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An ontology and crowd computing model for expert-citizen knowledge transfer in biodiversity management

By

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Submitted in fulfilment of the requirements of PhD in Information Technology in the Faculty of Engineering, Built, and Information Technology

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Abstract

Title: An ontology and crowd computing model for expert-citizen knowledge transfer in biodiversity management

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Knowledge transfer has been identified as a strategic process for bridging the persistent gap between theory and practice. In biodiversity management, experts generate different types of knowledge that is transferred to citizen communities for practice. On the other hand, citizens constantly interact with their biosphere and from time to time are requested to convey ground knowledge to the experts for scientific analysis and interpretation. The transfer of knowledge between experts and citizens is faced by different challenges key among them being the large volume of the knowledge, complexity of the knowledge, as well as variegated absorptive capacity among citizen communities. Knowledge transfer models adopted for expert-citizen engagement in the biodiversity management domain must therefore consider these characteristics of the domain. Advances in computing technologies present opportunities to create knowledge transfer models that can minimize these challenges. Current knowledge transfer models were created mainly for organizational knowledge transfer and without consideration of specific computing technologies as a mode of knowledge transfer. These challenges and opportunities highlighted a need to investigate how a technology-based knowledge transfer model for biodiversity management could be created.

The focus of this study was to explore enhancement of knowledge transfer in the biodiversity management domain using two specific technologies; knowledge representation using ontologies and crowd computing. The research draws from existing knowledge transfer models and properties of the two technologies. This study assumed the pragmatist philosophical stance and adopted the design science research (DSR) approach which is characterised by two intertwined cycles of ‘build’ and ‘evaluate’. The research produced two main contributions from the two cycles. The build cycle led to creation of a technology-based model for knowledge transfer between experts and citizens in the biodiversity domain and was named the Biodiversity Management Knowledge Transfer (BiMaKT) model. Evaluation cycle resulted in development of a platform for transfer of biodiversity management knowledge between experts and citizens.

The BiMaKT model reveals that two technologies; knowledge representation using ontologies and crowd computing, could be synergised to enable knowledge transfer between experts and citizens in biodiversity management. It is suggested that this model be utilised to guide development of biodiversity management applications where knowledge needs to be transferred between experts and citizens. The model also presents opportunity for exploration in other domains, especially where experts and citizens need to exchange knowledge. The knowledge transfer platform, reveals that the BiMaKT model could be used to guide development of biodiversity management knowledge transfer platforms. The study utilises a case of fruit fly control and management knowledge transfer between fruit fly experts and fruit farmers for evaluation of the contributions. An experiment using the case demonstrated that the challenges facing knowledge transfer in the domain could be reduced through ontological modelling of domain knowledge and harnessing of online crowds participation through crowd computing. The platform presents opportunity for more empirical studies on usage of the platform in knowledge transfer activities.

Declaration

I declare that,

"An ontology and crowd computing model for expert-citizen knowledge transfer in biodiversity management" is the result of my own work and that resources used are referenced and acknowledged.

C. C. Kiptoo

Publications from this research

Two scholarly articles were published from this study.

Kiptoo, C.C., Gerber, A. & Van der Merwe, A., 2016. The Ontological Modelling of Fruit Fly Control and Management Knowledge. In *Fruit Fly Research and Development in Africa - Towards a Sustainable Management Strategy to Improve Horticulture*. Springer International Publishing, pp. 235–249. Available at: http://link.springer.com/10.1007/978-3-319-43226-7_11.

Kiptoo, C.C., Gerber, A. & Van der Merwe, A., 2016. Towards Citizen-Expert Knowledge Exchange for Biodiversity Informatics: A Conceptual Architecture. *The African Journal of Information and Communication (AJIC)*

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4. Reviewers and editors of the works published during this research.
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6. Last but not least, my family for their overwhelming support and understanding through all the seasons of this journey

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Abbreviations

CBD - Convention on Biological Diversity

ICT - Information Communication Technology

DELTA - DEscription Language for Taxonomy

DSR - Design Science Research

ER - Entity Relationship

FloPO - Flora Phenotype Ontology

IS - Information Systems

IT – Information Technology

KMS - Knowledge Management Systems

OBA - Ontology of Biological Attributes

PTO - Plant Traits Ontology

R&D - Research and Development

RDBMS - Relational Database Management System

SDD - Standard Descriptive Data

TO - Trait Ontology

VT ontology - Vertebrate Trait ontology

Part I - Introduction and background

Part I of this thesis provides an introduction and background to the research question of this study. The part is made up of three chapters; the first chapter is the introduction, which provides an introduction to the study and presents the research question investigated in the thesis. The second chapter is the literature review and provides the relevant literature that help contextualize the study. The third chapter is the research methodology and provides the methodology used in answering the research question of the study. Part I is contextualised within the entire study as shown in Figure I-I.

