 3, paragraph 3.4.9.1) ↓
b	Refined Overall Conceptual Model Explored for this Research for Capital Projects 	"Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by eleven types of chaos attractors" (Chapter 3, paragraph 3.4.9.3) ↓ "Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by the following six chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange" (Chapter 3, paragraph 3.4.9.3)

The original conceptual model in Table 8-1(a) shows only four prominent chaos attractors that are, according to chaos theory, responsible for the production of order from chaos. These are the fixed-point chaos attractor, limit-cycle chaos attractor, torus chaos attractor and strange chaos attractor. However, during the literature survey in Chapter 2, a total of eleven different types of chaos attractors were identified (refer to paragraph 2.6.4). It was decided that the scope of this research would be limited to six chaos attractors as explained in in Chapter 3, paragraph 3.4.9.2 as well as the study of local and overall convergence from chaos to order in capital projects as shown in Table 8-1(b). This refined overall conceptual model with the derived theory for local and overall convergence in capital projects was used to structure the remainder of this research and to enable answering the main and sub-research questions.

8.4 Empirical Evidence Supporting the Application of Chaos Theory in Capital Projects

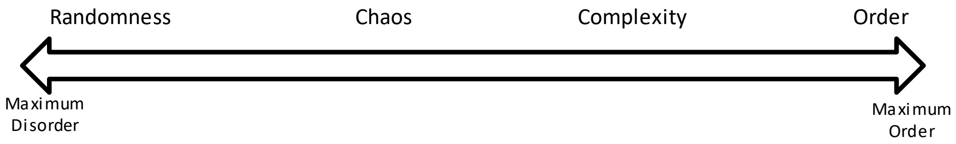
The refined conceptual model as shown in Table 8-1(b) consist of two elements: a) the continuum with decreasing levels of disorder in which capital project convergence is suspected to take place and b) the individual chaos attractors that are the mechanisms that cause local and overall capital project convergence. These two elements are presented separately with empirical evidence to provide supporting evidence for the existence of these theoretical concepts and theories.

8.4.1 Empirical Evidence for the Existence of a Randomness-Chaos-Complexity-Order Continuum (RCCO) in Capital Projects

8.4.1.1 Empirical Evidence for the Randomness-Chaos-Complexity-Order Continuum (RCCO) in Capital Projects

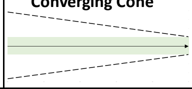
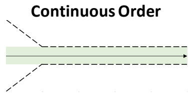
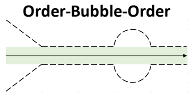
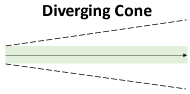
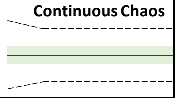
Both inductive (A and B) and deductive (C, D and E) research methodologies were used (refer to Chapter 4) to gather empirical evidence to demonstrate the existence of the randomness-chaos-complexity-order (RCCO) continuum for capital projects, as shown schematically in Table 8-2.

Table 8-2: Empirical Results for the Existence of the Randomness-Chaos-Complexity-Order Continuum (RCCO) in Capital Projects

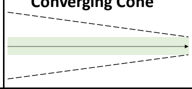
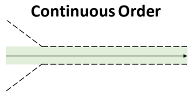
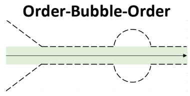
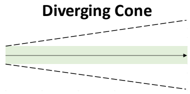
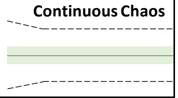
Theory	Descriptions and References			
A. Randomness-Chaos-Complexity-Order (RCCO) Continuum Definitions from Round 1 Respondents				
Continuum Concept				
Evidence for Grounded	Definition for Randomness ✓	Definition for Chaos ✓	Definition for Complexity ✓	Definition for Order ✓

Theory	Descriptions and References			
Definitions	Ch. 5, Par. 5.3.4	Ch. 5, Par. 5.3.3	Ch. 5, Par. 5.3.2	Ch. 5, Par. 5.3.1

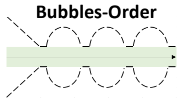
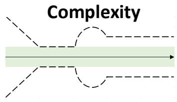
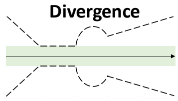
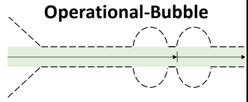
B. Archetype Characteristics Defined by Round 1 Respondents

Continuum Concepts	C1 Converging Cone 	C2 Continuous Order 	C3 Order-Bubble-Order 	D1 Diverging Cone 	D2 Continuous Chaos 
Evidence for Grounded Descriptions	Characteristics ✓ Ch. 6, Par. 6.3.2	Characteristics ✓ Ch. 6, Par. 6.3.3	Characteristics ✓ Ch. 6, Par. 6.3.4	Characteristics ✓ Ch. 6, Par. 6.3.5	Characteristics ✓ Ch. 6, Par. 6.3.6

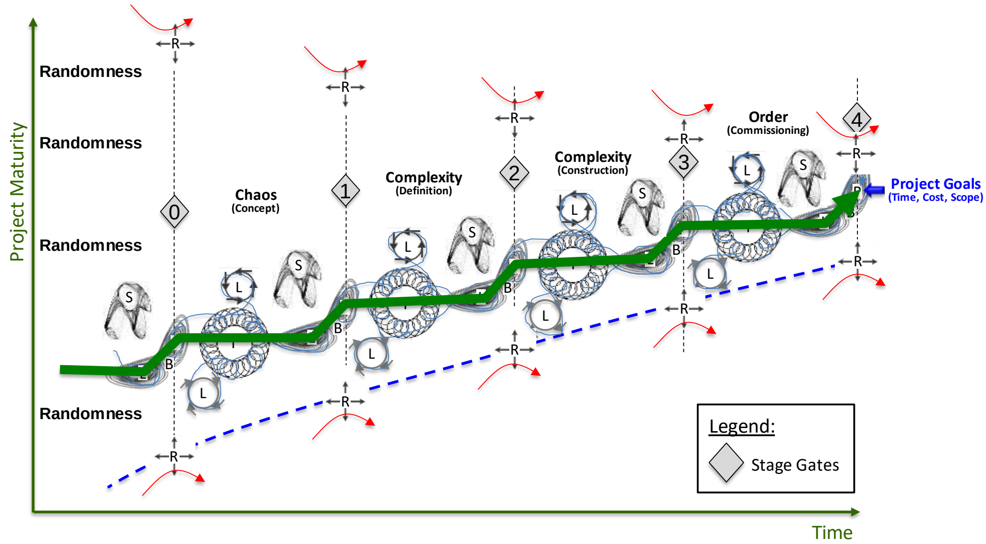
C. Archetype Confirmations by Round 2 Respondents

Continuum Concepts	C1 Converging Cone 	C2 Continuous Order 	C3 Order-Bubble-Order 	D1 Diverging Cone 	D2 Continuous Chaos 
Evidence for Archetype Confirmation	Examples and Characteristics ✓ Ch. 6, Par. 6.4.2.1	Examples and Characteristics ✓ Ch. 6, Par. 6.4.2.2	Examples and Characteristics ✓ Ch. 6, Par. 6.4.2.3	Examples and Characteristics ✓ Ch. 6, Par. 6.4.2.4	Examples and Characteristics ✓ Ch. 6, Par. 6.4.2.5

D. New Additional Archetypes Defined by Round 2 Respondents

Continuum Concepts	C3a Order-Multiple-Bubbles-Order 	C3b Order-Bubble-Complexity 	C3c Order-Bubble-Divergence 	C3d Order-Bubble-Order-Operational-Bubble 
Evidence for Grounded Descriptions	Examples and Characteristics ✓ Ch. 6, Par. 6.4.3.1	Examples and Characteristics ✓ Ch. 6, Par. 6.4.3.2	Examples and Characteristics ✓ Ch. 6, Par. 6.4.3.3.	Examples and Characteristics ✓ Ch. 6, Par. 6.4.3.4

E. Continuum Landscape of Chaos Attractors Confirmed by Round 2 Respondents

Continuum Concept	
Evidence for Landscape Confirmation	Examples and Characteristics ✓ Ch. 7, Par. 7.4.2.2 and Par. 7.4.2.3

<u>Table 8-2 Notes:</u> Results from Round 1 Interviews with Sample Size = 12 and Round 2 Interviews with Sample Size = 14

During the Round 1 interviews, capital project managers provided their own definitions for the domain elements of the randomness-chaos-complexity-order (RCCO) continuum (Chapter 5, paragraph 5.3), as derived in Chapter 2, paragraph 2.5.6 and shown in Table 8-2(A). The same group of respondents identified five different types of archetypes, shown in Table 8-2(B). These archetypes spanned the capital project life cycle (left-to-right) and were defined in terms of the vertical dimensions of randomness, chaos, complexity and order by respondents. An inductive research methodology was used, as suggested by Gioia et al. (2013), to extract this grounded information from respondents.

The five archetypes defined by the first group of respondents were confirmed by the second group of respondents (during the second round of interviews) as shown in Table 8-2(C). In addition, the second group of respondents identified four new archetypes, shown in Table 8-2(D). The second group of respondents thus confirmed the existence of a total of nine categories of archetypes that span the capital project life cycle in terms of the continuum domains of randomness, chaos, complexity and order.

During the Round 2 interviews a specifically designed landscape of chaos attractors that was mapped onto a capital project life cycle was shown to respondents, as shown in Table 8-2(E). Judged by the examples and characteristics obtained from experienced capital projects managers as summarised in Chapter 7, paragraph 7.4.2.4, it seems that many respondents agreed with this representation of the randomness-chaos-complexity-order continuum for capital projects. A deductive research methodology was employed in this instance.

It is concluded from the evidence provided by both groups of capital project managers that the RCCO continuum appears to exist for capital projects.

It is interesting to note that although the RCCO continuum is displayed from left (maximum disorder) to right (maximum order), the archetypes seem to have the same dimensions in the vertical dimension (Table 8-2(B-D)). This could suggest the existence of a 2-dimensional, vertical-horizontal continuum for capital projects when viewed with chaos theory in mind.

8.4.1.2 Empirical Evidence for Characteristics of the Randomness-Chaos-Complexity-Order Continuum (RCCO) in Capital Projects

The responses from experienced capital project managers who participated in both Round 1 and 2 interviews, captured in Chapters 5, 6, and 7 were searched for any statements that pertain to and support the concept of the RCCO continuum. The results are summarised in Table 8-3. The abbreviation "Rx-Ref." refers to the applicable round of interviews as either 1 = Round 1 or 2 = Round 2 and the Atlas.ti line reference number.

Table 8-3: Summary of Supporting Evidence for the Existence of the Randomness-Chaos-Complexity-Order (RCCO) Continuum in Capital Projects

No.	Concept	Description	Rx-Ref.	References
1	Capital Project Convergence does not Imply Project Success	An over budget project can end in order	2:84	Ch. 6, Par. 6.3.7
		Failed projects still move to order but miss the goal	1:80	
		Failed project eventually goes to order when completed	2:92	
		Late and over budget but goal is clear	1:79	
		Late and over budget but resources can be aligned	1:77	
		Project move to order but can still fail	1:70	
		An over budget project can end in order	2:84	
2				
3	Perceived Order in Capital Projects	[A capital project could be] perceived [to be in a state of] order but in reality, [there might be] very little order	1:75	Ch. 6, Par. 6.3.7
4				
5	New Goals in Capital Projects	Randomness and chaos [in a capital project] might produce a new goal	3:67	Ch. 6, Par. 6.3.7
6				
7	Randomness Trigger	Randomness [in a capital project] triggers chaos to cause divergence	3:71	Ch. 6, Par. 6.3.5
8				
9	New Technology	New technology and disruptors cause you to be more in a chaotic than ordered mode	1:78	Ch. 7, Par. 7.4.1.3
10				
11	Relationship Development and Capital Project Convergence	Transformation from Archetype C3 (Order-Bubble-Order) to C2 (Continuous Order) is caused by development of interrelationships	8:13	Ch. 6, Par. 6.4.4
		Interrelationship building creates order form chaos	13:13	
		Interrelationships actually determine the ability to create order	13:19	
		Interrelationships develop from loose too rigid during project life cycle	13:21	
		Definition of interrelationships as more information, battery limits, boundaries and performance targets become available	13:22	
		Interrelationships are non-existing at project start	13:23	

No.	Concept	Description	Rx-Ref.	References
		People start to form bonds as you move through the project	4:44	Ch. 7, Par. 7.4.2.3
12				
13	Transformation of Archetypes	Multi-unit type of projects causes a transformation from Archetype C3 (first units) to C2 (later units)	8:13	Ch. 6, Par. 6.4.4
		Transformation from Archetype C3 to C2 caused by forced learning	8:13	
14				
15	Combinations of Archetypes	Archetypes D1 and D2 are valid for project phase / stage but are followed by other Archetypes	1:15	Ch. 6, Par. 6.4.4
		Archetypes C1 and D1 are found in combination in a project	7:11	
16				
17	Fractal Nature of Archetypes	Archetypes are applicable at different scales and different teams	13:16	Ch. 6, Par. 6.4.4
		The durations of Archetype formations differ for each project	11:15	Ch. 6, Par. 6.4.4
		You have both overall converging cone and a converging cone for each project phase	11:55	Ch. 7. Par. 7.4.2.3

Table 8-3 Notes: Results from Round 1 Interviews with Sample Size = 12 and Round 2 Interviews with Sample Size = 14

The first insight obtained from the responses of the 26 respondents (12 + 14 = 26) was that capital project convergence does not imply project success, as shown in Table 8-3(1). This is because respondents indicated that a capital project could move towards and converge to an ordered state but still be over budget (R2-Ref. 2:84) and therefore fails (R2-Ref. 1:70). Thus, an overbudget capital project can finally end in an ordered state (R2-Ref. 2:84) but the goal and objectives of the capital project could have been missed. A failed project could still move towards and close-out in an ordered state (R2-Ref. 2:92) but misses the pre-determined set goal of the capital project (R2-Ref. 1:80). Similarly, a late and over-budget project could converge and achieve an ordered state, with all resources that are aligned (R2-Ref. 1:77) so that the goal becomes clear (R2-Ref. 1:79) but too late for the value and multiplication effect of a capital project to realise (refer to Chapter 1, paragraph 1.3, Table 1-1).

Another insight is that a capital project could be perceived to be in a state of order, but in reality, there might be very little order (R2-Ref. 1:75). This raises the question of how the level of disorder has been determined and who has determined the level of disorder? Is the state of order determined by the project manager, the project sponsor, the stakeholders, the project team or the client? This research focused on the views and perceptions of order from experienced capital project managers.

One respondent noted that randomness in a capital project could trigger chaos and cause divergence (R2-Ref. 3:71). However, a state of randomness and chaos in a capital project might produce a new project goal (R2-Ref. 3:67). This may imply that perhaps some external event triggered and caused the project to experience a chaotic state. The default mode should perhaps not always be to manage a project back to an ordered state (by using chaos attractors) but to scan the project environment to determine if the original goal of the capital project is still relevant in a changed environment. This notion is expressed by researchers in favour of the “re-thinking project management paradigm” (Svejvig and Andersen, 2015). Shenhar and Dvir (2007:11) for example refer to a change from traditional to adaptive project management where the project goal changes from “getting the job done on time, on budget, and within requirements” to “getting business results, meeting multiple criteria”. These business results that are referred to may mean a new project goal in a faster changing VUCA environment especially when new and disruptive technologies are involved (R2-Ref. 1:78).

A few comments were made that related to the development of relationships when a capital project or stages of capital project transition from disorder to order. These comments point to the development of relationships of capital project elements from loose to semi-structured to fixed, as shown in the derived RCCO continuum model in Figure 8-1.

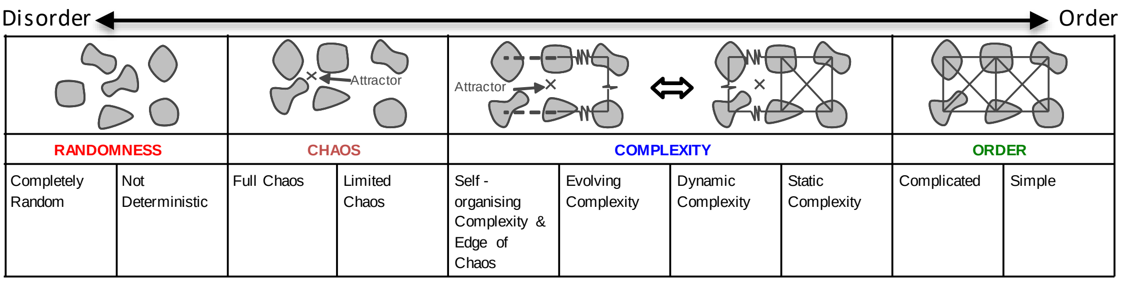


Figure 8-1: Sketch for the Randomness-Chaos-Complexity-Order Continuum (RCCO) Domains and Sub-Domains showing the Development of Capital Project Elements

Comments on the relationship development as shown in Table 8-3(11) were made by Respondents 4, 8 and 13. When a capital project starts, the interrelationships are non-existent (R2-Ref. 13:23) but people start to form bonds as they move through the project (R2-Ref. 4:44). These interrelationships develop as more information, battery limits, boundaries and performance targets become available in the capital project (R2-Ref. 13:22) and as they evolve from lose to rigid during the project life cycle (R2-Ref. 13:21). The development of interrelationships causes the transformation from one archetype to another, for example the transformation from archetype C3 (order-bubble-order) to C2 (continuous order) (R2-Ref. 8:13). Therefore, it seems that interrelationship building contributes to the ability to create order from chaos (R2-Ref. 13:13 and 13:19). These comments resemble the notion by Remington and Pollack (2007) when they described their chaos-complexity-order continuum and noted that the relationship between project elements changes from unstable in the chaotic domain, to stable in the complex domain and finally, to fixed in the ordered domain (refer to Chapter 2, paragraph 2.5.4, Figure 2-9). Note that it is suggested, in Figure 8-1, that the development of the project relationships is caused by chaos attractors (indicated by the small crosses between the capital project elements).

These archetypes, according to views from respondents, are able to transform from one type into another type (R2-Ref. 8:13) and also appear in combination with each other in the capital project life cycle (R2-Ref. 1:15 and 7:11). This result indicates that the RCCO continuum appears to be a dynamic landscape for a capital project.

The final characteristic of the capital project continuum relates to the fractal nature of archetypes (Fractal Foundation, 2009). The archetypes seem to appear at different scales, are applicable for different teams (R2-Ref. 13:16) and their duration differs for each project (R2-Ref. 11:15). Furthermore, the overall converging cone is applicable to the complete project life cycle but also for each project phase (R2-Ref. 11:55). Archetypes that represent typical capital project behaviour types, therefore appear at different levels and scales in capital projects.

Based on the combination of descriptions for the RCCO continuum characteristic from respondents of the Round 1 and 2 interviews, the dynamic features to this continuum are further confirmed. It appears that archetypes are able to transform from one type into another, combine with each other and be found at different levels and stages as a fractal structure in the capital project life cycle. New technology and randomness appear to trigger a chaotic state that may produce a new unplanned outcome of the capital project. The ordered appearance of a capital project along the continuum might be illusive as the actual state of the project may be based on subjective views and observations of individuals. Could the level of disorder in a capital project be objectively quantified and measured? The answer to this question may be explored in future research. Furthermore, it appears that relationships that develop in capital projects, along the continuum and project life cycle could contribute to the overall convergence.

An important conclusion is that a capital project that has reached convergence or an ordered state, may not always be regarded as a successful project because such convergence could have been achieved by exceedance of the time and budget of the project.

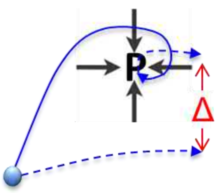
The next section will aim to provide supporting evidence for the mechanisms inside the RCCO continuum that are responsible for the production of order from chaos. These are the chaos attractors.

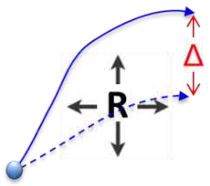
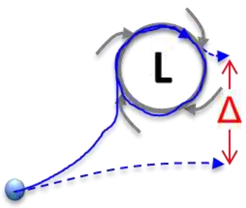
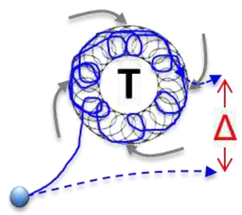
8.4.2 Empirical Evidence for the Local and Overall Convergence from Chaos to Order by Chaos Attractors in Capital Projects

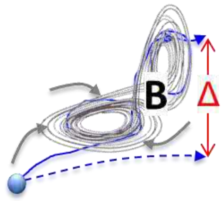
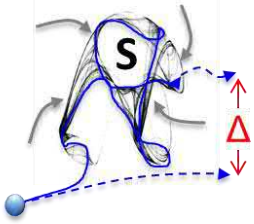
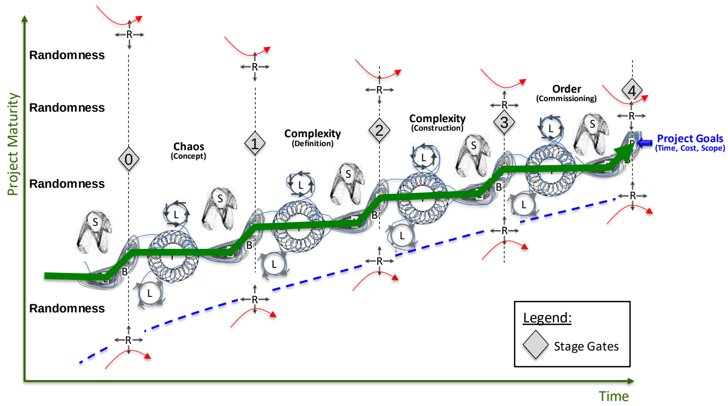
8.4.2.1 Empirical Evidence for the Local and Overall Convergence from Chaos to Order by Individual and a Landscape of Chaos Attractors in Capital Projects

Empirical evidence to support the existence of six individual chaos attractors; a landscape of chaos attractors; the local convergence effect of individual chaos attractors and the overall convergence effect of a landscape of chaos attractors for capital projects is shown in Table 8-4. Note that the term chaos attractor is also used in the literature to describe a specific type of chaos attractor that is known as a fixed-point repeller. This text will treat the fixed-point repeller as part of the collective term "chaos attractors".

Table 8-4: Empirical Evidence to Support the Existence of Derived Theories for Each of the Chaos Attractors and a Landscape of Chaos Attractors for Capital Projects

Theory	**Descriptions and References**				
1. Fixed-Point Chaos Attractor					
Theory Building	Metaphor:  Ch. 3, Par. 3.5.3.1		Derived Lower-Level Theory: "A fixed-point chaos attractor generates an attractor basin and causes capital project elements and their trajectories to converge to a fixed-point in the basin even if they are perturbed" Ch. 3, Par. 3.4.9.4		
Evidence for Exploratory Theory Testing	Metaphor Recognition ✓ Ch. 7, Par. 7.5.1	Examples ✓ Ch. 7, Par. 7.3.1.2	Characteristics ✓ Ch. 7, Par. 7.3.1.3	Value Statements ✓ Ch. 7, Par. 7.3.1.4	Variance Model - Local Convergence ✓ Ch. 7, Par. 7.3.1.5

<table>
<tr><td colspan="6">2. Fixed-Point Chaos Repeller</td></tr>
<tr><td>Theory Building</td><td colspan="2">Metaphor:

Ch. 3, Par. 3.5.3.2</td><td colspan="3">Derived Lower-Level Theory:
“A fixed-point chaos repeller generates a fixed point-of-repulsion and causes capital project elements and their trajectories to be diverted away from the fixed-point”
Ch. 3, Par. 3.4.9.5</td></tr>
<tr><td>Evidence for Exploratory Theory Testing</td><td>Metaphor Recognition
✓
Ch. 7,
Par. 7.5.1</td><td>Examples
✓
Ch7,
Par. 7.3.2.2</td><td>Characteristics
✓
Ch7,
Par. 7.3.2.3</td><td>Value Statements
✗
Ch7,
Par. 7.3.2.4</td><td>Variance Model - Local Convergence
✓
Ch7,
Par. 7.3.2.5</td></tr>
<tr><td colspan="6">3. Limit-Cycle Chaos Attractor</td></tr>
<tr><td>Theory Building</td><td colspan="2">Metaphor:

Ch. 3, Par. 3.5.3.3</td><td colspan="3">Derived Lower-Level Theory:
“A limit-cycle chaos attractor generates a cyclical pattern and causes capital project elements and their trajectories to converge towards the limit-cycles and to which it returns after small perturbations”
Ch. 3. Par. 3.4.9.6</td></tr>
<tr><td>Evidence for Exploratory Theory Testing</td><td>Metaphor Recognition
✓
Ch. 7,
Par. 7.5.1</td><td>Examples
✓
Ch. 7,
Par. 7.3.3.2</td><td>Characteristics
✓
Ch. 7,
Par. 7.3.3.3</td><td>Value Statements
✗
Ch. 7,
Par. 7.3.3.4</td><td>Variance Model - Local Convergence
✓
Ch. 7,
Par. 7.3.3.5</td></tr>
<tr><td colspan="6">4. Torus Chaos Attractor</td></tr>
<tr><td>Theory Building</td><td colspan="2">Metaphor:

Ch. 3, Par. 3.5.3.4</td><td colspan="3">Derived Lower-Level Theory:
“A torus chaos attractor generates multiple spiralling inner cycles that form part of a single outer cycle and cause capital project elements and their trajectories to converge towards the cycles”
Ch. 3, Par. 3.4.9.7</td></tr>
<tr><td>Evidence for Exploratory Theory Testing</td><td>Metaphor Recognition
✓
Ch. 7,
Par. 7.5.1</td><td>Examples
✓
Ch. 7,
Par. 7.3.4.2</td><td>Characteristics
✓
Ch. 7,
Par. 7.3.4.3</td><td>Value Statements
✓
Ch. 7,
Par. 7.3.4.4</td><td>Variance Model - Local Convergence
✓
Ch. 7,
Par. 7.3.4.5</td></tr>
<tr><td colspan="6">5. Butterfly Chaos Attractor</td></tr>
<tr><td>Theory Building</td><td colspan="2">Metaphor:</td><td colspan="3">Derived Lower-Level Theory:
“A butterfly chaos attractor generates two outcome basins and causes capital project</td></tr>
</table>

	 Ch. 3, Par. 3.5.3.5		elements and their trajectories to suddenly jump from one outcome basin to the other when a threshold value is reached" Ch. 3, Par. 3.4.9.8		
Evidence for Exploratory Theory Testing	Metaphor Recognition ✓ Ch. 7, Par. 7.5.1	Examples ✓ Ch. 7, Par. 7.3.5.2	Characteristics ✓ Ch. 7, Par. 7.3.5.3	Value Statements ✓ Ch. 7, Par. 7.3.5.4	Variance Model - Local Convergence ✓ Ch. 7, Par. 7.3.5.5
6. Strange Chaos Attractor					
Theory Building	Metaphor:  Ch. 3, Par. 3.5.3.6		Derived Lower-Level Theory: "A strange chaos attractor generates an attraction zone and causes capital project elements and their trajectories to converge towards this zone in strange ways" Ch3, Par. 3.4.9.9		
Evidence for Exploratory Theory Testing	Metaphor Recognition ✓ Ch. 7, Par. 7.5.1	Examples ✓ Ch. 7, Par. 7.3.6.2	Characteristics ✓ Ch. 7, Par. 7.3.6.3	Value Statements ✓ Ch. 7, Par. 7.3.6.4	Variance Model - Local Convergence ✓ Ch. 7, Par. 7.3.6.5
7. Landscape of Chaos Attractors					
Theory Building	Metaphor:  Ch. 3, Par. 3.5.4.2				Derived Lower-Level Theory: "A specifically designed landscape of chaos attractors consisting of a group of six different types of chaos attractors [fixed-point, repeller, limit-cycle, torus, butterfly and strange], generates a bounded landscape and causes capital project elements and

					their trajectories to converge towards a specified outcome” Ch. 3, Par. 3.4.9.10
Evidence for Exploratory Theory Testing	Metaphor Recognition ✓ Ch. 7, Par. 7.5.1	Examples ✓ Ch. 7, Par. 7.4.2.2	Characteristics ✓ Ch. 7, 7.4.2.3	Value Statements ✓ Ch. 7, Par. 7.4.2.4	Variance Model - Overall Convergence ✓ Ch. 7, Par. 7.4.2.5

Table 8-4 Notes: Results from Round 1 Interviews with Sample Size = 12 and Round 2 Interviews with Sample Size = 14

The empirical results as shown in Table 8-4(1-6) indicate that empirical evidence could be found for: metaphor recognition, examples characteristics; value statements and local convergence in capital projects for a fixed-point chaos attractor, fixed-point chaos repeller, limit-cycle chaos attractor, torus chaos attractor, butterfly chaos attractor and for the strange chaos attractor. The only exception was that no value statements were recorded for the fixed-point chaos repeller and limit-cycle chaos attractor as shown in Table 8-4(2, 3).

Similarly, the results as indicated in Table 8-4(7) indicate that empirical evidence could be found for: metaphor recognition; examples; characteristics; value statements and for the overall convergence in a capital project for a landscape of chaos attractors.

It is concluded based on the supporting evidence shown in Table 8-4 that the derived lower-level theories may by applicable for capital projects.

8.4.2.2 Empirical Evidence for Characteristics of Individual and a Landscape of Chaos Attractors

The responses that were captured from experienced capital project managers who participated in both Round 1 and 2 interviews in Chapters 5, 6, and 7 were searched for any statements that pertain to the characteristics of chaos attractors. The results are summarised as concepts in Table 8-5.

Table 8-5: Summary Supporting Evidence for the Existence of Chaos Attractors in Capital Projects

No.	Concept	Description	Rx-Ref.	References
1	Relative Difficulty in Understanding Different Chaos Attractors	It becomes very complex now	9:35	Ch. 7, Par. 7.3.4.4
		This is a bit difficult	10:34	Ch. 7, Par. 7.3.4.4
		"Yes, this (butterfly chaos attractor) is definitely more abstract"	3:42	Ch. 7, Par. 7.3.5.4
2				
3	Hard and Soft Aspects of Chaos Attraction	All respondents agreed that chaos attraction is a multi-dimensional concept that has to do with both hard aspects (project management, systems engineering etc.) as well as soft aspects (psychology and sociology)	N/A	Ch. 5, Par. 5.6.2.
4				
5	Intend vs Reality	An attractor represents the intend of a project	13:20	Ch. 6, Par. 6.4.4
6				
7	Fractal Structure of Chaos Attractors	The Fishbone Diagram (Figure 7-3) represents multiple repeatable layers of fixed-point chaos attractors.	N/A	Ch. 7, Par. 7.3.1.2
		Individual fixed-point attractors are subordinated to the overall fixed-point project objective	12:29	Ch. 7, Par. 7.3.1.3
		Triggered jumps at different levels [for the butterfly chaos attractor] also occur within a single phase (such as concept design)	3:46	Ch. 7, Par. 7.3.5.3
		The landscape schema is repeatable over the whole project	14:42	Ch. 7, Par. 7.4.2.3
8				
9	Dual Nature of Chaos Attractors	Leadership attitude and ownership attitude can be a repeller or an attractor	12:37	Ch. 7, Par. 7.3.2.2
		A strange attractor incorrectly constituted [in a landscape of chaos attractors] may become a dangerous repeller	5:35	Ch. 7, Par. 7.3.6.3
10				
11	Relative Strength and Position of Chaos Attractors	The torus chaos attractor is not as strong as the fixed-point chaos attractor	5:25	Ch. 7, Par. 7.3.4.3
		At the start of a capital project the limit cycle chaos attractors are bigger than later	2:69	Ch. 7, Par. 7.4.2.3
		From the middle of the capital project life cycle the torus chaos attractors are much bigger and the limit cycle chaos attractors much smaller	2:70	Ch. 7, Par. 7.4.2.3
		The butterfly chaos attractor is actually more dominant in explaining how a project progresses compared to the other chaos attractors in the landscape	3:57	Ch. 7, Par. 7.4.2.3
		You need a much stronger strange attractor during start-up and commissioning	11:57	Ch. 7, Par. 7.4.2.3
		A torus chaos attractor is good for improving and refining but bad for execution	13:45	Ch. 7, Par. 7.4.2.3

No.	Concept	Description	Rx-Ref.	References
		The torus chaos attractor is pivotal during the detail design phase	13:46	Ch. 7, Par. 7.4.2.3
12				
13	Once Size does not Fit All	The chaos attractor landscape will have to be tailored for each industry	3:55	Ch. 7, Par. 7.4.1.3
		Something that is good in one landscape is not good in another landscape	5:38	Ch. 7, Par. 7.4.1.3
		A landscape of chaos attractors requires fluidness - there is no fixed answer to anything	5:39	Ch. 7, Par. 7.4.1.3
		A good leader in one role is not necessarily a good leader in another role	5:40	Ch. 7, Par. 7.4.1.3
		The applicability, importance & impact of these chaos attractors differs for each project phase	2:74	Ch. 7, Par. 7.4.2.3
		A different set of chaos attractors may be required to keep a project in an ordered state	5:42	Ch. 7, Par. 7.4.2.3
		Maybe you need a different configuration of chaos attractors to deal with different issues	5:46	Ch. 7, Par. 7.4.2.3
		There are significant differences between project phases and the associated chaos attractor landscapes	13:43	Ch. 7, Par. 7.4.2.3
		The different chaos attractors might have different effectiveness and influence on the project outcome	13:44	Ch. 7, Par. 7.4.2.3
14				
15	Design and Effect of a Landscape of Chaos Attractors	Up-front positioning of attractor landscape, attractors & repellers provided a clear route for the contactor to follow	1:70	Ch. 7, Par. 7.4.1.3
		Project trajectory can definitely be influenced by a landscape of chaos attractors	1:72	Ch. 7, Par. 7.4.1.3
		Experience will indicate what attractors to put in place in order to guide project behaviour	2:67	Ch. 7, Par. 7.4.1.3
		An understanding of project management, the industry and the lay of the land is required to apply the landscape of chaos attractors	3:54	Ch. 7, Par. 7.4.1.3
		If you know what the different chaos attractors are doing - you can use them in capital projects	8:63	Ch. 7, Par. 7.4.1.3
		The landscape configuration depends on the type of project and on the government organisation responsible for the project	9:44	Ch. 7, Par. 7.4.2.3
		You need to understand the chaos attractors and what they can do and where to place them in the landscape	10:43	Ch. 7, Par. 7.4.2.3

Table 8-5 Notes: Results from Round 1 Interviews with Sample Size = 12 and Round 2 Interviews with Sample Size = 14

The two statements in Table 8-5(1) from respondents that the understanding and transfer of the chaos attractor concept to the capital project environment becomes very complex (R2-Ref. 9:35) and difficult (R2-Ref. 10:34) pertain to the torus chaos attractor. The respondents indicated that the fixed-point chaos attractor, fixed-point chaos repeller and limit-cycle chaos attractors were conceptually easier to understand than the torus chaos attractor metaphor. Also, the butterfly chaos attractor is more abstract (R2-Ref. 3:42) compared to the fixed-point chaos attractor, fixed-point chaos repeller, limit-cycle chaos attractor and the torus chaos attractor.

These statements seem to indicate that there is relative difficulty in understanding of the various types of chaos attractors covered in this research. Morgan and Reichert (1999) found that an effective metaphor must be easy to comprehend to avoid misinterpretation and that people with high cognitive abilities were better able to comprehend both concrete and abstract metaphors. Therefore, the sample for this research consisted of experienced capital project managers with at least 15 years' experience (Chapter 4, paragraph 4.3.2.5). Although 96% of the capital project managers that were interviewed during Round 2 recognised the chaos attractors (Chapter 7, paragraph 7.5.1, Figure 7-19), care should be taken in future research to ensure that respondents are able to understand and transfer the chaos attractors concepts to the capital project environment.

The results from the Round 1 interviews demonstrated that 100% of the respondents agreed that chaos attraction is a multi-dimensional concept that has to do with both hard aspects (project management, systems engineering etc.) as well as soft aspects (psychology and sociology) (Chapter 5, paragraph 5.6.2, Figure 5-8). This notion is similar to the typical ISO 21500 project management process approach that is presented as ten different and separate subject groups of integration, scope, time, cost, risk, quality, procurement, human resource, stakeholders and communication.

Using retroductive reasoning (Walwyn, 2016), these subject groups could be arranged into the same variance model format as used for this research, with integration as the dependent variable (DV), the other subject groups (SG) as the independent variables (IV) and local and overall convergence as the outcome, as shown in Figure 8-2. This variance model could perhaps provide a plausible hypothesis and theory on why applying the ISO 21500 principles seems to work for some projects and not for others.

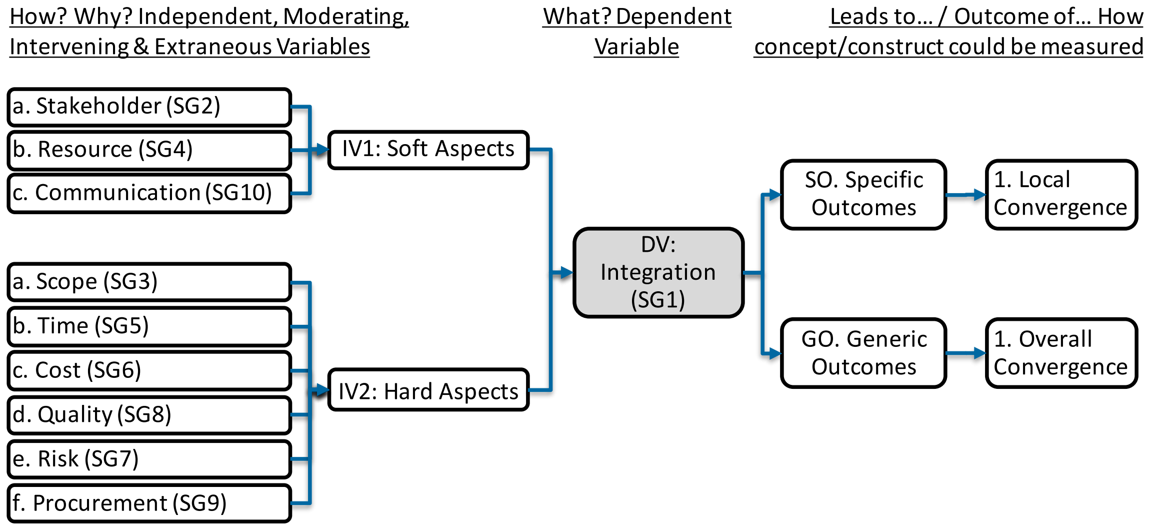


Figure 8-2: Suggesting a Variance Model for ISO 21500 Subject Groups Based on the Results of Chaos Theory Applied to Capital Projects for this Research

A comment was made by a Respondent that a chaos attractor represents the intent of a capital project (Table 8-5, R2-Ref. 13:20). The intent means the convergence from chaos to order as a result of a chaos attractor. It could also mean that a chaos attractor has an aspirational value as the convergence from chaos to order could be seen as a desired outcome of a capital project. The ISO 21500 international standard (ISO, 2012) also presents ten sets of processes that are to be integrated by the project managers to result in a desired successful project. Therefore, if a chaos attractor represents the intent of a capital project in the mind of a capital project manager, it could at least guide him towards an overall objective through phases of turbulence and chaos.

A number of Respondents described the fractal nature of chaos attractors. The Fractal Foundation provided the following definition of a fractal: “A fractal is a never ending pattern that repeats itself at different scales” (Fractal Foundation, 2009:3). Four responses were obtained from respondents on the repeatability at different levels for fixed-point chaos attractors (Fishbone diagram in Chapter 7, paragraph 7.3.1.2, Figure 7-3 and R2-Ref. 12:29), the butterfly chaos attractor (R2-Ref. 3:46) and the landscape of six different types of chaos attractors for capital projects (R2-Ref. 14:42). These responses provide supporting evidence for the existence of the fractal nature of chaos attractors. It is also in agreement with the suggestions made in the literature (Chapter 2 (paragraph 2.6.9) by Lorenz (1995:176) that “strange attractors are fractals” as well as similar references to the fractal nature of chaos attractors by Ramalingam et al. (2008) and Thietart and Forgues (1995).

Two references were obtained from respondents on the dual nature of chaos attractors. The first one is that a positive leadership attitude could resemble a chaos attractor while a negative leadership attitude could resemble a repeller (R2-Ref. 12:37). Secondly that a strange attractor incorrectly constituted in a landscape of chaos attractors may become a dangerous repeller (R2-Ref. 5:35). This result supports the notion of Dimitrov (2000:418) who stated that a “strange attractor is able to expand, shrink, merge with other attractors, collapse, or ‘explode’ into new dynamic patterns in the [individual member’s] agent’s mental space”. Also, a dynamic landscape of chaos attractors may change in a similar manner as the sea surface or shifting sand dunes (Remington and Pollack, 2007) that causes a chaos attractor to change into a repeller (Choi et al., 2012).