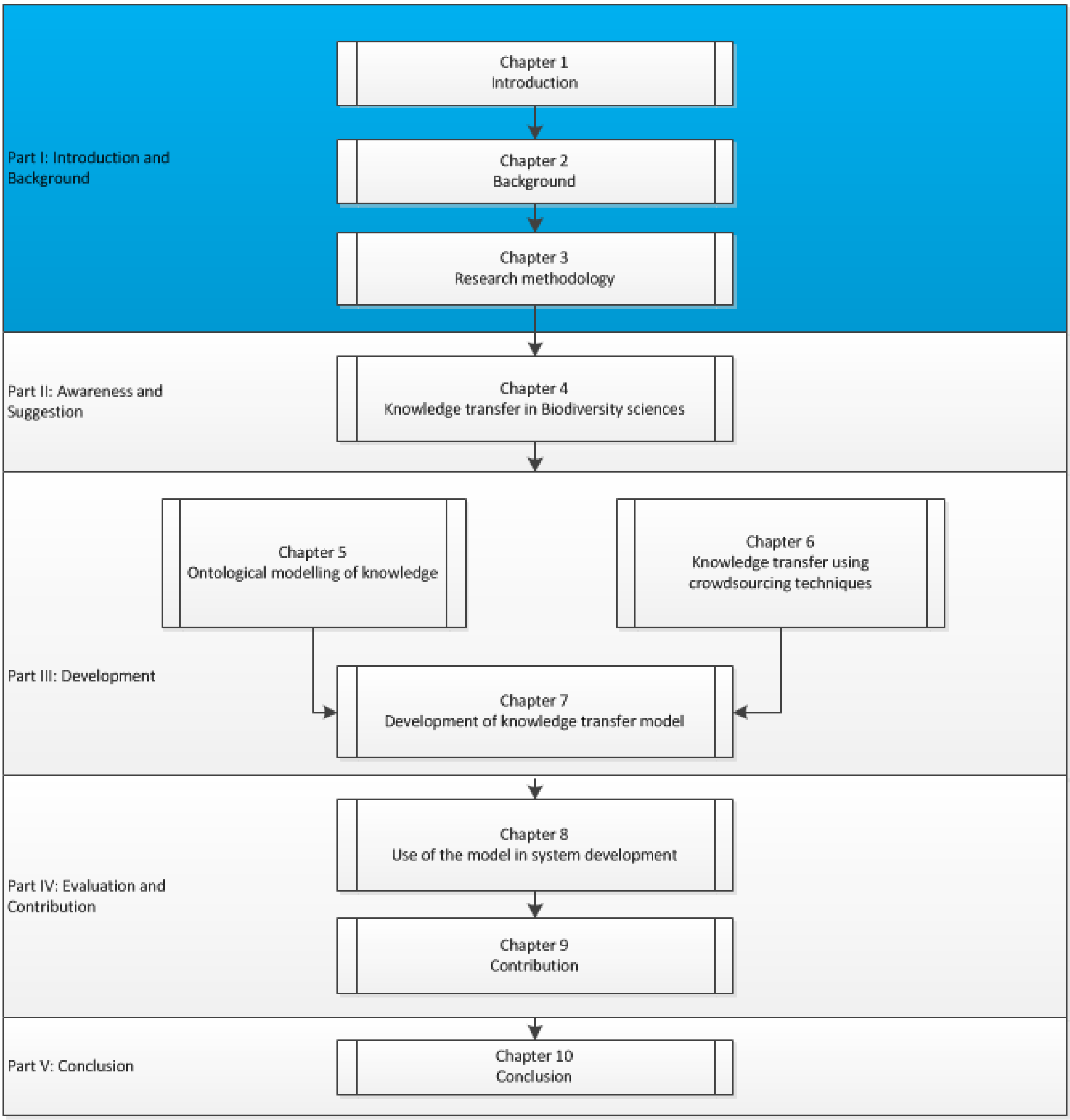

Figure I-1: Part I Outline

Chapter 1 - Introduction

1.1 INTRODUCTION

This thesis investigates knowledge transfer in order to develop a model for online knowledge transfer between experts and citizens in the biodiversity management domain using two technologies, ontologies and crowd computing. The study is multi-disciplinary and resides in the information systems domain, more specifically knowledge management systems. The study contributes by providing a model to guide development of applications that enable knowledge transfer between experts and citizens in biodiversity management.

Biodiversity management has been found to benefit greatly from close collaboration between expert scientists and local communities or citizens living in the specific biosphere (Hill et al. 2010; Velasco et al. 2015). Engagement of citizens is recognized by the United Nations' Convention on Biological Diversity (CBD) as a key component for ensuring conservation of biodiversity, sustainable use of natural resources and equitable sharing of biodiversity benefits (Soberon & Sarukhan 2009). Use of citizen science projects for biodiversity monitoring has saved substantial efforts and financial expenses that experts would need to carry out to achieve similar results (Hardisty et al. 2013). The biodiversity management activities collaborated upon include: - execution of specific actions that directly influence the state of biodiversity such as protection of certain endangered species (Salafsky & Wollenberg 2000); formulation of laws, policies and frameworks governing biodiversity management (Ellis & Waterton 2004; Mauro & Hardison 2000); species monitoring for example species data collection using citizen science approaches (Parr et al., 2014; Smith et al., 2011); and technology transfer for example transfer of biodiversity based agricultural knowledge from researchers to farmers (Benayas & Bullock 2012; Dollacker & Rhodes 2007; Fischer et al. 2008; Tscharntke et al. 2012).

The above-mentioned activities in biodiversity management require knowledge transfer between experts and citizens. Scientific knowledge consisting of intervention programmes, new control and management technologies and biodiversity-based approaches need to be transferred from experts to citizen communities for practical applications. On the other hand, ground knowledge on the status of biodiversity need to be transferred from citizens to experts for scientific analysis, interpretation and further research. In some projects, indigenous knowledge that resides within communities also needs to be transferred to experts. Knowledge transfer is therefore a necessary component in the symbiotic relationship between experts and citizens in biodiversity management (Yineger & Yewhalaw 2007; Roux et al. 2006).

The use of computing technologies to support knowledge transfer in the biodiversity management domain is not new. Different technologies have been explored in various activities and promising results have been realized. Expert knowledge transfer to citizens has been supported using different technologies such as emails, web technologies, online databases, online knowledge repositories, professional platforms and social media (Fischer et al. 2008; Folke 2004; Jain 2006; Meera et al. 2004; Newman et al. 2012; Park et al. 2007; Stafford et al. 2010; Wiggins & Crowston 2010). Furthermore, studies report on the transfer of ground knowledge to experts through different species monitoring and data collection citizen science projects conducted through several online portals (Conrad & Hilchey 2011; Teder et al. 2007; Wagner 2005; Wiersma 2008).

However, in spite of the reported studies, the use of computing technologies to support the knowledge transfer process is currently done in ad hoc ways with little if any benefit to the bigger biodiversity knowledge management agenda. The demand to use computing technologies in ways that add more value than simply making communication faster is on the rise and the lack of value addition artefacts and tools was identified as one of the challenges facing the biodiversity community. Specifically, the need to exploit computing technologies in novel ways is required to facilitate the biodiversity communities to achieve the individual project targets while contributing to the bigger call of creating a global biodiversity knowledge fabric (Hardisty et al. 2013).

Advances in computing technologies present opportunities to explore novel ways of enhancing knowledge transfer in biodiversity management. In order to realize maximum benefits of using the computing technologies to support knowledge transfer, there is a need to revise and model the processes to take maximum advantage of targeted computing technologies. The study presented in this thesis was aimed at creating a model for knowledge transfer using two computing technologies: - ontology technologies to capture expert knowledge and crowd computing technologies to support citizen participation.

In this chapter, a brief background to the thesis is presented followed by the research problem investigated in the study, the research strategy adopted and a summary of the contributions of the study. At the end of the chapter, the structure of the thesis is presented.

1.2 BACKGROUND

The gap between theory and practice is a persistent problem for scholars in applied research sectors, biodiversity management domain included. Van de Ven and Johnson (2006) discussed three different ways in which the gap between theory and practice has been framed: 1) as a knowledge transfer problem, 2) as a theory and practice representing distinct kinds of knowledge, 3) as a knowledge production problem. The debate of which frame is correct is avoided because it is beyond the scope of this thesis and not relevant in answering the research question being investigated. In this study, theory is assumed to inform practice to at least some extent, and therefore, the gap between theory and practice is as a result of delays or absence of the necessary translations, diffusion and transformations of the theoretical knowledge for practical use. The gap between theory and practice is therefore, a knowledge transfer problem that can be reduced through deliberate steps of transferring theory for practical use and vice-versa.

Knowledge transfer is an area of knowledge management concerned with the movement of knowledge across the boundaries created by specialized knowledge domains (Alavi & Leidner 2001; Carlile & Rebentisch 2003). Knowledge transfer is characterized by actively communicating to a knowledge recipient what is known and also actively seeking to know what the recipient does not know (van den Hooff & De Ridder 2004). Furthermore, knowledge transfer is about identifying (accessible) knowledge that already exists, acquiring it and subsequently applying this knowledge to develop new ideas or enhance the existing ideas to make a process/action faster, better or safer than they would have otherwise been (Christensen 2003). Knowledge transfer is therefore not concerned with replicating the source knowledge at the recipient's end but rather involves contextualizing it. Seaton (2002) explains the process of knowledge transfer as one that is concerned with *"this is what my knowledge means for you"* as opposed to *"this is what I know"* as often assumed. In this research the view that successful knowledge transfer has happened when the recipient uses the knowledge from the source for practical application, is adopted. A similar emphasis is made by Foss and Pedersen (2002), and they explain that *''what is transferred is (usually) not the underlying knowledge but rather applications of this knowledge in the form of solutions to specific problems''*. Knowledge transfer is therefore, not an *in toto* replication of knowledge at a new place but involves modification to suit the new context (Kumar and Ganesh, 2009).

Research in knowledge transfer has been conducted from highly diversified dimensions, for example, Kumarand Ganesh (2009) identified eight dimensions, namely: study, nature of knowledge, agents involved, direction of knowlegde flow, mechanism of transfer, contextual factors that influence transfer, geography and business context. Mechanisms of knowledge transfer are also discussed in Argote et al. (2003). Other dimensions from which knowledge transfer has been studied include the transfer process (Major & Cordey-Hayes 2000; Graham et al. 2006; Liyanage et al. 2009), as well as policy and strategy (Garforth et al. 2004; Goh 2002). This research is focused primarily on the knowledge transfer process dimension. The knowledge transfer process is widely documented in literature using frameworks and models that outline the key steps of knowledge transfer (Major & Cordey-Hayes 2000; Horton 1999; Cohen & Levinthal 1990; Liyanage et al. 2009).

Knowledge transfer models are influenced by different factors including actors in the transfer process, the nature of knowledge, contextual factors, domain requirements and mechanisms of knowledge transfer among others. Because of these influences, the need to develop contextualised knowledge transfer models is recognized in literature as an important activity in the knowledge transfer process (Kumar & Ganesh 2009; Liyanage et al. 2009). There is paucity in computing technology-based knowledge transfer models for expert and citizen knowledge transfer in the biodiversity management domain and a number of weaknesses can be seen. First, most key models do not address the mode of transfer that should be used together with these models (Horton 1999; Graham et al. 2006; Liyanage et al. 2009). Second, knowledge transfer between experts and citizens in biodiversity management is bi-directional, but current implementations focus more on active transfer of ground knowledge from citizens to experts and not the other way round. Finally, use of computing technologies to support any process requires re-engineering of the process to take full advantage of technology use. Knowledge transfer processes are yet to be adapted to benefit from support of specific computing technologies.

Use of ontologies in the representation of biodiversity knowledge has been explored. For example, ontologies have been used to represent knowledge on organisms' anatomy, morphology, genetics and phylogenetic knowledge (Haendel et al. 2007; Hughes et al. 2008; Mungall et al. 2012; Gerber et al. 2014). Different forms of crowd computing have also been used in biodiversity management projects, mainly citizen science projects. For example, web 2.0 has been used in different data collection projects where citizens are engaged in organism monitoring (Sullivan et al. 2009; Ingwell & Preisser 2011; Lee et al. 2006). Combining the two technologies arguably provides potential for knowledge transfer and support for domain requirements in biodiversity management.