Various opinions were obtained from respondents on the strength and position of chaos attractors in the specifically designed landscape of chaos attractors for capital projects (refer to Chapter 7, paragraph 7.4.2.1, Figures 7-16 and 7-17). Some respondents felt that the torus chaos attractor is not as strong as the fixed-point chaos attractor (R2-Ref. 5:25). Others that at the start of a capital project, the limit cycle chaos attractors are bigger than later on (R2-Ref. 2:69) and that from the middle of the capital project life cycle the torus chaos attractors are much bigger and the limit cycle chaos attractors much smaller (R2-Ref. 2:70). One respondent was of the view that the butterfly chaos attractor is actually more dominant in explaining how a capital project progresses compared to the other chaos attractors in the landscape (R2-Ref. 3:57) while another was of the view that a much stronger strange attractor is needed during start-up and commissioning (R2-Ref. 11:57). Finally, that a torus chaos attractor is good for improving and project refining but bad for project execution (R2-Ref. 13:45) and is pivotal during the detail design phase (R2-Ref. 13:46). These findings for capital projects relate well to the theoretical description of the relative strength and position of fixed-point chaos attractors as described by Pruitt and Nowak (2014) in Chapter 2. They described a landscape of fixed-point chaos attractors with different attractor basin widths and depths. According to them a wider attractor basin could affect and attract more dynamical system states while a deeper and steeper attractor basin provided more resilience to system behaviour. This is because even small perturbations (distrubances) will not cause a system trajectory to be flung out of a current deep chaos attractor basin. This empirical evidence thus supports the characteristic of relative strength and position chaos attractors i.e. chaos attractors do not have the same strength and their position in the chaos attractor landscape is important to have a desired influence on the system trajectory through the landscape.

Interview responses suggest that a single configuration of chaos attractors may not have the desired effect for all capital projects. Respondents felt that the chaos attractor landscape will have to be tailored for each industry (R2-Ref. 3:55) and differs for each project phase (R2-Ref. 2:74). This may be because there are significant differences between project phases and the associated chaos attractor landscapes (R2-Ref. 13:43). It seems that different chaos attractors might have different effectiveness and influence on the project outcome (R2-Ref. 13:44). A different set of chaos attractors may be required to keep a capital project in an ordered state (R2-Ref. 5:42). Chaos attractors that are good in one landscape are not necessarily good in another landscape (R2-Ref. 5:38). This could be because a landscape of chaos attractors requires fluidness - there is no fixed answer to anything (R2-Ref. 5:39). Perhaps a different configuration of chaos attractors is required to deal with different issues (R2-Ref. 5:46). Finally, a good leader in one role is not necessarily a good leader in another role (R2-Ref. 5:40). These responses support the notion of Shenhar et al. (2002:99) that “one size does not fit all” when he referred to the myth that “all projects are the same and you can use similar tools for all your project activities”. From these responses it is concluded that different chaos attractor landscapes may have to be designed for different types of projects in order to generate local and overall convergence from chaos to order in capital projects. However, the fractal nature of chaos attractors may offer the opportunity to unravel the context-independent characteristics of chaos attractors that may be applicable to all capital projects.

The final comments from respondents on the characteristics of chaos attractors relate to the design of a chaos attractor landscape for capital projects. The opinion has been voiced by a respondent that a project trajectory can definitely be influenced by a landscape of chaos attractors (R2-Ref. 1:72). The up-front positioning of an attractor landscape, attractors and repellers, provided a clear route for the contractor to follow (R2-Ref. 1:70). However, the landscape configuration may depend on the type of project and on the government organisation responsible for the project (R2-Ref. 9:44). Experience will indicate what attractors to put in place in order to guide desired project behaviour (R2-Ref. 2:67).

An understanding of project management, the industry and the “lay of the land” is required in order to apply the landscape of chaos attractors (R2-Ref. 3:54) effectively. An understanding of chaos attractors and what they can do and where to place them in the capital project landscape (R2-Ref. 10:43 and 8:63) is required for the effective design of a chaos attractor landscape for capital projects. It can be concluded that it is possible to design a capital project landscape before the start of the capital project, but knowledge and experience are required about the behaviour of chaos attractors in order to design an effective landscape that could lead to local and overall capital project convergence.

It is concluded from this section that additional characteristics of individual and a landscape of chaos attractor could be identified when viewing the research results of the two rounds of interviews in combination. It seems that all the chaos attractors are not similarly easy to understand but that they address both hard and soft aspects and could have an aspirational value. Although it seems that each landscape of chaos attractors for capital project needs to be designed individually, fractal structures exist which may be used for all capital projects. The detail design of the landscape of chaos attractors will need to be better understood in future research but it seems that chaos attractors have relative strengths and need to be positioned optimally to have the desired local and overall convergence effect. Chaos attractors appear to have a dual nature and my change from one type into another under certain circumstances.

8.5 Conclusion on the Existence of the Refined Chaos-to-Order Model and Various Chaos Theories for Capital Projects

Based on the empirical evidence provided in paragraph 8.4.1 for the randomness-chaos-complexity-order (RCCO) continuum for capital projects, the empirical evidence provided in paragraph 8.4.2 for the local convergence effect of a single chaos attractor and the overall convergence effect of a landscape of chaos attractors for capital projects, it can be concluded that the refined chaos-to-order model as shown in Table 8-1(b) for capital projects, may exist. Based on the empirical evidence obtained from experienced capital project managers, it could be further concluded that the various chaos theories that were derived for capital projects may be plausible.

A summary is given in Figure 8-3 for the scope of this research in terms of chaos theory building and theory testing activities presented in the Vee-Model layout format that is normally used in systems engineering to represent verification and validation activities of complex systems (INCOSE, 2015).

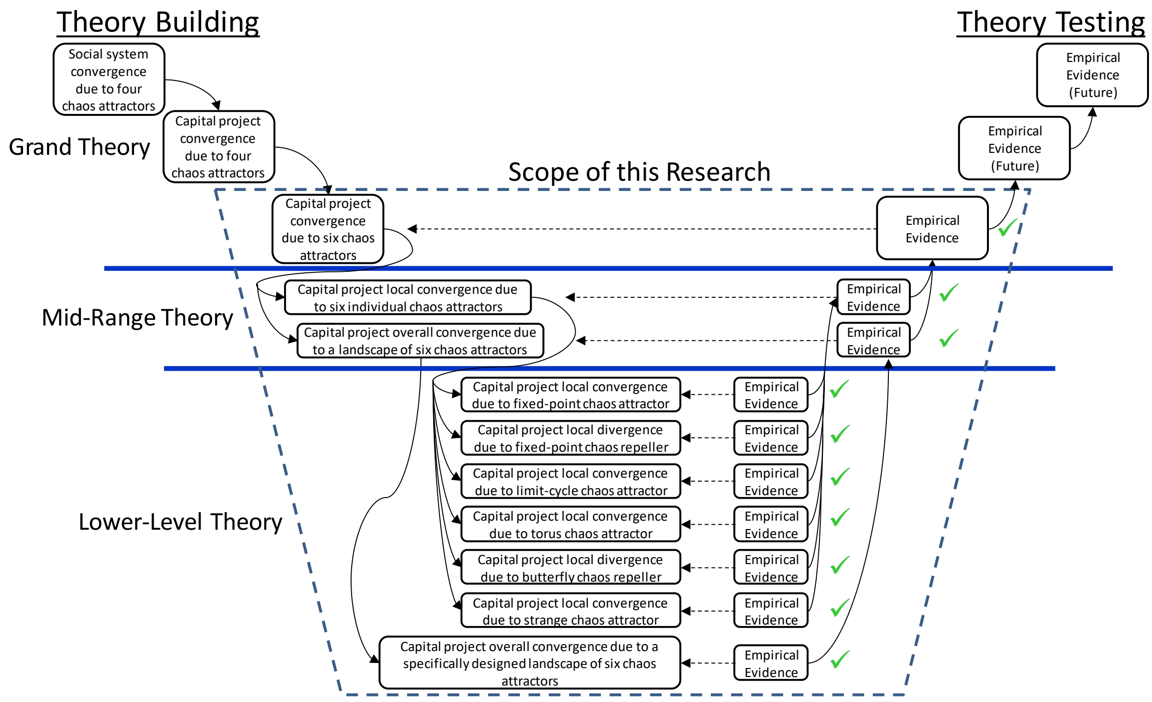


Figure 8-3: Summary of the Scope of this Research for the Grand, Mid-Range and Lower-Level Hierarchy of Theories that were Build and Developed (Left Side of Sketch) and Exploratory Tested (Right Side of Sketch) for Capital Projects

The scope of this research started with a derived grand chaos theory for capital projects that was then further developed into mid-range and lower-level theories as shown in Figure 8-3. Details of the theory development are found in Chapter 3, paragraph 3.4.9.

Only abbreviated versions of the three levels of chaos theories were presented in Figure 8-3. The full versions of these theories, for which supportive empirical evidence was found in this research, are given in Table 8-6.

Table 8-6: Summary of Grand, Mid-Range and Lower-Level Theories for Capital Projects for which Empirical Evidence were Found during this Research

No.	Chaos Theory for Capital Projects	Reference
A. Grand Chaos Theory for Capital Projects		
a	"Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by the following six chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange"	Ch. 3, Par. 3.4.9.3
B. Mid-Range Chaos Theories for Capital Projects		
a	"Chaos theory considers the local convergence from chaos to order a natural phenomenon in capital projects that is brought about by the following six individual chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange"	Ch. 3, Par. 3.4.9.3
b	"Chaos theory considers the overall convergence from chaos to order a natural	Ch. 3, Par.

No.	Chaos Theory for Capital Projects	Reference
	phenomenon in capital projects that is brought about by different configurations of the following six chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange"	3.4.9.3
C. Lower-Level Chaos Theories for Capital Projects		
a	"A fixed-point chaos attractor generates an attractor basin and causes capital project elements and their trajectories to converge to a fixed-point in the basin even if they are perturbed"	Ch. 3, Par. 3.4.9.4
b	"A fixed-point chaos repeller generates a fixed point-of-repulsion and causes capital project elements and their trajectories to be diverted away from the fixed-point"	Ch. 3, Par. 3.4.9.5
c	"A limit-cycle chaos attractor generates a cyclical pattern and causes capital project elements and their trajectories to converge towards the limit-cycles and to which it returns after small perturbations"	Ch. 3, Par. 3.4.9.6
d	"A torus chaos attractor generates multiple spiralling inner cycles that form part of a single outer cycle and cause capital project elements and their trajectories to converge towards the cycles"	Ch. 3, Par. 3.4.9.7
e	"A butterfly chaos attractor generates two outcome basins and causes capital project elements and their trajectories to suddenly jump from one outcome basin to the other when a threshold value is reached"	Ch. 3, Par. 3.4.9.8
f	"A strange chaos attractor generates an attraction zone and causes capital project elements and their trajectories to converge towards this zone in strange ways"	Ch. 3, Par. 3.4.9.9
g	A [specifically designed] landscape of chaos attractors consisting of a group of six different types of chaos attractors [fixed-point, repeller, limit-cycle, torus, butterfly and strange], generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome"	Ch. 3, Par. 3.4.9.10

Table 8-6 Notes: Results from Round 1 Interviews with Sample Size = 12 and Round 2 Interviews with Sample Size = 14

The question arises on the link between our current understanding and paradigm of projects according to ISO21500 and the new chaos theory and alternative understanding of capital projects as presented in this research.

8.6 Chaos Theory Concepts in Capital Projects Attributed to ISO 21500 Subject Groups

An attempt was made to interpret the interview responses from experienced capital project managers for chaos theory concepts in capital projects in terms of the current ISO 21500 project paradigm during the data analysis for this research. The responses of respondents of both interview groups for the RCCO continuum definitions, definitions and characteristics of archetypes as well as for chaos metaphors were assigned to the ten ISO 21500 subject groups using the ISO 21500 code book (Refer to Appendix D, paragraphs D.4 and D.8). The results for the normalised and average values for these assignments are shown in Table 8-7.

Table 8-7: Normalised and Average Results for Continuum Definitions, Archetype Characteristics and Chaos Attractor Metaphor Characteristics that were Assigned to ISO 21500 Subject Groups

SG No.	ISO 21500 Subject Groups (ISO, 2012)	Continuum Definitions (Ch. 5, Par. 5.7)	Archetypes (Ch6, Par. 6.4.6)	Chaos Attractor Metaphors (Ch. 7, Par. 7.5.2)	Average
SG1	Integration	0,92	1,00	1,00	0,97
SG4	Resource	0,76	0,35	0,91	0,67
SG7	Risk	1,00	0,19	0,02	0,40
SG5	Time	0,54	0,15	0,38	0,36
SG2	Stakeholder	0,62	0,23	0,18	0,34
SG3	Scope	0,46	0,19	0,27	0,31
SG10	Communication	0,30	0,00	0,05	0,12
SG9	Procurement	0,08	0,00	0,20	0,09
SG6	Cost	0,11	0,04	0,00	0,05
SG8	Quality	0,03	0,04	0,02	0,03

Legend: SG = Subject Group; Notes: Results from Round 1 Interviews with Sample Size = 12 and Round 2 Interviews with Sample Size = 14

A Spider Diagram of the results from Table 8-7 is shown in Figure 8-4.

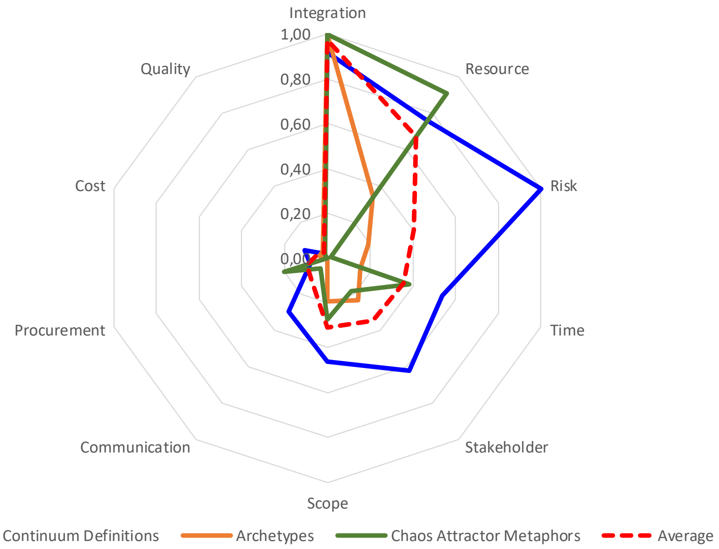


Figure 8-4: Normalised and Average Results for Continuum Definitions, Archetype Characteristics and Chaos Attractor Metaphor Characteristics that were Assigned to ISO 21500 Subject Groups. Round 1 and 2 Interviews. Sample Size n:12 + 14 = 26

Reponses for the four continuum definitions of randomness, chaos, complexity and order from capital project managers (refer to Chapter 5, paragraphs 5.3.1 – 5.3.4) were mostly assigned (blue line in Figure 8-4) to the ISO 21500 subject groups of integration, resource, risk, time, stakeholder, scope and communication and, to a limited extent, to procurement, cost and quality. The characteristics for nine archetypes (refer to Chapter 6, paragraphs 6.3.2 – 6.3.6, 6.4.2.1 – 6.4.2.5, 6.4.3.1 – 6.4.3.4) were mostly assigned (orange line in Figure 8-4) to the ISO 21500 subject groups integration and resource, moderately to stakeholder and scope and to a limited extend to communication, procurement, cost and quality. Finally, the characteristics of the seven chaos attractor metaphors (refer to Chapter 7, paragraphs 7.3.1.3 - 7.3.6.3 and 7.4.2.3) were mostly assigned (green line in Figure 8-4) to the ISO 21500 subject groups integration, resource, time, stakeholder, scope and to a limited extent to risk, communication, procurement, cost and quality.

But, the result for the average assignment of continuum definitions, archetype and chaos metaphors characteristics revealed a strong assignment (red dotted line in Figure 8-4) to the ISO 21500 subject groups of integration and resource, moderate assignment to risk, time, stakeholder and scope and weak assignment to communication, procurement, cost and quality. This outcome could indicate that the understanding, description, concepts and vocabulary of the current process-driven project paradigm viewed from an ISO 21500 point of view, partly overlaps with the descriptions of capital project paradigm when viewed from a chaos theory point of view.

It is concluded that the partial overlap in viewpoints, from a process driven description and chaos theory description, of capital project characteristics appear to be strongly related to the ISO 21500 subject groups of integration and resource; moderately to risk, time, stakeholder and scope and weakly to communication, procurement, cost and quality. The reason for this partial overlap of the two paradigms is not known and could form part of further research.

8.7 Answers to Research Questions

Two main and ten sub-research questions were formulated in Chapter 1 at the start of this research. Once the literature survey was completed in Chapter 2, an attempt was made to provide preliminary answers to these questions (refer to Chapter 2, paragraph 2.8.2 and Tables 2-10 and 2-11). The research questions were revisited in an attempt to provide further answers, based on the empirical results gathered during the two rounds of interviews with experienced capital project managers (Chapters 5, 6 and 7).

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8.7.1 Answers to Main Research Questions

Answers to the main research questions for this research, based on the literature survey (Chapter 2) and the empirical evidence presented in Chapters 5, 6, and 7 is given are Table 8-8.

Table 8-8: Answers to the Main Research Questions for this Research Based on the Literature Survey and the Empirical Research Results

No.	Description	Reference
A. Main Research Question 1		
a	Main Research Question 1 Does the use of individual chaos attractors lead to local convergence from chaos to order of capital project elements and their trajectories?	Ch. 1, Par. 1.9.1
b	Preliminary Answer to Main Research Question 1 from Literature Survey ● The butterfly chaos attractor metaphor has been used by Morgan (2006) in Figure 2-26 to demonstrate organisational change management from one paradigm to another paradigm ● Saynisch (2010) demonstrated the jump in project maturity at a stage-gate under the influence of a single butterfly chaos attractor as shown in Figure 2-33 ● Pedestrian behaviour was shown to be influenced by visual fixed-point chaos attractors as shown in Figure 2-27. Point attractors were able to attract local organisational behaviour to a fixed point in an attractor landscape as shown in Figure 2-23 ● A strange attractor was able to guide skier behaviour towards itself as was shown in Figure 2-20 ● Meade and Rabelo (2004) were able to identify a cyclic industry attractor to expose the current state of their product in the technology adoption life-cycle as shown in Figure 2-14	Ch. 2, Par. 2.8.2
c	Answer to Main Research Question 1 from Empirical Evidence ● Yes, local convergence from chaos to order in a capital project seems to be caused by a fixed-point chaos attractor ● Local divergence away from a fixed-point in a capital project seems to be caused by a fixed-point chaos repeller ● Yes, local convergence from chaos to order in a capital project seems to be caused by a limit-cycle chaos attractor ● Yes, local convergence from chaos to order in a capital project seems to be caused by a torus chaos attractor ● Yes, local convergence from chaos to order in a capital project seems to be caused by a butterfly chaos attractor ● Yes, local convergence from chaos to order in a capital project seems to be caused by a strange chaos attractor	Ch. 8, Par. 8.4.2
B. Main Research Question 2		
a	Main Research Question 2 Does the use of combinations of different types of chaos attractors lead to overall convergence from chaos to order of capital projects?	Ch. 1, Par. 1.9.1
b	Preliminary Answer to Main Research Question 2 from Literature Survey ● The movement of a whole organisation from the chaotic domain through the complex domain under the influence of chaos attractors was shown in Figure 2-30 (Kurtz and Snowden, 2003; Snowden, 2010) ● The presentation by Rossouw (2011) as shown in Figure 2-34 combines both the Stacey Matrix (Figure 2-6) and the Cynefin framework (Figure 2-8)	Ch. 2, Par. 2.8.2

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No.	Description	Reference
	to imply that a complete project trajectory could be guided under the influence of chaos attractors from chaos towards order	
c	Answer to Main Research Question 2 from Empirical Evidence ● Yes, a specifically designed landscape of chaos attractors for a capital project consisting of a fixed-point chaos attractor, fixed-point chaos repeller, limit-cycle chaos attractor, torus chaos attractor, butterfly chaos attractor and strange attractor seems to cause overall convergence from chaos to order	Ch. 8, Par. 8.4.2

Based on the empirical evidence presented in Table 8-8 as well as the limitations as explained in paragraph 8.8, it is concluded that the two main research questions could be answered sufficiently using an exploratory research methodology.

8.7.2 Answers to Sub-Research Questions

Answers to the sub-research questions for this research based on the literature survey that was done in Chapter 2 as well as the empirical evidence presented in Chapters 5, 6, and 7 are given in Table 8-9.

Table 8-9: Answers to the Sub-Research Questions for this Research Based on the Literature Survey as well as Empirical Research Results

No.	Description	Reference
A. Sub-Research Question 1		
a	Which attractor types and classes could be identified from the literature?	Ch. 1, Par. 1.9
b	● Eleven different attractor types were identified as shown in Figure 2-21. All types of attractors seem to originate from the four prominent attractors: point, cycle, torus and chaotic (strange).	Ch. 2, Par. 2.6.4
c	● Only six of the eleven types of chaos attractors were used as part of this research – refer to Figure 3-5	Ch. 3, Par. 3.4.9.2
B. Sub-Research Question 2		
a	What are the characteristics and functions of each attractor based on the literature?	Ch. 1, Par. 1.9
b	● Attractor attributes and examples for each attractor type based on the literature survey is given in Table 2-7	Ch. 2, Par. 2.6.5
c	● Empirical evidence was obtained for examples and characteristics of the following six chaos attractors in capital projects: fixed-point chaos attractors (Tables 7-1 and 7-2), fixed-point chaos repellers (Tables 7-4 and 7-5), limit-cycle chaos attractors (Tables 7-6 and 7-7), torus chaos attractors (Tables 7-8 and 7-9), butterfly chaos attractors (Tables 7-11 and 7-12) and strange chaos attractors (Tables 7-14 and 7-15)	Ch. 7, Par. 7.3.1 to Par. 7.3.6
C. Sub-Research Question 3		
a	What empirical studies have been done to demonstrate the effect of attractors?	Ch. 1, Par. 1.9
b	● A summary of attractors being applied in different fields of science according to literature is given in Table 2-8	Ch. 2, Par. 2.6.6.
c	● This research provided empirical evidence on the evaluation of six variance models for the local converging effect of individual chaos attractors	Ch. 7, Par. 7.3 to Par. 7.4

No.	Description	Reference
	and one variance model for the overall converging effect of a landscape of chaos attractors in capital projects in Figures 7-4, 7-6, 7-8, 7-10, 7-12, 7-14 and 7-17	
D. Sub-Research Question 4		
a	Do attractors only appear in chaotic types of systems, or also in random, complex and ordered system types?	Ch. 1, Par. 1.9
b	● From the literature survey attractors have been found to appear the ordered, complex and chaotic domains as shown in Table 2-9	Ch. 2, Par. 2.6.10
c	● Empirical evidence was provided for the presence of chaos attractors in the randomness, chaotic, complexity and ordered domain of a specifically designed landscape of chaos attractors in capital projects in Figure 7-17	Ch. 7, Par. 7.4.2.1
E. Sub-Research Question 5		
a	Do attractors appear simultaneously in systems, and what are the effects of attractors on each other and on the overall system behaviour?	Ch. 1, Par. 1.9
b	● The simultaneous appearance of fixed-point attractors and fixed-point repellers were shown in a three-dimensional attractor landscape in Figure 2-22 ● The simultaneous appearance of point, cyclic and chaotic attractors were shown in a two-dimensional attractor landscape in Figure 2-23	Ch. 2, Par. 2.8.3
c	● Empirical evidence was provided for the simultaneous appearance of chaos attractors in the specifically designed landscape of chaos attractors in capital projects in Figure 7-16 ● Empirical evidence was found that indicate that if you have three equally strong fixed-point chaos attractors that represent the time, cost and quality goals of a capital project, it may happen that the attraction is directed simultaneously to all three fixed-points with the result that no overall convergence could take place in Table 7-2 (R2-Ref. 12:28 and 12:31)	Ch. 7, Par. 7.4.2.1 Ch. 7. Par. 7.3.1.3
F. Sub-Research Question 6		
a	Do attractors only appear naturally in systems or could they be pre-designed?	Ch. 1, Par. 1.9
b	● Attractors both appear naturally in systems with an increase in a key variable as shown in in Figure 2-25 ● For organisation change management it was shown in Figure 2-26 that attractors need to be created and destroyed to obtain the desired outcome ● Multiple attractors could be created in the complex domain to guide organisational behaviour and undesirable attractors could be destroyed as show in Figure 2-30 ● A natural butterfly attractor seems to exist at the project stage-gate that could lead to either success or catastrophe as shown in Figure 2-33	Ch. 2, Par. 2.8.3
c	● Capital project managers that were interviewed agreed with various naturally appearing landscapes of chaos attractors as found in various sciences as shown in Figure 7-15 ● Capital project managers that were interviewed agreed with a specifically pre-designed landscape of chaos attractors for capital projects as shown in Figures 7-16 and 7-17	Ch. 7, Par. 7.4
G. Sub-Research Question 7		
a	Are there strong and weak attractors?	Ch. 1, Par. 1.9
b	● A strong butterfly attractor at a project stage-gate leads to a successful gate transition but a weak attractor leads to a catastrophe and failure as shown in Figure 2-33	Ch. 2, Par. 2.7.8
c	Capital project managers provided the following evidence during the interviews:	

No.	Description	Reference
	● The torus chaos attractor is not as strong as the fixed-point chaos attractor (Table 7-9, R2-Ref. 5:25) ● At the start of a capital project the limit cycle chaos attractors are bigger than later on (Table 7-21, R2-Ref. 2:69) ● From the middle of the capital project life cycle the torus chaos attractors are much bigger and the limit cycle chaos attractors much smaller (Table 7-21, R2-Ref. 2:70) ● The butterfly chaos attractor is actually more dominant in explaining how a project progresses compared to the other chaos attractors in the landscape (Table 7-21, R2-Ref. 3:57) ● You need a much stronger strange attractor during start-up and commissioning (Table 7-21, R2-Ref. 11:57)	Ch. 7, Par. 7.3.4.3 Ch. 7, Par. 7.4.2.3 Ch. 7, Par. 7.4.2.3 Ch. 7, Par. 7.4.2.3 Ch. 7, Par. 7.4.2.3
H. Sub-Research Question 8		
a	Where in the project life cycle do attractors occur naturally?	Ch. 1, Par. 1.9
b	● It seems that a butterfly attractor appears naturally at the project stage-gate as shown in Figure 2-33	Ch. 2, Par. 2.7.8
c	● Evidence was found for chaos attractors that appear naturally in mega projects with the following statement of a respondent: "[A] mega project represents a landscape of multiple kinds of chaos attractors" (Table 7-18, R2-Ref. 12:76)	Ch. 7, Par. 7.4.1.2
I. Sub-Research Question 9		
a	What is the effect of naturally occurring attractors on overall project behaviour and as part of the project life cycle?	Ch. 1, Par. 1.9
b	● This information could not be derived from the literature survey	Ch. 2, Par. 2.8.3
c	The following responses were obtained from capital project managers: ● Mega projects - more than one route exists in the landscape of chaos attractors (Table 7-18, R2-Ref. 12:72) ● [Capital] project trajectory can definitely be influenced by landscape of chaos attractors (Table 7-19, R2-Ref. 1:72)	Ch. 7, Par. 7.4.1.2 Ch. 7, Par. 7.4.1.3
J. Sub-Research Question 10		
a	Could attractors be designed and positioned as part of the pre-project architecture to have an overall project convergence effect?	Ch. 1, Par. 1.9
b	● This information could not be derived from the literature survey	Ch. 2, Par. 2.8.3
c	The following empirical evidence was obtained from capital project managers: ● Referring to the specifically designed chaos attractor landscape of a capital project as shown in Figure 7-17, a respondent noted that: "My current project looks like this landscape if you look backwards" (Table 7-20, R2-Ref. 7:34) ● If you are missing either leadership [strange chaos attractor] or processes [torus chaos attractor] overall convergence is not going to happen (Table 7-21, R2-Ref. 8:64) ● You need to continuously apply management energy [strange chaos attractor?] to obtain convergence (Table 7-21, R2-Ref. 5:34) ● The different chaos attractors might have different effectiveness and influence on the project outcome (Table 7-21, R2-Ref. 13:44) ● The overall convergence effect of a specifically designed landscape of chaos attractors was confirmed by most of the capital project managers with a mode score of 4 for the variance model outcomes as shown in Figure 7-18	Ch. 7, Par. 7.4.2.2 Ch. 7, Par. 7.4.2.3 Ch. 7, Par. 7.4.2.3 Ch. 7, Par. 7.4.2.3 Ch. 7, Par. 7.4.2.5

Based on the empirical evidence presented in Table 8-9, as well as the limitations as explained in paragraph 8.8, it is concluded that the sub-research questions could be answered sufficiently using an exploratory research methodology.

8.8 Summary of the Limitations of the Research Results

A summary of the limitations of the research results is given in this section. The limitations that pertain to the Round 1 interviews in terms of sample size, data collection and data analysis is given in Table 8-10.

Table 8-10: Summary of the Limitations of the Research Results for the Round 1 Interviews

No.	Limitation	Descriptions for this Research	Reference
1	Chaos Attractor Definition and Understanding	Some respondents thought that "chaos attractor" meant the attraction of chaos - the researcher had to provide explanations for certain terminology in order to gain a common understanding among respondents. The definitions obtained from respondents for the continuum elements were not consistent	Ch. 4, Par. 4.5.2.6, Table 4-13
2	Handwriting Recognition	Some of the respondents did not write legibly on the interview questionnaire and that data was lost	Ch. 4, Par. 4.5.3.1, Table 4-14
3	Quality of Voice Recording	Some portions of the voice recordings were difficult to transcribe as respondents spoke softly or were not speaking into the microphone. Such data may have been misinterpreted or lost	Ch. 4, Par. 4.5.3.1, Table 4-14
4	Non-Recognition of Voice Recording	In a few cases specific words or phrases could not be recognised by the researcher. Such data was lost	
5	Atlas.ti Software	The voice recording transcription function of the Atlas.ti software was employed to convert voice recordings into typed transcriptions. It was found that several transcriptions had to be redone due to software malfunction. The researcher was not able to use the same software for simultaneous voice recording transcription and content analysis and data errors may have occurred in the translation process	
6	Iterative Content Analysis	It was found that summative content analysis was iterative in nature. Using the code book and keyword assignments (Atlas.ti) a number of transcribed texts had to be analysed iteratively before the results could be consistently extracted. Errors may have occurred in the consistent extraction of results	Ch. 4, Par. 4.5.3.4, Table 4-15
7	Code Book for Consistent Keyword Categorisation	The code book was found to be an important anchor to ensure maximum consistency during content analysis. Each respondent used both similar but also sometimes completely different terminology in their responses that have the same meaning. Errors may have occurred in the consistent use of terminology	
8	Sample	The demographic profiles of the 12 experienced project managers for Round 1 included exposure to project management (71%), program management (15%) and portfolio management (7%). The unit of analysis was the capital project and therefore the results may have been skewed towards program and portfolio management	Ch. 4, Par. 4.5.3.5, Table 4-16
9	Sample Size	A total of 12 experienced project managers were interviewed in	

No.	Limitation	Descriptions for this Research	Reference
		four groups of three during Round 1. Although the representation of the twelve respondents covered a wide range of desired criteria, a larger sample would have given better representation of the sampling frame and population	
10	Data Collection	The interview duration was limited to 1,5 hours. More relevant data may have been captured if respondents were allowed more time for free participation during the interviews	
11	Data Analysis	The summative content analysis method required keywords to be identified with the help of the code book and categorised as first order concepts. Although care has been taken to be consistent in the categorisation of keywords some errors may have occurred as the data analysis was only done and checked by the researcher	

A summary of the limitations for the research results that pertains to the Round 2 interviews in terms of sample size, data collection and data analysis is given in Table 8-11.

Table 8-11: Summary of the Limitations of the Research Results for the Round 2 Interviews

No.	Limitation	Descriptions for this Research	Reference
1	Comprehension of Chaos Attractor Metaphor	Most of the respondents were able to understand the chaos attractors metaphors and were able to map them to the capital project environment. However, the researcher had to explain the origin of these metaphors in detail to respondents. Errors may have occurred in the repeatability and consistency of these explanations	Ch. 4, Par. 4.6.2.6, Table 4-22
2	Scoring of the Chaos Attractor Variance Models	The respondents were able to do a Likert scoring of all the variance models. The researcher had to explain each of the elements of each variance model in detail to respondents. Errors may have occurred in the repeatability and consistency of these explanations	
3	Quality of Voice Recording	Some portions of some of the voice recordings were difficult to transcribe as respondents spoke softly or were not speaking into the microphone. Errors may have occurred during the transcription process	
4	Non-Recognition of Voice Recording	In a few cases specific words or phrases could not be recognised by the researcher either by replay of the voice recording or by reading the associated hand-written response from the respondent – this data was lost	Ch. 4, Par. 4.6.3.1, Table 4-23
5	Atlas.ti Software	The voice recording transcription function of the Atlas.ti software was employed to convert voice recordings into typed transcriptions. It was found that several transcriptions had to be redone due to software malfunction. The researcher was not able to use the same software for simultaneous voice recording transcription and content analysis and data errors may have occurred in the translation process	
6	Iterative Content Analysis	It was found that direct content analysis method was iterative in nature. Using the code book and keyword assignments (Atlas.ti), a few transcribed texts had to be analysed before the results could be consistently extracted. Errors may have occurred in the consistent use of this method	

No.	Limitation	Descriptions for this Research	Reference
7	Code Book for Consistent Keyword Categorisation	The code book was found to be an important anchor to ensure maximum consistency during content analysis. Each respondent used both similar but also sometimes completely different terminology in their responses that have the same meaning. Errors may have occurred in the consistent use of terminology	
8	Delayed Grasping of the Metaphor Concepts	One respondent had difficulty in grasping and applying some of the metaphors to the capital project environment. However, when the landscape of chaos attractors and the overall convergence effect were discussed later on during the interview, the respondent was able to identify the metaphors which were previously unrecognisable. It seems that some respondents needed more time and perhaps a different viewpoint of the same concept to enable understanding of the metaphors in the capital project environment. More interview time may have facilitated better metaphor recognition results	Ch. 4, Par. 4.6.3.4, Table 4-24
9	Sample	The demographic profile of the sample of 14 experienced project managers for the Round 2 interviews covered respondent exposure to project management (53%), program management (19%) and portfolio management (20%). The demographic profile of the sample of 12 experienced project managers for the Round 1 interviews covered project management (71%), program management (15%) and portfolio management (7%). The unit of analysis was the capital project and the results may be skewed towards program and portfolio management	
10	Sample Size	A total of 14 experienced project managers were interviewed individually during Round 2. Although the representation of the 14 respondents seems to cover a wide range of the desired criteria, a larger sample size would have been a better representation of the sample frame and population	
11	Data Collection	During the interview of the first respondents for Round 2 (respondent code KS), a technical error occurred with the voice recording of the first two questions. After the interview the researcher wrote down as many of the interview content for these two questions as he could remember. The results were sent back to the respondent for verification. Some of the data may have been lost	Ch. 4, Par. 4.6.3.5, Table 4-25
12	Data Analysis	The direct content analysis method required codes to be identified with the help of the code book and categorised as first order concepts. Although care has been taken to be consistent in the categorisation of codes some errors may have occurred as the data analysis was only done and checked by the researcher	

The limitations of the research results, as given in Table 8-10 and Table 8-11, for the sample size, data collection and data analysis methodologies are similar and could be taken as a consistent error in the final results.

Referring to the pre-designed research triangulation design strategy as given graphically in Figure 4-7 (Chapter 4, paragraph 4.3.2.9), both groups of experienced capital project managers were able to recognise, identify, describe and give capital project examples for the three model types that were exploratory tested during this research. Model type 1 was for the continuum concept and the landscape of chaos attractors, model types 2 and 3 for the chaos attractor concept, chaos attractor metaphors and models. In addition, a new model type in the form of archetypes was identified and confirmed by both groups of respondents. The recognitions of chaos theory concepts were done during two rounds of interviews using different samples (12 vs 14), different data collection methods (Nominal Group Technique vs Mixed Methods) and different data analysis methods (summative vs direct). Finally, the self-assessment results indicated that respondents of both groups were able to understand and transfer the metaphors to the capital project environment (mode 4 and 5).

It is concluded that although some errors occurred during the data capturing and analysis process, the triangulation strategy that was employed for this research supports the validity and rigor of the results that were obtained and presented.

8.9 Summary of Results

The objective of this chapter was collate the three sets of results on: a) the capital project randomness-chaos-complexity-order (RCCO) continuum; b) initial views from respondents on chaos attraction (Chapter 5), the definition and confirmation of nine archetypes (Chapter 6); and c) the description of six individual chaos attractors and a group of chaos attractors causing local and overall convergence in capital projects (Chapter 7).

This Chapter started by re-stating the main and sub-research questions after which the refined overall conceptual model that was explored with its accompanying grand theory. This overall conceptual model and grand theory guided the activities of this research in order to answer the research questions.

Two sets of empirical evidence were presented. The first set was for the randomness-chaos-complexity-order continuum (RCCO) in capital projects and the second set was for the local converging effect of individual chaos attractors and the overall converging effect of a group of chaos attractors.

Although these two sets of results were presented separately, they form part of the same integrated concept of a chaos attractor and a group of chaos attractors in a capital project life cycle.

Based on the empirical evidence presented for this exploratory research it is concluded that supporting evidence was found for the existence of the grand chaos theory, mid-rand chaos theory and lower-level chaos theories for capital projects.

The empirical results across two interview groups indicated that chaos theory descriptions of capital project characteristics seem to be strongly related to the ISO 21500 subject groups of integration and resource, moderately to risk, time, stakeholder and scope and weakly to communication, procurement, cost and quality. The reason for this result is not clear and further research was suggested.

An attempt was made to provide answers to the main and sub-research questions based on the empirical results of this research. All research questions could be answered.

The limitations of this research were summarised for the Round 1 and Round 2 interviews with experienced capital project managers. The triangulation design is believed to provide sufficient rigor for the use of the empirical results that were obtained through the qualitative research method and employed in both data collection and data analysis.

Finally, the main result that emerged from this Chapter is that local and overall convergence from chaos to order in capital projects seems possible when using individual or a group of chaos attractors.

The final Chapter 9 will conclude on the results and provide some recommendations for future research.

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CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

This final chapter of this research aims to provide a backward-looking view, summary and conclusions on the key ideas, concepts and results of the previous chapters. The previous chapters include: problem statement (Chapter 1); literature review (Chapter 2); theory and model development (Chapter 3); research methodology (Chapter 4); empirical results (Chapters 5, 6 and 7) and a discussion of the combined empirical results (Chapter 8). The major conclusion of this research as well as a summary of individual contributions to theory development are provided in this Chapter. This is followed by a self-assessment and finally by a forward-looking view on recommendations for future research in terms of aspects of chaos theory related to capital projects.

9.1.1 Major Conclusion of this Research

Although the starting point for this research was the observation of historical capital project cost overruns with seemingly no improvement, despite the increase in knowledge in project management, it is argued that this problem is just a manifestation of two dilemmas. Two paradigm shifts are suggested as remedies for the dilemmas and it is shown that chaos theory could perhaps be considered as a possible theoretical foundation for addressing both of these dilemmas.

9.1.2 Two Dilemmas, Two Paradigm Shifts and Chaos Theory

The origin of this research revolved around capital project cost overruns and the resulting delayed multiplier effect of these projects to society as portrayed in Chapter 1. It was shown that historical data on capital project cost overruns for periods of 21 years, 54 years and even 80 years revealed no improvement. This despite a rapid increase in the knowledge on project management that is published in scientific research journals, the rise of project management institutions and the availability of regularly updated best practices (refer to Chapter 1, paragraph 1.1). This situation creates the following dilemma in knowledge creation and capital project cost overruns:

Dilemma 1:

Despite an increase in knowledge about project management, projects historically appear to continue to have substantial cost overruns and be considered as failed projects.

The world is changing at an accelerated pace since the industrial revolution in multiple dimensions (Steffen et al., 2011) and technological development seems to have a profound influence on the accelerated rate of development (Kurzweil, 2005), as shown in Chapter 1 and Appendix A. Bennett and Lemoine (2014) characterised this world as volatile, uncertain, complex and ambiguous (VUCA) to give expression to what Gandhi (2017:2) described as the "chaotic, turbulent, and rapidly changing business environment". The capital project internal and external environments seem therefore to be subjected to trends, megatrends, paradigm shifts, Black Swan events as well as disruptive technologies (refer to the construct in Chapter 1, Figure 1-5 and Appendix A).

The dominant manner in which new knowledge is created for the understanding of complex problems in the VUCA world still seems to revolve around linear thinking and seeing and treating complex problems as big divisional cause-and-effect "clockwork masterpiece(s)" (Cicmil et al., 2009:22). It appears as if these complex problems could be reduced and broken down into their lowest level elements, with the illusion that by solving each element on its own, the complex problem is solved (Cleden, 2009). Kurtz and Snowden (2003) reasoned that humans are not limited to one identity, act according to pre-determined rules or act on a local pattern as they are "self-determining, self-willed, self-motivated and selfish" (Remington and Pollack, 2007:1). How could such increased levels and dimensions of complexity be characterised and assessed to benefit project management in the VUCA world?