1.3 PROBLEM STATEMENT AND PURPOSE OF THE STUDY

Models for knowledge transfer in different contexts have been proposed by knowledge management researchers. The importance of models for knowledge transfer in specific domains and contexts is discussed in literature (Liyanage et al. 2009; Mitton et al. 2007; Simonin 1999; van den Hooff & De Ridder 2004) As discussed in the background section, biodiversity management is characterized by multiple factors that must be considered to attain successful knowledge transfer. The issues and requirements that characterize the biodiversity management domain include:

- **Expert and novice knowledge transfer requirements**: Biodiversity management like most participatory processes is characterized by knowledge transfer between stakeholders (Reed 2008; Fazey et al. 2013). The focus of this study was the transfer of knowledge between experts and non-expert citizens or novices. Expert knowledge transferred to citizens includes intervention programmes developed in scientific ways, while citizen knowledge includes indigenous knowledge, the ground knowledge and results of different intervention programmes(Johnson et al. 2004; Mapinduzi et al. 2003).

- **Biodiversity data requirements:** Understanding biodiversity requires collecting biodiversity data at various spatial and temporal scales. Biodiversity informatics research communities recognize the need to integrate data from different sources in order to answer deeper global questions regarding biodiversity (Hardisty et al., 2013; Loos et al., 2015; Peterson et al., 2010). Currently, biodiversity data is characterized by data validity and standards problems and analysing data from disparate sources remains a challenge. To mitigate this challenge, the biodiversity informatics community have developed different standards to guide data contributions in this domain (Wieczorek et al., 2012). It is therefore, important to consider not only the user requirements but also these standards when creating a knowledge transfer model if the outcomes of activities that utilize the model are to contribute to global data needs, an important requirement of biodiversity data by the biodiversity informatics community.

- **The requirement for frameworks and models for ICT use in biodiversity knowledge management**: It has been observed that introduction of different ICT technologies in biodiversity knowledge management lack frameworks and models to guide the data and knowledge management activities and processes. Hardisty et al. (2013) observed that biodiversity informatics is characterised by introduction of different systems looking for problems to solve. The need to have models and frameworks has therefore been emphasised as an important prerequisite if ICTs are to effectively and progressively address the needs of biodiversity management communities.

Though specific models for knowledge transfer in the biodiversity domain were not found in literature, some of the existing models could be adapted. The knowledge transfer models in literature were developed without explicit consideration of ICT as a mechanism that can aid knowledge transfer. Use of these models in a technology-mediated context would therefore imply minimal benefits from advancements in the adopted computing technologies. This research adopted two types of technologies, knowledge representation technologies, specifically ontological modelling and crowd computing technologies. Ontological modelling was selected for representation of expert knowledge while crowd computing technologies were selected to harness crowd participation in knowledge transfer. Ontological modelling was selected for the representation of expert knowledge because it enables knowledge representation using decidable fragments of first-order logic. This means that logical deductions can be made from the represented knowledge making it possible to use both explicit and implied facts for answering questions. The Web Ontology Language (OWL) 2 is a standardised semantic language designed to enable representation of complex knowledge and is part of the W3C standards. Knowledge represented using ontologies can be published in the web and used together with other ontologies to answer domain questions (Horrocks et al. 2003; Krötzsch et al. 2012; Bruijn 2006).

Crowd computing technologies as stated above were selected for harnessing the citizens. Crowd computing technologies have become useful in solving complex problems that cannot be solved using computational means such as data annotation (Bernstein 2013; Welinder, Steve Branson, et al. 2010; Quinn & Bederson 2011). Knowledge transfer is characterized by such problems and crowd computing presents an opportunity to address such challenges thus enabling knowledge transfer without requiring continuous engagement of experts. There is, however, a gap in literature, which is the lack of a model that combines knowledge representation and crowd computing technologies for knowledge transfer between experts and citizens.

In light of the gap identified above and the potential presented by the two technologies, the main objective of this study was therefore, to create a knowledge transfer model that uses ontologies to capture expert knowledge and crowd computing technologies to harness crowd participation for biodiversity knowledge transfer between experts and citizen communities.

1.4 RESEARCH QUESTION AND OBJECTIVES

The main research question (MQ) that guided this research was:

MQ: What are the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management?

To answer the main questions, three sub-questions (SQ) were formulated as follows:

SQ 1) Which knowledge transfer model is applicable for expert-citizen knowledge transfer in biodiversity management?

SQ 2) How can ontologies be used to capture biodiversity management expert knowledge?

SQ 3) How can crowd computing technologies be used to support biodiversity management knowledge transfer?

The research questions were translated into research objectives starting with the main objective (MO) as follows:

MO: To identify the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management.

The sub-Objectives (SO) are:

SO 1) To identify a knowledge transfer model applicable for expert-citizen knowledge transfer in biodiversity management.

SO 2) To establish how ontologies can be used to capture biodiversity management expert knowledge.

SO 3) To establish how crowd computing technologies can be used to support biodiversity management knowledge transfer.

1.5 RESEARCH STRATEGY

This research adopted the pragmatic paradigm view, which is the philosophical view that believes that the primary reason for doing research is to pursue what is true for the sake of improving human life (Seyppel 1953) and usually involves the introduction of new artefacts to help solve existing problems. The novel solutions introduce new ‘wicked’ problems, and this prompts new research efforts to solve them making the reality cycle persistent with a new set of problems that drive pragmatists (Hevner et al., 2004). Within the pragmatism view, Design Science Research (DSR) was adopted. The DSR view is a problem solving paradigm that aims to generate knowledge through the creation of artefacts that are relevant to addressing practical problems (Benbasat & Zmud 1999). The study was aimed at contributing a design theory which is a form of utility theory that “links some solution technology concept or group of concepts to the aspect(s) of the problem(s) that it/they address’’ (Venable, 2006).

The research was conducted using the DSR research process presented in Kuechler and Vaishnavi (2008) consisting of five circumscriptive stages, namely:

(1) Awareness,

(2) Suggestion,

(3) Development,

(4) Evaluation and

(5) Conclusion

The main question formed the main research cycle, and the sub-questions were subsequently answered in the respective sub-cycles within the suggestion and development stages of the main cycle. The research process adopted is as summarised in Figure 1-1 and the outputs of each phase were as indicated. The main research question was answered through executing the main research cycle and the sub-questions were answered during execution of the sub-cycles. The main cycle contributed the model, which was named the BiMaKT model. The first sub-cycle identified a model that was adopted in the creation of the BiMaKT model, the second sub-cycle cycle resulted in an ontology model for representing biodiversity expert knowledge and the third sub-cycle contributed crowd computing model for knowledge transfer support.

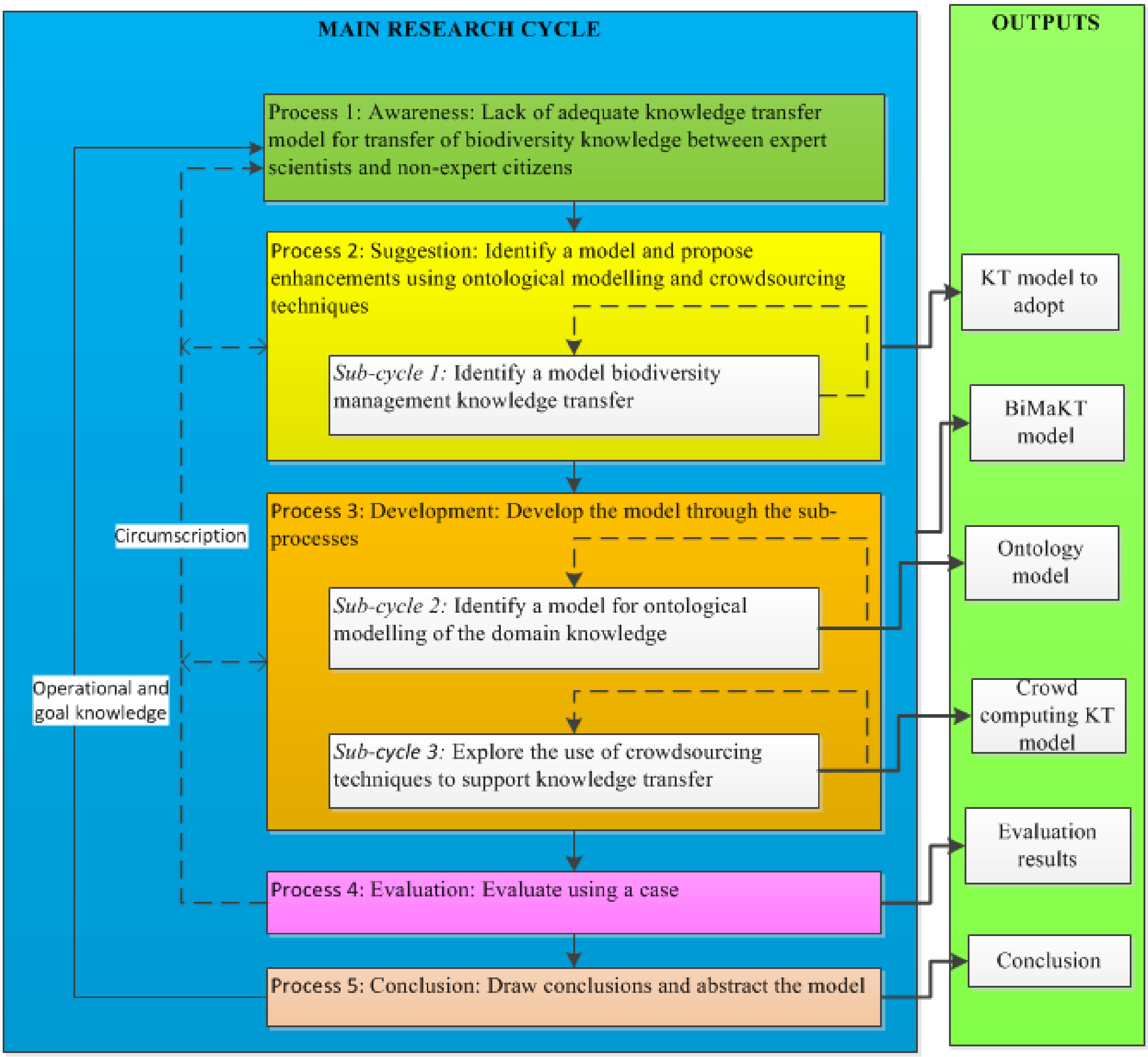

Figure 1-1: Research Process

1.6 SCOPE AND LIMITATIONS OF SCOPE

The research reported on in this thesis aimed to contribute a knowledge transfer model for the transfer of biodiversity knowledge between experts and citizens using ontological modelling and crowd computing technologies. Given this objective, the study was made possible through further delimitation as follows:

- **Type of knowledge:** Models for knowledge transfer have been found to differ depending on the type of knowledge, whether explicit or tacit knowledge. Although the two kinds of knowledge are not considered entirely dichotomous, but rather reinforce each other (Defillippi et al. 2006; Nonaka & Toyama 2003), this research focussed on the transfer of explicit knowledge.
- **Computing technologies:** The research considered two technologies as mechanisms for knowledge transfer, namely: Ontological modelling for knowledge representation and codification of the expert knowledge and crowd computing technologies for harnessing citizen participation.

- **Actors**: Knowledge transfer presumes the presence of two categories of actors in the knowledge transfer process, source and receivers (Kumar & Ganesh 2009). In this research, the actors included expert scientists and non-expert citizens. The two act as both source and receivers since the model is multidirectional. For transfer of scientific knowledge, the source is the scientists and receivers is the citizens and in the transfer of ground knowledge, the source is the citizens and receivers is the experts.