Gharajedaghi (2011:9) is of the opinion that a dilemma exists between interdependency and independency when he states that:

> Dilemma 2:
>
> ***"While the organization as a whole is becoming more and more interdependent, the parts increasingly display choice and behave independently."***

Gharajedaghi (2011) notes that a dual shift of paradigm is required to resolve this dilemma. He suggests that the first is a shift of paradigm in the nature of reality. He reasons that nature of organizations has changed from a mindless system (mechanistic view) to a uni-minded system (biological view) to a multi-minded system (socio-cultural view). The second required shift in paradigm is in the nature of analysis. He states that a change in the method of inquiry is required from “analytical thinking (the science of dealing with independent sets of variables) to holistic thinking (the art and science of handling interdependent sets of variables)” (Gharajedaghi, 2011:8). It could be argued that the same paradigm shifts are required for resolving Dilemma 2 in project management.

Remington and Pollack (2007:1) state that “’systemic pluralism’ is an approach that practitioners need to pursue if they are to survive and deliver successful project outcomes in complex contexts“. Gharajedaghi (2011:69) supports this line of thinking by referring to plurality in terms of theories that are required that are able to consider simultaneous change in structure, function and process of systems in the “same or different environment(s)”. He references the ground-breaking work done by Ackoff and Emery (2008) and describes ideal-seeking purposeful systems theory that states that systems are “capable of redesigning themselves by new functions, structures and processes creating new modes of organization at the higher levels of order and complexity” (Gharajedaghi, 2011:72). Gharajedaghi (2011:57) reasons that chaos theory is at work in systems with this level of complexity and that “chaos theory considers the tendency toward order a *natural phenomenon* produced by the action of four types of attractors: point attractors, cycle attractors, torus attractors and strange attractors”.

It follows therefore that chaos theory seems to hold the promise to give expression to the required dual paradigm shift, in terms of the nature of reality and the nature of analysis of complex systems that are immersed in the VUCA world. Chaos theory was therefore chosen as the theoretical foundation for this research for the convergence from chaos to order in capital projects.

9.1.3 Major Conclusion on Chaos Theory Applied to Capital Projects

Based on derived chaos theories and models that were exploratory tested using responses from 26 experienced capital project managers, and employing qualitative research methodology, supporting evidence was found to suggest that the local and overall convergence behaviour from chaos to order of capital projects may be understood and predicted using chaos theory concepts. Local and overall convergence neither imply a successful capital project nor a reduction of capital project cost overruns. However, chaos theory holds the promise to aid local and overall project convergence and thereby contribute to the minimisation of capital project cost overruns.

Bredillet (2008:4) summarised nine schools of thought, since 1940, that were used by researchers to describe key ideas about the characteristics of projects using metaphors. The nine schools of thought with their metaphors are: 1) optimisation - the project as a machine; 2) modelling - the project as a mirror; 3) governance - the project as a legal entity; 4) behaviour - the project as a social system; 5) success - the project as a business objective; 6) decision - the project as a computer; 7) process - the project as an algorithm; 8) contingency - the project as a chameleon; and 9) marketing - the project as a billboard. Perhaps the results of this research could form the 10th school of thought as: "10) chaos - capital project as a landscape of chaos attractors" as shown in Table 9-1.

Table 9-1: New Additional School of Thought in Project Management

No.	School	Metaphor	Key Idea
10	Chaos	The (capital) project as a landscape of chaos attractors	Chaos attractors cause local and overall convergence from chaos to order

The refined overall refined conceptual model using chaos theory concepts that was explored for this research for capital projects is shown schematically in Figure 9-1.

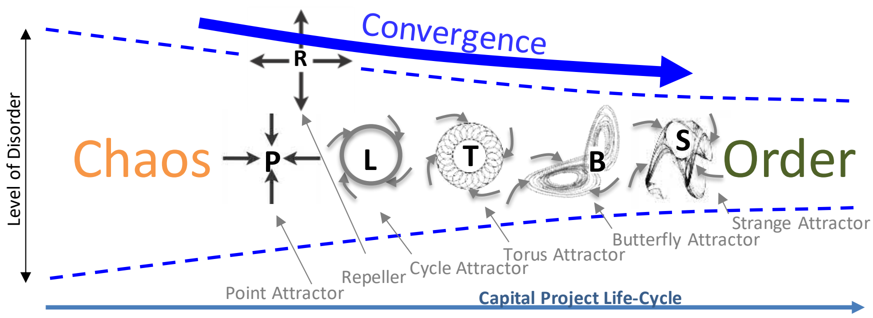

Figure 9-1: Overall Refined Conceptual Model Using Chaos Theory Concepts Applied to Capital Projects that was Explored for this Research

The conceptual model in Figure 9-1 depicts a derived grand chaos theory (see also Chapter 3, paragraph 3.4.9.3, Table 3-8) for capital projects that states the following:

> ***"Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by the following six chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange".***

Based on this theory, it was possible to generate various contributions during this research to the capital project management domain.

9.2 Contributions to Chaos Theory in the Capital Project Domain

This research contributed to the generation of new theoretical knowledge and empirical evidence on the use of chaos theory concepts in the capital project domain.

Chaos attractor metaphors from various fields of science were mapped to the capital project domain to enable the use of these metaphors for capital projects. Various levels of chaos theory were then developed using these metaphors, borrowed theoretical concepts and empirical material. The derived chaos theories were also used to guide the generation of various variance models.

Empirical evidence was obtained suggesting the validity of these chaos theories and models. After completion of the analysis of the empirical evidence, it was possible by means of a retroductive approach to suggest a chaos attractor model using ISO 21500 subject groups.

9.2.1 Metaphor Mapping from Various Fields of Science to the Capital Project Domain

A comprehensive literature survey was done in Chapter 2 to identify references to chaos theory and specifically to chaos attractors. Information on chaos attractor metaphors was organised according to their type and mapped (refer to Appendix C) from the various source domains to the capital project target domain (Cornelissen and Kafouros, 2008), as schematically shown in Figure 9-2.

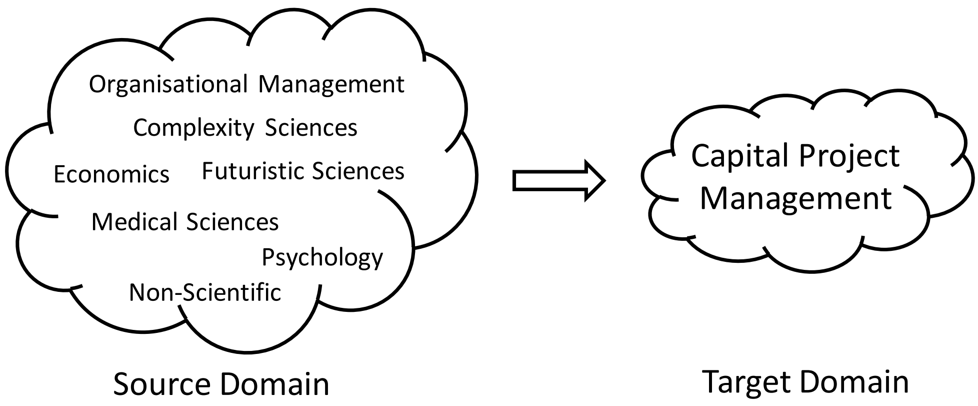

Figure 9-2: Schematic Representation of the Process that was Followed to Map Chaos Attractor Metaphors from Various Fields of Science (Source Domain) to the Capital Project Management Field of Science (Target Domain)

Published literature on chaos attractor metaphors was found in a wide variety of international journals that covered multiple sciences such as organisational management, complexity, economics, futuristic, medical, psychology as well as non-scientific sources of information as shown in Figure 9-2. The objective of the mapping of chaos attractor metaphors from other sciences to the capital project domain was done with the objective to test for their applicability and use in the project management field of science and thereby contribute to the creation of new knowledge in this field.

9.2.2 Metaphor Development for Capital Projects

During the literature survey on chaos attractors, a total of 11 different types of chaos attractors (refer to Chapter 2, paragraph 2.6.4, Figure 2-21) were identified that originate from the four prominent chaos attractors. The four prominent chaos attractors were mentioned by Gharajedaghi (2011:57) in his chaos theory as "point attractors, cycle attractors, torus attractors and strange attractors". Saynisch (2010) tried to explain the fast jumps that happened in second order evolutionary processes and that it could perhaps explain maturity jump at a project stage gate. In addition, references were found in the literature on the possible existence of landscapes of chaos attractors and the potential overall convergence and bounded guidance effect of such landscapes by groups of different chaos attractors (refer to Chapter 3, paragraph 3.5.4). It was then decided to choose and develop six of the eleven types of chaos attractor metaphors for exploring their individual and overall convergence effect in capital projects (refer also to Chapter 3, Figure 3-5) as shown in Figure 9-3.

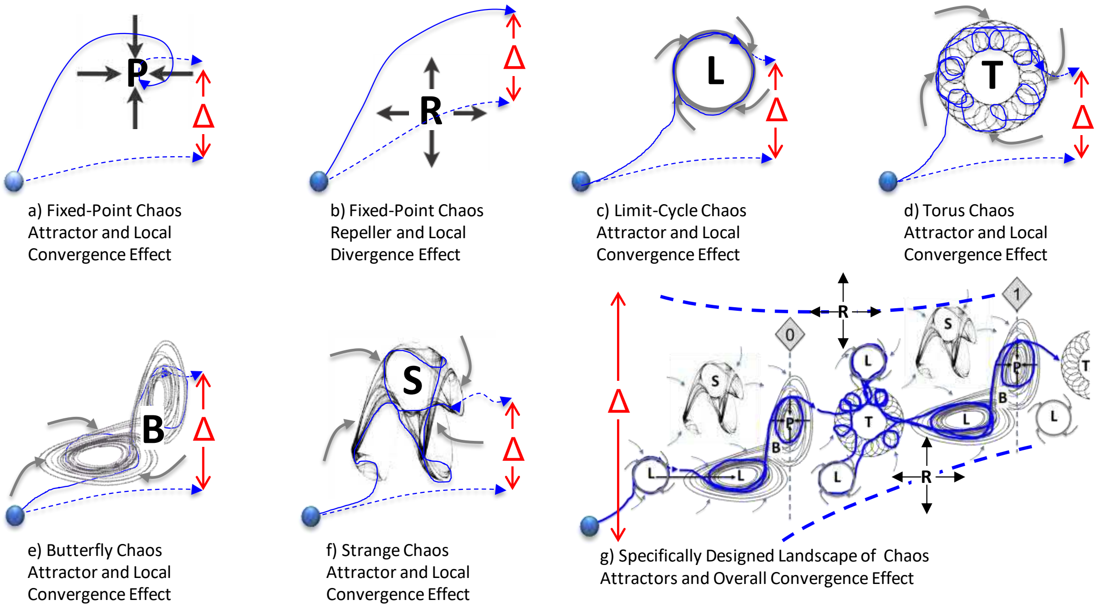

Figure 9-3: Selection and Development of Six Individual Chaos Attractor Metaphors and a Specifically Designed Landscape of Chaos Attractors for Use in Capital Projects

Symbols were developed for these chosen chaos attractors to show their "chaos attraction" effect (light grey arrows) as shown in Figure 9-3. Also, the influence in the presence and absence of a chaos attractor on the trajectory of capital project elements is shown as a delta (Δ). Chaos theory states that a chaos attractor is able to attract and cause local convergence of capital project elements and influence their trajectories, as shown in Figure 9-3(a-f). However, when a specifically pre-designed landscape of these six chaos attractors is configured as shown in Figure 9-3(g), chaos theory states that such a landscape influences the trajectory of the capital project by causing both local convergence and overall capital project convergence. In the absence of such a specifically designed landscape of chaos attractors the overall convergence effect is much weaker as indicated by the delta (Δ) in overall convergence of the capital project in Figure 9-3(g). These chaos attractors and the landscape of chaos attractors were tested using qualitative research methodology (Chapter 4) based on responses from 26 experienced capital project managers (Chapters 5 and 7).

9.2.3 Building Chaos Theories for Capital Projects

The starting point for theory building for this research was taken from the formulation of chaos theory by Gharajedaghi (2011:57) that states: "Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by point, cycle, torus and strange chaos attractors". Using the framework of grand, mid-range and lower-level theories from Bacharach (1989) and Noyes et al. (2016); the techniques of horizontal and vertical theory borrowing by Whetten et al. (2009) and the theory building model by Boxenbaum and Rouleau (2011), a number of layered chaos and chaos attractor theories could be derived for this research (refer to Chapter 3) as shown in Table 9-2. Note that in the literature and in this research the fixed-point chaos repeller is considered to be part of the term "chaos attractors".

Table 9-2: Summary of Grand, Mid-Range and Lower-Level Chaos Theories that were built for Capital Projects for this Research

No.	Chaos Theory for Capital Projects	Reference
A. Grand Theory		
1	"Chaos theory considers the convergence from chaos to order a natural phenomenon in capital projects that is brought about by the following six chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange"	Ch. 4, Par. 3.4.9.3
B. Mid-Range Theories		
1	"Chaos theory considers the local convergence from chaos to order a natural phenomenon in capital projects that is brought about by the following six individual chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange"	Ch. 3, Par. 3.4.9.3
2	"Chaos theory considers the overall convergence from chaos to order a natural phenomenon in capital projects that is brought about by different configurations of the following six chaos attractors: fixed-point, repeller, limit-cycle, torus, butterfly and strange"	Ch. 3, Par. 3.4.9.3
C. Lower-Level Theories		
1	"A fixed-point chaos attractor generates an attractor basin and causes capital project elements and their trajectories to converge to a fixed-point in the basin even if they are perturbed"	Ch. 3, Par. 3.4.9.4
2	"A fixed-point chaos repeller generates a fixed point-of-repulsion and causes capital project elements and their trajectories to be diverted away from the fixed-point"	Ch. 3, Par. 3.4.9.5
3	"A limit-cycle chaos attractor generates a cyclical pattern and causes capital project elements and their trajectories to converge towards the limit-cycles and to which it returns after small perturbations"	Ch. 3, Par. 3.4.9.6
4	"A torus chaos attractor generates multiple spiralling inner cycles that form part of a single outer cycle and cause capital project elements and their trajectories to converge towards the cycles"	Ch. 3, Par. 3.4.9.7
5	"A butterfly chaos attractor generates two outcome basins and causes capital project elements and their trajectories to suddenly jump from one outcome basin to the other when a threshold value is reached"	Ch. 3, Par. 3.4.9.8
6	"A strange chaos attractor generates an attraction zone and causes capital project elements and their trajectories to converge towards this zone in strange ways"	Ch. 3, Par. 3.4.9.9
7	A [specifically designed] landscape of chaos attractors consisting of a group of six different types of chaos attractors [fixed-point, repeller, limit-cycle, torus, butterfly and strange], generates a bounded landscape and causes capital project elements and their trajectories to converge towards a specified outcome"	Ch. 3, Par. 3.4.9.10 and Ch. 3, Par 3.5.4.1

The theory building model of Boxenbaum and Rouleau (2011) that was used contained empirical material, borrowed theoretical concepts and metaphors. Therefore, the six metaphors and the one landscape of chaos attractors that were developed for this research as shown in Figure 9-3, were used to build the theories as shown in Table 9-2. Empirical evidence for various aspects of these theories was given in Chapters 5, 6 and 7 and was summarised in Chapter 8.

9.2.4 Building Variance Models for Capital Projects

The characteristics of phenomena could also be formulated and studied using variance models (snapshot in time) that are based on variance theory or process models (evolution over time) that are based on process theory (Langley, 1999). For the purpose of this research the literature survey information on each chaos attractor and the effect of a chaos attractor on nearby elements were arranged as variance models (Chapter 3). Relevant information form literature was analysed and presented as independent variables, the chaos attractors as the dependent variables and the generic and specific outcomes and effects as a result of the chaos attractor. A total of seven variance models were built (Chapter 3, paragraph 3.5) as part of this research and is summarised in Table 9-3.

Table 9-3: Summary of Variance Models for Chaos Attractors as Dependent Variable that were Built and Evaluated for Capital Projects for this Research

No.	Variance Models Chaos Theory for Capital Projects	Reference
1	Variance model for a fixed-point chaos attractor for capital projects	Ch. 3, Par. 3.5.3.1
2	Variance model for a fixed-point chaos repeller for capital projects	Ch. 3, Par. 3.5.3.2
3	Variance model for a limit-cycle chaos attractor for capital projects	Ch. 3, Par. 3.5.3.3
4	Variance model for a torus chaos attractor for capital projects	Ch. 3, Par. 3.5.3.4
5	Variance model for a butterfly chaos attractor for capital projects	Ch. 3, Par. 3.5.3.5
6	Variance model for a strange chaos attractor for capital projects	Ch. 3, Par. 3.5.3.6
7	Variance model for a landscape of chaos attractors for capital projects	Ch. 3, Par. 3.5.4.3

These seven variance models were evaluated using a mixed methods approach (Chapter 4, paragraph 4.3.2.6, Figure 4-4) and the results were presented in Chapter 7, paragraphs 7.3 and 7.4.

9.2.5 Building a Randomness-Chaos-Complexity-Order (RCCO) Continuum Model for Capital Projects

The literature survey in Chapter 2 revealed that continuum frameworks were described by researchers that suggested the existence of different system states with different levels of order and that systems seem to be able to move from one system state or domain to another under the influence of chaos attractors. All references that could be found to describe the RCCO continuum were summarised in Appendix B, paragraph B2. A subset of this continuum was selected for this research in capital projects as shown in Figure 9-4.

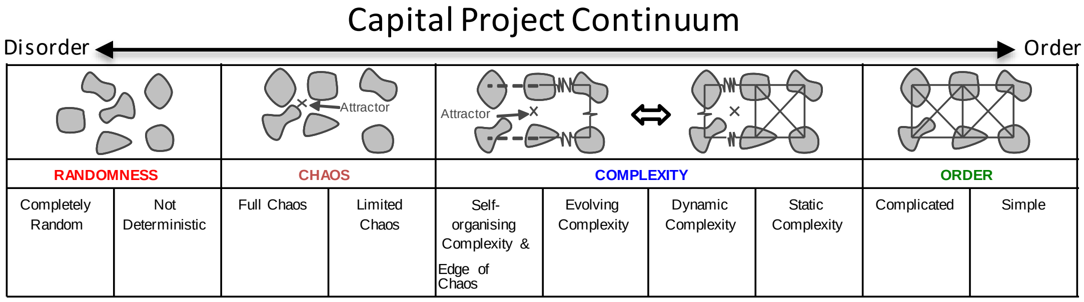

Figure 9-4: Derivation of the Randomness-Chaos-Complexity-Order Continuum from a Literature Survey for Application in Capital Projects

A grounded inductive research approach (Gioia et al., 2013) was used to allow experienced capital project managers to define the continuum stages as shown in Figure 9-4, as well as the movement of capital projects within this disorder-order continuum as given in Chapter 5. Capital project managers provided further descriptions of this continuum as well as the progressive formation of relationships during capital projects in Chapter 7.

9.2.6 Capital Project Archetypes Emerging from Empirical Evidence

Two rounds of interviews were conducted with experienced capital project managers. It was realised during the first round of interviews that while respondents were defining the continuum domains as shown in Figure 9-4, they were also describing types of projects or archetypes (Senge, 2006). These archetypes seemed to contain a level of disorder in the y-axis of randomness, chaos, complexity and order, while the capital project is unfolding along the x-axis or the project life cycle. The 26 experienced capital project managers identified a total of nine different archetypes (refer to Chapter 6) of capital projects based on the archetype format as shown in Figure 9-5.

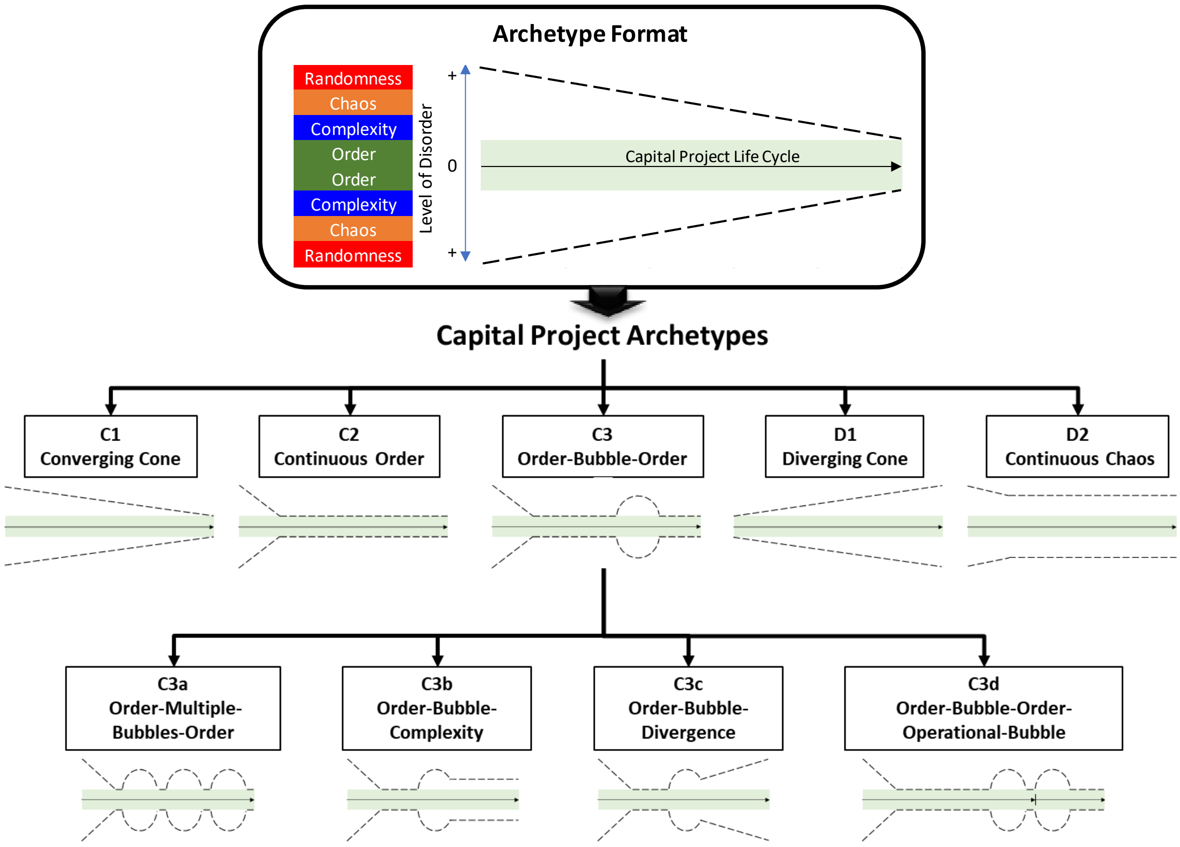

Figure 9-5: Identification of Nine Archetypes in Capital Projects that Emerged from Empirical Research Results

The significance of these archetypes is that the respondents were able to use chaos theory concepts such as randomness, chaos, complexity and order to describe the generic forms or formats of typical capital projects.

9.2.7 Empirical Evidence Suggesting the Validity of Models and the Existence of Chaos Theory for Capital Projects

A qualitative research design (Chapter 4) was used for this research in order to capture and analyse empirical data. A research triangulation strategy (Chapter 4, paragraph 4.3.2.9, Figure 4-7) was designed in order to maximise the rigor in terms of techniques, procedures, methods and analysis (Merriam and Tisdell, 2016). The different types of empirical evidence gathered to support the existence of the derived theories and models are shown in Table 9-4.

Table 9-4: Different Types of Empirical Evidence Gathered on Chaos Attractor Theory Characteristics in a Capital Project Continuum that Influence the Local and Overall Behaviour of Capital Project Elements and their Trajectories

No.	Type of Evidence	Reference
1	Chaos Metaphor Recognition	Ch. 7, par. 7.5.1, Figure 7-19
2	Definition of Continuum Domains	Ch. 5, par. 5.3
3	Recognition of Archetypes in Capital Projects	Ch. 6, par. 6.4.2.6, Figure 6-16
4	Examples of Metaphors in Capital Projects	Ch. 7, par. 7.3 and 7.4
5	Characteristics of Metaphors in Capital Projects	Ch. 7, par. 7.3 and 7.4
6	Scoring of Metaphor Variance Models	Ch. 7, par. 7.3 and 7.4
7	Value Statements on the Continuum and Chaos Attractors	Ch. 7, par. 7.3 and 7.4
8	Evidence for Chaos Attractor Local and Overall Convergence	Ch. 7, par. 7.3 and 7.4
9	Respondent Interview Self-Assessments	Ch. 4, par. 4.5.2.5, Table 4-12 Ch. 4, par. 4.6.2.5, Table 4-21

Reflection on these results as shown in Figure 9-4 for capital projects allowed for the re-thinking of the configuration of the ISO 21500 subject groups in terms of chaos attractor theory.

9.2.8 Retroductive Model Derivation for ISO 21500 Subject Groups for Capital Projects

Could chaos theory and chaos attractors as revealed during this research explain why the ISO 21500 subject groups sometimes seem relevant in managing capital projects successfully? Using the variance model format of this chaos attractor research and applying it to the ISO 21500 subject groups retroductively (Walwyn, 2016) produces a variance model as shown in Figure 9-6.

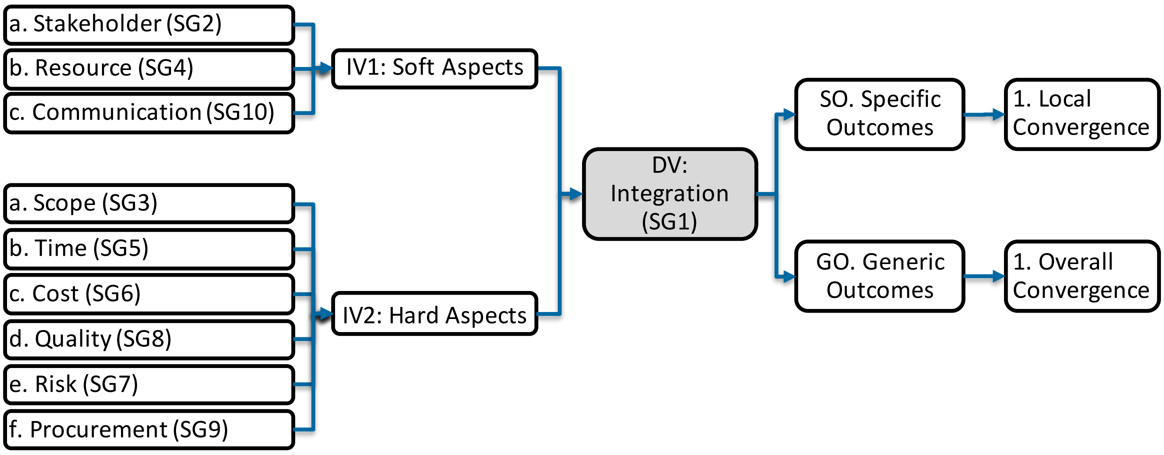

Figure 9-6: Retroductive Derivation of a Chaos Attractor Model for Project Management Using the Ten ISO 21500 Subject Groups

The subject groups (SGs) that could be associated with soft aspects and subject groups associated with hard aspects could form the independent variables, while the integration subject group forms the dependent variable as shown in Figure 9-6. This model further suggests that effective integration could lead to both local and overall convergence of projects.

9.2.9 Answers to the Main and Sub-Research Questions

The final contribution of this research in terms of chaos theory in capital projects was by providing answers to the main and sub-research questions that were stated in Chapter 1. Answers were provided for the local and overall convergence effect of capital projects as a result of chaos attractors as well as to various characteristics of chaos attractors as shown in Table 9-5.

Table 9-5: Answers Provided to the Major and Sub-Research Questions for this Research

No.	Type of Evidence	Reference
1	Answers provided to the major research questions	Ch. 8, par. 8.7.1, Table 8-8
2	Answers provided to the sub-research questions	Ch. 8, par. 8.7.2, Table 8-9

9.3 Self-Assessment

Merriam and Tisdell (2016:6, 24) indicate that the focus of qualitative research is to gain a better understanding of the "nature", "essence of the underlying structure" and "understanding of the meaning" of a phenomenon. Using their benchmark, the researcher provides a summary of achievements and shortcomings of this research as shown in Table

9-6.

Table 9-6: Researcher Self-Assessment of the Achievements and Shortcomings of this Research

No.	Description
1. Achievements	
a	Thorough literature survey on chaos attractors
b	Broad scope and wide coverage of key concepts
c	Theory building
d	Model building
e	Research methodology using triangulation to demonstrate rigor
f	Obtaining empirical evidence to suggest validity of chaos theory concepts, models and theories for capital projects
g	Answering the major and sub-research questions
2. Shortcomings	
a	Broad scope and limited depth on exploring concepts
b	Small sample size – repeatability of results
c	Qualitative methodology with inherent challenges in data collection and data analysis

This research, in the opinion of the researcher, succeeded in revealing some aspects of the phenomena of chaos attractors in capital projects. This was achieved by: a) conducting a thorough literature survey on chaos attractors; b) covering a broad scope of concepts; c) building theories; d) building models; e) defining a research methodology that used triangulation to demonstrate rigor; f) obtaining empirical evidence to support validity of chaos theory concepts, models and theories for capital projects; and finally g) by answering the main and sub-research questions. The shortcomings of this research lie in the broad scope and limited depth on exploring chaos theory concepts in capital projects, the small sample size and the inherent challenges of employing a qualitative research methodology.

9.4 Recommendations for Further Research

The nature of this research was exploratory. It is therefore suggested further research be conducted to verify the repeatability of the empirical results that were obtained as well as other aspects that did not form part of the scope of this research.

9.4.1 Repeatability of Empirical Research Results in Capital Projects

The major conclusion from this research is that supporting evidence was found to suggest that capital project behaviour may also be understood and predicted using chaos theory concepts, such as the capital project continuum, individual chaos attractors and a landscape of chaos attractors (refer to paragraph 9.1.3). This empirical evidence was obtained during two rounds of interviews with a total of 26 experienced capital project managers using a qualitative research methodology (Chapter 4). The question arises if these results are representative of the population and could they be repeated?

It is suggested that the sampling frame be expanded beyond South Africa and that a longitudinal study be considered across a number of countries. Also, the respondents for this research originate predominantly from the power utility and mining industries. It is suggested to include experienced capital project managers from other industries to determine the context independence of the chaos attractor theory in capital projects.

It is suggested to repeat this research for IT type of capital projects. It was shown in the German study that IT projects had average cost overruns that ranged from 101% for unfinished projects to 394% for finished projects (Chapter 1, paragraph 1.3.2 in Figure 1-3).

9.4.2 Further Chaos Theory Development and Testing for Capital Projects

A deductive "top-down" theory building approach with horizontal and vertical theory borrowing (Whetten et al., 2009) was used during this research to derive grand, mid-range and lower level theories (paragraph 9.2.3). A "bottom-up" inductive grounded theory building approach, as suggested by Gioia et al. (2013), could also be used to develop chaos attractor theories based only on the responses from experienced capital project managers. The advantage of the Gioia approach is that no prior concepts or constructs are required and the theory building process originates only from the responses from respondents. In addition, theories could also be constructed using the methodologies of case study research or process research as suggested by Gehman et al. (2017).

Grand, mid-range and lower-level theories were derived for this research as summarised in Chapter 8, Figure 8-3 and Table 8-6. These theories were only tested in an exploratory manner during this research as a result of the ability of respondents to understand and transfer the metaphors, describe the characteristics and examples of chaos attractors and by scoring variance models. Colquitt and Zapata-Phelan (2007) describe five levels of theory testing ranging from: a) logical speculation, b) references to past findings, c) existing conceptual arguments, d) existing models, diagrams and figures and e) existing theory. They indicate that the highest theoretical contribution to theory testing originates from testing d) existing models, diagrams and figures and e) existing theory using hypothesis.

This research followed a "low level of theory testing" (Colquitt and Zapata-Phelan, 2007:1285) approach with a lack of time to do comprehensive model or hypothesis testing. It is therefore suggested to conduct "high theoretical contribution" theory testing (Colquitt and Zapata-Phelan, 2007:1283) in future research.

9.4.3 Other Types of Chaos Attractors in Capital Projects – The Latent Chaos Attractor

A total of 11 chaos attractors were identified during the literature survey in Chapter 2, but only six chaos attractors were chosen to form part of the scope of this research as explained in paragraph 9.2.2. The chaos attractors that were not investigated as part of the scope of this research were: a) periodic point attractors, b) spiral attractors, c) spiral repellers, d) structural attractors and e) latent attractors. (refer to Chapter 3, paragraph 3.4.9.2, Figure 3-5).

Vallacher and Nowak (2007) describe the latent chaos attractor that is formed by thoughts, beliefs and attitudes. This attractor may not be visible to participants in the system, could build up until the system to reaches a tipping point and can lead to unexpected system behaviour and outcomes. Vallacher and Nowak (2007) refer to the work of other researchers and cites examples of hidden conflict between team members, stereotyping and racism. According to Vallacher and Nowak (2007:9) "latent attractors are nonetheless important in the long run because they determine which states are possible for the system when conditions change".

In capital projects the identification of this type of chaos attractor as part of the landscape of chaos attractors may be crucial for the determination of possible bounded project trajectories towards local and overall convergence. Although the other chaos attractors that were not investigated as part of this research (periodic point attractors, spiral attractors, spiral repellers and structural attractors) may also be important, the researcher believes that the latent chaos attractor may be more important for capital projects due to its hidden nature. It is therefore suggested that both latent chaos attractors and repellers be further investigated for application in capital projects.

9.4.4 Do Other Archetypes Exist for Capital Projects?

Nine archetypes were identified as part of this research as shown in Figure 9-5. The first five archetypes emerged from the Round 1 interviews. When these five archetypes were shown to the respondents of the Round 2 interviews, they were able to both confirm their existence and define four new types. All of these archetypes were based on the continuum domains of randomness, chaos, complexity and order as was defined by the Round 1 respondents. Due to the limited interview duration only nine archetypes for capital projects could be identified by respondents based on chaos theory concepts.

Different project types are described by researchers. For example, Shenhar and Dvir (2007) described different types of projects in their risk based diamond model according to the dimensions of novelty, technology, complexity and pace (NTCP model). Hass (2008) provided three categories of projects in terms of complexity as independent, moderately complex or highly complex. Carver (2011) refers to four categories of projects according to their structural and dynamic complexities. It is therefore suggested to investigate if other archetypes exist for different capital project types.

9.4.5 Further Investigating of the Landscape of Chaos Attractors

This research provided empirical results for the bounded and overall convergence effect of static landscape of chaos attractors (Chapter 7, paragraph 7.4.1.1, Figure 7-15) and one specifically designed landscape of six chaos attractors for capital projects (Chapter 7, paragraph 7.4.2.1, Figures 7-16 and 7-17).

Wysocki (2010) referred to four project management approaches that could be used to manage projects based on the clarity of the project goal and solution. He denoted these four methods: a) traditional project management (TPM) approach, b) agile project management (APM) approach, c) extreme project management approach (xPM) and the d) emertxe project management approach (MPx). How do the configurations of the specifically pre-designed landscape of chaos attractors look like or should it look like for each of these project management approaches? What will the influence of local and overall capital project convergence, with different configurations and different types of chaos attractors in the landscape be?

Although reference was made to a dynamic landscape of chaos attractors (Chapter 7, paragraph 7.4.1.1, Figure 7-15(b-d)) in which a chaos repeller could become an attractor in a short space of time (Choi et al., 2012), insufficient time was available during this research to test the viability of this concept with respondents. An understanding of the characteristics and influence on local and overall capital project convergence of a dynamic landscape of chaos attractors could be important for projects that are submerged in a VUCA (Bennett and Lemoine, 2014) environment. In such an environment changes occur at an accelerated pace and the capital project is subjected to the simultaneous and accelerated influences of trends, megatrends, paradigm shifts, Black Swan events and disruptive technologies (refer to Chapter 1, paragraph 1.4, Figure 1-5).

It is therefore suggested that the local and overall convergence effect of landscapes of chaos attractors, that are composed of different types of chaos attractors, that are differently configured across the capital project life cycle, as well as dynamic landscapes of chaos attractors be further investigated.

9.4.6 Further Investigation of the Variance Models in Capital Projects

For this research, only a number of independent variables were tested for their ability to influence the dependent variable (each of the chaos attractors) as well as the effect or outcome of the dependent variable to generate local or overall convergence (refer to Chapter 3, paragraph 3.5). The developed and tested variance models represented a simple “cause-effect” relationship (Page and Meyer, 2003:67) between the independent and dependent variables.

Due to the exploratory nature of this research and because a first attempt was made to map independent variables and chaos attractor converging effect from various source domains (various sciences) to the target domain (capital projects), no consideration was given to other types of variables such as moderating, intervening or extraneous variables (Page and Meyer, 2003). For example, a well-defined milestone may help to generate an effective fixed-point chaos attractor, but a difficult and counter-productive team member may moderate the local converging effect of the chaos attractor. Future research may be done to investigate the effect of other types of variables such as moderating, intervening or extraneous variables on chaos attractors and thereby improve the validity and accuracy of the variance models.

An attempt was made by the researcher to assign the independent variables that were obtained from the metaphor mapping process in Appendix C, to five groups: a) metaphor geometry, b) project management, c) systems engineering, d) psychology and e) sociology. It is suggested to retain the independent variables in the various variance models that obtained a mode score of 4 or 5 but also identify new independent variables. Such variables could be identified from the project management (ISO, 2012; PMI, 2017), systems engineering management (ISO/IEC/IEEE, 2015; INCOSE, 2015) as well as psychology, sociology and other literature.

9.4.7 The Harmonious Resonance Theorem for Capital Projects?

The two necessary conditions for achievement of harmonious resonance in organisations, as formulated by Dimitrov (2000) were stated and discussed in Chapter 2, paragraph 2.6.8. According to this theorem a condition of “resonance” or “amplification” may be achieved when the “strange attractors representing the agents [member] purposes coalesce into an all-embracing fractal structure of one and only one strange attractor - the strange attractor corresponding to the overall purpose of the organization” Dimitrov (2000:419). What does this mean for capital projects with individual team members and an overall goal and purpose? Could a condition be achieved where resonance is achieved and what does this mean for local and overall capital project convergence? It is therefore suggested to investigate the Harmonious Resonance Theorem for capital projects as part of future research efforts.

9.4.8 Visualisation of Chaos Attractors

Chaos attractor visualisation was discussed in Chapter 2, paragraph 2.6.2. It was shown that chaos attractor visualisation in the time domain is difficult and therefore many researchers use a transformation from the time domain to the Phase-Space domain (Bums, 2002; Goldstein, 2011; Ramalingam et al., 2008) to reveal the attractors. However, Meade and Rabelo (2004) provided a method to high tech firms to quantitively determine and understand their position in the technology adoption life-cycle in their industry using the rate of change of one key variable as was shown in Chapter 2, paragraph 2.6.2.3 in Figure 2-14. Similarly, Kiel (1993) was able to transform labour cost behaviour form the time domain to the Phase-Space domain by plotting the labour costs for the current week on the y-axis and the labour cost for the previous week on the x-axis to reveal the cyclic attractor as was shown in Figure 2-15. He was able to reveal the cyclic attractor for the system and could determine if the system was stable, unstable or if the chaos attractor was moving. Green Jr and Twigg (2014) provided a plot of service process control data by transforming time domain data to the Phase-Space domain by plotting time period (T) on the y-axis against the previous time period (T-1) on the x-axis as shown in Figure 2-16.

Given these examples, would it be possible to reveal chaos attractors in capital projects by plotting historical cost, schedule, performance or other data in the Phase-Space domain in plots for single variables in the format data at time “t” versus data at time “t-1” to reveal chaos attractors? It is suggested to conduct these investigations as part of future research.

9.4.9 Measurement of the Level of Disorder in a Capital Project

The randomness-chaos-complexity-order capital project continuum as shown in Figure 9-4 indicates a level of decreased disorder for the randomness domain towards the ordered domain. What is the level of disorder in a capital project? How does the level of disorder differ from a capital project in the different states of randomness, chaos, complexity and order? How can the level of disorder in a capital project be quantified and measured?

It has been shown in Figure 2-25 (Chapter 2, paragraph 2.6.11) that chaos attractors were activated when a key variable of a system reached a specific value and that a system moved from an ordered state to chaos with an increase in the value of the key variable. Could this key variable be a measure or level of disorder in a capital project?

Remington and Pollack (2007) refer to a complexity mapping tool where the level of complexity ranging from low to high in a project is mapped against different types of complexity such as structural, technical, directional and temporal complexity. It is recommended to investigate the possibility to quantify the level of disorder in capital projects in further research.

9.4.10 The Relationship Between Order and Cost Overruns in Capital Projects

This research started in Chapter 2 with examples of historical capital cost overruns and the expected increase in these overruns with an increased complex and fast changing chaotic environment. It was shown that chaos theory suggests that order can be produced from chaos to order using chaos attractors (refer to paragraph 9.1.1).

The researcher was initially of the opinion that an ordered capital project could imply a successful project. Empirical evidence from respondents revealed that an ordered capital project does not imply a successful capital project (refer to Chapter 8, paragraph 8.4.1.2 and Table 8-3(1)). Also, the definition of a successful project has evolved over time (Jugdev and Müller, 2005) and may now include measuring specific outcomes a few months, two years and even five years after completion of the project (Shenhar and Dvir, 2007).

What is the value of applying chaos attractors to a capital project and achieving an ordered and converged state in term of project success metrics? What is the relationship between an ordered capital project and capital project success? These questions could be further researched.

9.4.11 Exploratory Testing of the ISO 21500 Variance Model for Local and Overall Convergence

The ten ISO 21500 (ISO, 2012) subject groups were arranged in the same variance model format as shown in Figure 9-6 for the chaos attractors and landscape of chaos attractors for this research. The retroductive reasoning (Walwyn, 2016) is that perhaps chaos theory in terms of local and overall convergence could offer an explanation of why the use of the ten ISO 21500 subject groups leads to project success in some cases and project failure in others. It is suggested to test this variance model in further research.

9.4.12 Changing the Unit of Analysis to Capital Programs and Portfolios

The chosen unit of analysis for this research was the project as was shown in Chapter 4, paragraph 4.3.2.3, Figure 4-3. The demographic profiles of the experienced capital project managers indicated that respondents in the Round 1 interviews had 71% project management responsibility and 53% project management responsibility for the Round 2 respondents (refer to Appendix D, paragraphs D3 and D7). The remainder of their experience was in program and portfolio management. Respondents also had experience as program managers, portfolio managers and project directors.

It is thus concluded that the results for this research is not only originating from experienced capital project managers alone but may also be applicable to programs and portfolios. It is suggested to conduct further research to verify if chaos attractors could be applied beyond a single capital project to programs and portfolios of projects.

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APPENDIX A: MODEL FOR FIVE INFLUENCES ON CURRENT AND FUTURE CAPITAL PROJECTS

A.1 Introduction

The objective of this Appendix is to summarise information from literature on five changes that are taking place in society and that are believed to influence the current and future capital project environment. The influences are: trends and megatrends; paradigm shifts; disruptive technologies; and Black Swan events. It is speculated that these five changes are able to exert known and unknown influences on the capital project internal and external environment. A model is generated to show the influence of the suspected changes on current and future capital project environments.

A.2 Trends and Megatrends

One way to obtain a view of what the future world changes might look like and the type of future capital projects that will be required, is to consider global trends and megatrends.

Megatrends are defined by Frederic de Meyer as referenced in Rozen et al. (2012:6) as global trends that are "long lasting (5-10 years), amplifying (widespread adoption), strongly impacting society across political, economic, technical, and legal dimensions, and having a feeling of inevitability". These megatrends are "slow to form, nearly impossible to reverse, significantly influences the future, has an aura of inevitability and has a far- and wide-reaching impact on society" (Rozen et al., 2012:1).

Categories of different megatrends, as identified and described in the literature by three global consulting houses (i.e. A.T. Kearney, EY and PwC) and one multinational company (Alcatel Lucent), are indicated in Table A-1. Different names are used by these companies to describe the same megatrends. In order to simplify the discussion on megatrends, common category names were selected. These common category names are: Digital Globalisation; Global Marketplace; Individualism and Activism; Resources, Climate and Environment; Demographics; Urbanisation, Health; Technology and Entrepreneurship; and Sustainability.

Table A-1: Categorisation of Nine Groups of Global Megatrends

No.	Common Category Names for Megatrends	Megatrends According to A. T. Kearney *	Megatrends According to EY **	Megatrends According to PwC ***	Megatrends According to Rozen ****
1	Digital Globalisation		Digital Future		168 (24x7) Connectivity, Ed-you-cation, Digital Natives
2	Global Marketplace	Consumption Patterns	Global Marketplace	Shift in Economic Power	
3	Individualism and Activism	Governance and Activism			Netizens to Government (N2G)
4	Resources, Climate and Environment	Resources and Environment	Resourceful Planet	Climate Change and Resource Scarcity	
5	Demographics	Demographics		Demographic Shifts	
6	Urbanisation		Urban World	Accelerating Urbanisation	Neo-Urbanisation
7	Health		Health Reimagined		Rejuvenation
8	Technology and Entrepreneurship	Technology and Innovation	Entrepreneurship Rising	Technological Breakthroughs	
9	Sustainability				Sustainability by Design (SBD)

* A. T. Kearney (2012)

** EY (2015)

*** PwC (2013)

**** Rozen et al. (2012).

A.2.1 Megatrend 1 (MT1) – Digital Globalisation

At least five trends seem to make up the Digital Globalisation or the Digital Future megatrend as shown in Table A-2. These trends seem to generate new types of capital projects, systems and products now and in the near future.

Table A-2: Megatrend for Digital Globalisation - Trends and Related Capital Projects, Systems and Related Products

Megatrend	Trends within the Megatrend	Type of Capital Projects, Systems and Products Envisaged Now and in the Near Future
MT1: Digital Globalisation	T1: Rise of the Internet of Things (IoT)	Universal wireless 24/7 Internet access, 99.999% connectivity, cloud computing and services, harvesting and analysis of real-time Big Data, developing best-of-breed digital IT platforms and tools, applications and interfaces on mobile platforms, upgrade of old/legacy IT infrastructure, mobile learning (m-learning), cyber theft and job automation and industrial robotics
	T2: Shift from PC First-to-Mobile technologies for web page views and e-commerce	
	T3: Surge in best-of-breed platforms by non-traditional technology firms	
	T4: Surge in global cross-border data flows	
	T5: Surge in Big Data content and storage	

The first trend that makes up the Digital Globalisation megatrend is the "Internet of Things" (IoT) or "connection of objects rather than people" (Rozen et al., 2012:25). PwC (2013) estimates that in 2015 there were already 3.47 connected devices per person on average globally. This number is expected to rise to 6.58 connected devices per person by 2020 and is triggered by the multitude of different ways in which customers and clients interact using the Internet as medium. There will be a growing demand for anytime anywhere access to information ("always-on") (EY, 2015).

The second trend is the shift from technologies to appear first on mobile applications (First-To-Mobile) and then only on personal computers. Mobile devices and technologies are becoming the preferred tools for work, leisure and communication and users are demanding higher functionality regarding the cloud, IT platforms and information provided (EY, 2015).

A third trend is the surge in best-of-breed IT platforms by non-traditional technology firms. Non-IT companies are beginning to develop in-house platforms and solutions to serve their digital customers better.

The fourth trend is the surge in global cross-border data flows. Global cross-border bandwidth has increased 45 times from 2005 to 2014 in terms of information, searches, communications, transactions, video, and intracompany traffic, mainly as a result of the lower cost of communication and the growth in scale and sophistication of digital platforms (McKinsey & Company, 2016).

These trends are likely to create capital projects, products and systems for new wireless Internet access, best-of-breed digital IT platforms and mobile platforms, cloud computing, harvesting and analysis of real-time Big Data, upgrade of old/legacy IT infrastructure, mobile learning applications and infrastructure, job automation with industrial robotics and cyber threat projects as shown in Table A-2.

A.2.2 Megatrend 2 (MT2) – Global Marketplace

The four trends that is believed to make up the second megatrend, Global Marketplace, and the associated capital projects, systems and products that is expected to be generated now and into the future, are shown in Table A-3.

Table A-3: Megatrend for Global Marketplace - Trends and Related Capital Projects, Systems and Related Products

Megatrend	Trends within the Megatrend	Type of Capital Projects, Systems and Products Envisaged Now and in the Near Future
MT2: Global Marketplace	T1: Shift of economic power to rapid growth countries	High value-added goods such as cars, office equipment and technology, high protein foods, tourism services and consumer durables, new digital distribution channels such as the Cloud, integrating digital technologies into product development, Prosumers will require online platforms for introducing and testing of new products and big data analytics
	T2: Growth of the global middle class in Asia-Pacific	
	T3: Different models on how customers access goods and services	
	T4: Surge in available customer data	

The first trend is the shift of economic power to rapid growth countries (i.e. the East). It is expected that 47% of global capital inflows will be towards rapid-growth markets by 2030 – a substantial increase from 23% in 2010 (EY, 2015). This is due to the changing nature of the BRIC (Brazil, Russia, India and China) and other countries from "centres of labour and production to consumption-oriented economies" (PwC, 2013:3).

The second trend is the growth of the global middle class in Asia-Pacific from less than a third of the population in 2009 to two-thirds in 2030 (EY, 2015). There is a rapidly growing young population in Asia, that combined with strong economic growth and the disposable income of the upper middle-class, is expected to create a significant future spending power.

The third trend is how customer behaviour is changing to access goods and services from a "push model" to include a "pull model" using digital technologies. The combination of Internet, mobile devices, cloud computing and data analytics gives rise to new and different ways customers and clients could interact (PwC, 2013) and results in new and different business models.

The fourth trend is the surge in available customer data as a result of the digital transformation. Large volumes of customer data are available and individual consumers want their voices to be heard by manufacturers (i.e. producers + consumers = Prosumers) and to influence the available products and services (EY, 2015:10).

The Global Marketplace megatrend gives rise to capital projects, products and systems that include the procurement of high value-added goods such as cars, office equipment and technology, high protein foods, tourism services and consumer durables, new digital distribution channels such as the Cloud, the integrating of digital technologies into product development, new online platforms for Prosumers and big data analytics as shown in Table A-3.

A.2.3 Megatrend 3 (MT3) – Individualism and Activism

Two trends are distinguishable for the Individualism and Activism Megatrend that is believed to give rise to capital projects, systems and products that is expected to be generated now and into the future as shown in Table A-4.

Table A-4: Megatrend for Individualism and Activism - Trends and Related Capital Projects, Systems and Related Products

Megatrend	Trends within the Megatrend	Type of Capital Projects, Systems and Products Envisaged Now and in the Near Future
MT3: Individualism and Activism	T1: Digital Native Acceleration	Higher broadband penetration, re-design of current education systems for digital learners i.e. m-learning, virtual reality, video, gaming and gesture-based computing, e-government, e-democracy, m-government, e-voting and e-visas applications, new communication channels such as "G-to-G" (government to government), "G-to-B" (government to business) and "G-to-C" (government to citizens / consumers / constituents)
	T2: Rise of Netizens to Government (N2G) communication	

The first trend Digital Native Acceleration refers to two categories in society (generation Y and generation Z) that were born since 1981. These generations have grown up with digital technology, use these devices for every-day use, integrate technology into all aspects of their lives and everyone else's and expect the world to function at the same 'Internet time' and 'network speed' (Rozen et al., 2012).

The second trend involves the rise of Netizens to Government (N2G) communication. Connected citizens are becoming much more involved in challenging their governments and their service delivery performance using online polls, discussion boards, online petitions, Facebook pages, YouTube videos and other social media (Rozen et al., 2012). For example, Rozen et al. (2012) reports that there was a global increase in the number of government web sites from fewer than 50 in 1996 to more than 50,000 in 2001.

Capital projects will be required for new software platforms, wireless, broadband ICT ecosystems with the emergence of G-G (Government-to-Government), G-B (Government-to-Business) and G-C (Government-to-Citizens) communication mode. It is expected that current education systems will be redesigned for digital learners (m-learning) as well as the evolution of gesture-based computing, E-government, M-government, E-voting and E-visas as shown in Table A-4.

A.2.4 Megatrend 4 (MT4) – Resources, Climate and Environment

Three trends are believed to constitute the Resources, Climate and Environment megatrend with associated capital projects, systems an products as shown in Table A-5.

Table A-5: Megatrend for Resources, Climate and Environment - Trends and Related Capital Projects, Systems and Related Products

Megatrend	Trends within the Megatrend	Type of Capital Projects, Systems and Products Envisaged Now and in The Near Future
MT4: Resources, Climate and Environment	T1: Increase in cost to adapt to climate change and extreme weather events	Solar energy deployment in developing countries, clean energy research and development, clean energy deployment, reduction in urban emissions, build (and retrofit) infrastructure that is climate-resilient, COP 21 nationally binding contributions to reduce greenhouse gas emissions, early-warning systems, resilient infrastructure and resistant crops in agriculture, energy and resource efficiency at the consumer, corporate and national levels, water provision, deployment of clean, distributed power generation solutions such as rooftop
	T2: Increase in competition for limited and scarce resources	

Megatrend	Trends within the Megatrend	Type of Capital Projects, Systems and Products Envisaged Now and in The Near Future
	T3: Change in global energy mix	solar photovoltaic units, changing energy mix and empowerment of consumers will produce significant infrastructure demands from the public and private sector, energy efficiency in the industry, buildings and transport sectors, investment in renewable energy technologies, reduction in methane emissions in oil and gas production

The first trend of the Resources, Climate and Environment Megatrend as shown in Table A-5 is the increase in cost to adapt to climate change and extreme weather conditions due to the increased occurrence of extreme weather events as well as rising sea levels. The suspected driving force is the six times rise in the earth's average surface temperature between 1950 – 2010 compared to 1890 – 1950 (EY, 2015). The expected cost for developing countries to adapt to climate change in terms of strengthening legacy infrastructure, building of new climate-resistant infrastructure and early-warning systems is estimated to be between USD70bn – USD100bn per year up to 2050 (EY, 2015). The global signatories to the COP 21 (Conference of Parties) Paris Agreement will have to declare binding "Nationally Determined Contributions" (NDCs) that will have to be reported and regularly audited and will outline policy, plans and funding for capital projects and programs to reduce Greenhouse Gas Emissions (C2ES, 2015).

The second trend is the increase in competition for limited and scarce resources that is visible as physical conflict and political tension (PwC, 2013) as a result of the earth's population growth, economic development and more middle-class consumers (EY, 2015). The global demand for energy is expected to increase by 50%, water withdrawals by 40% and food by 35% by 2030 and is expected to lead to extreme weather conditions and rising sea levels (PwC, 2013). Under these circumstances an increase in levels of government regulation (incentives/disincentives) are expected as well as a drive for resource efficiency at consumer, corporate and national levels (EY, 2015).

The third trend is the change in the global energy mix that is visible as an increased supply of unconventional and renewable sources of energy (EY, 2015). The COP 21 Paris Agreement is expected to give new impetus to signatory countries to launch capital projects and programmes to move towards a lower carbon footprint and a more energy-efficient system (IEA, 2015). It is expected that renewable energy could comprise 50% of the global energy mix by 2050 (EY, 2015).

Due to these trends, a substantial increase in capital projects, programmes and systems is expected that relates to the more efficient use of resources and environment- and climate-friendly operations. These include deployment of solar energy systems, green energy infrastructure, energy-efficient technologies for transportation and buildings as well as climate-resistant infrastructure and water provision as shown in Table A-5.

A.2.5 Megatrend 5 (MT5) – Demographics

Three trends seem to contribute to the Demographics Megatrend and related capital projects, systems and products as shown in Table A-6.

Table A-6: Megatrend for Demographics - Trends and Related Capital Projects, Systems and Related Products

Megatrend	Trends within the Megatrend	Type of Capital Projects, Systems and Products Envisaged Now and in the Near Future
MT5: Demographics	T1: Growth in global youth work force from developing countries	Mobile, social and cloud technologies, Wi-Fi and broadband connectivity, freelance IT platforms, further automation in industries ranging from agriculture to medicine, rejuvenation products and services, physical impairments requiring adapted devices, such as mobile phones that are compatible with hearing devices or computers with an integrated web cam for visual assistance, educational telephone conferencing
	T2: Increase in the war for different talent	
	T3: Growth in population 60 years and older	

The first trend is the growth in the global youth work force from developing countries, as currently 54% of college graduates are originating from leading emerging markets. This figure is expected to grow to 60% in ten years' time (EY, 2015). The availability of mobile, social and cloud technologies with WiFi and broadband connections makes it possible for employees to work at times and places as they choose and that firms increasingly connect to these skills and resources on demand instead of owning them (EY, 2015). Firms are therefore increasingly becoming "network orchestrators" (EY, 2015:13).

The second trend is the increase in the war for different talent as a changing world requires different skill sets. It was estimated that by 2015 about 60% of the new jobs would require skills that only 20% of the population possesses (EY, 2015). As automation becomes the norm in industries ranging from agriculture to medicine, there is a demand for highly skilled workers. The compounding challenge of this development is that the workforce is increasingly diverse and by 2020 it is expected that multiple generations will be working side-by-side (EY, 2015), in the workplace. The effective management of this situation is expected to demand competent leadership (EY, 2015).

The third trend is the growth in the population aged over 60 years. This is mainly due to medical breakthroughs, advancements in medicine and the pursuit of wellness, and global life expectancy that is now reaching 80 years (Rozen et al., 2012). The global population of people aged over 60 years is expected to increase to 21% by 2050 (PwC, 2013) and is expected for the first time in history, to be as large as the global population under 15 years (Rozen et al., 2012).

These three trends are expected to lead to capital projects, products and systems related to the proliferation of mobile, social and cloud technologies, Wi-Fi and broadband connectivity, freelance IT platforms, further automation in industries ranging from agriculture to medicine, rejuvenation products and services, physical impairments requiring adapted devices such as mobile phones that are compatible with hearing devices or computers with an integrated web cam for visual assistance and educational telephone conferencing as shown in Table A-6.

A.2.6 Megatrend 6 (MT6) – Urbanisation

Four trends are believed to contribute to the Urbanisation Megatrend that in turn could lead to capital projects, systems and products as shown in Table A-7.

Table A-7: Megatrend for Urbanisation - Trends and Related Capital Projects, Systems and Related Products

Megatrend	Trends within the Megatrend	Type of Capital Projects, Systems and Products Envisaged Now and in the Near Future
MT6: Urbanisation	T1: Rural-to-urban shift	Sustained investment in railroads, highways, bridges, ports, airports, water, power, energy, telecommunications, and other types of infrastructure, mega cities, mega regions, mega corridors, giga-cities, reduction in urban greenhouse gas emissions, improve vulnerability of low-lying

<table>
<tr><th>Megatrend</th><th>Trends within the Megatrend</th><th>Type of Capital Projects, Systems and Products Envisaged Now and in the Near Future</th></tr>
<tr><td rowspan="3"></td><td>T2: Growth of mega-hubs and mega-cities</td><td rowspan="3">coastal settlements to extreme weather and climate change impacts, resolving slum and informal settlement problems, megaprojects will be required to build city infrastructure, support new trade flows (airports, sea ports), address education, health, security, employment demands, smart city solutions that support economy, buildings, mobility, energy, information, communication, technology, planning, citizens, governance, sustainability, education and health, machine-to-machine complex ecosystems, technology and ecosystem convergence for energy and infrastructure, IT, telecoms and government, zero-waste and zero-carbon technologies, products and systems and home automation</td></tr>
<tr><td>T3: Birth of smart cities</td></tr>
<tr><td>T4: Increase in rural conversion</td></tr>
</table>

The first trend is the rural-to-urban shift when people, prompted by the industrial revolution, move from rural agricultural areas to the cities for employment and a better life (Berglee, 2013). A United Nations (UN) report indicated that 54% of the world population currently lives in cities and this number is to grow to 66% by 2050 (EY, 2015). Africa and Asia are urbanising at the fastest rate. Urbanisation drives economic growth as it creates a shift in spending power and encourages the formation of market economies and consumer societies (Berglee, 2013).

The second trend is the worldwide growth in mega-hubs and mega-cities both in number and in scale (EY, 2015) as higher density populations are made possible due to improvements in technology, medicine and the prevention of diseases (FIG, 2010). The global population that lives in cities is expected to increase from 30% in the 1950's to 50% by 2030 (PwC, 2013). Although cities cover only about 2% of the global land area, they are responsible for 70% of greenhouse gas (GHG) emissions and coastal cities are exposed to extreme weather events and rising sea levels (Allianz, 2015) and 30% of urban populations are living in slums and informal settlements (FIG, 2010). These mega-cities will require mega-infrastructure projects (i.e. capital projects).

The third trend is the creation of more and more newly designed and built smart cities that strive to have a zero-carbon and zero-waste ecology with the lowest carbon footprint using green technologies (Rozen et al., 2012). These smaller self-contained cities develop due to the increased environmental pressure and the global drive for sustainability and give rise to the convergence of technology and ecosystems (Rozen et al., 2012).

The fourth trend is the increase in rural conversion that occurs when technology such as broadband Internet are made available in remote areas. Internet maturity has been shown to correlate with wealth creation and allows for advancement in education and medical care and a migration towards rural areas (Rozen et al., 2012).

This megatrend will create a myriad of capital projects, systems and products relating to railroads, highways, bridges, ports, airports, water, power, energy, telecommunications, and other types of infrastructure, mega-cities, mega-regions, mega-corridors, giga-cities and capital projects related to green initiatives as shown in Table A-7.

A.2.7 Megatrend 7 (MT7) – Health

An aged population gives rise to the Health Megatrend with global average life-expectancy approaching 80 years. This is expected to create a need for 24/7 patient monitoring, diagnoses, surgical coaching, E-health and M-heath devices, software, platforms (Rozen et al., 2012). The Health Megatrend comprises four trends as shown in Table A-8 and is expected to give rise to capital projects, systems and related products.

Table A-8: Megatrend for Health - Trends and Related Capital Projects, Systems and Related Products

Megatrend	Trends within the Megatrend	Type of Capital Projects, Systems and Products Envisaged Now and in the Near Future
MT7: Health	T1: Shift from health care to health management	Tele-stroke treatment through telemedicine (two-way broadband video connections) in small towns / rural areas, mobile health solutions to expand access in rural areas, sophisticated analytics will allow providers to focus on prevention and disease management, preventive health solutions and patient centric care, wellness and fitness solutions, combine behavioural economics with mobile health technologies, real-time data and enabling real-time medical interventions, wearable and implantable sensors, predictive and preventive health care, gene expression profiling, personalized medicine diagnostics, 24/7 patient monitoring, diagnoses and surgical coaching, E-health, M-heath, change from delivery of health care to management of health, use of big data, real-time health monitoring and personalised medicine
	T2: Surge in chronic diseases	
	T3: Surge in digital and health interventions and services	
	T4: Surge in personalised medicine	

The shift from health care (i.e. sick-care) to health management (i.e. healthy behaviours, prevention and real-time care) is brought about by the need for economic sustainability and the availability of new health management technologies as a result of digital disruption (EY, 2015). In order to achieve sustainable global health care systems, three challenges in terms of escalating costs, improving the quality of outcomes and expanding access to health services need to be overcome (EY, 2015).

The surge in chronic or non-communicable diseases such as cancer, diabetes, obesity and chronic respiratory disease are the cause of 60% of all deaths globally and 80% in low and middle income countries (WMA, 2016). The World Health Organisation (WHO) estimates that global deaths as a result of non-communicable diseases will rise by 17% during the next 10 years (WMA, 2016). This is due to the aging populations in the West and China, increasing incomes, changing diets and sedentary lifestyle (no or irregular physical activity) (EY, 2015). Both preventive and predictive solutions will be required to address this trend (PwC, 2016).

The third trend is the surge in digital and health interventions and solutions due to an "explosion" in mobile health technologies that are connecting patients and service providers, that allow them to interact in new ways and to learn from each other (EY, 2015).

The fourth trend is the surge in personalised medicine due to the lower cost of personal genome sequencing that enables the tailoring of health care and medicine to each person's unique genetic makeup (Jackson Laboratory, 2016).

The health care megatrend gives rise to capital projects, systems and products related to mobile health solutions, sophisticated analytics, patient-centric care, wellness and fitness solutions, real-time medical interventions, wearable and implantable sensors, predictive and preventative health care, personalised medicine diagnostics, 24/7 patient monitoring, surgical coaching, E-health and M-health as shown in Table A-8.

A.2.8 Megatrend 8 (MT8) – Technology and Entrepreneurship

Four trends can be distinguished in the Technology and Entrepreneurship Megatrend as shown in Table A-9 that is expected to result in capital projects, systems and products.

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Table A-9: Megatrend for Technology and Entrepreneurship - Trends and Related Capital Projects, Systems and Related Products

Megatrend	Trends within the Megatrend	Type of Capital Projects, Systems and Products Envisaged Now and in the Near Future
MT8: Technology and Entrepreneurship	T1: Technological convergence	Product convergence, nanotechnology, nanotechnology + ICT = nana-devices and nano-sensors; nanotechnology + biotechnology = bio-electronic applications, nanotechnology + biotechnology + ICT = biosensor solutions, waste emissions, repetitive and mechanical tasks using industrial robots, inventory and network optimization tools, sensors and automatic identification, cloud computing and storage, predictive analytics, wearable and mobile technology, robotics and intelligent automation, driverless vehicles and drones, 3D printing, automation of knowledge work, advanced robotics, advanced materials, advanced oil and gas recovery, renewable energy
	T2: Increase in technology adoption rates	
	T3: Rise in high impact entrepreneurship and disruption	
	T4: Advancement in disruptive innovations	

The first trend in Table A-8 is technological convergence that occurs when the functions of multiple products are found in a single product (Olawuyi and Friday, 2012). For example: Telecom industry + cameral technology = camera phone; building industry + information technology = intelligent buildings (Hacklin et al., 2009). The cause of this trend lies in innovations that emerge at the interfaces of established and clearly defined industries and results in technological trajectories of which the performance of products and services exceeds the sum of their parts (Hacklin et al., 2009).

The second trend is an increase in the adoption rates of new technologies and is measured as the number of people who adopt a new idea / product in a specific period of time (Rogers, 1983). The telephone required 56 years to be adopted by half of the US households while it only took 7 years for the smartphone to achieve the same adoption rate (Black Rock, 2014).

The third trend is the rise in high impact entrepreneurship that results in global industry disruption. High impact entrepreneurship, to be distinguished from necessity-driven entrepreneurship, creates a significant commercial opportunity and disrupts existing industries and creates new industries and industry segments (EY, 2015). Digital technologies enable the scale up of new businesses at relatively lower costs for high impact entrepreneurial companies such as Google, Facebook, Twitter, Virgin Airlines and GoPro (EY, 2015). Other examples of disruption created by these types of companies include Tesla that disrupts energy storage, Google that disrupts mobile phones, Amazon that disrupts eBooks and Uber that disrupts food delivery (Diamonds, 2015).

The fourth trend is the advancement of disruptive innovations and technologies in the global marketplace. These innovations are not as good as currently available products, appeal to less demanding customers but once adopted by the mainstream markets will have a significant disruptive impact on existing markets and products (Christensen and Raynor, 2003).

The list of disruptive innovations includes the mobile Internet, automation of knowledge work, Internet of Things (IoT), cloud technology, advanced robotics, autonomous or near autonomous vehicles, next generation genomics, energy storage and 3D printing. This megatrend will therefore create a multitude of capital projects, products and services that will require the management of deep technical know-how as shown in Table A-9.

A.2.9 Megatrend 9 (MT9) – Sustainability

The Sustainability Megatrend has at least two trends that fuel its existence as shown in Table A-10. This megatrend is expected to lead to the formation of capital projects, systems and products now and in the near future.

Table A-10: Megatrend for Sustainability - Trends and Related Capital Projects, Systems and Related Products

Megatrend	Trends within the Megatrend	Type of Capital Projects, Systems and Products Envisaged Now and in the Near Future
MT9: Sustainability	T1: Move towards a global agenda, policies and reporting on sustainability measures	Economy-wide capital projects to achieve COP21 absolute emission reduction targets, capital projects related to: poverty, hunger, health, clean water and sanitation, industry, innovation and infrastructure, sustainable cities and communication, climate action, life below water and on land, universal product and system designs, energy productivity, air pollution, waste management, soil contamination, fully recyclable products, green telecoms, green IT, smart metering for energy consumption, diagnosis and optimization
	T2: Increased demand, standards and legislation for sustainable and environment? Sustainability and friendly life-cycle designs?	

The first trend is the global move towards agreements, policies and compulsory reporting on sustainability measures by United Nations (UN) signatory countries in order to eradicate extreme poverty and to integrate the three dimensions of development i.e. social, economic and environment (UN, 2016). The UN has defined 17 sustainable development goals and 169 targets to be achieved by signatory countries in the next 15 years (UN, 2016; UN, 2014). The 17 goals will spawn a myriad of implementation capital projects in terms of: a) Goal 1 = no poverty; b) Goal 2 = zero hunger; c) Goal 3 = good health and well-being; d) Goal 4 = quality education; e) Goal 5 = gender equality; f) Goal 6 = clean water and sanitation; g) Goal 7 = affordable and clean energy; h) Goal 8 = decent work and economic growth; i) Goal 9 = industry; innovation and infrastructure; j) Goal 10 = reduced inequalities; k) Goal 11 = sustainable cities and communities; l) Goal 12 = responsible consumption and production; m) Goal 13 = climate action; n) Goal 14 = life below water; o) Goal 15 = life on land; p) Goal 16 = peace; justice and strong institutions; and a) Goal 17 = partnerships for the goals.

The second sustainability trend is the increased demand, standards and legislation for sustainable and environmentally friendly life-cycle designs. The drivers of this trend are the consumers with their green thinking and purchasing trends of green products (Rozen et al., 2012), international environmental standards such as ISO 14001:2015 (ISO, 2015) and the globalisation of environmental law (Yang, 2014). There is an increased need for products to be fully recyclable (once discarded, each part can be turned back into itself again) and fully traceable ("know the objects' past and future – whether it's made of renewable or recyclable materials, how much energy went into its production, how it's going to be disposed of" (Rozen et al., 2012:34)). A focus on life-cycle thinking to take all environmental aspects of products into consideration throughout the entire life will be required by industry (ISO, 2015). Paradigms such as Universal Designs (Ostroff, 2011), initiatives such as the doubling of energy productivity (B4ESummit, 2015) and smart metering for energy consumption, diagnosis and optimisation will form part of this megatrend and is also known as Sustainability by Design (SBD) (Rozen et al., 2012). This megatrend is expected to also help to fuel the megatrend for technology and entrepreneurship (as shown in Table A-9) as well as social, economic and ecological sustainability, fully recyclable products, green telecoms and green IT.

A.3 Paradigm Shifts

A paradigm shift is defined by the Cambridge Dictionary (2016) as; "a time when the usual and accepted way of doing or thinking about something changes". The words 'paradigm', 'paradigm shift' and 'paradigm change' originate from the work of Thomas Kuhn (Kuhn, 1970) who showed that scientific research did not advance through incremental changes but through "revolutions". He reasoned that any science requires a paradigm in order for the problems to be defined and solutions to be found. The current and future capital project environment might be subjected to the progression and impact of some of the current paradigm changes that are occurring in the business, technology and social environments.

Four paradigm changes or shifts in terms of Globalisation (Networking), the Web (Knowledge), Industrialisation (Manufacturing) and Society (Being) are considered and mapped against a common timeline as indicated in Figure A-1. Each of these paradigm shifts is discussed to try and understand the current and future volatile and radically changing environment in which capital projects will have to be successfully completed.

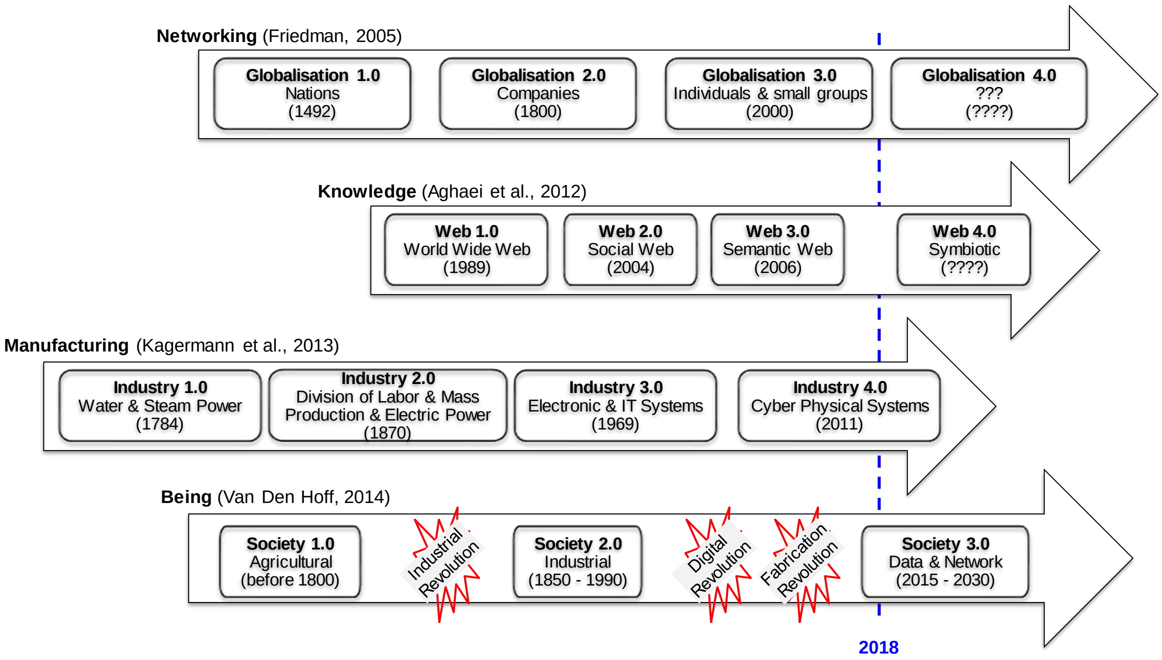

Figure A-1: Four Global Changing Paradigms that are Simultaneously Unfolding in the World

A.3.1 Paradigm Shift 1 – Globalisation

The first changing paradigm is that of Globalisation. Globalisation is defined by the Levin Institute (University of New York, 2015:1 of 2) as: "a process of interaction and integration among the people, companies, and governments of different nations, a process driven by international trade and investment and aided by information technology". They further state that globalisation has an effect on the environment, culture, political systems, economic development, prosperity and the well-being of societies. In his view of globalisation Friedman (2005) stated that Globalisation 1.0 (1492 - 1800) was conducted by nations for resources and imperial conquest, Globalisation 2.0 (1800 - 2000) by multinational companies for markets and labour and Globalisation 3.0 (2000 onwards) by individuals and small groups. Globalisation 1.0 and 2.0 were driven by Europe and the USA while Globalisation 3.0 is driven by non-western individuals and groups as shown in Figure A-1. Globalisation 4.0 is believed to be driven by Industrial Revolution 4.0 (digitisation, integration, smart-isation, virtualisation and designation) towards higher levels of global cooperation complexity (Schwab, 2019). However, the Chinese “one belt one road” strategy is aimed at using Globalisation 4.0 to create a new global order where participants share in global benefits more equally (Zhang and Cai, 2015). The Globalisation Paradigm Shift is resulting in a shift of economic power from north to south (A. T. Kearney, 2012) and from east to west (Bricklemyer, 2014) and may lead to investment and a need for capital projects related to infrastructure, ICT, health and energy.

It is interesting to note that the global over-investment into IT infrastructure during the dot com boom has led to a more connected world after this era and has helped the formation of other megatrends (Friedman, 2005) such as the Digital Future and the Global Marketplace. Global trade policies and the rise of the Internet and related technologies resulted in a “flat world” and “anyone with smarts, access to Google and a cheap wireless laptop” could participate in innovation and trade and create value (Friedman, 2005:3 of 9). This value was not created by silos but by horizontal communication and networking within companies, between companies and among individuals. Friedman (2005:6 of 9) refers to the paradigm changes in China (and India) during the past 30 years and states that there was a progression from "sold in China" to "made in China" to "designed in China" to "dreamed up in China".

Anders (2008) also categorised the three waves of globalisation and showed the paradigmatic changes to have taken place across at least five dimensions of technology, political leadership, commerce, capital movement and migration. It is interesting to note that for a dimension such as capital movement, a paradigm could revert and cycle back to an earlier form i.e. free, then regulated and then back to free. Furthermore, according to Anders (2008), advancement in technology seemed to be an important trigger for the next paradigm shift to take place.

Very limited information is currently available on Globalisation 4.0 and what paradigm changes to expect but such global paradigm changes are expected to have an influence on the current and future capital project management environment.

A.3.2 Paradigm Shift 2 – Web

The second paradigm shift to consider is found in the most prominent part of the Internet known as the World-Wide Web (www) or commonly known as the Web. The shifts in paradigms from Web 1.0 to Web 4.0 are described by Aghaei et al. (2012) and shown schematically in Figure A-1. Web 1.0 was established in 1989 by Tim-Lee Burgers with the intention to create a common global space where people could share information freely. Information was uploaded onto the Web using a file directory structure and copyright protected "brochure-ware" was accessed or pulled from the Internet by a single person using a single server.

The bi-directional communication capability of Web 2.0 was born in 2004 when the Internet could be used as a platform for communication between people. It is known as "wisdom web, people-centric web and participative web" (Aghaei et al., 2012:3) and technologies such as Blogs, Really Simple Syndication (RSS), Wikis, Mashups, Tags, Folksonomy, and Tag Clouds were used by people to create content in a collaborative way. The data structure was organised in a cold manner with tags, algorithms and information was open, content was created by users as "creative commons or cc". Cloud computing was done where storage and processing was automatically adjusted for performance. Information was pushed to a targeted user according to his personal profile.

Web 3.0, also known as the Semantic Web, was born in 2006, with the aim to intelligently link, integrate and analyse data from various sources to create new information and assist the user in an automatic synchronous manner to predict user actions. It was therefore possible to use the user context to refine and limit his choices and provide information, just prior to request, so that the Web response seems instantaneous for the user. This is only possible as information on the Web is made readable and interpretable by other machines on the Web that are all inter-connected (Anders, 2008).

Web 4.0 is known as the symbiotic web or intelligent web where "computers, understand your desires, plan your life and direct your activities" (Witt, 2016:7 of 30). Davis (2008:3 of 31) describes Web 4.0 as the “ubiquitous Web where both people and things reason and communicate together". Where computers automatically created code for a desired function in Web 3.0, these connected computers in the Web 4.0 paradigm will, without human intervention, instantly modify code to improve performance and user experience. Machine intelligence will determine the optimal use of all connected resources and will use bio-sensory input as part of its decision-making.

Based on this paradigm shift a question might be posed on how project management should be reconfigured / setup / constructed to capitalise on available web technology to improve the success of capital projects in the current and future world.

A.3.3 Paradigm Shift 3 – Industry

Richards (2016) summarised the paradigm changes throughout the four industrial revolutions as is schematically shown in Figure A-1. The first industrial revolution started at the end of the 18th century when water and steam power were introduced in mechanical production equipment. The second industrial revolution at the end of the 19th century commenced with the introduction of electricity and mass production lines. The third industrial revolution took place by 1970 with the use of IT (Programmable Logic Controllers or PLCs) to further automate production.

The current Fourth Industrial Revolution (4IR) is unfolding by connecting Information Technology (IT) and Operational Technology (OT), via the Internet of Things (IoT), to create Cyber Physical Systems (CPS) and Cyber Physical Production Systems (CPPS) using the newly defined Internet protocol IPv6 (Almada-Lobo, 2016; Bloem et al., 2014; Kagermann et al., 2013).

The stark changes as a result of these Industrial Revolutions are evident from a textile manufacturing example as given by Richards (2016). Manufacturing technology has changed from hand woven (pre-industrial) to a Spinning Jenny (1st Industrial Revolution) to an industrial sewing machine (2nd Industrial Revolution), to digital screen printing on fabric (3rd Industrial Revolution) and finally to a personalised clothing design and 3D printing (4th Industrial Revolution). The speed of communication also sped up during the four revolutions from locomotive and ships, the telegraph, digital communication and the expected tracking of all assets, machines and people.

It is noteworthy that all four industrial revolutions were triggered by improved technology, i.e. water and steam, electricity, IT and IoT as shown in Figure A-1. The Internet of Things (4th Industrial Revolution) was made possible in 2012 when the Internet protocol IPv4 was changed to IPv6. This allowed the increase of allocation of Internet Protocol (IP) addresses from 4.3 x 10^9 (4.3 billion) to 3.4 x 10^{38} (340 sextillion), with the implication that it is now possible to connect all people, devices and machines now and into the future with each other, to enable automatic Human to Machine (H2M), Machine to Machine (M2M) and Machine to Human (M2H) communications (Bloem et al., 2014; Kagermann et al., 2013).

The current and future capital projects is expected to be influenced by the paradigm shift from Industry 3.0 to Industry 4.0 as IT and OT will now become part of the technical aspects that the project manager should understand, as well as its negative and positive effects on the project life cycle.

A.3.4 Paradigm Shift 4 – Society

Henry Morgan (Morgan, 1877) has shown in his seminal work on the development of the human race that mankind has progressed from savagery to barbarism to civilisation and that inventions and discoveries such as fire, the bow and arrow, pottery, irrigation, smelting of ore and the phonetic alphabet have played a key role in this progress from one stage or paradigm to another.

Technology thus seems to trigger social development and paradigmatic shifts. Van Den Hoff (2014) is also of the opinion that the advent of technology caused the impetus for paradigmatic changes in society. The invention of the steam engine caused the onset of the Industrial Revolution and a change from an agricultural society (Society 1.0) to an industrial society (Society 2.0). As people moved to the cities, society was reinvented and reorganised and new structures for politics, organisation, finance and education were formed. The Digital Revolution (Web) and fabrication (3D printing) is, according to Van Den Hoff (2014), currently responsible for another big fundamental reorganising of society (Society 3.0) in terms of environment (Environment 3.0), work (Work 3.0), money (Money 3.0), education (Education 3.0), culture (Culture 3.0), leadership (Leadership 3.0) and business (Business 3.0). Moravec (2013) refers to the three different paradigms as the Industrial Society (Society 1.0), the current Knowledge Society (Society 2.0) and the near future Knowmad Society (Society 3.0) as shown schematically in Figure A-1. “The shift to the knowledge society therefore puts the person in the center" (Moravec, 2013:265). The characteristics of a Knowmad Society are the "accelerated technological and social changes, continuing globalization, horizontalization of knowledge and relationships and an innovation-oriented society fuelled by Knowmads" (Moravec, 2013:265).