- **Dimension of biodiversity**: Biodiversity is broad and different aspects are studied in different spatial and temporal scales. Two broad categories of knowledge constitute biodiversity knowledge: ecosystem and organism. In this research, the focus was on the organism knowledge and the case of tephritid fruit fly was used in evaluation of the model, see description of the case below.

- **Nature of knowledge:** Enormous biological knowledge exists on different organism, ranging from molecular and genetic knowledge to traits and relationships with other organisms and their environment. Three kinds of traits knowledge were considered in this research, including: taxonomic knowledge, relationship with other organisms and lures knowledge.

- **Biodiversity case:** The organism used as a case for evaluating this research was a family of flies called *Tephritid fruit flies.* These fruit flies are notorious pests in the horticulture industry and scientists have developed biodiversity friendly ways for controlling and managing them (Ekesi & Muchugu 2007). This knowledge is useful yet not readily accessible to farmers who are mostly non-experts and are the targeted users of the knowledge. In the fruit fly case, the knowledge included identification knowledge from a simplified taxonomic key for thirty species considered to be of most economic importance in Africa, host plant preference for the different fly species and lures that can be used on fly traps for the different species (Billah et al. 2007; Manrakhan 2007; Nagaraja et al. 2014) .

1.7 RATIONALE OF THIS STUDY

The rationale for this study has both theoretical and practical dimensions. Technology based knowledge transfer in biodiversity management has been undertaken through diverse projects that focus on knowledge transfer from either experts to citizens or vice-versa but not as complementary activities. Different web technologies have been used to support the transfer of knowledge without carefully developed models to guide the development of these applications (Hardisty et al. 2013). Theoretically, knowledge transfer in biodiversity management needs to be guided by scientifically developed design theories. Biodiversity informatics communities have pointed out the importance of such theories in literature since developing application without carefully designed models lead to collection of data that cannot be jointly processed with datasets from other sources. The lack of a model to guide development of expert-citizen knowledge transfer applications in biodiversity management was the main rationale for this study.

Availability of models and methodological constructs to guide application development is an essential tool in the development of any application. Practically, this research provided a model to guide development of applications for knowledge transfer between experts and citizens in biodiversity management. Lack of a model means each application developer has to create a model as a starting point to application development. A knowledge transfer model therefore saves development time by providing a reference point for developers when creating knowledge transfer systems.

Biodiversity knowledge transfer is complex especially when the requirements of the domain are considered. Different standards for data in biodiversity management have been created to ensure that data from diverse sources can be combined and jointly analysed (Wieczorek et al. 2012). For biodiversity knowledge transfer activities to contribute relevant biodiversity data, adhering to existing standards is necessary. A model that incorporates these data standards makes it easy for applications that utilise the model to adhere to such guidelines since development of the model was done with consideration of the biodiversity data standards.

1.8 CONTRIBUTION OF THE STUDY

The study contributed a model for online knowledge transfer between experts and citizens in the biodiversity management domain. The model, called the BiMaKT model, is the main contribution and answer to the main research question of the study. Other contributions were the result of answering the sub-questions of the study. The BiMaKT model outlines a set of processes that link the source of knowledge to the destination and is supported by two technologies, crowd computing and knowledge representation technologies, specifically ontologies.

Other key contributions made during the sub-cycles and iterative stages include:

- **Ontology of knowledge on fruit flies**: an ontology of fruit fly knowledge, which represents necessary knowledge for citizens to effectively manage the fruit flies.
- **Fruit fly knowledge transfer platform:** a platform that uses the BiMaKT model was developed and enabled expert and citizen participation in knowledge transfer. The platform uses the ontology of Fruitfly knowledge as source of expert knowledge and different crowd computing techniques to facilitate citizen participation in the knowledge transfer process.
- **A literature review of biodiversity knowledge transfer:** systematic literature review was performed on knowledge transfer models and a model that can be adopted for technology based transfer of biodiversity management knowledge identified.
- **A conceptual architecture for citizen-expert knowledge exchange in biodiversity informatics Crowd computing data:** The architecture provides a structure for conceptualization of applications that enable citizens to perform expert services supported by expert knowledge represented in ontologies.
- **Methodological contribution:** The development of the knowledge transfer platform resulted in a methodological contribution. The methodology proposes incorporation of a model to the Feature Driven Development (FDD) agile methodology.

1.9 STRUCTURE OF THE DOCUMENT

The thesis consists of five parts, and 10 chapters as depicted in Figure 1-2. Part I the introduction and background has three chapters consisting of the introduction to the study, the background and the research methodology used in conducting the study.

Part II, the awareness and suggestion has one chapter, Chapter 4 and presents a review and selection of a knowledge transfer model that is adopted for this research. The chapter also establishes ways in which the model can be enhanced using the selected computing technologies.

Part III presents the development phase and has three chapters: Chapter 5 presents ontological modelling of biodiversity management knowledge, Chapter 6 presents creation of a crowd computing model for biodiversity management knowledge transfer and Chapter 7 presents creation of a knowledge transfer model that combines both ontological modelling from Chapter 5 and crowd computing techniques from Chapter 6.

In Part IV, evaluation of the model and contributions of the study are presented in Chapter 8 and Chapter 9 respectively. Chapter 8, presents the evaluation of the model developed in Chapter 7. The evaluation is done using a case of application development using the model and an empirical experiment using a case of knowledge transfer in the control and management of fruit flies. Chapter 9 presents the contributions of the study consisting of the main contribution, secondary contributions and other contributions made during the study.

Part V is the conclusion and has one chapter, Chapter 10 which documents the conclusion of the study

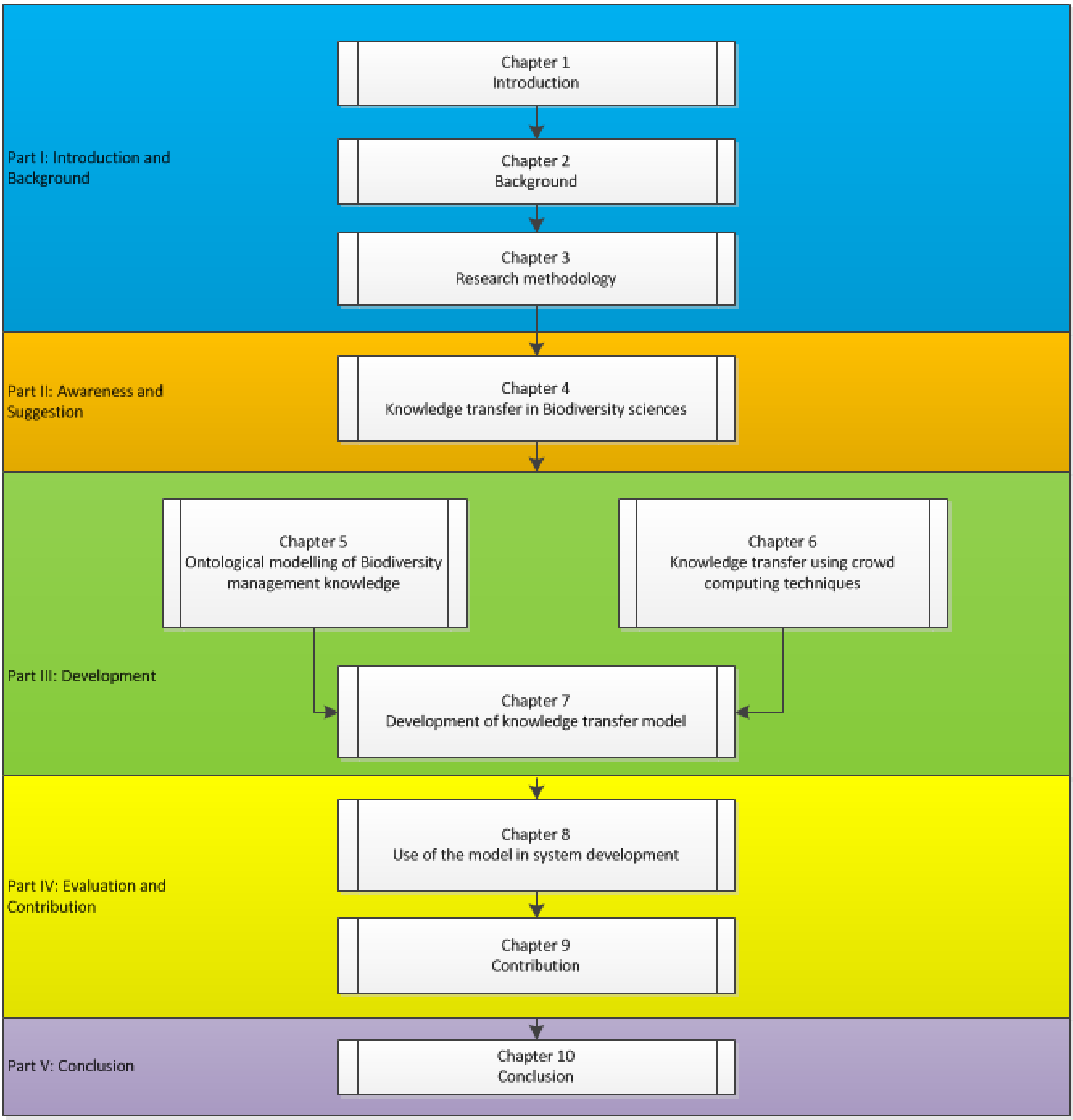

Figure 1-2: Outline of the study

Chapter 2 - Literature Review

2.1 INTRODUCTION

The purpose of this chapter is to provide the background knowledge on the concepts that contextualize the research question of the study presented in this thesis as highlighted in Table 2-1 below. The main concepts discussed includes an *overview of knowledge*, *knowledge transfer*, *knowledge transfer frameworks and models*, *knowledge transfer in biodiversity management*, and the computing technologies explored in the study, specifically: *ontologies and crowd computing*.

Table 2-1: Research questions

MQ: What are the components of an expert-citizen online *knowledge* transfer model for *biodiversity management*? SQ 1) Which *knowledge transfer model* is applicable for online expert-citizen knowledge transfer in biodiversity management? SQ 2) How can *ontologies* be used to capture biodiversity management expert knowledge? SQ 3) How can *crowd computing* techniques be used to facilitate biodiversity management knowledge transfer

The structure of this chapter is shown in Figure 2-1. In Section 2.2 the basic concepts of knowledge are introduced. This includes the definition of knowledge, types of knowledge and the knowledge creation process. The section introduces concepts relevant to all the chapters of this thesis. Section 2.3 delves into knowledge transfer and it begins with definition of what knowledge transfer is, followed by dimensions from which knowledge transfer has been studied. Two mechanisms of knowledge transfer namely: codification and personalization are the subject of focus at the end of the section. Codification is reviewed in detail in Section 2.3.4.1, while Section 2.3.3.2 is a review of the personalization mechanism. Section 2.3.4 is a review of frameworks and models for the knowledge transfer process. A review of computing technologies for codification and personalization are presented in Section 2.4 and 2.5 respectively. Section 2.6 consists of review of knowledge transfer in biodiversity management and provides the relevant background and foundation for a knowledge gap, presented in Section 2.7. Section 2.8 concludes with a summary of the chapter.