Moravec (2013:40, Table 1) elaborates on the fundamental paradigmatic changes that have taken place in various dimensions from Society 1.0 to Society 3.0. He states that the *fundamental relationships between people have changed from simple-to-complex to complex-creative while the understanding of order has changed from hierarchical-to-hererarchic (elements unranked or differently ranked) to self-organising (overall order appears from local part behaviours of a disordered system)*. The relationships between members of society have changed from mechanical (one plus one equals two) to holographic (the whole represented in every part) to synergetic (outcome greater than count of parts).

Moravec (2013) continues to explain that the worldview of society has changed from deterministic to indeterminate to the realisation that the future can be designed. Causality, he states, has been viewed by Society 1.0 as linear (cause-effect), is currently (Society 2.0) viewed as mutual (cause-effect-cause) and will be viewed by Society 3.0 as anti-causal (outputs and internal states depend on future inputs). The nature of change processes changed from assembly of parts to morphogenic (biological processes that cause an organism to change its shape) to creative destruction (newer configurations replace older ones). Reality was viewed by society 1.0 as being objective, by society 2.0 it was viewed from different perspectives and by society 3.0 it is seen as context dependent. Thinking about place has changed from local to globalising (towards globalising) to being globalised. Duivestein (2014) presented Society 4.0 where every device and every human are digitised, possesses multiple sensors and is connected to the Internet in real-time. Artificial Intelligence (AI) is added and every device and human have a representation of the brain. He cites an example of a vending machine that will operate as an independent entity with its own bank account and being responsible for the management of sales of its own inventory.

It seems difficult to comprehend the different society paradigm changes as described in this paragraph and the effect that these changes might have on capital projects and the project environment. However, paradigm changes in society is expected to influence the capital project environment as these projects are done by members of society subjected to these changes.

One implication could be that the team members of future capital projects might consist of a number of Knowmads, i.e. "nomadic knowledge and innovation workers who are creative, imaginative, and innovative, and able to work with almost anybody, anytime, and anywhere" (Moravec, 2013:265) and that the Internet of Things (IoT) is expected to play a significant role in the capital project environment and the system under design.

A.4 Disruptive Technologies (DTx)

In a survey done by McKinsey on twelve disruptive technologies, they state that these technologies have the “potential for massive impact on how people live and work, and on industries and economies” (Manyika et al., 2013). Deloitte completed a study on eight emerging technologies and their expected adoption rates by industry (Deloitte, 2016) and indicated the effect of these disruptive technologies to create “always-on” global supply chains. Their results show that at least one of these eight technologies could either be a competitive advantage or could be responsible for the disruption of supply chains in the next 10 years. Disruptive technologies have the potential to transform industry business models (Manyika et al., 2013), business operating models (Panetta, 2016) and the introduction of new players in established markets (Christensen et al., 2015).

For the purpose of this discussion on the influence of disruptive technologies on current and future capital projects, disruptive technologies were selected from lists produced by Manyika et al. (2013); Deloitte (2016); Accenture (2016); Vanian (2016) as: a) inventory and network optimisation tools; b) sensors and automatic identification; c) cloud computing and storage; d) big data and predictive analysis; e) wearable and mobile technologies; f) advanced robotics and intelligent automation; g) driverless vehicles and drones; h) 3D printing; i) automation of knowledge work; j) advanced materials and miniaturisation; k) bio-technologies; l) genomic sequencing; and renewable technologies.

A.5 Black Swan Events (BSx)

Taleb (2003:6) defined the Black Swan Theory as; “a random event that cannot be predicted or computed from past history with a very small probability of occurrence, has an extremely large impact and comes as a surprise with no convincing evidence of the onset of the event”. Due to the absence of early warning signs it is not possible to identify or prepare for such an event. He states that such events are considered as extreme outliers and "off-model risks" (Taleb, 2003:4) but taken collectively, play a much larger role in society than regular occurrences. A Black Swan event is not a measurable and quantifiable "risk" but an immeasurable and unquantifiable "uncertainty" (Taleb, 2003:9). Uncertainty is characterised by Cleden (2009:13) as containing hidden knowledge, unknown relationships between key variables, unpredictable events and as "bolts from the blue". Examples of Black Swan events are shown in Table A-11. Thus, capital projects and the capital project environment could be assumed to be subjected to Black Swan events, wild card and uncertain events that cannot be identified in advance.

Table A-11: Black Swan Events According to Taleb (2003); A. T. Kearney (2012)

No.	Blank Swan Event
1	BS1: World Trade Centre attack on 11 September 2001 (9/11)
2	BS2: Nuclear detonation
3	BS3: Bio-terror attack
4	BS4: Global pandemic
5	BS5: Viruses that disable GPS satellites
6	BS6: Currency collapse

A.6 Model for Five Influences on Current and Future Capital Projects

It is assumed that the discussion in this Appendix A on trends and megatrends, paradigm shifts, disruptive technologies and Black Swan events do have an influence on the current and future capital projects internal and external environment. A model is generated to show these influences on the different types of capital projects is shown in Figure A-2.

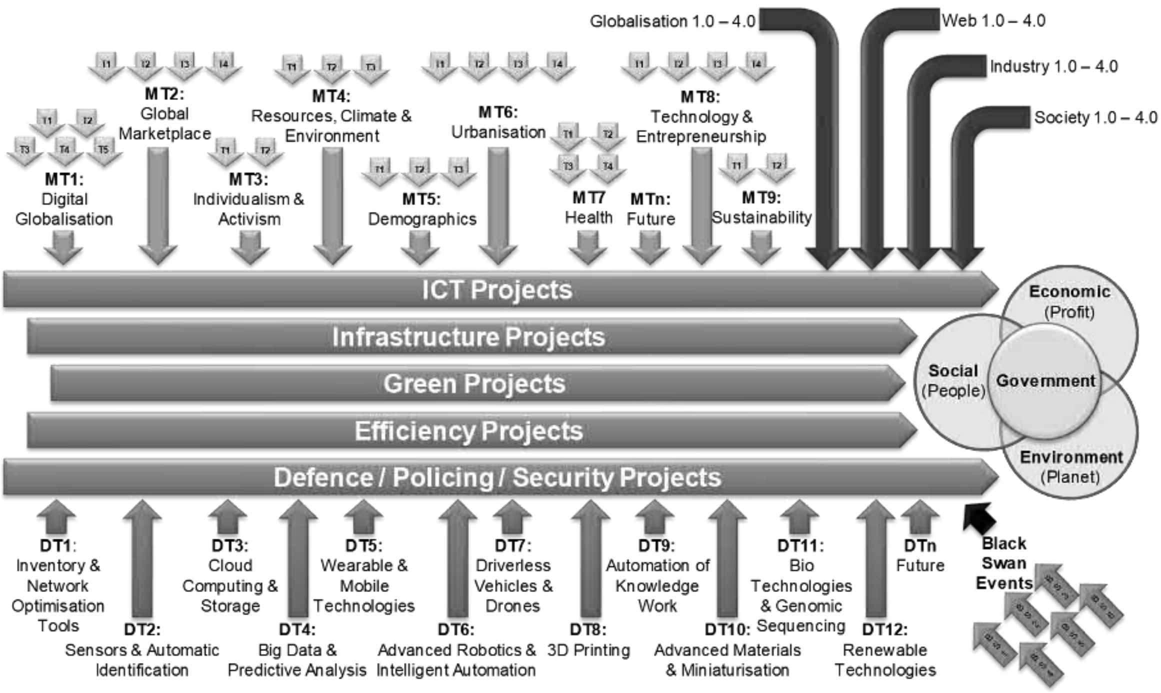

Figure A-2: Model for Five Influences on Current and Future Capital Projects in Terms of Megatrends and their Trends, Paradigm Shifts, Disruptive Technologies and Black Swan Events

The capital project types such as ICT, infrastructure, green and efficiency projects were derived from the typical capital projects that result from trends and megatrends as shown in the last columns of Table A-2 to Table A-10. Defence, police and security types of capital projects are added to this list as the latest technologies and/or disruptive technologies are normally used in these types of industries as they are executed on behalf of government and society to maintain law and order. Capital projects are commissioned to execute strategies of governments and to address the needs of society (people), the economy (profit) and the environment (planet). People, profit and the planet are referred to as the key elements of sustainability and as the Triple Bottom Line of business (Crul and Diehl, 2006).

It is speculated that these influences on current and future capital projects might sustain and even increase the capital project cost overruns. An understanding of causes and effects of such influences that could occur at various speeds in society is unknown. New and added theories, models and methods need to be developed for capital projects to quantify these influences to ensure that the current and future capital project manager is well equipped to understand and manage the complexities that occur in these projects. The lists of indicated trends, megatrends, disruptive technologies and paradigm shifts that were cited in this Appendix A are by no means exhaustive but appeared noteworthy in the literature surveyed.

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APPENDIX B: RANDOMNESS TO ORDER CONTINUUM AND ATTRACTOR CHARACTERISTICS

The objective of this Appendix is to provide additional descriptions for domains and sub-domains of a randomness-chaos-complexity-order continuum as well as a summary of descriptions by various researchers for continuum domains and sub-domains. A summary is also given for attractor categories.

B.1 Description of Additional Continuum Elements

A description of additional continuum elements for the complexity, chaos and randomness domains is given in this paragraph. These descriptions originate from various authors without further contextualisation as the objective is to provide a first order definition of the randomness-chaos-complexity-order continuum framework for use and testing in capital projects.

B.1.1.1 Complexity – Static Complexity

Lucas (2006) states that static complexity is the simplest form of complexity and is normally related to fixed systems with the assumption that the system structure does not change with time. The method of analysis, according to Lucas, for this system type is both pattern recognition and quantification using statistical methods. However, multiple levels of structure exist in systems with static complexity for example at molecular level, cellular level, organism level and ecosystem level. Interestingly, Remington and Pollack (2007) also describe multiple levels that exist in complex adaptive systems (CAS) for their concept of structural complexity.

B.1.1.2 Complexity – Dynamic Complexity

In dynamic complexity, the time dimension is added to an existing fixed structure (Lucas, 2006). Categorisation of the behaviour of a dynamic system is difficult as the system attributes could change as time passes. For example, the leaves of a tree (i.e. fixed system) are green in spring and summer, yellow in autumn and dead in winter (changes with time).

B.1.1.3 Complexity – Evolving Complexity

In evolving complexity, the fixed system structure is able to change. These complex systems are able to evolve as they consist of many individual parts that could be reconfigured into different and new configurations that result in different system behaviours (Lucas, 2006). This form of holistic thinking is also expressed by Gharajedaghi (2011) when he states that different structural configurations of system elements with different processes applied to each of the system configurations, are able to produce a myriad of same or different functions in a specific context. This means that a system is able to evolve when a change occurs in its structural configuration of its elements and / or when the same or different processes are applied. The theory of evolution as described by Darwin (1872) in terms of variety generation, selection and retention (inheritance), describes a similar process that might be responsible for the evolution of complexity in systems.

B.1.1.4 Complexity – Self-Organising Complexity

Lucas (2006) categorises a self-organising system as one in which the internal constraints of closed systems (such as machines) are combined with the creative evolution of open systems (such as people). These types of systems are co-evolving within its environment and its functionalities cannot be understood without consideration of the relevant environment in which it is evolving.

B.1.1.5 Complexity – Edge of Chaos

Morgan (2006:254) explains that the edge of chaos happens when a system is “pushed” far from its point of equilibrium towards chaos. Bifurcation points or sudden changes in system states are present in this domain and could causes a system to flip from one state to another. The sudden change of state is due to the availability of sufficient energy to affect a system change according to Morgan. However, if the “old dominant attractor” (p. 254) is able to dissipate the energy and instability of the system, the outcome will only be small changes of the current system state. The system will thus reside within the current attractor basin and may not further evolve. But for the same system at the edge of chaos, bifurcation points and their associated attractors are always present as “latent potentials” (p. 255) and could cause a system to change and self-organise into a new state and pattern of behaviour.

B.1.1.6 Chaos - Limited Chaos

Lorenz (1995:207) explains that limited chaos is a property of a dynamical system for which “some special orbits are nonperiodic but most are periodic or almost periodic”. Lorenz continues to explain that limited chaos exists for a dynamical system that inherently has a slight amount of randomness. A limited amount of chaos is thus perceived to be present in these types of systems.

B.1.1.7 Chaos - Full Chaos

Lorenz (1995:207) explains his definition for full chaos as “the property that characterises a dynamical system (a deterministic system with a slight amount of randomness) in which most orbits exhibit sensitive dependence on initial conditions”. Slight changes in any initial conditions of system behaviour therefore creates totally different and unexpected follow-on behaviour.

B.1.1.8 Randomness- Not Deterministic

Lorenz (1995:211) defined a random system as "a system in which the progression from earlier states to later states is not completely determined by any law; a system that is not deterministic".

B.1.1.9 Randomness – Completely Random

Lorenz (1995:6) defined "a random sequence of events is one in which anything that can ever happen can happen next" such as the toss of a coin. Due to human intervention, the outcome of the next toss of the coin cannot be determined based on the outcome of the previous toss. The process is not deterministic and not governed by any laws due to the intermittent involvement of a human being. Lorenz (1995:212) defined a completely random system as "a system in which later states occur completely independently of earlier states".

B.2 Summary of Contributions to the Randomness-Chaos-Complexity-Order Continuum

A summary of descriptions by various researchers for continuums with their domains and sub-domains as well as references to individual continuum elements were combined in to a single framework as shown in Table B-1.

Table B-1: A Summary of Contributions to the Randomness-Chaos-Complexity-Order Continuum from Various Researchers

No.	Randomness	Chaos	Complexity	Order	Reference
1	Randomness	Chaos			Lorenz (1995)
	• *Completely random* • *Not deterministic*	• *Full chaos* • *Limited chaos*			
2			Complexity		Lucas (2006)
			• *Self-organising complexity* • *Evolving complexity* • *Dynamic complexity* • *Static complexity*		
3		Chaos	Complexity	Order	Remington and Pollack (2007)
			• Edge of chaos		
4		Chaos	Complexity	Equilibrium	Hass (2008)
			• Edge of chaos	Complicated	
5	Disorder	Chaos	Complexity	Order	Snowden and Boone (2007); Snowden (2010)
		• Chaotic	• Complex	• *Complicated* • *Simple*	

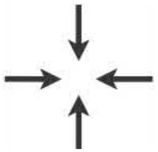
<table>
<tr><th>No.</th><th>Randomness</th><th colspan="2">Chaos</th><th>Complexity</th><th colspan="3">Order</th><th>Reference</th></tr>
<tr><td colspan="9"></td></tr>
<tr><td rowspan="2">6</td><td>Zone of Randomness</td><td colspan="3">Strange Attractor Zone</td><td colspan="3">Zone of Stability</td><td rowspan="2">Bums (2002)</td></tr>
<tr><td>• Anarchy
• Disintegration</td><td colspan="3">• Dynamic turbulence
• Self-organisation (single and double loop learning)</td><td colspan="3">• Ossification</td></tr>
<tr><td colspan="9"></td></tr>
<tr><td rowspan="2">7</td><td>Disorder</td><td colspan="2">Chaotic System</td><td>Complexity</td><td colspan="3">Order</td><td rowspan="2">Galanter (2003);
Galanter (2014)</td></tr>
<tr><td>• Randomisation</td><td>• Stochastic fractals</td><td>• Stochas-tic L-Systems</td><td>• Generic Systems and Artificial-Life</td><td>• L-Systems</td><td>• Fractals</td><td>• Symmetry and tiling</td></tr>
</table>

B.3 Attractor Categories and Attributes

A summary of references to different types or categories of attractors from various researchers is shown in Table B-2. Attributes for attractors were derived from the citations.

Table B-2: Summary for a Literature Survey on Attractor Categories and Attributes

No.	Attractor Type and Symbol	Description	Attributes	Reference
1	Point / Fixed Point Attractor	"most basic attractor… moves towards a highly equilibrium state" e.g. book falling to the ground	Moves towards highly equilibrium state	Gilstrap (2005:59)
		“A "fixed point attractor" can be easily illustrated with a system like a free-swinging pendulum operating in an atmosphere where friction will eventually cause the pendulum to stop moving at a specific point where there is zero velocity”	Zero velocity	Bums (2002:44).

No.	Attractor Type and Symbol	Description	Attributes	Reference
	 Sketch obtained from Butner et al. (2015:19, Figure 19)	“A fixed-point attractor is “a state… toward which the system returns after it has been perturbed”	A state towards which a system returns after a perturbation	Pruitt and Nowak (2014:389)
		“The basin of attraction for Attractor A is somewhat wider than the basin for Attractor B. This means that a wider variety of states will evolve toward Attractor A than toward Attractor B”	Wider attractor basin potentially captures more system dynamical states compared to a narrower attractor basin	Vallacher and Nowak (2007:738)
		“Attractors can also vary in their respective strength – their resistance to escalation – which is depicted as the relative depth of the two [attractor] valleys”	Steeper attractor basin potentially retains system dynamical states better compared to shallower attractor basin	Vallacher and Nowak (2007:738)
		“Attractors can also vary in their respective strength, which is depicted as the relative depth of the two valleys. Attractor B, then, is stronger than Attractor A. This means that when a system is at Attractor B, it is more difficult for it to be dislodged by external influence”	Systems inside deep attractors are less prone to dislodgement by external influences	Vallacher and Nowak (2007:7)
2	Periodic Point Attractor	"moves in a linear or orbital pattern toward and away from a set point a given number of times… no deviation in its trajectory" e.g. gear or piston	Moves towards and away from a set point	Gilstrap (2005:59)
3	Limit Cycle / Periodic Attractor	“the periodic attractor follows an orbital or linear trajectory towards a set point, yet the trajectory of the object can change from iteration to iteration… bounded stability" e.g. planets orbiting the sun	Orbital trajectory towards a set point bounded stability	Gilstrap (2005:59)
		“A topological feature of a state space in which a system changes in a constant repetition. An example would be the seasons.	Attraction toward a cyclical pattern	Butner et al. (2015:25)

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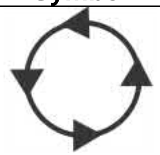
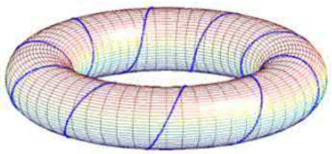
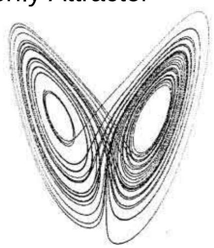
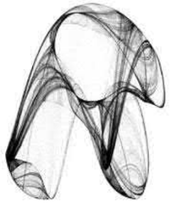
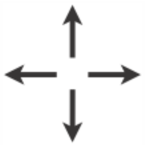
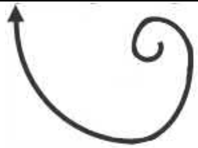
No.	Attractor Type and Symbol	Description	Attributes	Reference
	 Sketch obtained from Butner et al. (2015:19, Figure 19)	"systems display sustained rhythmic behaviour rather than convergence on a stable value over time. This temporal pattern is referred to as a periodic or limit-cycle attractor… a pattern on which the system converges, and to which it returns after small perturbations"	Sustained rhythmic behaviour A pattern on which the system converges System returns to pattern after small perturbations	Vallacher and Nowak (2007:10 & 11)
4	Torus Attractor  Sketch obtained from Springer Link (2017:2 of 5, Figure 1.49)	"The dynamics of a torus are marked by self-similarity. while the behaviour of any nonlinear natural or social system, including individuals, firms and entire societies, may be similar from day to day, year to year or generation to generation, no one embodiment in any given cycle or iteration of the behaviour any given system is precisely like a previous embodiment. Thus variation is the natural state of social forms which take the geometry of a torus. One can predict that a system will be somewhere inside the boundaries of the torus but one cannot predict exactly where the system will be"	Self-similarity Repeat smaller cycles bounded by larger cycle	Young and Kiel (1994:3)
5	Butterfly Attractor  Sketch obtained from Hilborn (2004:426, Figure 1)	"Strange attractors with more than one predictable outcome basins are called butterfly attractors. The butterfly attractor is being formed, through the formation of two causality fields, when a key parameter of a torus increases its value more than three times"	Formation of two causality fields	Radu et al. (2014:1552)
6	Strange Attractor	"In contrast, the 'strange attractor' operates differently [compared to a fixed point attractor] in that the <u>system never settles at a</u>	System never settles at a specific point –	Bums (2002:45)

No.	Attractor Type and Symbol	Description	Attributes	Reference
	 Sketch obtained from De Jong (2004:2 of 4)	specific fixed point, but rather seems to 'orbit' around the attractor [i.e. Butterfly pattern of Lorenz (1995)]".	orbits around the attractor	
		"The behaviour within the system is a paradox in that it defies specific long-term prediction while at the same time demonstrating consistent long-term pattern of organization"	Long term prediction not possible but remains within long term pattern	Bums (2002:44)
		"As the values of the nonlinear calculations change over time the locations of points change, never having a single point intersect with another point"	System trajectory never repeats itself exactly	Bums (2002:45)
		"we can have attractors that follow an orbit (like that of the planets round the sun) or we may have a system that never returns to the same place - this we call a 'Strange Attractor'"	System that never returns to the same place	Lucas (2004)
		"An attractor, in which the behaviour follows a pattern but never repeats itself, is called a complex attractor or a 'strange' attractor"	Behaviour follows a non-repeatable pattern	Romenska (2006:129)
		"there is an underlying pattern of order that is recognisable when the phase space of the system is mapped, known as a strange attractor"	Underlying pattern of order	Ramalingam et al. (2008:37)
		"This strange attractor shows that complexity – although seemingly completely disordered, actually displays order at the level of its trajectory, and that although it may be unpredictable in its detail, it always moves around the same attractor shape"	Displays order at the level of its trajectory but unpredictable in detail	Ramalingam et al. (2008:38)
		"If any part of the strange attractor were magnified, it would reveal a multi-layered sub-structure in which the same patterns are repeated. Complexity plays out in identical ways at different levels of a system"	Similar patterns / attractors at multiple deeper levels	Ramalingam et al. (2008:38)
		"…chaotic regimes have demonstrated the existing of patterns. Such patterns are called 'attractors' since a system appears to be "pulled" toward a region in an outcome field during its cycles or periods"	System behaviour is pulled towards attractor	Radu et al. (2014:1551)
		"Some attractors are called 'strange' attractors since a system behaves in ways not expected by Newtonian physics,	System behaves in ways not as expected by Newtonian	Radu et al. (2014:1551)

No.	Attractor Type and Symbol	Description	Attributes	Reference
		propositional logic, rational numbering systems or Euclidean geometry”	physics, propositional logic or rational numbering systems	
7	Spiral Attractor  Sketch obtained from Butner et al. (2015:19, Figure 19)	“A topological feature that combines a fixed point attractor with a limit cycle so that the state of the system spirals toward a set point”	Combination of a fixed piont and limit cycle attractors	Butner et al. (2015:25)
8	Repeller / Fixed Point Repeller  Sketch obtained from Butner et al. (2015:19, Figure 19)	“like a mountain peak. We could stand at the peak of the mountain, but the moment we begin to move in any direction, we quickly move away from the peak. So, repellers generate change away from the set point rather than toward it… An unstable state that a system or variable moves away from in time… In a one-dimensional topology repellers function as the borders between two attractors…	Unstable state System or variables moves away in time from this position or state	Butner et al. (2015:4, 25)
		“The state that a system changes to be farther away from a set value. A system is unstable at the location of a fixed point repeller. It is extremely rare to directly observe a fixed point repeller. An example would be a pen balanced on its tip—a small change in any direction would make it fall… The fixed point repeller is analogous to a mountaintop, where the set point is the peak.”	A system is unstable at the location of a fixed point repeller	Butner et al. (2015:4, 10, 25)
		“From a dynamical perspective, states in which a system cannot stabilize and from which the system escapes are termed repellors”	System cannot stabilise System escapes from current point / state	Vallacher and Nowak (2007:10)
9	Spiral Repeller	“A topological feature that combines a fixed point attractor with a limit cycle so that the state of the system spirals away from a set point”	System spirals away from a set point	Butner et al. (2015:25)

No.	Attractor Type and Symbol	Description	Attributes	Reference
	 Sketch obtained from Butner et al. (2015:19, Figure 19)			
10	Structural Attractor	“The structural attractor therefore represents a reduced set of activities from all those possible in principle. It reflects the ‘discovery’ of a subset of agents whose attributes and dimensions have properties that provide positive feedback. This is different from a classical dynamic attractor that refers to the long-term trajectory traced by the given set of variables… The whole process leads to the evolution of a complex, a ‘community’ of agents whose activities, whatever they are, have effects that feedback positively on themselves and the others present. It is an emergent ‘team’ or ‘community’ in which positive interactions are greater than the negative ones”	Agents with attributes that provide for positive feedback	Allen (2001:36)
		“the self-organization of our system leads to a highly cooperative system, where the competition per individual is low, but where loops of positive feedback and synergy are high”	Highly cooperative system with low competition and high synergy	Allen (2001:37)
11	Latent Attractor	“When a system is at one of its attractors, other attractors for the system’s behaviour may not be visible to observers, perhaps not even to the actors themselves… they determine states which are possible for the system when conditions change”	Attractors that are not visible but becomes available when conditions change	Vallacher and Nowak (2007:9)

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APPENDIX C: IDENTIFICATION OF VARIANCE MODEL ELEMENTS FOR CAPITAL PROJECTS USING METAPHOR MAPPING

Literature references for the use of each type of chaos attractors from various fields of science have been identified. These concepts have been mapped from their origin (source domain) to the capital project environment as the target domain. The principle of metaphor mapping as described by Boxenbaum and Rouleau (2011) has been applied. The format of the mapping tables conforms to the variance models architecture as shown in Chapter 3, paragraphs 3.5.3 and 3.5.4. The independent variables that are suggested to influence the characteristics of the dependent variable (chaos attractor) are identified first and then the converging effect of the dependent variable is shown. It is shown that the dependent variable (chaos attractors) have both a specific converging effect (SO) and a general converging effect (GO). The specific effects were taken from the literature while the general effect was taken from three converging effects that were generally referenced by researchers to be the general converging effect of all types of chaos attractors. This Appendix is concluded with a list of literature references.

C.1 Metaphor Mapping for Fixed-Point Chaos Attractors

The metaphor mapping from references to fixed-point chaos attractors from various sciences to the capital project domain is shown in Table C-1.

Table C-1: Source-Target Domain Mapping of Metaphors for Fixed-Point Chaos Attractors for Capital Projects

No.	Source Domain Metaphors – Fixed-Point Chaos Attractor	➔	Target Domain Metaphors – Capital Project Fixed-Point Chaos Attractor
1	Independent Variables (How? Why?)		Independent Variables (How? Why?)
2	Metaphor Geometry: "The basin of attraction for Attractor A is somewhat wider than the basin for Attractor B. This means that a wider variety of states will evolve toward Attractor A than toward Attractor B" (Vallacher and Nowak, 2007:738)	➔	IV1a) Metaphor Geometry: The width (reach) of a fixed-point chaos attractor basin determines the number of capital project elements and their trajectories under the influence of the attractor
3	Metaphor Geometry: "Attractors can also vary in their respective strength – their resistance to escalation – which is depicted as the relative depth of the two [attractor] valleys" (Vallacher and Nowak, 2007:738)	➔	IV1b) Metaphor Geometry: The depth of a chaos attractor basin determines the strength of attraction of capital project elements and their trajectories
4	Project Management: "We do not want to animate the complex behaviour of the actors (or agents) of the local food systems,	➔	IV2a) Project Management: A milestone causes the formation of a fixed-point

No.	Source Domain Metaphors – Fixed-Point Chaos Attractor	➔	Target Domain Metaphors – Capital Project Fixed-Point Chaos Attractor
	but the various nodes or milestones toward which their behaviours are expected to navigate and accumulate. These nodes may be conceptualised by means of attractors" (Kuhmonen, 2017:217)		chaos attractor of capital project elements and their trajectories
5	Psychology and Systems Engineering: CAS: "In socio-economic CAS [Complex Adaptive Systems] the attractors may be comprised by habits, routines, norms, dominant designs, preferences, ideals, innovations, demand trends etc. which turn specific locations in the system to more desirable, probable or common state spaces than others" (Kuhmonen, 2017:215)	➔	IV3a) Systems Engineering: A dominant design causes the formation of a fixed-point chaos attractor of capital project elements and their trajectories
		➔	IV3b) Systems Engineering: Design norms causes the formation of a fixed-point chaos attractor of capital project elements and their trajectories
		➔	IV3c) Systems Engineering: Innovations causes the formation of a fixed-point chaos attractor of capital project elements and their trajectories
6	Psychology and Systems Engineering: CAS: "In socio-economic CAS [Complex Adaptive Systems] the attractors may be comprised by habits, routines, norms, dominant designs, preferences, ideals, innovations, demand trends etc. which turn specific locations in the system to more desirable, probable or common state spaces than others" (Kuhmonen, 2017:215)	➔	IV4a) Psychology: Personal norms cause the formation of a fixed-point chaos attractor of capital project elements and their trajectories
		➔	IV4b) Psychology: Personal preferences cause the formation of a fixed-point chaos attractor of capital project elements and their trajectories
7	Psychology: "When a person habitually returns to the same pattern of thought or emotional state over time, this individual's dynamics are likely governed by a fixed-point attractor." (Vallacher et al., 2013:168)	➔	IV4c) Psychology: The personal pattern of thought causes the formation of a fixed-point chaos attractor of capital project elements and their trajectories
8	Psychology: "The point attractors represent the behaviour of social beings in pursuit of their natural instincts – fear, love, hate, desire to share, or self-interest" (Gharajedaghi, 2011:51)	➔	IV4d) Psychology: Personal fear causes the formation of a fixed-point chaos attractor of capital project elements and their trajectories
		➔	IV4e) Psychology: Personal hate causes the formation of a fixed-point chaos attractor of capital project elements and their trajectories
		➔	IV4f) Psychology: Personal desire to share causes the formation of a fixed-point chaos capital attractor of project elements and their trajectories
		➔	IV4g) Psychology: Personal self-interest causes the formation of a fixed-point chaos attractor of capital project elements and their trajectories
9	Outcome / Result of Fixed-Point Chaos Attractor		

No.	Source Domain Metaphors – Fixed-Point Chaos Attractor	→	Target Domain Metaphors – Capital Project Fixed-Point Chaos Attractor
10	Specific Outcome: "Moves towards a highly equilibrium state" e.g. book falling to the ground" (Gilstrap, 2005:59)	→	SO1) Specific Outcome: A fixed-point chaos attractor causes capital project elements and their trajectories to converge towards a highly equilibrium state
11	Specific Outcome: "A fixed-point attractor is "a state […] toward which the system returns after it has been perturbed" (Pruitt and Nowak, 2014:389)	→	SO2) Specific Outcome: A fixed-point chaos attractor causes capital project elements and their trajectories to return towards convergence after they have been perturbed
12	Specific Outcome: "Pendulum… where friction will eventually cause the pendulum to stop moving at a specific point where there is zero velocity" (Bums, 2002:44)	→	SO3) Specific Outcome: A fixed-point chaos attractor causes capital project elements and their trajectories to converge towards a stationary termination point
13	General Outcome: "the emerging food systems share some common elements or 'attractors' around which the diversity organises" (Kuhmonen, 2017:215)	→	GO1) General Outcome: Fixed-point chaos attractors cause diverse capital project elements and their trajectories to converge around the attractor
14	General Outcome: "visions are expected to act as attractors for managing transitions, i.e. by creating expectations which attract support, actors, ideas and funding. Although, visions are important for guiding the transition process, if visions do indeed act as attractors, they can reduce the number of possible directions in which the system can unfold" (Vasileiadou and Safarzyńska, 2010:1178)	→	GO2) General Outcome: Fixed-point chaos attractors cause a reduction in the number of possible directions in which capital project elements and their trajectories can evolve
15	General Outcome: "…chaotic regimes have demonstrated the existance of patterns. Such patterns are called "attractors" since a system appears to be "pulled" toward a region in an outcome field during its cycles or periods" (Radu et al., 2014:1551)	→	GO3) General Outcome: Fixed-point chaos attractors cause capital project elements and their trajectories to be pulled towards a region of convergence

C.2 Metaphor Mapping for Fixed-Point Chaos Repellers

The metaphor mapping from references to fixed-point chaos repellers from various sciences to the capital project domain is shown in Table C-2.

Table C-2: Source-Target Domain Mapping of Metaphors for Fixed-Point Chaos Repellers for Capital Projects

No.	**Source Domain Metaphors – Fixed-Point Chaos Repeller**	➔	**Target Domain Metaphor – Capital Project Fixed-Point Chaos Repeller**
1	Independent Variables (How? Why?)		Independent Variables (How? Why?)
2	Metaphor Geometry: “Like attractors, repellers also have a set point, which is like a mountain peak.” (Butner et al., 2015:4)	➔	IV1a) Metaphor Geometry: Fixed-point chaos repellers of capital project elements and their trajectories have set points that are similar to mountain peaks
3	Metaphor Geometry: “Variables that have the capacity to alter the topology are known as control parameters. Control parameters have the ability to alter topological features in one of three ways. First, they can strengthen or weaken an attractor or repeller. Second, they can move a set point to a different location relative to other set points. Third, control parameters can drastically change the topology by completely extinguishing set points or turning it into a different kind of topological feature (e.g. change an attractor into a repeller, or vice versa).” (Butner et al., 2015:5)	➔	IV1i) Metaphor Geometry: Fixed-point chaos repellers of capital project elements and their trajectories have topological control parameters that cause the formation of stronger or weaker Fixed-point chaos repellers
			IV1b) Metaphor Geometry: Fixed-point chaos repellers of capital project elements and their trajectories have topological control parameters that cause movements of the set points
			IV1c) Metaphor Geometry: Fixed-point chaos repellers of capital project elements and their trajectories have topological control parameters that are able to alter the topology and cause the appearance or disappearance of Fixed-point chaos repellers
4	Outcome / Result of Fixed-Point Chaos Repeller		
5	Specific Outcome: “A system is unstable at the location of a fixed point repeller” (Kent and Stump, No Date)	➔	SO1) Specific Outcome: A fixed-point chaos repeller causes unstableness of capital project elements and their trajectories at the set point
6	Specific Outcome: “The state that a system changes to be farther away from a set value” (Kent and Stump, No Date)	➔	SO2) Specific Outcome: A fixed-point chaos repeller causes quick change away from the set point (i.e. mountain peak) of capital project elements and their trajectories
7	Specific Outcome: “Like attractors, repellers also have a set point, which is like a mountain peak. We could stand at the peak of the mountain, but the moment we begin to move in any direction, we quickly move away from the peak. So, repellers generate change away from the set point rather than toward it.” (Butner et al., 2015:4)		
8	Specific Outcome: “By definition, repellors are states from which a system is forced away.” (Vallacher et al., 2013:176)	➔	SO3) Specific Outcome: A fixed-point chaos repeller causes forceful diversion away from the set point (i.e. mountain peak) of capital project elements and their trajectories
9	General Outcome: “the emerging food systems share some common elements or ‘attractors’ around which the diversity organises” (Kuhmonen, 2017:215)	➔	GO1) General Outcome - **Antithesis**: Fixed-point chaos repellers cause diverse capital project elements and their trajectories to diverge away from the repeller

No.	Source Domain Metaphors – Fixed-Point Chaos Repeller	➔	Target Domain Metaphor – Capital Project Fixed-Point Chaos Repeller
10	General Outcome: “visions are expected to act as attractors for managing transitions, i.e. by creating expectations which attract support, actors, ideas and funding. Although, visions are important for guiding the transition process, if visions do indeed act as attractors, they can reduce the number of possible directions in which the system can unfold” (Vasileiadou and Safarzyńska, 2010:1178)	➔	GO2) General Outcome - **Antithesis**: Fixed-point chaos repellers cause an increase the number of possible directions in which capital project elements and their trajectories can evolve
11	General Outcome: “…chaotic regimes have demonstrated the existance of patterns. Such patterns are called "attractors" since a system appears to be "pulled" toward a region in an outcome field during its cycles or periods” (Radu et al., 2014:1551)	➔	GO3) General Outcome - **Antithesis**: Fixed-point chaos repellers cause capital project elements and their trajectories to be pushed towards divergence

C.3 Metaphor Mapping for Limit-Cycle Chaos Attractors

The metaphor mapping from references to limit-cycle chaos attractors from various sciences to the capital project domain is shown in Table C-3.

Table C-3: Source-Target Domain Mapping of Metaphors for Limit-Cycle Chaos Attractor for Capital Projects

No.	Source Domain Metaphors – Limit-Cycle Chaos Attractor	➔	Target Domain Metaphor – Capital Project Limit-Cycle Chaos Attractor
1	Independent Variables (How? Why?)		Independent Variables (How? Why?)
2	Metaphor Geometry: “the periodic attractor follows an orbital or linear trajectory towards a set point, yet the trajectory of the object can change from iteration to iteration"; for example: “each year, the syllabus must be modified slightly to account for time and classroom changes, yet the content of the syllabus remains relatively the same.” (Gilstrap, 2005:59)	➔	IV1a) Metaphor Geometry: A repetition of nearly similar activities causes the formation of a limit-cycle chaos attractor of capital project elements and their trajectories
3	Metaphor Geometry: “A topological feature of a state space in which a system changes in a constant repetition. An example would be the seasons.” (Butner et al., 2015:25)	➔	IV1b) Metaphor Geometry: System change by constant repetition of capital project elements and their trajectories causes the formation of a limit-cycle chaos attractor

No.	Source Domain Metaphors – Limit-Cycle Chaos Attractor	→	Target Domain Metaphor – Capital Project Limit-Cycle Chaos Attractor
4	Socio-cultural: “The cycle attractors (dialectic/self-maintaining) would correspond to our principle of multidimensionality, pursuit of seemingly opposite but complementary tendencies: stability and change, security and freedom, and, in general, differentiation and integration. Cyclicality, or periodic shift of emphasis from one orientation to another, is the result of sub optimization” (Gharajedaghi, 2011:51)	→	IV2a) Development: Periodic shift between integration and differentiation causes the formation of a limit-cycle chaos attractor of capital project elements and their trajectories
5	Psychology: “Routines, habits, and automatic forms of thinking (judging a new situation according to pre-existing schemata) all demonstrate the general attractor concept” (Vallacher et al., 2013:168) CAS: “In socio-economic CAS [Complex Adaptive Systems] the attractors may be comprised by habits, routines, norms, dominant designs, preferences, ideals, innovations, demand trends etc. which turn specific locations in the system to more desirable, probable or common state spaces than others” (Kuhmonen, 2017:215)	→	IV3a) Psychology: Personal routines cause the formation of a limit-cycle chaos attractor of capital project elements and their trajectories
		→	IV3b) Psychology: Personal habits causes the formation of a limit-cycle chaos attractor of project elements and their trajectories
6	“A metaphor for periodic attractors at the micro level might be the editing of a syllabus for a class. Each year, the syllabus must be modified slightly to account for time and classroom changes, yet the content of the syllabus remains relatively the same.” (Gilstrap, 2005:59)	→	IV4a) Process: Near-similar activities of a repetitive cycle causes the formation of a limit-cycle chaos attractor of capital project elements and their trajectories.
7	Outcome / Result of Limit-Cycle Chaos Attractor		
8	Metaphor Geometry: “The arrows correspond to trajectories starting outside the attractor, but ending up in a continuing cycle along the attractor… The final trajectory in which the system settles may have a very irregular shape, without any apparent periodicity. Yet, this eventual trajectory is still an attractor, because neighbouring trajectories are "sucked" into it, losing their freedom to get out again.” (Principia Cybernetica, 2017)	→	SO1) Specific Outcome: A limit-cycle chaos attractor causes the convergence of nearby capital project elements and their trajectories towards the attractor
9	Metaphor Outcome: “Periodic attractive systems are attracted to a periodic attractor” (Avnet, 2006)	→	SO2) Specific Outcome: A limit-cycle chaos attractor causes the attraction of periodic capital project elements and their trajectories
10	Metaphor Outcome: Limit cycle attractors: “move systems into loops of predictable but dynamic patterns” (Pascale et al., 2000:70)	→	SO3) Specific Outcome: A limit-cycle chaos attractor causes capital project elements and their trajectories to converge towards loops of predictable dynamic patterns

No.	Source Domain Metaphors – Limit-Cycle Chaos Attractor	→	Target Domain Metaphor – Capital Project Limit-Cycle Chaos Attractor
11	Metaphor Outcome: "A [cyclical] pattern on which the system converges, and to which it returns after small perturbations" (Vallacher and Nowak, 2007:11)	→	SO4) Specific Outcome: A limit cycle chaos attractor causes the capital project elements and their trajectories to return to the limit cycle after small perturbations
12	Metaphor Outcome: "In a daily cycle of activity, for example, a departure (e.g. a sleepless night) might temporarily disrupt the pattern (e.g., oversleeping the next few days), but eventually the pattern will be restored [to a normal sleeping pattern]". (Vallacher and Nowak, 2007:11)	→	
13	Metaphor Outcome: "Periodic attractors also are considered to operate in equilibrium-oriented systems, as their patterns exist in bounded stability. A metaphor for periodic attractors at the micro level might be the editing of a syllabus for a class. Each year, the syllabus must be modified slightly to account for time and classroom changes, yet the content of the syllabus remains relatively the same." (Gilstrap, 2005:59)	→	SO5) Specific Outcome: A limit-cycle chaos attractor causes capital project elements and their trajectories to be bounded stability once in the attractor cycle
14	General Outcome: "the emerging food systems share some common elements or 'attractors' around which the diversity organises" (Kuhmonen, 2017:215)	→	GO1) General Outcome: Limit-cycle chaos attractors cause diverse capital project elements and their trajectories to converge around the attractor
15	General Outcome: "visions are expected to act as attractors for managing transitions, i.e. by creating expectations which attract support, actors, ideas and funding. Although, visions are important for guiding the transition process, if visions do indeed act as attractors, they can reduce the number of possible directions in which the system can unfold" (Vasileiadou and Safarzyńska, 2010:1178)	→	GO2) General Outcome: Limit-cycle chaos attractors cause a reduction in the number of possible directions in which capital project elements and their trajectories can evolve
16	General Outcome: "…chaotic regimes have demonstrated the existing of patterns. Such patterns are called "attractors" since a system appears to be "pulled" toward a region in an outcome field during its cycles or periods" (Radu et al., 2014:1551)	→	GO3) General Outcome: Limit-cycle chaos attractors cause capital project elements and their trajectories to be pulled towards a region of convergence

C.4 Metaphor Mapping for Torus Chaos Attractors

The metaphor mapping from references to torus chaos attractors from various sciences to the capital project domain is shown in Table C-4.

Table C-4: Source-Target Domain Mapping of Metaphors for Torus Chaos Attractors for Capital Projects

No.	Source Domain Metaphors – Torus Chaos Attractor	➔	Target Domain Metaphor – Capital Project Torus Chaos Attractor
1	Independent Variables (How? Why?)		Independent Variables (How? Why?)
2	Metaphor Geometry: "The torus attractor is a more complex pattern that forms an orbit, but also contains sub-orbits within the orbit, thus resembling a donut when graphed in phase space." (Crandall et al., 2013:56)	➔	IV1a) Metaphor Geometry: A torus chaos attractor of capital project elements and their trajectories has an outer orbit / cycle with multiple inner sub-orbits / cycles
3	Metaphor Geometry: "Mathematically the Torus is depicted in the shape of a large donut or bagel as shown above. It is made up of a spiraling circle on many planes which may, or may not, eventually hook up with itself after completing one or more full revolutions" (School of Wisdom, No Date)??	➔	IV1b) Metaphor Geometry: A torus chaos attractor of capital project elements and their trajectories has multiple inner cycles that may or may not eventually link up with itself after completing one or more revolutions
4	Metaphor Geometry: "The dynamics of a torus are marked by self-similarity. While the behavior of any nonlinear natural or social system, including individuals, firms and entire societies, may be similar from day to day, year to year or generation to generation, no one embodiment in any given cycle or iteration of the behavior any given system is precisely like a previous embodiment." (Young and Kiel, 1994:3)	➔	IV1c) Metaphor Geometry: A torus chaos attractor of capital project elements and their trajectories has self-similar but not exactly repeating inner cycles
5	Socio-Cultural: "The dynamics of a torus are marked by self-similarity. While the behavior of any nonlinear natural or social system, including individuals, firms and entire societies, may be similar from day to day, year to year or generation to generation, no one embodiment in any given cycle or iteration of the behavior any given system is precisely like a previous embodiment. ." (Young and Kiel, 1994:3)	➔	IV2a) Project Management: The self-similar behaviour of programs, projects and individual team members causes the formation of a torus chaos attractor of capital project elements and their trajectories
6	Socio-Cultural: "Routine dynamics inside a factory, an office, a hospital, a school or a prison have the character of a torus; they are familiar but are never the exactly the same from day to day" (Young and Kiel, 1994:3)	➔	IV2b) Project Management: Near similar routine dynamics in a project causes the formation of a torus chaos attractor of capital project elements and their trajectories
7	Socio-Cultural: "An example of the Torus attractor at work would be a more complex set of attracting events which occur to a person on many levels over a	➔	IV2c) Project Management: Repetitive attracting events in a project causes the formation of a torus chaos attractor of capital project elements and their trajectories

No.	**Source Domain Metaphors – Torus Chaos Attractor**	➔	**Target Domain Metaphor – Capital Project Torus Chaos Attractor**
	course of a year, and repeat again, year in and year out. For example, a desire to golf each summer, hike each fall, and eat and drink too much on holidays." (School of Wisdom, No Date)??		
8	Socio-Cultural: "They develop systems for doing things at set times and in nominated places. Consistency, routine, classification, hierarchy and organization are their catch-cries… inflexible bureaucracy. Everything is systematized; there are prescriptions for all actions; work is structured around set schedules and timeframes; people and information are 'processed', which usually means identified with some part of the system and treated according to standard procedures." (Pryor and Bright, 2011:44)	➔	IV2d) Project Management: Standard procedures and processes cause the formation of a torus chaos attractor of capital project elements and their trajectories
9	Outcome / Result of Torus Chaos Attractor		
10	Specific Outcome: "One can predict that a [social] system will be somewhere inside the boundaries of the torus but one cannot predict exactly where the system will be" (Young and Kiel, 1994:3)	➔	SO1) Specific Outcome: A torus chaos attractor of capital project elements and its trajectories causes them to be located inside the torus (boundedness) but it is not possible to predict their exact location
11	Growth Cycle: "an indoor nurseryperson produces plants indoors all year round. He or she follows routines in terms of planting, nurturing, harvesting, and selling the plants." (Bright and Pryor, 2005:301)	➔	SO2) Specific Outcome: A torus chaos attractor of capital project elements and its trajectories causes growth from successive processes within a single overall cycle
12	Socio-Cultural: "They develop systems for doing things at set times and in nominated places. Consistency, routine, classification, hierarchy and organization are their catch-cries. In organizational terms the classic example of this is inflexible bureaucracy." (Pryor and Bright, 2011:44)	➔	SO3) Specific Outcome: A torus chaos attractor of capital project elements and its trajectories causes bureaucracy
13	General Outcome: "the emerging food systems share some common elements or 'attractors' around which the diversity organises" (Kuhmonen, 2017:215)	➔	GO1) General Outcome: Torus chaos attractors cause diverse capital project elements and their trajectories to converge around the attractor
14	General Outcome: "visions are expected to act as attractors for managing transitions, i.e. by creating expectations which attract support, actors, ideas and funding. Although, visions are important for guiding the transition process, if visions do indeed act as attractors, they can reduce the number of possible directions in which the system can unfold" (Vasileiadou and Safarzyńska, 2010:1178)	➔	GO2) General Outcome: Torus chaos attractors cause a reduction in the number of possible directions in which capital project elements and their trajectories can evolve

No.	Source Domain Metaphors – Torus Chaos Attractor	➔	Target Domain Metaphor – Capital Project Torus Chaos Attractor
15	General Outcome: "…chaotic regimes have demonstrated the existing of patterns. Such patterns are called "attractors" since a system appears to be "pulled" toward a region in an outcome field during its cycles or periods" (Radu et al., 2014:1551)	➔	GO3) General Outcome: Torus chaos attractors cause capital project elements and their trajectories to be pulled towards a region of convergence

C.5 Metaphor Mapping for Butterfly Chaos Attractors

The metaphor mapping from references to butterfly chaos attractors from various sciences to the capital project domain is shown in Table C-5.

Table C-5: Source-Target Domain Mapping of Metaphors for Butterfly Chaos Attractor for Capital Projects

No.	Source Domain Metaphors – Butterfly Chaos Attractor	➔	Target Domain Metaphor – Capital Project Butterfly Chaos Attractor
1	Independent Variables (How? Why?)		Independent Variables (How? Why?)
2	Metaphor Geometry: "Strange attractors with more than one predictable outcome basins are called butterfly attractors. The butterfly attractor is being formed, through the formation of two causality fields, when a key parameter of a torus increases its value more than three times" (Radu et al., 2014:1552)	➔	IV1a) Metaphor Geometry: A butterfly chaos attractor of capital project elements and their trajectories has more than one predictable outcome basin
3	Metaphor Geometry: "Strange attractors with more than one predictable outcome basins are called butterfly attractors. The butterfly attractor is being formed, through the formation of two causality fields, when a key parameter of a torus increases its value more than three times" (Radu et al., 2014:1552)	➔	IV1b) Specific Outcome: A butterfly chaos attractor of capital project elements and their trajectories cause a bifurcation jump of the long-term behaviour when the value of a particular dimension becomes higher or lower than some critical value
4	Specific Outcome: "Such a jump, usually referred to as a bifurcation, is an abrupt change in the long-term behaviour of a system, when the value of a particular dimension becomes higher or lower than some critical value." (Ramalingam et al., 2008:31)	➔	
5	Metaphor Geometry: "The cusp on the control surface is; called the bifurcation set of the cusp catastrophe, and it defines the thresholds where sudden	➔	IV1c) Metaphor Geometry: A butterfly chaos attractor of capital project elements and their trajectories has a bifurcation zone where sudden jumps may take place

No.	Source Domain Metaphors – Butterfly Chaos Attractor	➔	Target Domain Metaphor – Capital Project Butterfly Chaos Attractor
	changes can take place. (Zeeman, 1976:68)		
6	Metaphor Geometry: "Everywhere inside the bifurcation set there are two possible modes of behavior: outside it there is only one mode." (Zeeman, 1976:68)	➔	IV1d) Metaphor Geometry: A butterfly chaos attractor for capital projects has a bifurcation set – everywhere inside the set two possible modes of behaviour are possible but only one mode outside of it
7	Metaphor Geometry: "As one gets close to the bifurcation points - which may be seen as those points where the system moves from one wing of the attractor to the other, the values of fluctuations increase dramatically." (Ramalingam et al., 2008:31)	➔	IV1e) Metaphor Geometry: A butterfly chaos attractor for capital projects experience large fluctuations in key parameter values close to the point of bifurcation
8	Metaphor Geometry "If any part of the strange attractor were magnified, it would reveal a multi-layered sub-structure in which the same patterns are repeated. Complexity plays out in identical ways at different levels of a system… (Gleick, 1987)" (Ramalingam et al., 2008:38)	➔	IV1f) Metaphor Geometry: A butterfly chaos attractor for capital projects displays similar patterns of behaviour at different levels of its sub-structure
9	Psychological: "Systems often have more than one attractor. For instance, some people swing from good mood to bad mood and back again in the course of a few days, weeks or months. Both good and bad moods tend to be stable in their periods of ascendancy, quickly re-establishing themselves after a momentary disturbance" (Pruitt and Nowak, 2014:389)	➔	IV2a) Project Politics: Alternating attitudes of project sponsors towards project elements or their trajectories causes the formation of a butterfly chaos attractor
10	Financial Markets: "The butterfly effect concept has become important in the finance world as globalization continues to increase and capital markets connect. Volatility in one small area of the international markets can grow rapidly and bleed into other markets, and a hiccup in one corner of the international markets can have global consequences." (Edwards, 2016)	➔	IV2b) Project Management: Volatility in project scope in one project area that can grow quickly into other project areas causes the formation of a butterfly chaos attractor of capital project elements and their trajectories
11	Megaproject: "An oil and gas megaproject is highly sensitive to change. A small change to the system such as a delay in the completion of an activity may have significant effect on a company's financial performance." (Olaniran et al., 2015:912)	➔	IV2c) Project Management: Time constraint projects where small delays in the completion of an activity results in significant negative financial performance causes the formation of a butterfly attractor of capital project elements and their trajectories
12	Specific Outcome: "At certain [bifurcation] points on the behaviour surface (near the fold line) a small	➔	IV2d) Specific Outcome: Small changes in control variables such as trust and hope cause the formation of a butterfly chaos attractor of

No.	Source Domain Metaphors – Butterfly Chaos Attractor	➔	Target Domain Metaphor – Capital Project Butterfly Chaos Attractor
	change in trust and/or hope can lead to an abrupt change in identification (with the organization's culture), i.e. a sudden lack [or acceptance] of identification." (Karathanos et al., 1994:18)		capital project elements and their trajectories (sensitive dependence on initial conditions)
13	Outcome / Result of Butterfly Chaos Attractor		
14	Specific Outcome: "Complex systems can have a chaotic dynamic, and develop through a series of sudden jumps (Feigenbaum, 1978)" (Ramalingam et al., 2008:31)	➔	SO1) Specific Outcome: A butterfly chaos attractor causes project development through a series of sudden bifurcation jumps of capital project elements and their trajectories
15	Specific Outcome: "The principles of Evolution Second Order like rapid, jumping changes; creation of new formations (emergence); bifurcations; and dynamic chaos, as well as grand strides. This can cause a dangerous situation, a breakdown, or a collapse within the process or system. We have the dual situation of rapid changes to a new formation or a possible "breakdown."" (Saynisch, 2010:28)	➔	SO2) Specific Outcome: A butterfly chaos attractor causes successful evolution second order outcomes in terms of jumping changes; creation and emergence of new formations, bifurcations and grand strides for capital project elements and their trajectories
16	Specific Outcome: "New levels of organization, complexity, energy, and entropy can be reached by fluctuations, catastrophic bifurcations (chaos theory), punctuated equilibrium, evolutionary jump, and disequilibrium… creation of new and higher levels of quality, organization, and complexity, ordered by fluctuation and bifurcation." (Saynisch, 2010:32)	➔	SO3) Specific Outcome: A butterfly chaos attractor causes bifurcation jump to new and higher levels of quality, organization and complexity of capital project elements and their trajectories
17	Evolution: "The principles of Evolution Second Order like rapid, jumping changes; creation of new formations (emergence); bifurcations; and dynamic chaos, as well as grand strides. This can cause a dangerous situation, a breakdown, or a collapse within the process or system. We have the dual situation of rapid changes to a new formation or a possible "breakdown."" (Saynisch, 2010:28)	➔	SO4) Specific Outcome: A butterfly chaos attractor causes failed evolution second order outcomes in terms of breakdown and collapse for capital project elements and their trajectories
18	General Outcome: "the emerging food systems share some common elements or 'attractors' around which the diversity organises" (Kuhmonen, 2017:215)	➔	GO1) General Outcome: butterfly chaos attractors cause diverse capital project elements and their trajectories to converge around the attractor
19	General Outcome: "visions are expected to act as attractors for managing transitions, i.e. by creating	➔	GO2) General Outcome: Butterfly chaos attractors cause a reduction in the number of

No.	Source Domain Metaphors – Butterfly Chaos Attractor	➔	Target Domain Metaphor – Capital Project Butterfly Chaos Attractor
	expectations which attract support, actors, ideas and funding. Although, visions are important for guiding the transition process, if visions do indeed act as attractors, they can reduce the number of possible directions in which the system can unfold" (Vasileiadou and Safarzyńska, 2010:1178)		possible directions in which capital project elements and their trajectories can evolve
20	General Outcome: "…chaotic regimes have demonstrated the existing of patterns. Such patterns are called "attractors" since a system appears to be "pulled" toward a region in an outcome field during its cycles or periods" (Radu et al., 2014:1551)	➔	GO3) General Outcome: Butterfly chaos attractors cause capital project elements and their trajectories to be pulled towards a region of convergence

C.6 Metaphor Mapping for Strange Chaos Attractors

The metaphor mapping from references to strange chaos attractors from various sciences to the capital project domain is shown in Table C-6.

Table C-6: Source-Target Domain Mapping of Metaphors for Strange Chaos Attractor for Capital Projects

No.	Source Domain Metaphors – Strange Chaos Attractor	➔	Target Domain Metaphor – Capital Project Strange Chaos Attractor
1	Independent Variables (How? Why?)		Independent Variables (How? Why?)
2	Metaphor Geometry: "A strange attractor [is] able to expand, shrink, merge with other attractors, collapse, or 'explode' into new dynamic patterns in the agent's mental space." (Dimitrov, 2000:418)	➔	IV1a) Metaphor Geometry: A strange chaos attractor of capital project elements and their trajectories is able to expand
		➔	IV1b) Metaphor Geometry: A strange chaos attractor of capital project elements and their trajectories is able to shrink
		➔	IV1c) Metaphor Geometry: A strange chaos attractor of capital project elements and their trajectories is able to merge with other attractors
		➔	IV1d) Metaphor Geometry: A strange chaos attractor of capital project elements and their trajectories is able to collapse
		➔	IV1e) Metaphor Geometry: A strange chaos attractor of capital project elements and their trajectories is able to explode into new dynamic patterns
3	Organisational: "Strange attractors are then metaphorically described in organizational settings as shared vision, team processes,	➔	IV2a) Project Management: A shared project vision causes the formation of a strange chaos attractor of capital project elements and their trajectories

No.	Source Domain Metaphors – Strange Chaos Attractor	➔	Target Domain Metaphor – Capital Project Strange Chaos Attractor
	and information flows used as positive feedback mechanisms" (Gilstrap, 2005:55)	➔	IV2b) Project Management: Team processes cause the formation of a strange chaos attractor of capital project elements and their trajectories
4	Organisation: "Attractors such as values emerge after a period of information and instance-gathering. Once they have been established we can jump straight to a judgement without thought. As already suggested, values are just one small set of examples within a far broader set of similar phenomena. Other attractors include identity, brand, image, loyalty, flexibility, emotion, happiness, sadness, changeability, service, motivation, culture, climate, beauty, spirit, and uniqueness." (Robertson, 2014:39)	➔	IV2c) Project Management: Project culture causes the formation of a strange chaos attractor of capital project elements and their trajectories
5	Organisational: "However complex and chaotic the dynamics of an organization, they are always pulled towards the purpose of this organization as a whole. The purpose of the organization propels - informs, motivates, and inspires… The purpose of the organization plays the role of a strange attractor" (Dimitrov, 2000:418)	➔	IV2d) Project Management: The ultimate purpose of a capital project causes the formation of a strange chaos attractor of capital project elements and their trajectories
6	Organisational: "an organization's ultimate purpose and its core values are the essence of the strange attractor which functions to define the system's "orbit" of behavior within the Zone of Phase Transition." (Bums, 2002:45)	➔	IV2e) Project Management: The core values espoused in a capital project cause the formation of a strange chaos attractor of capital project elements and their trajectories
7	Organisational "New contexts [strange attractors] can be created by generating new understandings of a situation, or by engaging in new actions… new action can catalyse new understandings…" (Morgan, 2006: 259-262)	➔	IV2f) Project Management: A new understanding of a project context creates the formation of a strange chaos attractor of capital project elements and their trajectories
8	Socio-cultural: "Much of the current social science research concerning complexity is based on discursive metaphors, e.g. claiming that leadership is a "strange attractor." (Begun et al., 2003:270)	➔	IV3a) Socio-cultural: Leadership causes the formation of a of a strange chaos attractor for capital project elements and their trajectories
9	Socio-cultural: "'values might be seen as (strange) attractors... only a pattern of deeds over a period of time, none of them necessarily perfectly fitting the value, will create a value… we recognise values as values when they endure rather than just display themselves in one act, so they are attractors." (Robertson, 2014:37&39)	➔	IV3b) Socio-cultural: A pattern of deeds done over time creates values that cause the formation of a strange chaos attractor for capital project elements and their trajectories
10	Psychology: "Routines, habits, and automatic forms of thinking (judging a new situation according to pre-existing	➔	IV4a) Psychology: Personal automatic forms of thinking (judging a new situation according to pre-existing schemata) causes

No.	Source Domain Metaphors – Strange Chaos Attractor	➔	Target Domain Metaphor – Capital Project Strange Chaos Attractor
	schemata) all demonstrate the general attractor concept" (Vallacher et al., 2013:168)		the formation of a strange chaos attractor of capital project elements and their trajectories
11	Psychology: "In socio-economic CAS [Complex Adaptive Systems] the attractors may be comprised by habits, routines, norms, dominant designs, preferences, ideals, innovations, demand trends etc. which turn specific locations in the system to more desirable, probable or common state spaces than others" (Kuhmonen, 2017:215)	➔	IV4b) Psychology: Personal ideals cause the formation of a strange chaos attractor of capital project elements and their trajectories
12	Socio-cultural: "Strange attractors (multifinal / self-organizing / purposeful) reflect the behaviour of sociocultural systems with choices of end and means; unpredictable patterns emerge out of stylistic preferences of purposeful actors." (Gharajedaghi, 2011:52)	➔	IV4c) Socio-cultural: Personal preferences create unpredictable patterns of socio-cultural behaviour that cause the formation of a strange chaos attractor of capital project elements and their trajectories.
13	Outcome / Result of Strange Chaos Attractor		
14	Specific Outcome: "In contrast, the "strange attractor" operates differently [compared to a fixed point attractor] in that the system never settles at a specific fixed point, but rather seems to "orbit" around the attractor" (Bums, 2002:45)	➔	SO1) Specific Outcome: A strange chaos attractor causes capital project elements and their trajectories never to settle at a specific point but to orbit around the attractor shape
15	Specific Outcome: "This strange attractor shows that complexity – although seemingly completely disordered, actually displays order at the level of its trajectory, and that although it may be unpredictable in its detail, it always moves around the same attractor shape" (Ramalingam et al., 2008:38)	➔	
16	Specific Outcome: "we can have attractors that follow an orbit (like that of the planets round the sun) or we may have a system that never returns to the same place - this we call a 'Strange Attractor'" (Lucas, 2004)	➔	SO2) Specific Outcome: A strange chaos attractor causes capital project elements and their trajectories never to return to the same place
17	Specific Outcome: "An attractor, in which the behaviour follows a pattern but never repeats itself, is called a complex attractor or a 'strange' attractor" (Romenska, 2006:129)	➔	SO3) Specific Outcome: A strange chaos attractor causes capital project elements and their trajectories never to repeat themselves
18	Specific Outcome: "If any part of the strange attractor were magnified, it would reveal a multi-layered sub-structure in which the same patterns are repeated. Complexity plays out in identical ways at different levels of a system" (Ramalingam et al., 2008:38)	➔	SO4) Specific Outcome: A strange attractor causes capital project elements and their trajectories to form repeated patterns of complexity at different system levels
19	Specific Outcome: "The behavior within the system is a paradox in that it defies specific	➔	SO5) Specific Outcome: A strange chaos attractor causes a consistent long-term

No.	Source Domain Metaphors – Strange Chaos Attractor	➔	Target Domain Metaphor – Capital Project Strange Chaos Attractor
	long-term prediction while at the same time demonstrating consistent long-term pattern of organization" Bums (2002:44)		pattern of behaviour for capital project elements and their trajectories
20	General Outcome: "the emerging food systems share some common elements or 'attractors' around which the diversity organises" (Kuhmonen, 2017:215)	➔	GO1) General Outcome: Strange chaos attractors cause diverse capital project elements and their trajectories to converge around the attractor
21	General Outcome: "visions are expected to act as attractors for managing transitions, i.e. by creating expectations which attract support, actors, ideas and funding. Although, visions are important for guiding the transition process, if visions do indeed act as attractors, they can reduce the number of possible directions in which the system can unfold" (Vasileiadou and Safarzyńska, 2010:1178)	➔	GO2) General Outcome: Strange chaos attractors cause a reduction in the number of possible directions in which capital project elements and their trajectories can evolve
22	General Outcome: "…chaotic regimes have demonstrated the existing of patterns. Such patterns are called "attractors" since a system appears to be "pulled" toward a region in an outcome field during its cycles or periods" (Radu et al., 2014:1551)	➔	GO3) General Outcome: Strange chaos attractors cause capital project elements and their trajectories to be pulled towards a region of convergence

C.7 Metaphor Mapping for Groups of Different Types of Chaos Attractors

The metaphor mapping from references to groups of different types of chaos attractors from various sciences to the capital project domain is shown in Table C-7.

Table C-7: Source-Target Domain Mapping of Metaphors for Landscapes of Chaos Attractors Consisting of Groups of Different Types of Chaos Attractors for Capital Projects

No.	SOURCE DOMAIN METAPHORS – Landscape of Chaos Attractors	➔	TARGET DOMAIN METAPHOR – Capital Project Landscape of Chaos Attractors
1	Independent Variables (How? Why?)		Independent Variables (How? Why?)
2	Metaphor Geometry: "As various parts of the brain influence one another, the attractors appear and disappear, in some cases rapidly and in others slowly. As one attractor gives way to another the stability of the system may be preserved, but often it is not; then there is a catastrophic jump in the state of the brain… Abrupt changes in mood are encountered when the stability of an attractor breaks down, allowing the mood-determining system to come under the influence of another attractor, toward which it immediately moves." (Zeeman, 1976:75)	➔	IV1a) The appearance and disappearance of chaos attractors at different speeds occurs in a landscape of chaos attractors for capital projects
		➔	IV1b): Chaos attractors may appear and disappear harmoniously in a landscape of chaos attractors for capital projects
		➔	IV1c): Chaos attractors may appear and disappear non-harmoniously in a landscape of chaos attractors for capital projects

No.	SOURCE DOMAIN METAPHORS – Landscape of Chaos Attractors	➔	TARGET DOMAIN METAPHOR – Capital Project Landscape of Chaos Attractors
3	Metaphor Geometry: "The butterfly attractor is being formed, through the formation of two causality fields, when a key parameter of a torus [attractor] increases its value more than three times" (Radu et al., 2014:1552)	➔	IV1d): Chaos attractor evolution and transformation occurs i.e. a butterfly attractor could be formed from a torus attractor, when a key system parameter increases and reaches a threshold value in a landscape of chaos attractors for capital projects
4	Metaphor Geometry: "Bifurcation(s) result when certain parameters on the dynamical equations, that is conditions affecting the system, reach critical thresholds" (Goldstein, 2011:12)	➔	
5	Metaphor Geometry: "There are different routes to the occurrence of bifurcation, one of them being the Ruelle-Takens scenario described above (see also Bifurcation Theory, No date) in which a periodic attractor bifurcates into a torus (a donut like shape) and the torus into a strange attractor... another route to bifurcation is period doubling… the period of the attractors keeps doubling until the attractors pass into a chaotic attractor" (Goldstein, 2011:13)	➔	
6	Metaphor Geometry: "Control parameters can drastically change the topology by completely extinguishing set points or turning it into a different kind of topological feature (e.g., change an attractor into a repeller, or vice versa). (Butner et al., 2015:5)	➔	IV1e) Control parameters are able to change the topology of the landscape of chaos attractors in capital projects and could strengthen or weaken chaos attractors, move set points or extinguish an attractor
7	Phases of Dynamical Systems: "These different regimes of a dynamical system are understood as different phases "governed" by a different attractor(s)." (Goldstein, 2011:2)	➔	IV2a): Different chaos attractors make up different phases of the landscape of chaos attractors of capital projects
8	System Behaviour: "we do not want to animate the complex behaviour of the actors (or agents) of the local food systems, but the various nodes or milestones toward which their behaviours are expected to navigate and accumulate. These nodes may be conceptualised by means of attractors… the systems are driven by their "genes", by the attractors" (Kuhmonen, 2017:217 & 218)	➔	IV2b): Multiple fixed-point chaos attractors represent project milestones in the landscape of chaos attractors of capital projects
9	Outcome / Result of a Landscape of Chaos Attractors		
10	Specific Outcome: "the systems are driven by their "genes", by the attractors" (Kuhmonen, 2017:217 & 218)	➔	SO1) Specific Outcome: A landscape of chaos attractors constrains and bound the ultimate trajectories of capital projects
11	Specific Outcome: "that the dynamics of each phase of a dynamical system are constrained within the circumscribed range	➔	

<table>
<tr><th>No.</th><th>SOURCE DOMAIN METAPHORS – Landscape of Chaos Attractors</th><th>➔</th><th>TARGET DOMAIN METAPHOR – Capital Project Landscape of Chaos Attractors</th></tr>
<tr><td></td><td>allowable by that phase’s attractor(s).” (Goldstein, 2011:2)</td><td></td><td></td></tr>
<tr><td>12</td><td rowspan="2">Specific Outcome: “As various parts of the brain influence one another, the attractors appear and disappear, in some cases rapidly and in others slowly. As one attractor gives way to another the stability of the system may be preserved, but often it is not; then there is a catastrophic jump in the state of the brain… Abrupt changes in mood are encountered when the stability of an attractor breaks down, allowing the mood-determining system to come under the influence of another attractor, toward which it immediately moves.” (Zeeman, 1976:75)</td><td>➔</td><td>SO2) Specific Outcome: A landscape of chaos attractors causes stability of capital projects when harmonious attractor interactions prevail</td></tr>
<tr><td>13</td><td>➔</td><td rowspan="2">SO3) Specific Outcome: A landscape of chaos attractors causes catastrophic breakdown of capital projects when non-harmonious attractor interactions prevail</td></tr>
<tr><td>14</td><td>Specific Outcome:: “When a system operates according to multiple interacting attractors, the system can exhibit chaotic behaviour - a sequence of changes in behavior that appears random but is actually constrained by a finite number of attractors that exert mutual influence on the behavior.” (Vallacher et al., 2013:171)</td><td>➔</td></tr>
<tr><td>15</td><td>Specific Outcome: “Complex systems can have a chaotic dynamic, and develop through a series of sudden jumps” (Ramalingam et al., 2008:38)</td><td>➔</td><td>SO4) Specific Outcome: A landscape of chaos attractors causes capital project development</td></tr>
<tr><td>16</td><td>“Phase space can be thought of as like a landscape, with rolling valleys, deep potholes, hills and mountains… The motion of a single particle through phase space (its trajectory) represents the way the whole system changes with time, and the amount of time the particle spends in each part of phase space is proportional to the volume of that region of phase space. You can’t say exactly where the single particle will go, any more than you can predict the exact trajectory of a single molecule of water in a swollen river; but you can say that there is an overwhelming likelihood that it will follow a certain kind of trajectory through phase space, just as our water molecule has little choice but to stay within the banks of the river.” (Gribbin, 2005)</td><td>➔</td><td rowspan="2">SO5) Specific Outcome: A landscape of chaos attractors causes boundedness and better prediction of the possible capital project trajectory</td></tr>
<tr><td>17</td><td>“There is some measure of predictability in chaotic systems because of the way the attractors of the system are constrained to particular regions of phase space. For example, if the weather is modeled as a chaotic system, so that particular states of the weather are unpredictable (for example, what temperature will it be in New York City</td><td>➔</td></tr>
</table>

No.	SOURCE DOMAIN METAPHORS – Landscape of Chaos Attractors	➔	TARGET DOMAIN METAPHOR – Capital Project Landscape of Chaos Attractors
	on September 11, 2015?), it nevertheless predictable that the temperature will fall within a range, say, between 72 and 95 degrees Fahrenheit" (Goldstein, 2011:11)		
18	Generic Outcome: "If we consider the use of the word "attractor" in nonlinear dynamics, its meaning is associated with the long-term destination of system trajectories. These can either end at a steady final value—a point attractor—or in stationary cyclic or chaotic motion." (Allen, 2001:29)	➔	SO6) Specific Outcome: A landscape of chaos attractors causes capital project trajectories to migrate towards long term destinations
19	General Outcome: "the emerging food systems share some common elements or 'attractors' around which the diversity organises" (Kuhmonen, 2017:215)	➔	GO1) General Outcome: A landscape of chaos attractors cause diverse capital project elements and their trajectories to converge around the attractor
20	General Outcome: "visions are expected to act as attractors for managing transitions, i.e. by creating expectations which attract support, actors, ideas and funding. Although, visions are important for guiding the transition process, if visions do indeed act as attractors, they can reduce the number of possible directions in which the system can unfold" (Vasileiadou and Safarzyńska, 2010:1178)	➔	GO2) General Outcome: A landscape of chaos attractors cause a reduction in the number of possible directions in which capital project elements and their trajectories can evolve
21	General Outcome: "…chaotic regimes have demonstrated the existing of patterns. Such patterns are called "attractors" since a system appears to be "pulled" toward a region in an outcome field during its cycles or periods" (Radu et al., 2014:1551)	➔	GO3) General Outcome: A landscape of chaos attractors cause capital project elements and their trajectories to be pulled towards a region of convergence

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APPENDIX D: RESEARCH METHODOLOGY SUPPORTING DOCUMENTATION

The supporting documentation for the research methodology as explained in Chapter 4 is provided in this Appendix. The supporting documentation covers both round 1 and 2 interviews.

D.1 Letter of Conditional Approval for the Ethics Committee to Conduct Research

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Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

Reference number: EBIT/122/2017

6 December 2017

Mr GW Hasse
GSTM
University of Pretoria
Pretoria
0028

Dear Mr Hasse

FACULTY COMMITTEE FOR RESEARCH ETHICS AND INTEGRITY

Your recent application to the EBIT Research Ethics Committee refers.

Conditional approval is granted.

This means that the research project entitled "The effectiveness of chaos attractors as alignment and convergence mechanisms in capital project – An explorative study" is approved under the strict conditions indicated below. If these conditions are not met, approval is withdrawn automatically. The applicant is not required to submit an updated application.

Conditions for approval

- Informed consent requires the addition of a participation opt-out option in which the participants are made aware of their right to stop participating in the study at any given moment. A participant should not feel obliged to continue participating when Informed Consent has been given.

This approval does not imply that the researcher, student or lecturer is relieved of any accountability in terms of the Code of Ethics for Scholarly Activities of the University of Pretoria, or the Policy and Procedures for Responsible Research of the University of Pretoria. These documents are available on the website of the EBIT Ethics Committee.

If action is taken beyond the approved application, approval is withdrawn automatically.

According to the regulations, any relevant problem arising from the study or research methodology as well as any amendments or changes, must be brought to the attention of the EBIT Research Ethics Office.

The Committee must be notified on completion of the project.

The Committee wishes you every success with the research project.

Prof JJ Hanekom
Chair: Faculty Committee for Research Ethics and Integrity
FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

Figure D-1: Conditional Approval to Conduct the Proposed Research

D.2 Round 1 Updated Interview Questionnaire

Semi-Structured Interview Questionnaire Using the Nominal Group Technique – Round 1

The Effectiveness of Chaos Attractors as Alignment and Convergence Mechanisms in Capital Projects – An Explorative Study

PhD Student: Günther Hasse (85092712)
Study Leader: Dr. Giel Bekker

Faculty of Engineering, Built Environment and Information Technology
Graduate School of Technology Management
University of Pretoria, South-Africa

1. Objective of the Study

Chaos theory states that order could be created out of chaos by using four types of chaos attractors. These are: point attractors, limit cycle attractors, torus attractors and strange attractors. Conceptual models were developed for these chaos attractors for application to capital projects to aid local and overall project convergence and thereby help to avoid capital project cost overruns. The objective of this explorative study is to gain a better understanding of the effectiveness of these models in a capital project environment.

2. Confidentiality

The following confidentiality measures are applied:

- Names of respondents will be captured for administration proposes but will not be used in the research report.
- Respondents may reveal the specific name of a capital project that was done for a specific company and with a specific budget and specific outcome. Such information will be recorded, transcribed and coded, but these specifics will not be published as part of the research report.
- Respondents have the right to stop participating in the study at any given moment. A participant should not feel obliged to continue participating even when Informed Consent has been given.

3. Respondents Demographic Profiles

The researcher requested respondents to record the information as shown in Figure D-1.

• Definition of capital project: "Long-term investment project requiring relatively large sums (of capital) to acquire, develop, improve, and/or maintain a capital asset (such as land, buildings, dykes, roads)" http://www.businessdictionary.com/definition/capital-project.html

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Table D-1: Demographic Profile of Respondents

A. Respondent Identifier | PhD-85092712-IQAR1-xx

B. Date: / /2018

C. Years' experience: Total cumulative number of years of capital project experience (✓):

1)<10 ___

2) 10 – 19 ___

3) 20 – 30 ___

4) >30 ___

D. Management responsibility – Indicate percentage of time exposure when working in the capital project environment:

1) Project manager ___%

2) Program manager ___%

3) Portfolio Manager ___%

4) Project Director ___%

E. Average size of capital projects managed – Indicate percentage of time exposure when working in the capital project environment :

1) Projects (10's million USD) (R15 million – R1.4 billion) ___%

2) Major projects (100's million USD) (R1.5billion – R14 billion) ___%

3) Mega projects / major programs (1bn USD) (R15 billion – R740 billion) ___%

4) Giga projects (50bn – 100bn USD) (R750 billion – R1.4 trillion) ___%

5) Tera projects (1000bn USD) (>R15 trillion) ___%

F. Level of capital project complexity – Indicate percentage of time exposure when working in the capital project environment:

1) Low complexity - Simple / Linear capital project ___%

2) Hierarchical complexity - Large capital project with multiple layers & stakeholders ___%

3) Directional complexity – Volatility in project direction: multiple stakeholders/politics ___%

4) Technical complexity – One or multiple new technologies incorporated ___%

G. Exposure to the management of specific dimensions of capital projects – Indicate percentage of time exposure when working in the capital project environment:

1) Technical management ___%
2) Cost management ___%
3) Schedule management ___%
4) People management ___%
5) Stakeholder relationship management ___%
6) Other, please specify __________________ ___%

H. Industry – indicate all relevant categories – Indicate percentage of time exposure when working in the capital project environment:

1) Petro-chemical	___%
2) Power Generation & Utilities	___%
3) Mining	___%
4) Infrastructure	___%
5) Other, please specify___________	___%

I. Sector – indicate all relevant categories – Indicate percentage of time exposure when working in the capital project environment:

1) Public	___%
2) Private	___%
3) NGO/NPO	___%
4) Other, please specify___________	___%

J. Capital project outcome – indicate all relevant categories – Indicate percentage of time exposure when working in the capital project environment:

1) <u>Successful capital project</u>: • <25% Cost overrun relative to FID baseline (Financial Investment Decision) • <25% Schedule overrun relative to FID baseline • No significant reduced production / full functionality achieved within 2 years after commissioning	%
2) <u>Failed capital project:</u> • >25% Cost overrun relative to FID baseline (Financial Investment Decision) • >25% Schedule overrun relative to FID baseline • Significant reduced production / full functionality <u>not</u> achieved within 2 years after commissioning	%

4. Proposed Semi-Structured Research Questions

The researcher reads and explains each question to the respondents. Each respondent records his own response. The researcher requests each respondent to respond in the group with this response and free-flowing discussion among respondents is facilitated by the researcher (Nominal Group Technique).

SECTION A – DEFINITIONS ON CONTINUUM AND CHAOS ATTRACTORS

IQ1)	**Grounded definitions – Continuum and movement**

IQ1.1) Provide your own definition of <u>order</u> in capital projects? Generic example?

IQ1.2) Provide your own definition of complexity in capital projects? Generic example?

IQ1.3) Provide your own definition of chaos in capital projects? Generic example?

IQ1.4) Provide your own definition of randomness in capital projects? Generic example?

IQ1.5) Rank the above categories in order of increased disorder?

1) Order ___
2) Complexity ___
3) Chaos ___
4) Randomness ___

IQ1.6) Provide your opinion and comment on the following statement: "A successful capital project ultimately moves from a state of randomness and chaos towards order"

IQ1.7) Provide your opinion and comment on the following statement: "A failed capital project ultimately moves from a state of order towards chaos and randomness (maximum disorder)"

IQ2)	**Grounded definition – Chaos attractor and multi-dimensionality**

IQ2.1) What is your intuitive definition of a chaos attractor in capital projects?

IQ2.2) **How** is chaos converted into order?

IQ2.3) **When** is chaos converted into order?

IQ2.4) What is your view on the statement that chaos attraction is a multidimensional concept i.e. it has to do with both project management, systems engineering management etc. (**hard aspects**) as well as psychology, sociology (**soft aspects**)?

SECTION B – VISUAL CHAOS ATTRACTOR METAPHOR VARIANCE MODEL – OVERALL CAPITAL PROJECT CONVERGENCE

No.	Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
		1	2	3	4	5
1	Did your understanding of the chaos attractor concept improve throughout the interview?					
2	Did the visualisation of the chaos attractor metaphors (sketches) help to better understand the objective of the metaphor?					
3	Did the visualisation of the chaos attractor metaphors (sketches) help to better map the concept to the capital project environment?					
4	Did the visualisation of the chaos attractor metaphors (sketches) as well as explanations help to better map the concept to the capital project environment?					
5	Would you now be able to apply the concept of chaos attraction in capital projects?					
6	The duration of the interview was sufficient to allow meaningful contribution?					
7	The other respondents and facilitator allowed you an opportunity to contribute meaningfully?					

Comments for improvements of the interview process?

D.3 Round 1 Demographic Profile of Respondents

The following graphs indicate the demographic profile of the 12 respondents that participated in the Round 1 interviews.

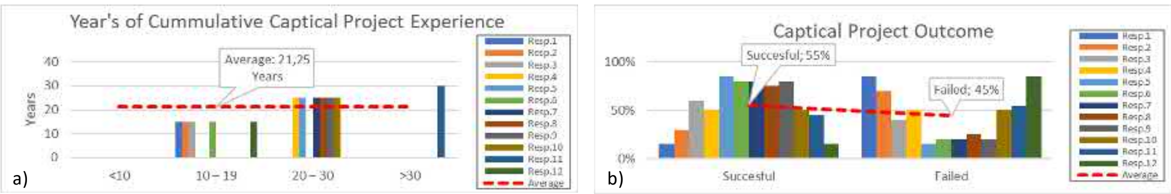

Figure D-2: Year of Cumulative Capital Project Experience (a) and Experience in Successful and Failed Capital Projects (b) of Round 1 Respondents

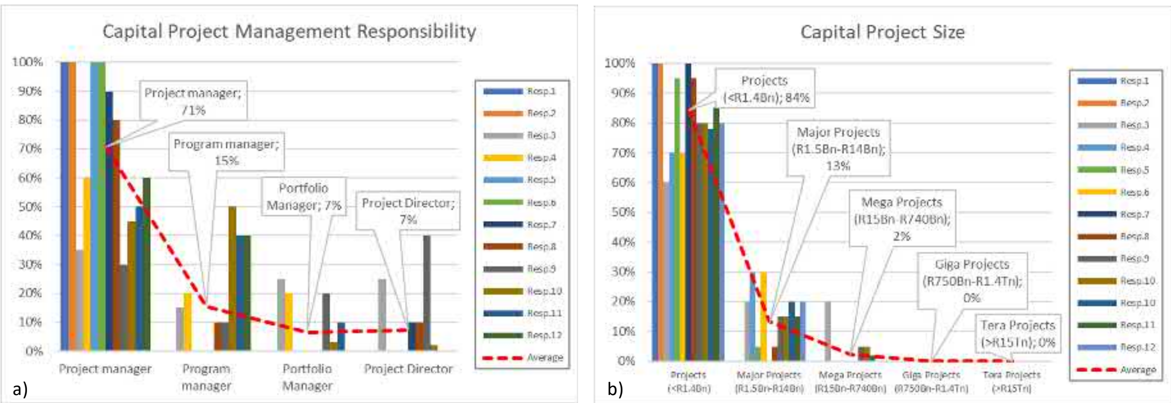

Figure D-3: Capital Project Management Responsibility (a) and Capital Project Size (b) of Round 1 Respondents

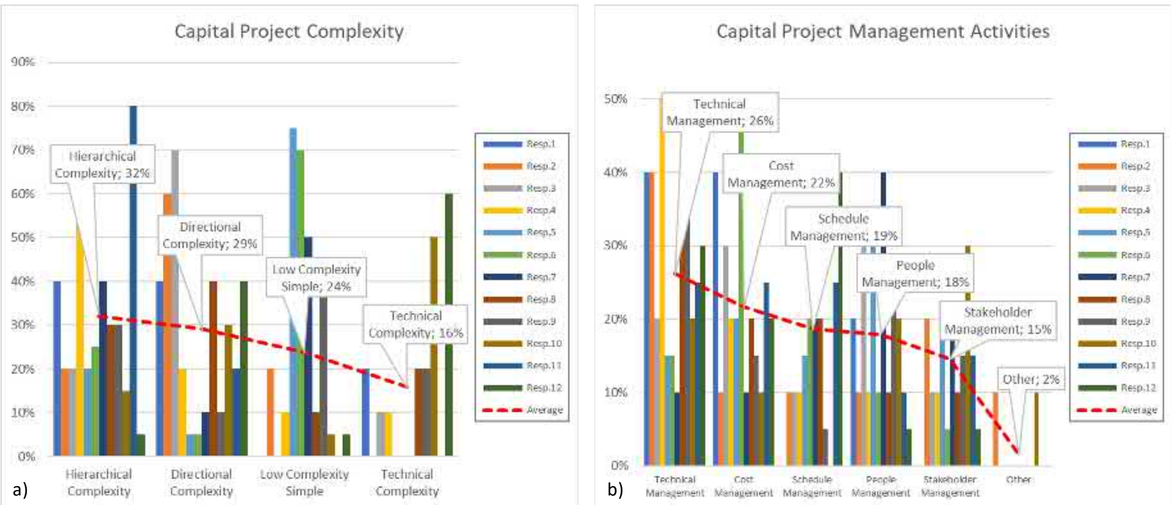

Figure D-4: Capital Project Complexity (a) and Capital Project Management Activities (b) of Round 1 Respondents

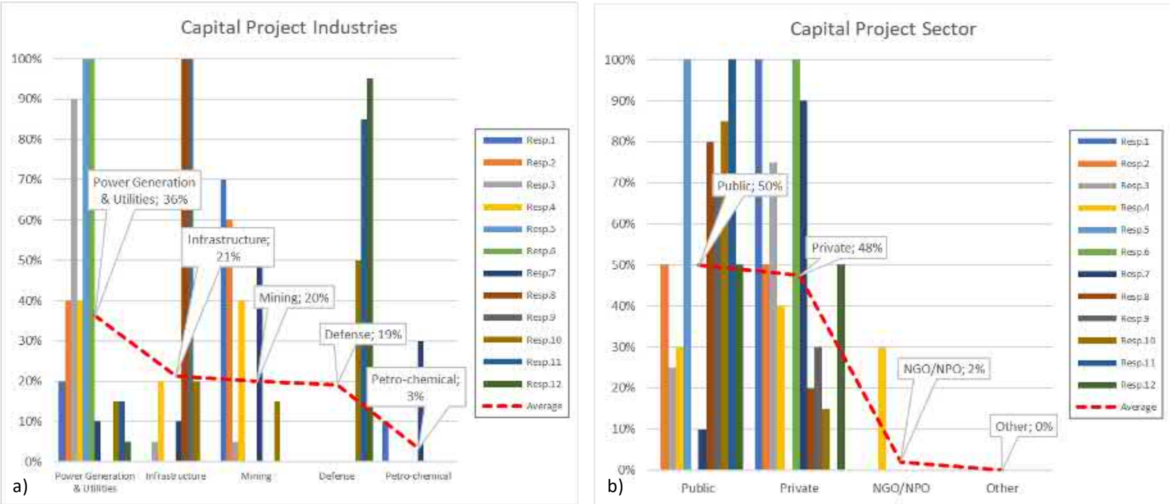

Figure D-5: Capital Project Industries (a) and Capital Project Sector (b) of Round 1 Respondents

D.4 Round 1 Code Book used for Data Analysis

The code book that was used for the data analysis of Round 1 is shown in Table D-2.

Table D-2: Code Book Used for Content Analysis of Round 1 Research Results

<table>
<tr><th rowspan="2">Subject Group No.</th><th rowspan="2">Subject groups</th><th colspan="5">Process groups</th></tr>
<tr><th>Initiating</th><th>Planning</th><th>Implementing</th><th>Controlling</th><th>Closing</th></tr>
<tr><td rowspan="3">SG1</td><td rowspan="3">Integration</td><td>4.3.2 Develop project charter</td><td>4.3.3 Develop project plans</td><td>4.3.4 Direct project work</td><td>4.3.5 Control project work
4.3.6 Control changes</td><td>4.3.7 Close project phase or project
4.3.8 Collect lessons learned</td></tr>
<tr><td colspan="5"><u>Terminology added from this standard:</u> Processes required to identify, define, combine, unify, coordinate, control and close, integration of scope, time , cost and other subjects, roles, responsibilities, organisation and procedures for management of subject groups, baselines for scope, quality, schedule, cost, resources and risks, implementation, monitor, closure, procedures, issues, configuration</td></tr>
<tr><td colspan="5"><u>New terminology added:</u> Project execution, project definition, systems engineering, synchronisation, reporting, timeous management, intervention</td></tr>
<tr><td rowspan="2">SG2</td><td rowspan="2">Stakeholder</td><td>4.3.9 Identify stakeholders</td><td></td><td>4.3.10 Manage stakeholders</td><td></td><td></td></tr>
<tr><td colspan="5"><u>Terminology added from this standard:</u> Internal or external, individuals, groups, organisations, expectations</td></tr>
</table>

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		New terminology added: Disciplines, interfaces, stakeholder alignment, politics				
SG3	Scope		4.3.11 Define scope 4.3.12 Create work breakdown structure 4.3.13 Define activities		4.3.14 Control scope	
		Terminology added from this standard: Objectives, deliverables, contribution to goals & benefits, requirements, boundaries				
		New terminology added: Expectations				
SG4	Resource	4.3.15 Establish project team	4.3.16 Estimate resources 4.3.17 Define project organization	4.3.18 Develop project team	4.3.19 Control resources 4.3.20 Manage project team	
		Terminology added from this standard: Human & other resources, organisation chart, role descriptions, staff assignments, staff contracts, roles, responsibilities & authorities, skills & expertise, competencies, behaviour, personalities, group dynamics, define project organisation, organisational structure, motivation & performance				
		New terminology added: Team focus				
SG5	Time		4.3.21 Sequence activities 4.3.22 Estimate activity durations 4.3.23 Develop schedule		4.3.24 Control schedule	
		Terminology added from this standard: Logical relationships, logical sequence, internal and external dependencies, critical path, leads, lags, constraints, learning curve, approval cycles, schedule baseline, milestones, progress in time, schedule variance				
		New terminology added: Timelines, mathematical modelling				
SG6	Cost		4.3.25 Estimate costs 4.3.26 Develop budget		4.3.27 Control costs	
		Terminology added from this standard: Reserves, contingency, cost performance, baseline cost, cost at completion				
		No new terminology added				
SG7	Risk		4.3.28 Identify risks 4.3.29 Assess risks	4.3.30 Treat risks	4.3.31 Control risks	
		Terminology added from this standard: Threats, opportunities, probability, consequence, tolerance, trigger conditions, contingency plan				
		New terminology added: Unforeseen requirements, Unknowns, technology, surprises, mitigation, technical				

SG8	Quality		4.3.32 Plan quality	4.3.33 Perform quality assurance	4.3.34 Perform quality control	
		Terminology added from this standard: Quality requirements, standards, policy & plan, review deliverables, conformance to performance requirements, detecting defects, preventative actions, corrective actions				
		No new terminology added				
SG9	Procurement		4.3.35 Plan procurements	4.3.36 Select suppliers	4.3.37 Administer procurements	
		Terminology added from this standard: Procurement strategy, procurement plan, preferred suppliers, contract type				
		New terminology added: Contract model, contract management				
SG10	Communication		4.3.38 Plan communications	4.3.39 Distribute information	4.3.40 Manage communications	
		Terminology added from this standard: Information needs, communication requirements, resolve issues & misunderstandings, timely accurate and unbiased information				
		New terminology added: Contract model, contract management				

Table D-2 Notes: The Code Book Originated from (ISO, 2012:10, Table 1) with Added Terminology from the ISO Standard as well as Newly Defined Terminology for each Subject Group

D.5 Round 2 Updated Variance Model for Fixed-Point Repeller

The variance model that was used during the Round 2 pilot interview is shown in Figure D-6.

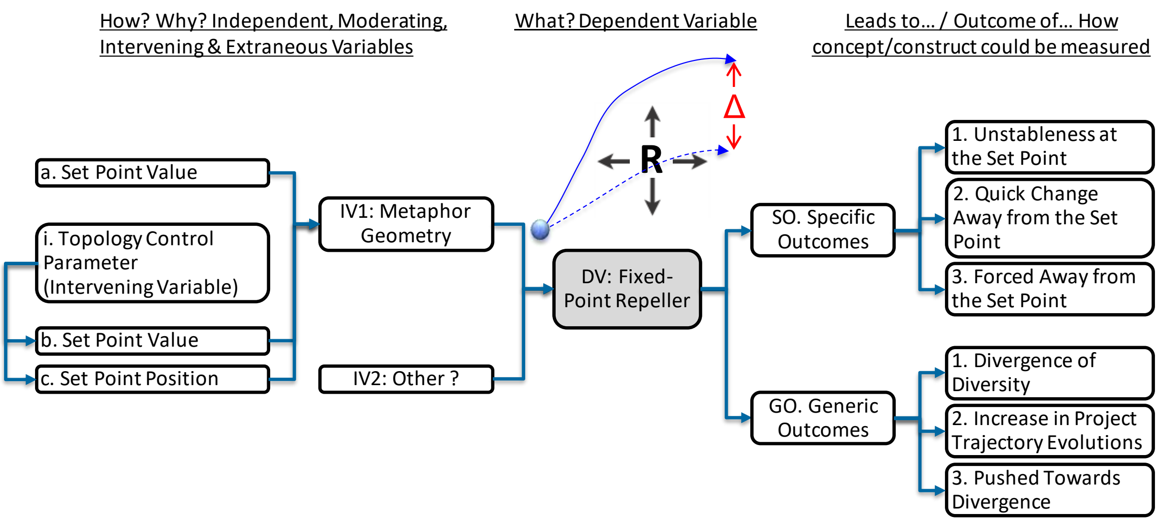

Figure D-6: Round 2 Pilot Interviews – Initial Variance Model for Fixed-Point Repeller

The variance model as shown in Figure D-6 was updated with changes to the independent variables as suggested by the respondent during the pilot interview. The updated variance model that was used for the Round 2 interviews is shown in Figure D-7.

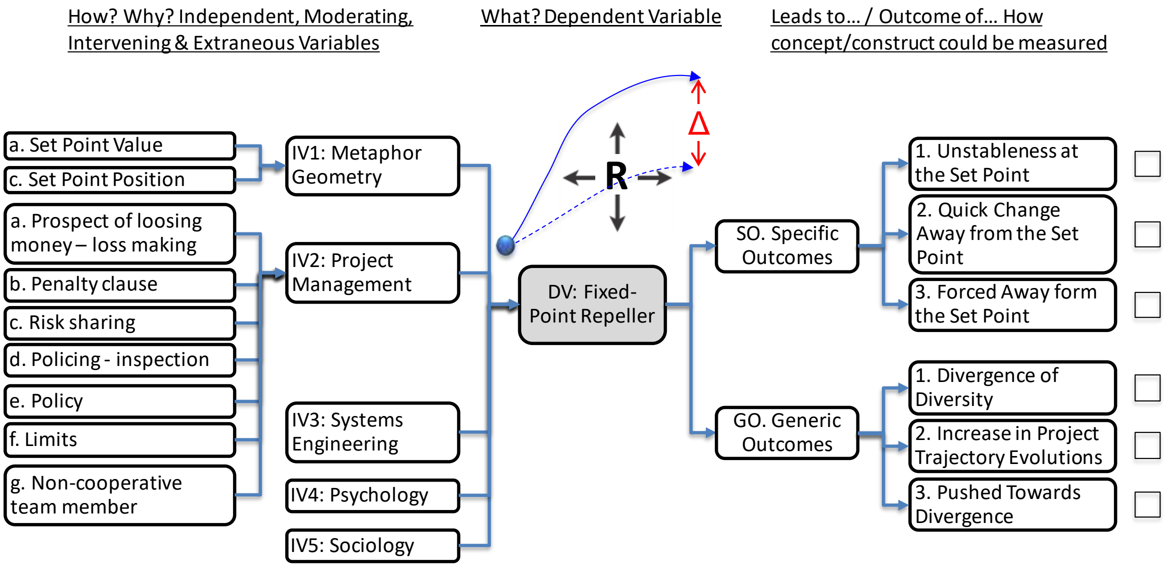

Figure D-7: Round 2 Interviews – Updated Variance Model for Fixed-Point Repeller

D.6 Round 2 Updated Interview Questionnaire

The Effectiveness of Chaos Attractors as Alignment and Convergence Mechanisms in Capital Projects – An Explorative Study

PhD Student: Günther Hasse (85092712)

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1. Objective of the Study

Chaos theory states that order could be created out of chaos by using four types of chaos attractors. These are: point attractors, limit cycle attractors, torus attractors and strange attractors. Conceptual models were developed for these chaos attractors for application to capital projects to aid local and overall project convergence and thereby help to avoid capital project cost overruns. The objective of this explorative study is to gain a better understanding the effectiveness of these models in a capital project environment.

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2. Confidentiality

The following confidentiality measures are applied:

- Names of respondents will be captured for administration proposes but will not be used in the research report.
- Respondents may reveal the specific name of a capital project that was done for a specific company and with a specific budget and specific outcome. Such information will be recorded, transcribed and coded, but these specifics will not be published as part of the research report.
- Respondents have the right to stop participating in the study at any given moment. A participant should not feel obliged to continue participating even when Informed Consent has been given.

3. Respondents Demographic Profiles

The researcher requested respondents to record the information as shown in Figure D-3.

Definition of capital project: "Long-term investment project requiring relatively large sums (of capital) to acquire, develop, improve, and/or maintain a capital asset (such as land, buildings, dykes, roads)" http://www.businessdictionary.com/definition/capital-project.html

Table D-3: Demographic Profile of Respondents

Respondent Identifier	PhD-85092712-IQAR2-xx		
Date:	/ /2018		
Years' experience: Total cumulative number of years of capital project experience (✓): 1)<10 ___ 2) 10 – 19 ___ 3) 20 – 30 ___ 4) >30 ___			
Management responsibility – Indicate percentage of time exposure when working in the capital project environment: 1) Project manager ___% 2) Program manager ___% 3) Portfolio Manager ___% 4) Project Director ___%			
Average size of capital projects managed – Indicate percentage of time exposure when working in the capital project environment : 1) Projects (10's million USD) (R15 million – R1.4 billion) ___% 2) Major projects (100's million USD) (R1.5billion – R14 billion) ___% 3) Mega projects / major programs (1bn USD) (R15 billion – R740 billion) ___% 4) Giga projects (50bn – 100bn USD) (R750 billion – R1.4 trillion) ___% 5) Tera projects (1000bn USD) (>R15 trillion) ___%			

Level of capital project complexity – Indicate percentage of time exposure when working in the capital project environment:
1) Low complexity - Simple / Linear capital project ___%
2) Hierarchical complexity - Large capital project with multiple layers & stakeholders ___%
3) Directional complexity – Volatility in project direction: multiple stakeholders/politics ___%
4) Technical complexity – One or multiple new technologies incorporated ___%

Exposure to the management of specific dimensions of capital projects – Indicate percentage of time exposure when working in the capital project environment:
Technical management ___%
Cost management ___%
Schedule management ___%
People management ___%
Stakeholder relationship management ___%
Other, please specify __________________ ___%

Industry – indicate all relevant categories – Indicate percentage of time exposure when working in the capital project environment:
1) Petro-chemical ___%
2) Power Generation & Utilities ___%
3) Mining ___%
4) Infrastructure ___%
5) Other, please specify____________ ___%

Sector – indicate all relevant categories – Indicate percentage of time exposure when working in the capital project environment:
1) Public ___%
2) Private ___%
3) NGO/NPO ___%
4) Other, please specify____________ ___%

Capital project outcome – indicate all relevant categories – Indicate percentage of time exposure when working in the capital project environment:	
1) Successful capital project: • <25% Cost overrun relative to FID baseline (Financial Investment Decision) • <25% Schedule overrun relative to FID baseline • No significant reduced production / full functionality achieved within 2 years after commissioning	%
2) Failed capital project: • >25% Cost overrun relative to FID baseline (Financial Investment Decision) • >25% Schedule overrun relative to FID baseline • Significant reduced production / full functionality not achieved within 2 years after commissioning	%

4. Section 0: Link to Round 1 Research Results on Order and Convergence in Capital Projects

The results of Round 1 of this research indicated that the capital project life-cycle may be characterised by stages of a randomness-chaos-complexity-order continuum as shown in Figure D-8.

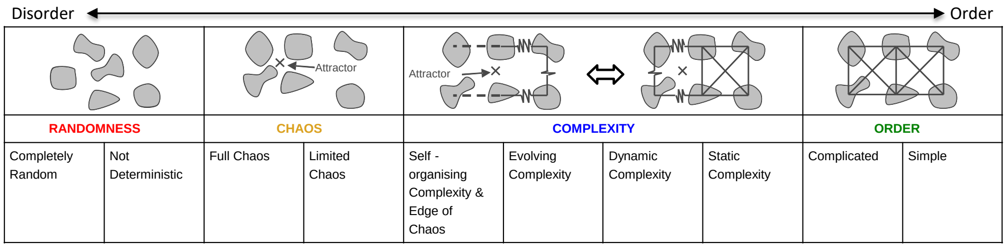

Figure D-8: The Randomness-Chaos-Complexity-Order Continuum for Capital Projects based on a Literature Survey

The research explored the convergence and divergence in capital projects as indicated in Figure D-9.

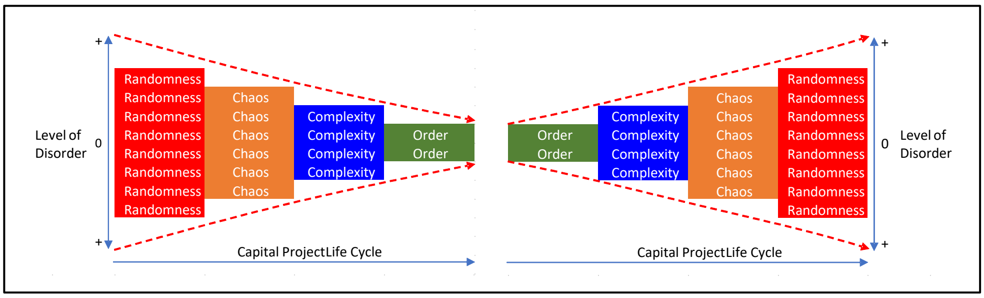

Figure D-9: Theoretical Convergence and Divergence Suggested to Take Place in the Execution of Capital Projects

The interview results based on responses from 16 experienced capital project managers indicated that at least three archetypes seem possible to represent project overall convergence towards order and two for project divergence as indicated in Figure D-10.

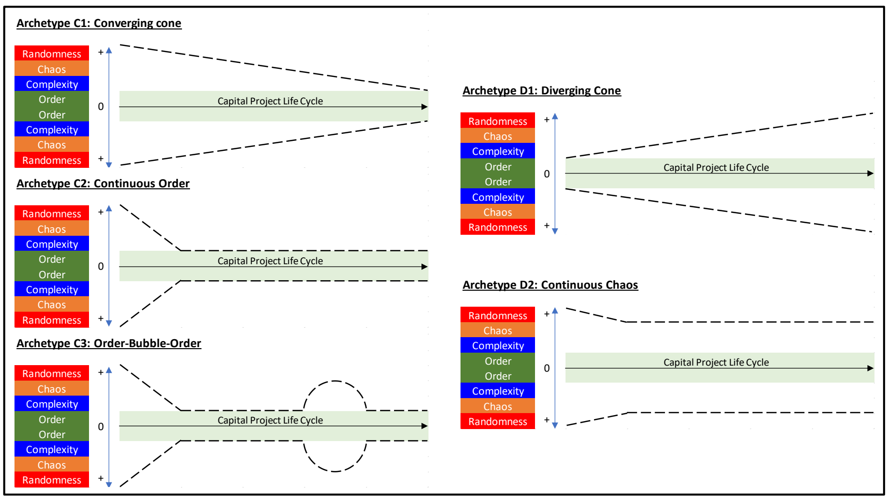

Figure D-10: Previous Research Results Showing Archetypes for Capital Project Convergence towards Order and Project Divergence / Not Reaching Order

IQ0.1) Please comment on your agreement / disagreement with the previous research results?

Objective of Round 2 Research

The objective of Round 2 research is to obtain a grounded view from experienced capital project managers on the use of chaos attractors in capital projects to answer the following two research questions:

- **Major Research Question 1**
Does the use of individual chaos attractors lead to local convergence of capital project elements and their trajectories?
- **Major Research Question 2**
Does the use of groups of different types of chaos attractors lead to overall capital project convergence?

Chaos theory states that it is possible to create order from chaos by using four primary chaos attractors i.e. fixed-point, limit-cycle, torus and strange chaos attractors.

Will the use of individual as well as groups of chaos attractors cause local and overall convergence towards order in capital projects as schematically shown in Figure D-11?

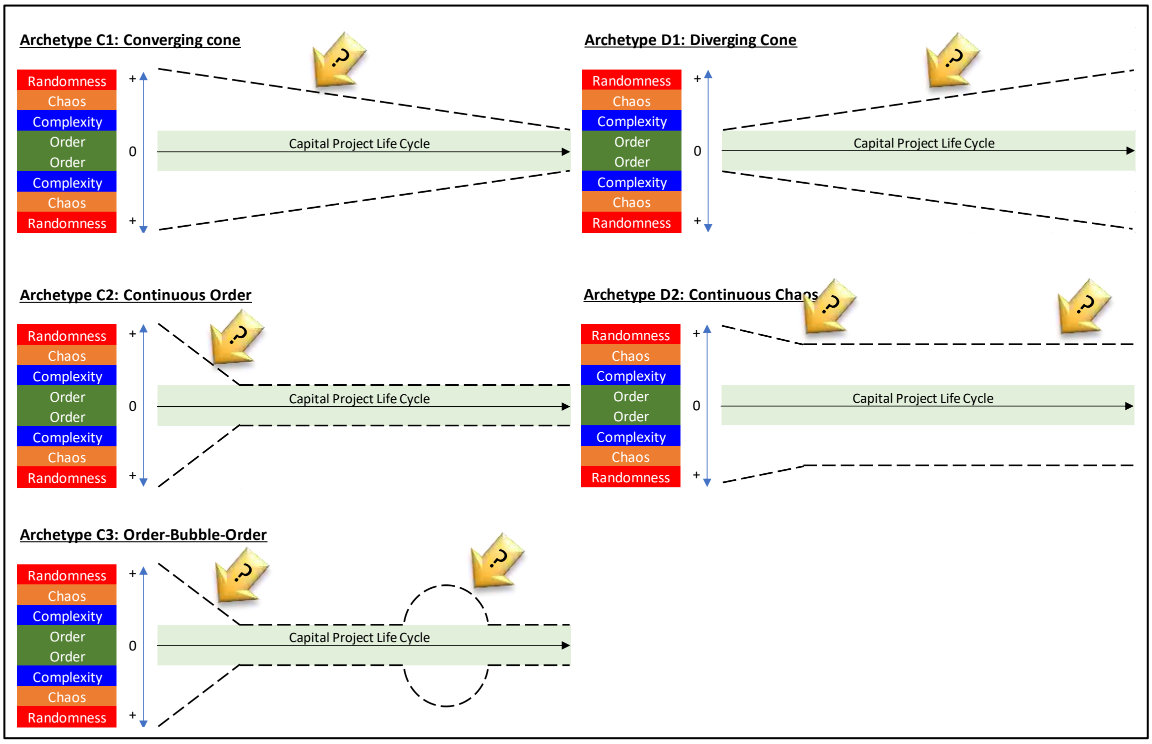

Figure D-11: Application of Chaos Attractors during the Capital Project Life Cycle

5. Section A: Metaphor mapping of individual chaos attractors to the Capital Project Domain to cause local project convergence

5.1 The researcher explains the visual representations for fixed-point chaos attractors as shown in Figure D-12.

IQ1.1) What would cause fixed-point attraction and convergence in capital projects? Please explain

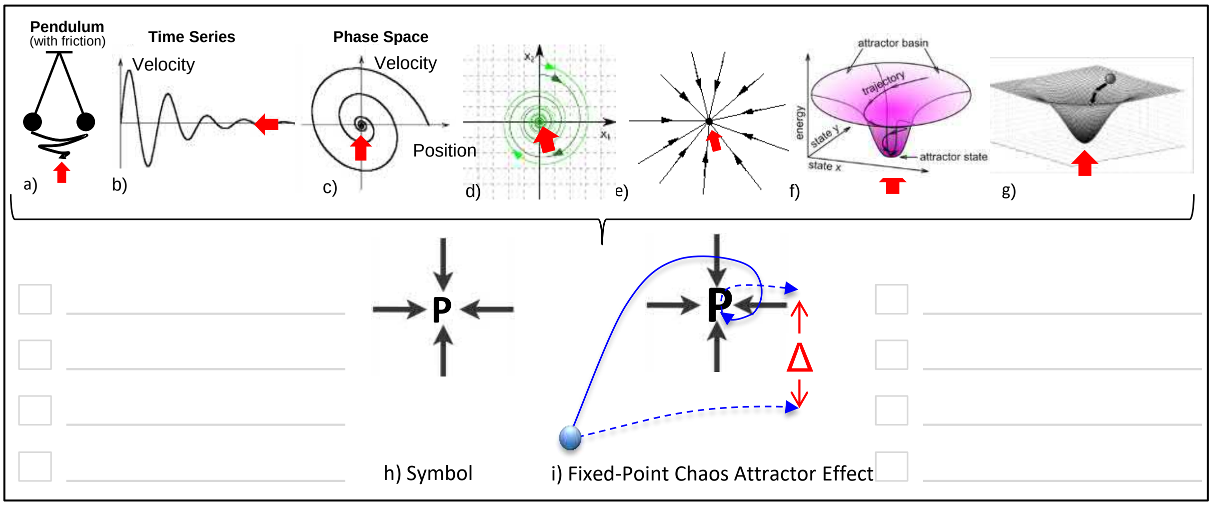

Figure D-12: Visual Representations for Fixed-Point Chaos Attractors

A variance model for a fixed-point chaos attractor for capital projects has been derived from references from various managerial and other sciences. The researcher explains the model to the respondent.

IQ1.2) Please add the elements and attributes as identified in IQ1.1 and provide a Likert scoring to the model displayed in Figure D-13.

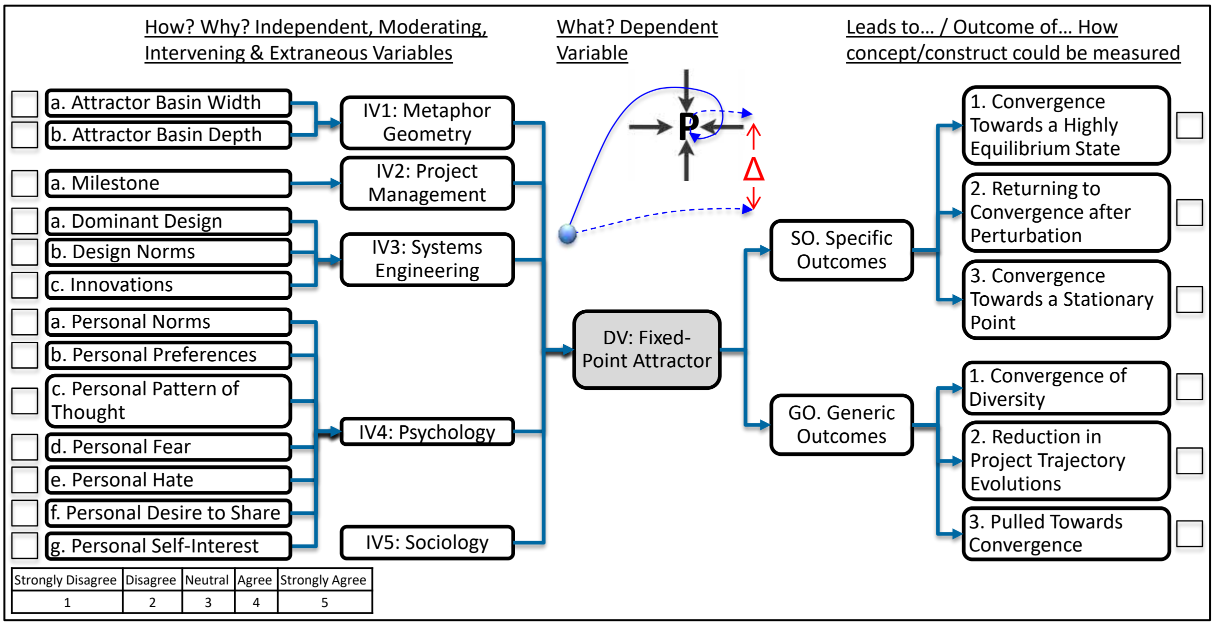

Figure D-13: Variance Model for a Fixed-Point Chaos Attractor for Capital Projects based on a Literature Survey

IQ1.3) Would a fixed-point chaos attractor cause local convergence in a capital project?

5.2 The researcher explains the visual representations for fixed-point chaos repeller as shown in Figure D-14.

IQ2.1) What would cause a fixed-point repeller in capital projects? Please explain

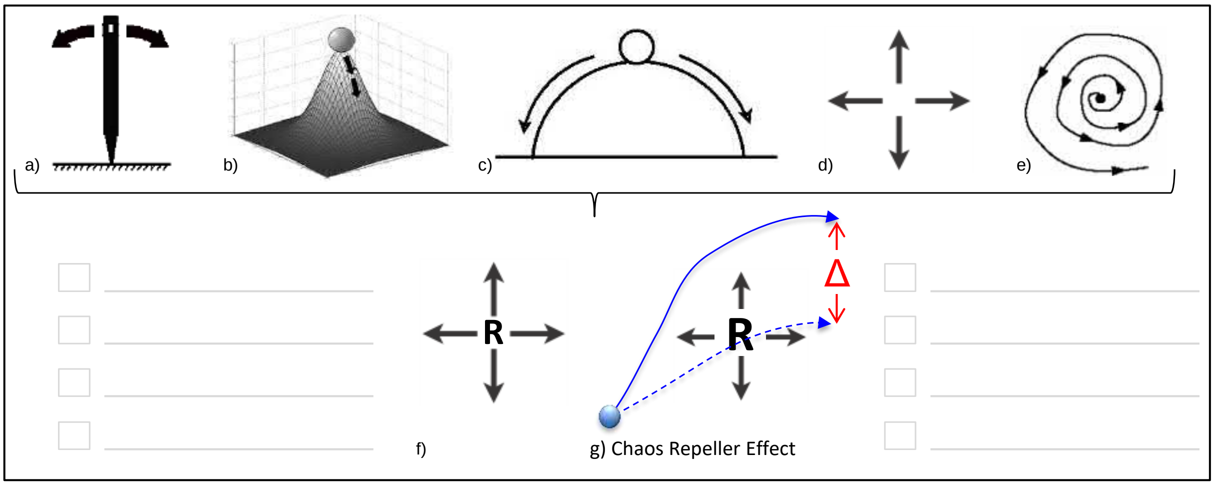

Figure D-14: Visual Representations for Fixed-Point Chaos Repellers

A variance model for a fixed-point chaos repeller for capital projects has been derived from references from various managerial and other sciences. The researcher explains the model to the respondent.

IQ2.2) Please add the elements and attributes as identified in IQ2.1 and provide a Likert scoring to the model displayed in Figure D-15.

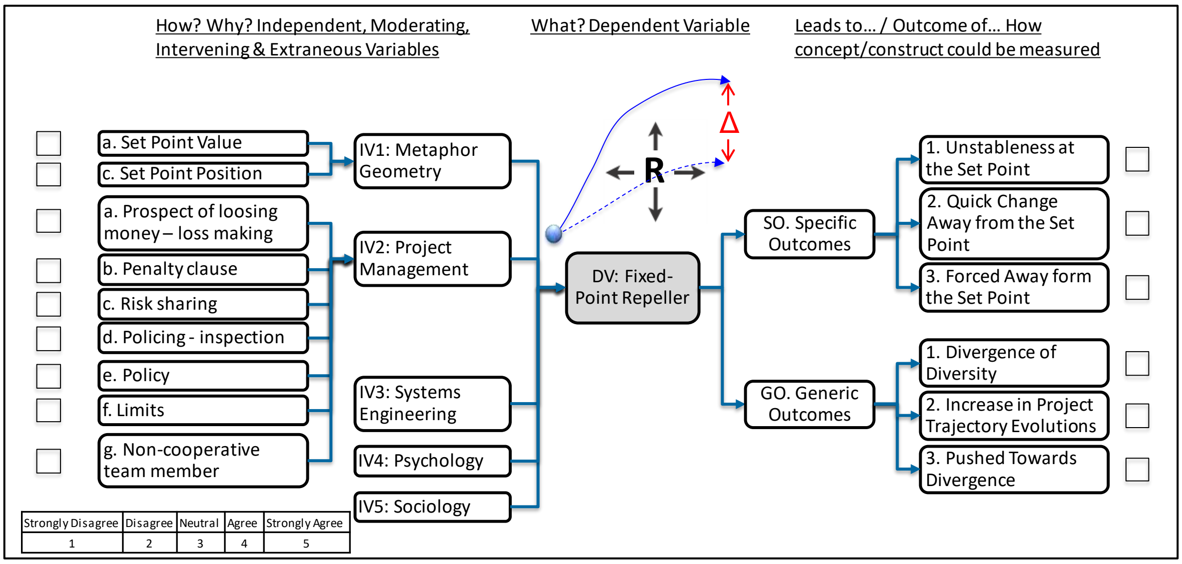

Figure D-15: Variance Model for a Fixed-Point Chaos Repeller to be Further Developed for Capital Projects

IQ2.3) Would a chaos repeller cause <u>local</u> divergence in a capital project?

5.3 The researcher explains the visual representations for limit cycle chaos attractor as shown in Figure D-16.

IQ3.1) What would cause a limit cycle chaos attractor in capital projects? Please explain

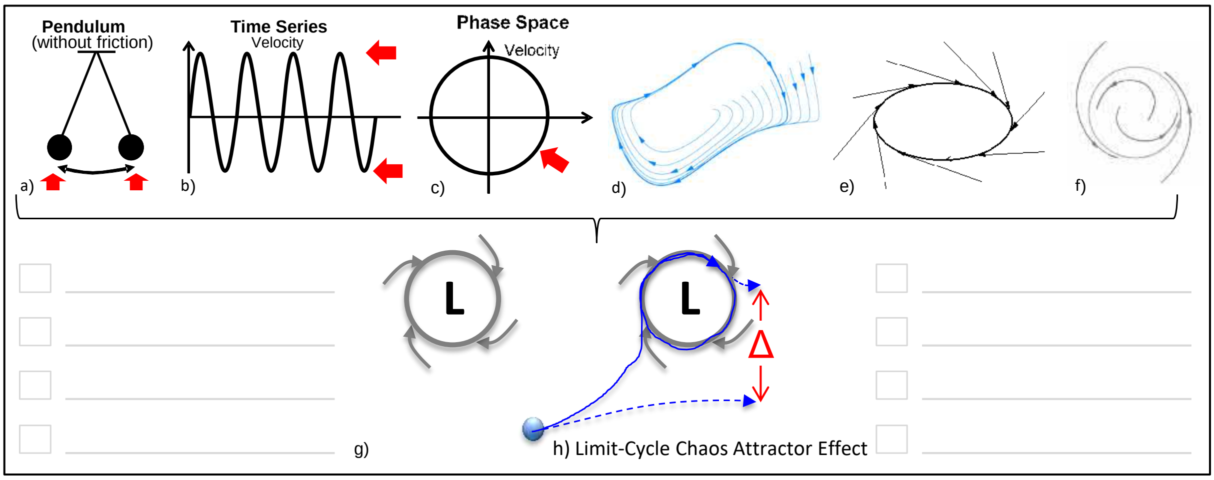

Figure D-16: Visual Representations for Limit Cycle Chaos Attractors

A variance model for a limit cycle chaos attractor for capital projects has been derived from references from various managerial and other sciences. The researcher explains the model to the respondent.

IQ3.2) Please add the elements and attributes as identified in IQ3.1 and provide a Likert scoring to the model displayed in Figure D-17.

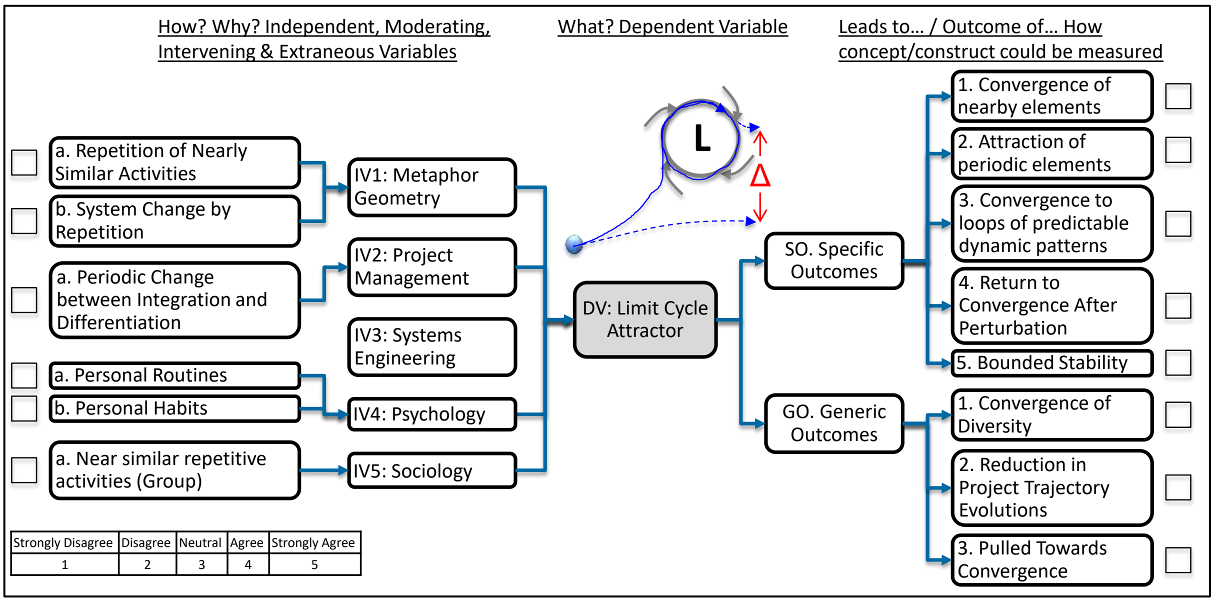

Figure D-17: Variance Model for a Limit Cycle Chaos Attractor to be Further Developed for Capital Projects

IQ3.3) Would a limit cycle chaos attractor cause <u>local</u> convergence in a capital project?

5.4 The researcher explains the visual representations for limit cycle chaos attractor as shown in

Figure D-18.

IQ4.1) What would cause a torus chaos attractor in capital projects? Please explain

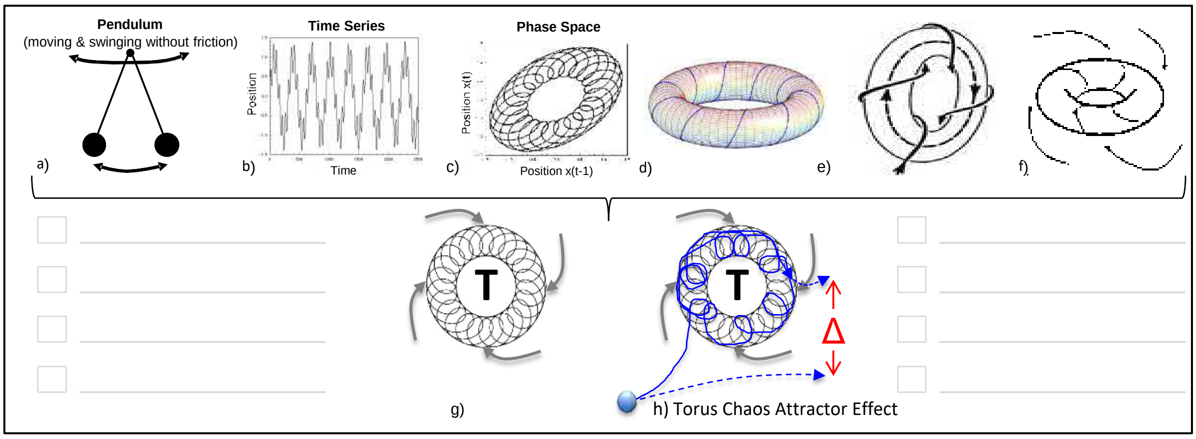

Figure D-18: Visual Representations for Torus Chaos Attractors

A variance model for a torus chaos attractor for capital projects has been derived from references from various managerial and other sciences. The researcher explains the model to the respondent.

IQ4.2) Please add the elements and attributes as identified in IQ4.1 and provide a Likert scoring to the model displayed in Figure D-19.

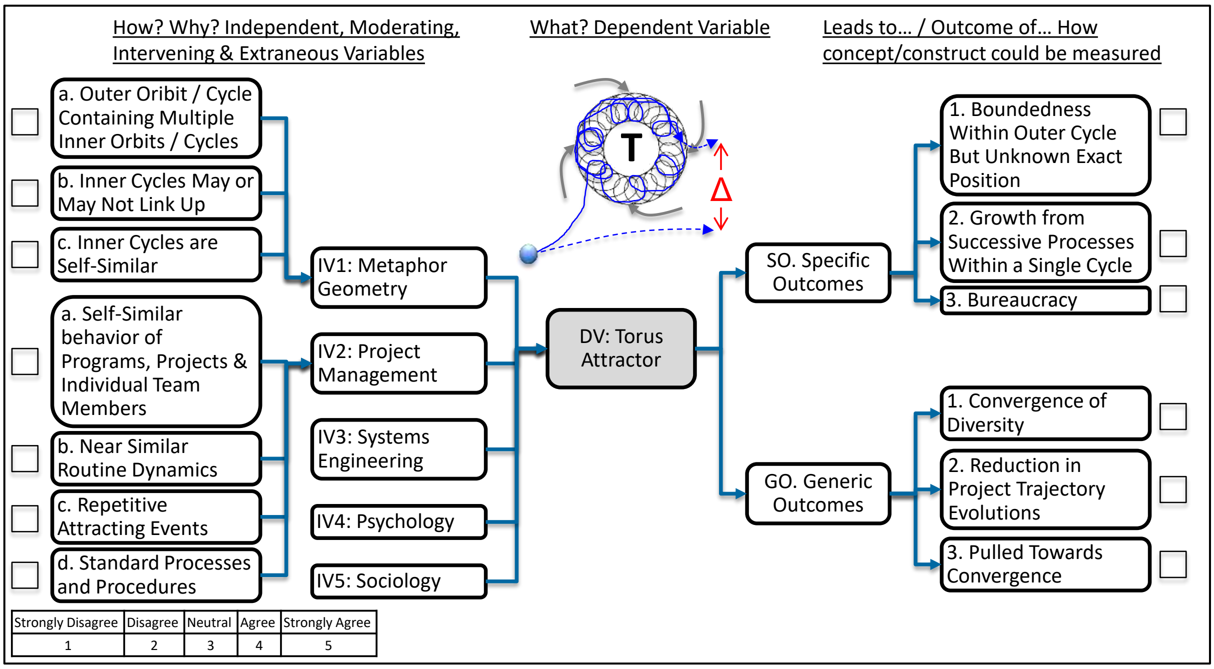

Figure D-19: Variance Model for a Torus Chaos Attractor to be Further Developed for Capital Projects

IQ4.3) Would a torus chaos attractor cause local convergence in a capital project?

5.5 The researcher explains the visual representations for Butterfly chaos attractor as shown in Figure D-20.

IQ5.1) What would cause a Butterfly chaos attractor in capital projects? Please explain

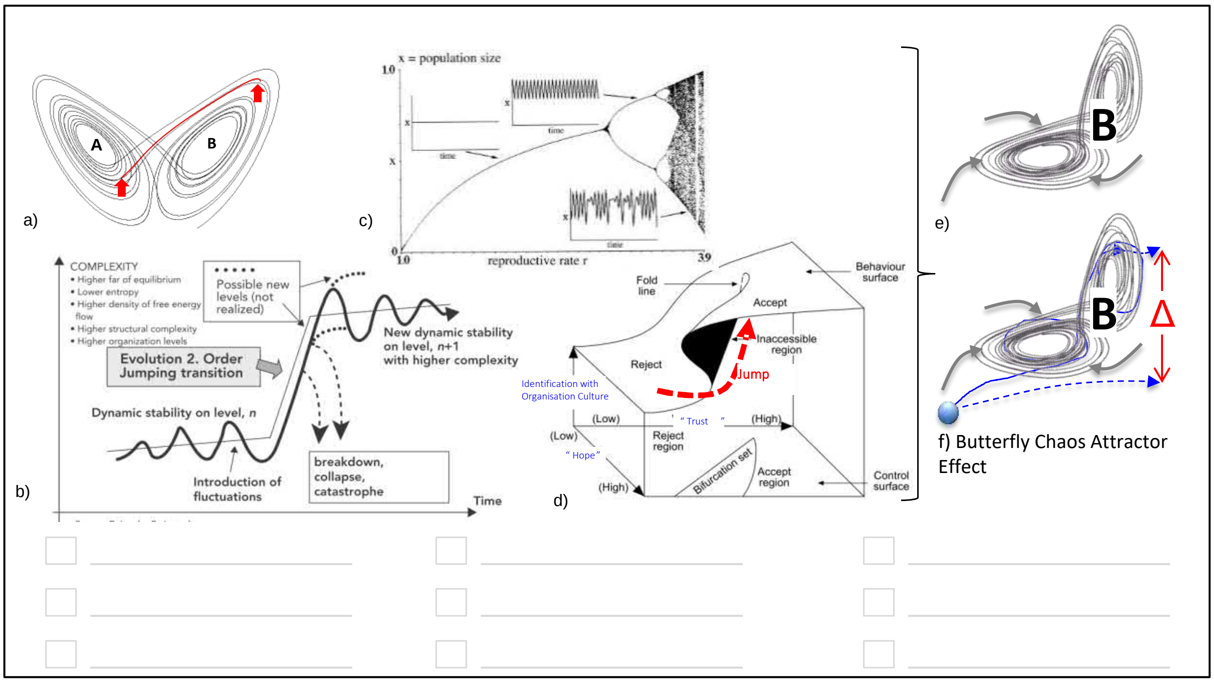

Figure D-20: Visual Representations for Butterfly Chaos Attractors

A variance model for a Butterfly chaos attractor for capital projects has been derived from references from various managerial and other sciences. The researcher explains the model to the respondent.

IQ5.2) Please add the elements and attributes as identified in IQ5.1 and provide a Likert scoring to the model displayed in Figure D-21.

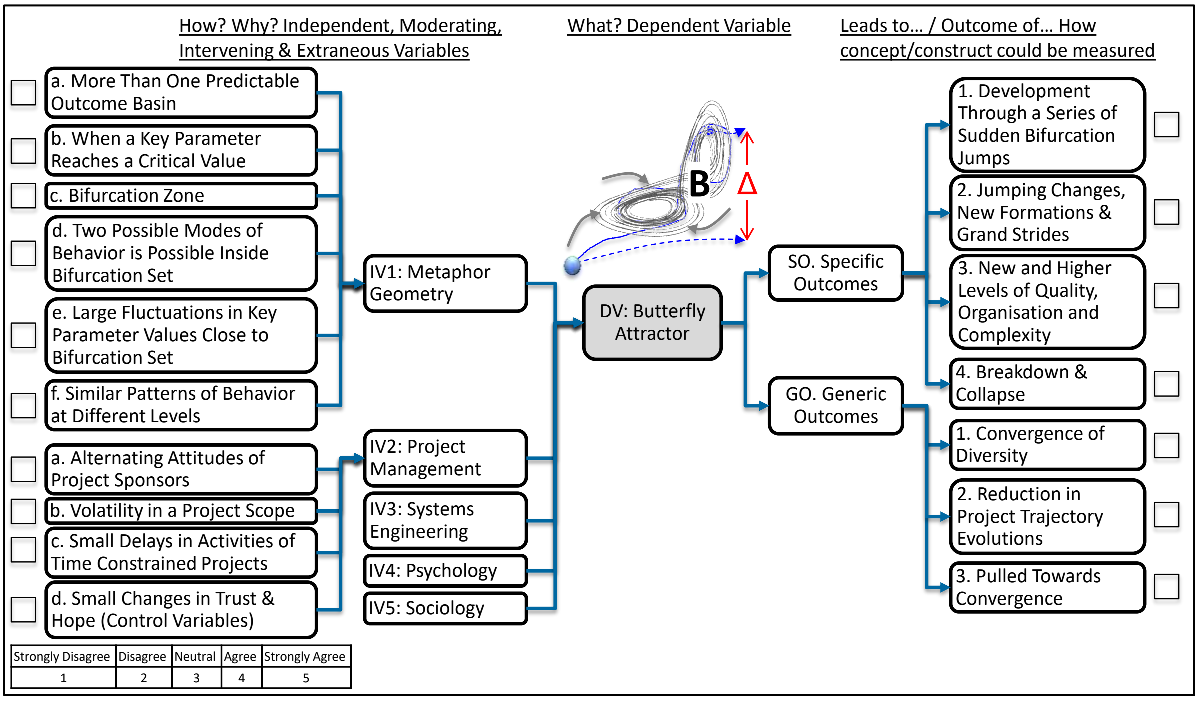

Figure D-21: Variance Model for a Butterfly Chaos Attractor to be Further Developed for Capital Projects

IQ5.3) Would a Butterfly chaos attractor cause local convergence in a capital project?

5.6 The researcher explains the visual representations for Butterfly chaos attractor as shown in Figure D-22.

IQ6.1) What would cause a strange chaos attractor in capital projects? Please explain

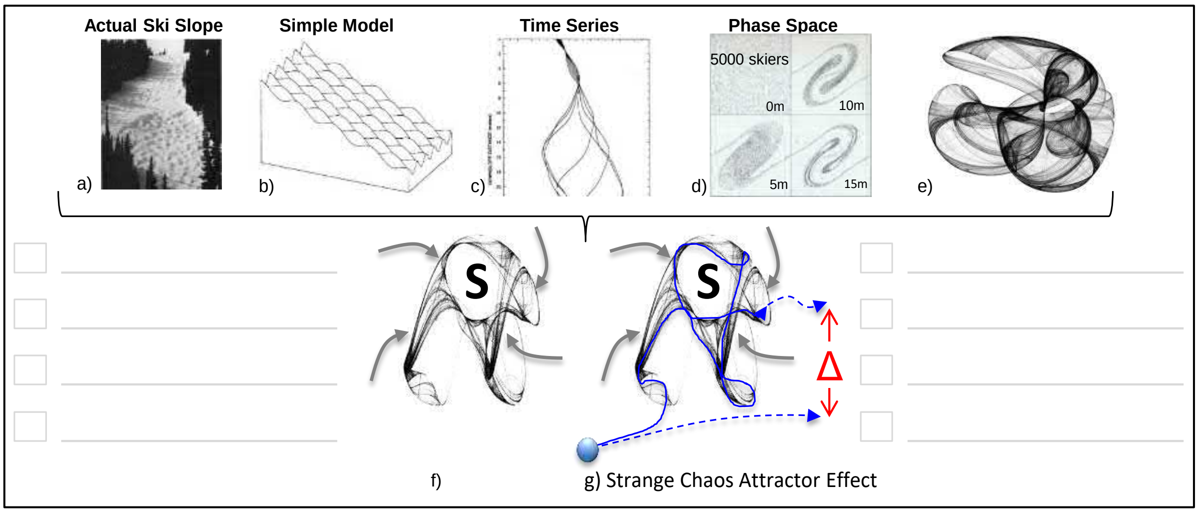

Figure D-22: Visual Representations for the Strange Chaos Attractor

A variance model for a strange chaos attractor for capital projects has been derived from references from various managerial and other sciences. The researcher explains the model to the respondent.

IQ6.2) Please add the elements and attributes as identified in IQ6.1 and provide a Likert scoring to the model displayed in Figure D-23.

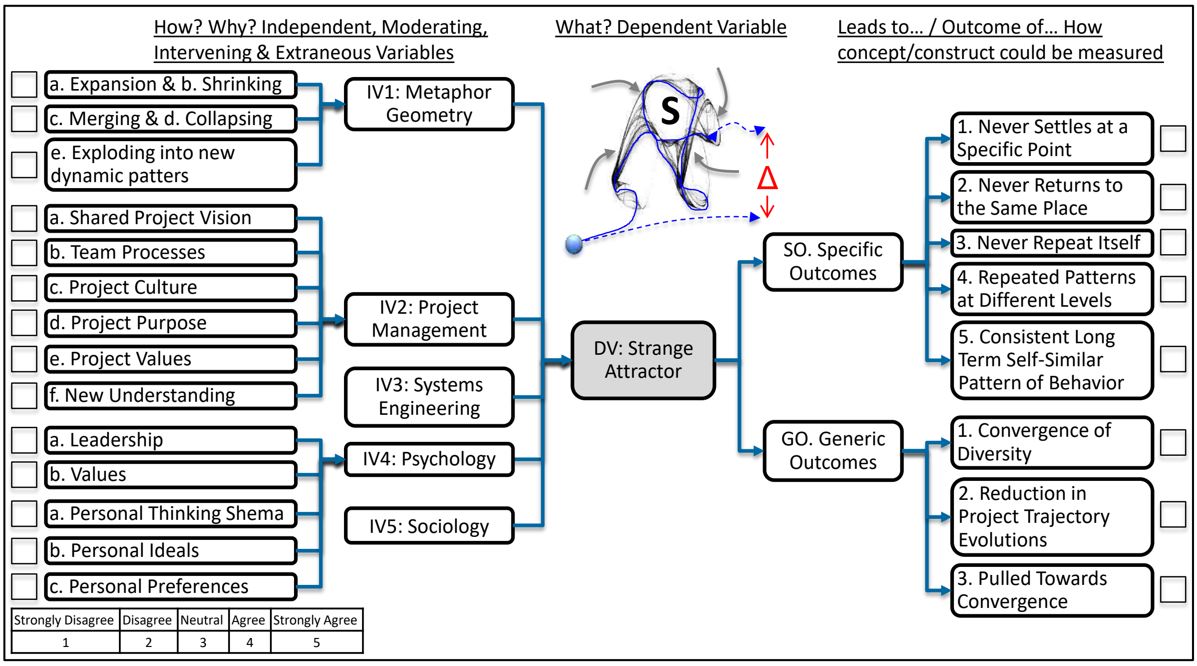

Figure D-23: Variance Model for a Strange Chaos Attractor to be Further Developed for Capital Projects

IQ6.3) Would a strange chaos attractor cause <u>local</u> convergence in a capital project?

6. Section B: Metaphor mapping of a group of individual chaos attractors to the Capital Project Domain to cause overall project convergence

6.1 The researcher explains the visual representations for a group of chaos attractors as shown in Figure D-24 & Figure D-25.

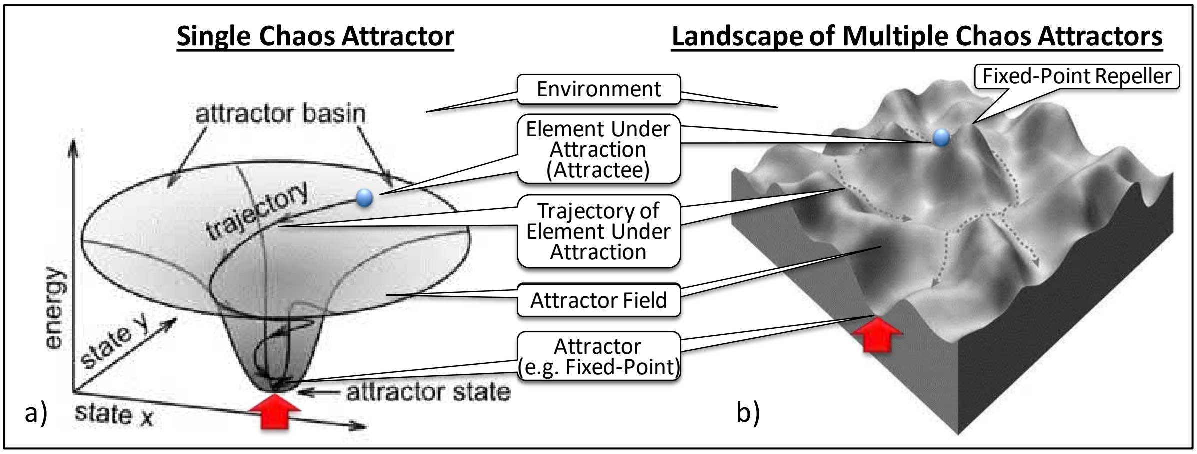

Figure D-24: Visual Representation of a Single Chaos Attractor and a Landscape of Multiple Chaos Attractors

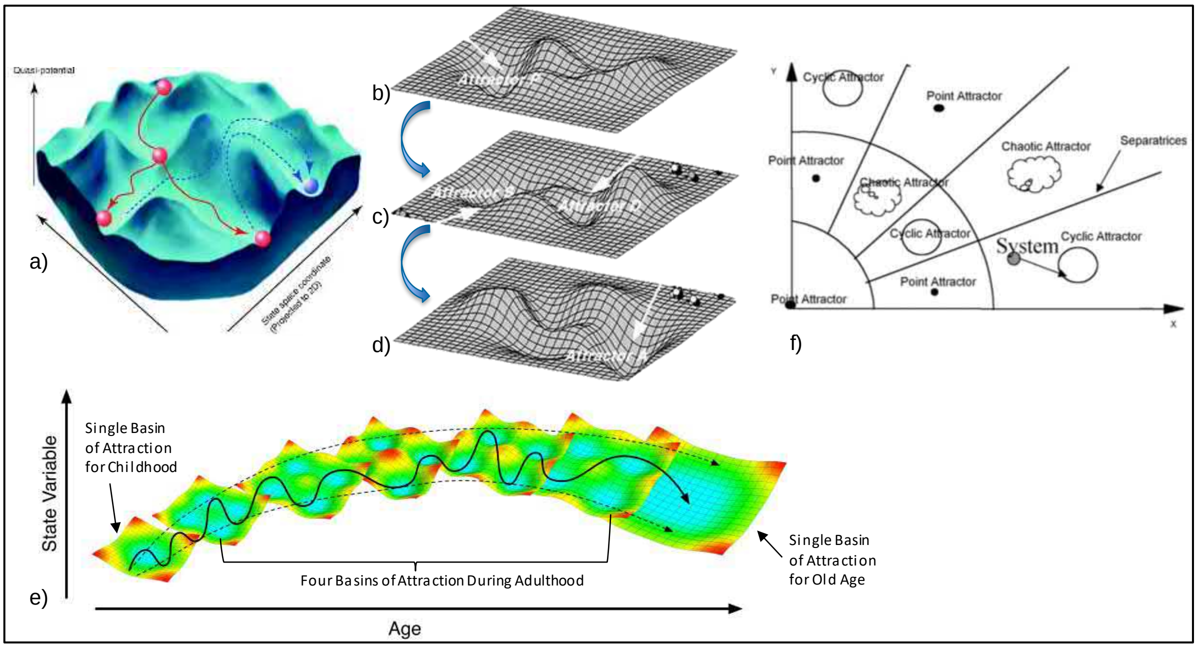

Figure D-25: Visual Representations for a Landscape of Chaos Attractors

IQ7.1) Comment on the use of a group of chaos attractors to cause <u>overall</u> capital project convergence? Please explain

A group of six chaos attractors has been configured across capital project stage gates as shown in Figure D-26 & Figure D-27.

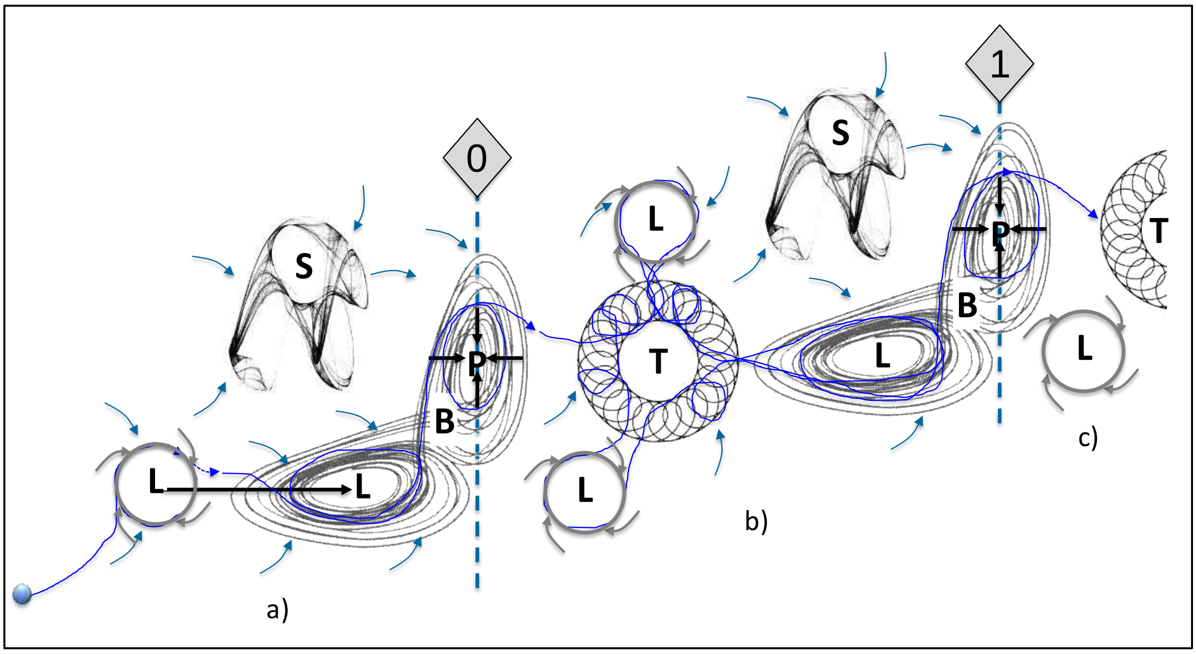

Figure D-26: A Configuration of Different Types of Chaos Attractors between Stage-Gates in Capital Project

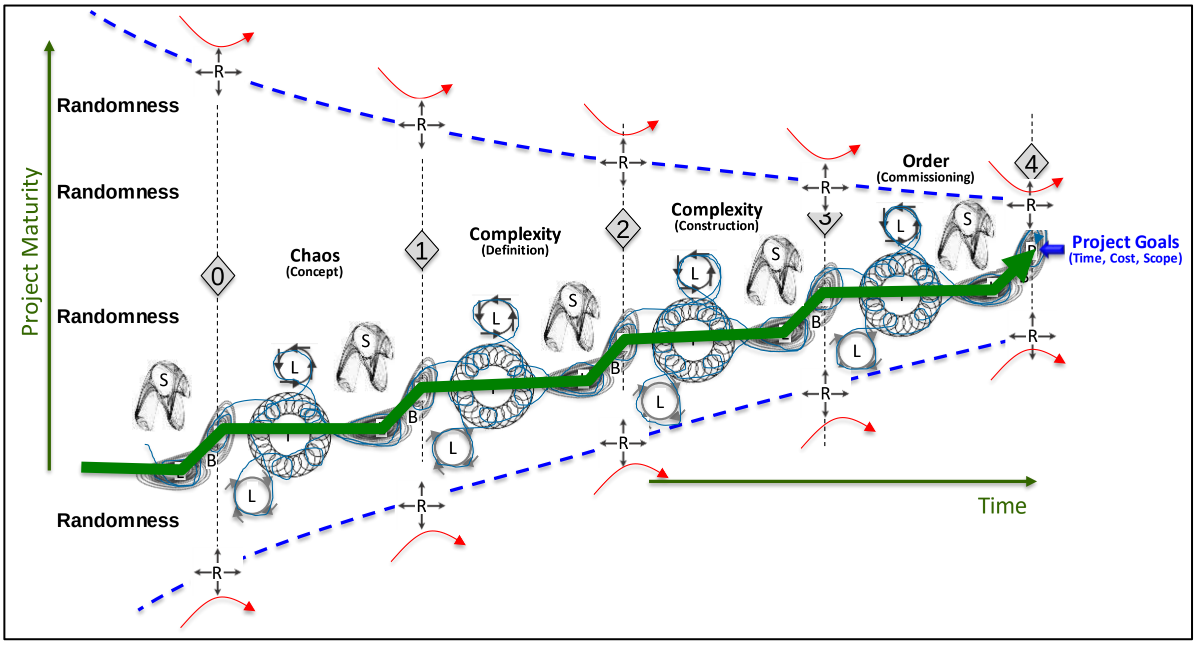

Figure D-27: Suggested Convergence Effect on Overall Capital Projects for a Harmonious Attractor Landscape

IQ7.2) What is your view on the possibility of this configuration causing overall convergence in capital projects? Otherwise, how should this configuration of the six individual chaos attractor types be changed to achieve overall convergence in capital projects?

A variance model for a group of chaos attractor for capital projects has been derived from references from various managerial and other sciences. The researcher explains the model to the respondent.

IQ7.3) Please add the elements and attributes as identified in IQ7.2 and provide a Likert scoring to the model displayed in Figure D-28.

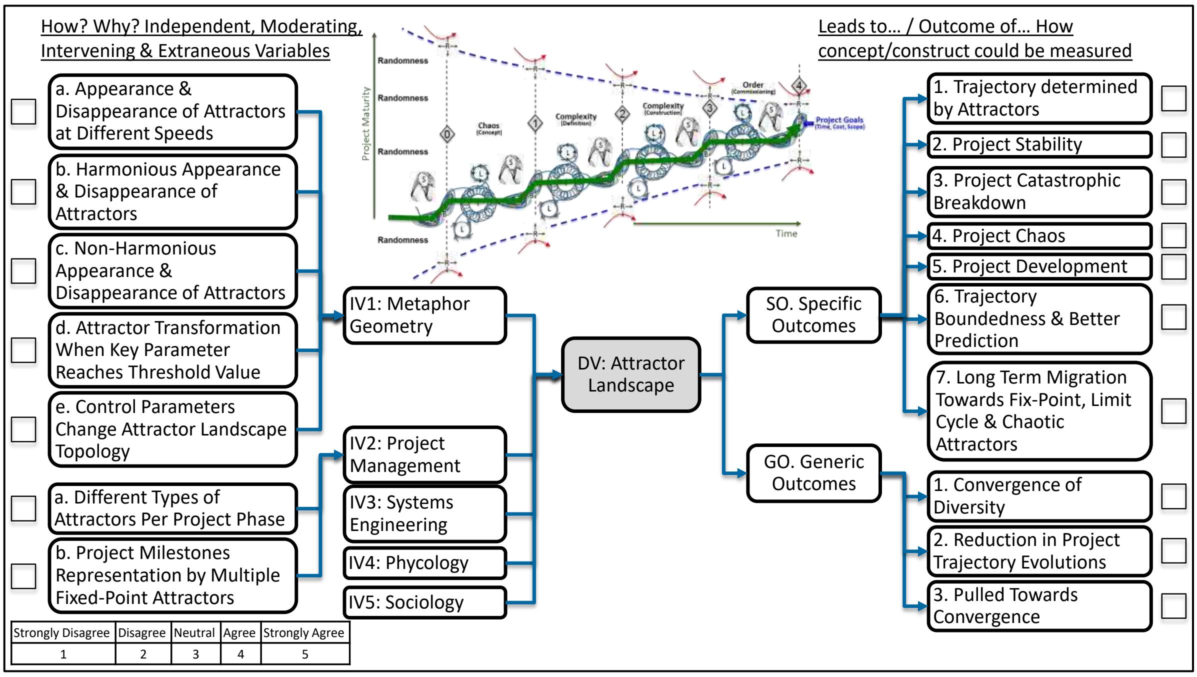

Figure D-28: Variance Model for Chaos Attractor Landscape in Capital Projects

IQ7.4) Would a group of chaos attractor cause overall convergence in a capital project?

7. Section C: Self-evaluation

IQ8.1) Please score each question using a Likert scale value between 1 – 5.

No.	Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
		1	2	3	4	5
1	Did your understanding of the chaos attractor concept improve throughout the interview?					

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2	Did the visualisation of the chaos attractor metaphors (sketches) help to better understand the objective of the metaphor?					
3	Did the visualisation of the chaos attractor metaphors (sketches) help to better map the concept to the capital project environment?					
4	Did the visualisation of the chaos attractor metaphors (sketches) as well as explanations help to better map the concept to the capital project environment?					
5	Would you now be able to apply the concept of chaos attraction in capital projects?					
6	The duration of the interview was sufficient to allow meaningful contribution?					

Comments for improvements of the interview process?

D.7 Round 2 Demographic Profile of Respondents

The following graphs indicate the demographic profile for 14 respondents that participated in the Round 2 interviews.

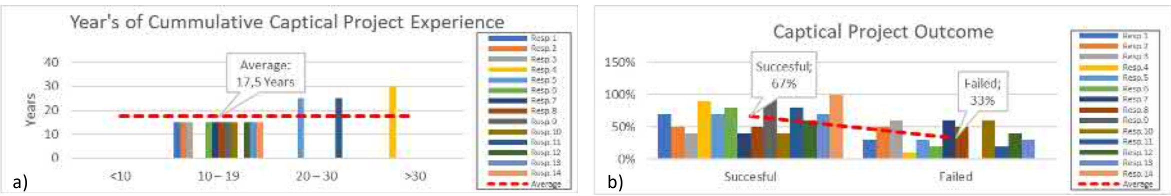

Figure D-29: Year of Cumulative Capital Project Experience (a) and Experience in Successful and Failed Capital Projects (b) of Round 2 Respondents

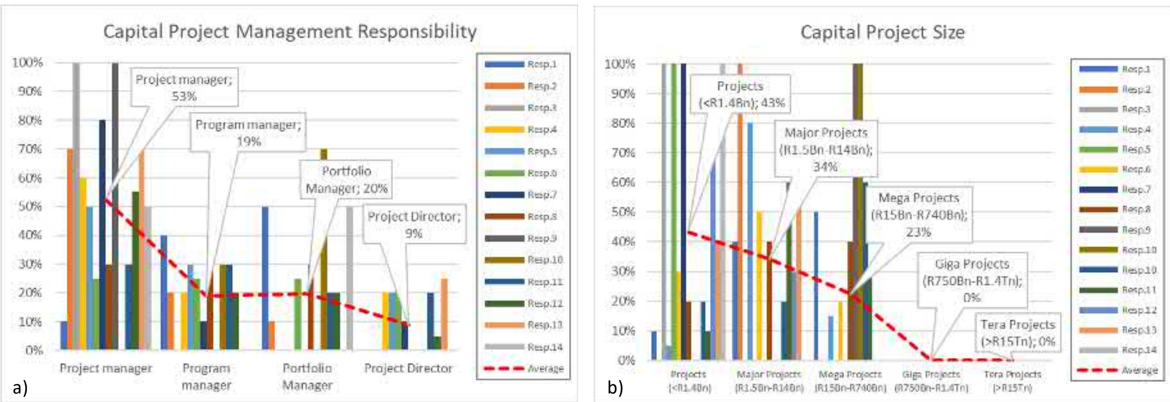

Figure D-30: Capital Project Management Responsibility (a) and Capital Project Size (b) of Round 2 Respondents

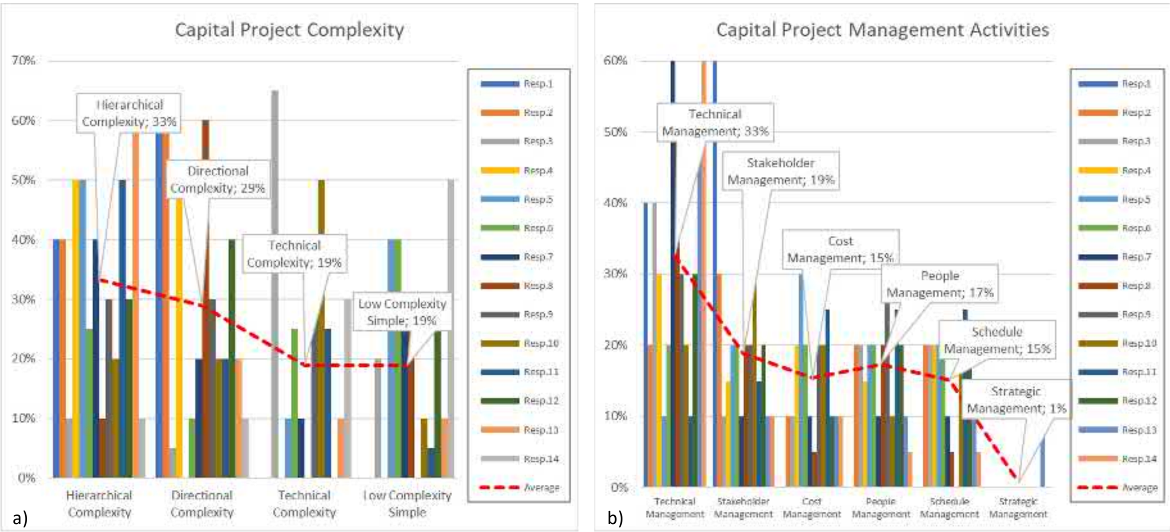

Figure D-31: Capital Project Complexity (a) and Capital Project Management Activities (b) of Round 2 Respondents

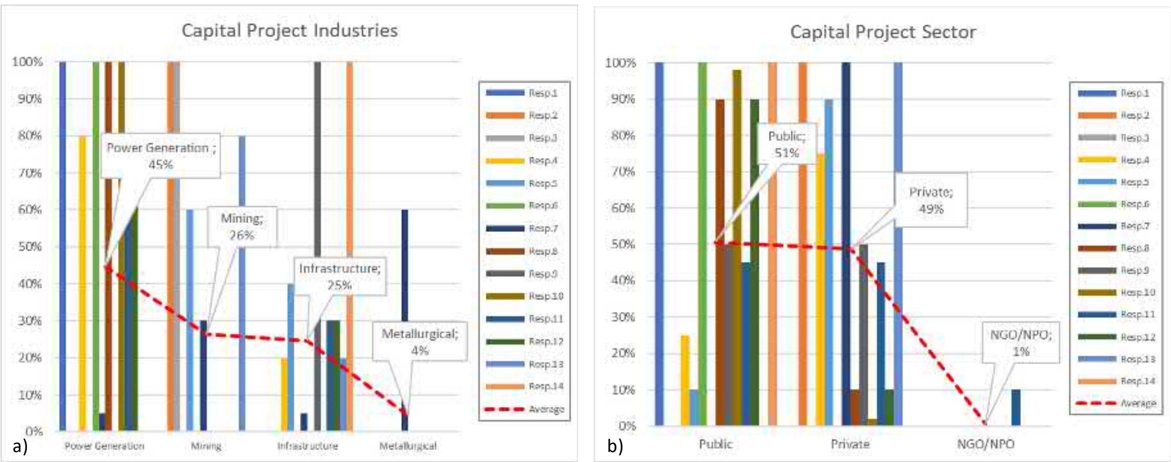

Figure D-32: Capital Project Industries (a) and Capital Project Sector (b) of Round 2 Respondents

D.8 Round 2 Code Book used for Data Analysis

The code book that was used for the data analysis of round 2 is shown in Table D-4.

Table D-4: Code Book Used for Content Analysis of Round 2 Research Results

Subject Group No.	Subject groups	Process groups				
		Initiating	**Planning**	**Implementing**	**Controlling**	**Closing**
SG1	Integration	4.3.2 Develop project charter	4.3.3 Develop project plans	4.3.4 Direct project work	4.3.5 Control project work 4.3.6 Control changes	4.3.7 Close project phase or project 4.3.8 Collect lessons learned
		Terminology added from this standard: Processes required to identify, define, combine, unify, coordinate, control and close, integration of scope, time , cost and other subjects, roles, responsibilities, organisation and procedures for management of subject groups, baselines for scope, quality, schedule, cost, resources & risks, implementation, monitor, closure, procedures, issues, configuration				
		Terminology added during round 1: Project execution, project definition, systems engineering, synchronisation, reporting, timeous management, intervention				
		Terminology added during round 2: Governance, maturity				
SG2	Stakeholder	4.3.9 Identify stakeholders		4.3.10 Manage stakeholders		

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		Terminology added from this standard: Internal or external, individuals, groups, organisations, expectations				
		Terminology added during round 1: Disciplines, interfaces, stakeholder alignment, politics				
		Terminology added during round 2: Reputation, integration meeting				
SG3	Scope		4.3.11 Define scope 4.3.12 Create work breakdown structure 4.3.13 Define activities		4.3.14 Control scope	
		Terminology added from this standard: Objectives, deliverables, contribution to goals & benefits, requirements, boundaries				
		Terminology added during round 1: Expectations				
SG4	Resource	4.3.15 Establish project team	4.3.16 Estimate resources 4.3.17 Define project organization	4.3.18 Develop project team	4.3.19 Control resources 4.3.20 Manage project team	
		Terminology added from this standard: Human & other resources, organisation chart, role descriptions, staff assignments, staff contracts, roles, responsibilities & authorities, skills & expertise, competencies, behaviour, personalities, group dynamics, define project organisation, organisational structure, motivation & performance				
		Terminology added during round 1: Team focus				
		Terminology added during round 2: Incentives, leadership, vision, trust				
SG5	Time		4.3.21 Sequence activities 4.3.22 Estimate activity durations 4.3.23 Develop schedule		4.3.24 Control schedule	
		Terminology added from this standard: Logical relationships, logical sequence, internal & external dependencies, critical path, leads, lags, constraints, learning curve, approval cycles, schedule baseline, milestones, progress in time, schedule variance				
		Terminology added during round 1: Timelines, mathematical modelling				
SG6	Cost		4.3.25 Estimate costs 4.3.26 Develop budget		4.3.27 Control costs	
		Terminology added from this standard: Reserves, contingency, cost performance, baseline cost, cost at completion				
		No new terminology added				
SG7	Risk		4.3.28 Identify risks 4.3.29 Assess risks	4.3.30 Treat risks	4.3.31 Control risks	

		Terminology added from this standard: Threats, opportunities, probability, consequence, tolerance, trigger conditions, contingency plan				
		Terminology added during round 1: Unforeseen requirements, Unknowns, technology, surprises, mitigation, technical				
SG8	Quality		4.3.32 Plan quality	4.3.33 Perform quality assurance	4.3.34 Perform quality control	
		Terminology added from this standard: Quality requirements, standards, policy & plan, review deliverables, conformance to performance requirements, detecting defects, preventative actions, corrective actions				
		No new terminology added				
SG9	Procurement		4.3.35 Plan procurements	4.3.36 Select suppliers	4.3.37 Administer procurements	
		Terminology added from this standard: Procurement strategy, procurement plan, preferred suppliers, contract type				
		Terminology added during round 1: Contract model, contract management				
		Terminology added during round 2: Penalties				
SG10	Communication		4.3.38 Plan communications	4.3.39 Distribute information	4.3.40 Manage communications	
		Terminology added from this standard: Information needs, communication requirements, resolve issues & misunderstandings, timely accurate and unbiased information				
		Terminology added during round 1: Contract model, contract management				

Table D-4 Notes: The Code Book Originate from (ISO, 2012:10, Table 1) and was used for the Round 1 Content Analysis. Some Terminology was added for during the Round 2 Content Analysis.

D.9 References

ISO. 2012. Guidance on Project Management. *BS ISO 21500:2012.* Geneva: International Standards Organisation.