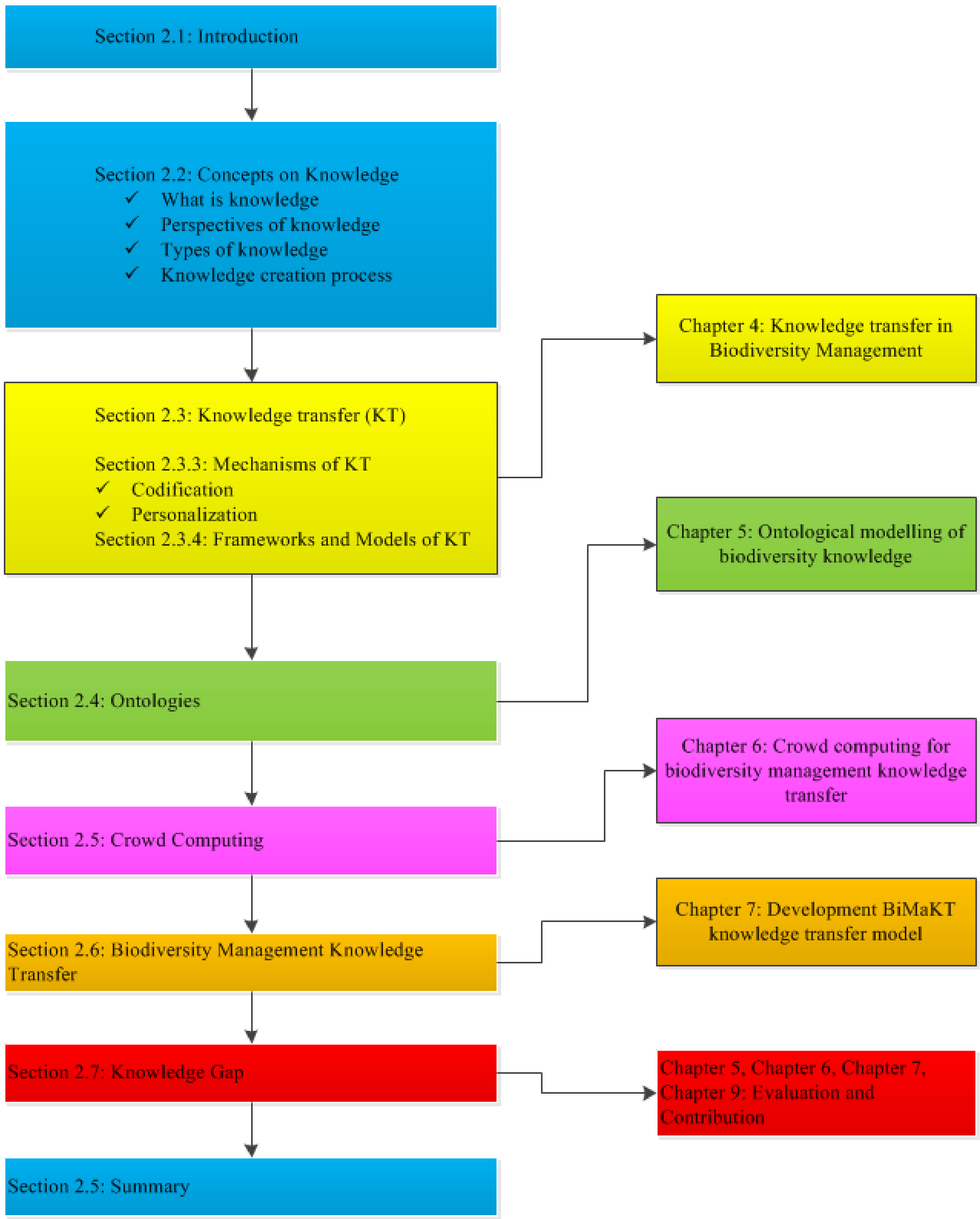

Figure 2-1: Chapter 2 outline: Literature reviewed and how it related to other chapters of the thesis.

2.2 BASIC CONCEPTS ON KNOWLEDGE

In this Section, literature on knowledge and knowledge transfer is presented. The section begins by delimiting what knowledge is and what it is not. After delimiting what knowledge is, the section proceeds with review on different perspectives on knowledge, different kinds of knowledge and the knowledge creation process. Review of these concepts sets the stage for review on knowledge transfer which follows in Section 2.3.

2.2.1 What is knowledge?

The definition of knowledge has been a subject of philosophical debates since the classical Greek era. Review of literature on these debates to seek the "Universal Truth" or redefine the term was not necessary in order to answer the questions of this thesis. However, various views on knowledge were considered from the Knowledge Transfer (KT) domain and other related domains such as Knowledge Management (KM),) and Information Technology (IT).

The term knowledge has been defined by different researchers. Examples include: - "Knowledge is authenticated information" (Vance 1997), Knowledge is "information made actionable" (Machlup 1993), and "Knowledge is a state of knowing" (Schubert et al. 1998). Davenport and Prusak (1998) emphasised that knowledge goes beyond data and information and defined knowledge as "a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and new information".

Researchers in ICT commonly define knowledge by distinguishing it from data and information. Fahey and Prusak (1998) pondered that "If knowledge is not something that is different from information and data, then there is nothing new and interesting about knowledge management". The same observation can be made with respect to knowledge transfer. To clarify the definition of knowledge from data and information, Alavi and Leidner (2001) defined data as raw numbers and facts, information as processed data and knowledge as authenticated information. In an effort to differentiate between knowledge and expertise, Bender and Fish (2000) defined and outlined the relationship between data, information, knowledge and expertise. They claimed that knowledge and expertise could have hierarchical relationship, and subsequent expertise is built from data and information as shown in Figure 2-2. Data is defined as discrete and objective fact without any judgement, information as data that meaning has been added through analysing for some purpose, knowledge as the outcome of transformation of information by individuals and incorporation of their own personal experiences and expertise as deep knowledge acquired over a long time through experience and added training.

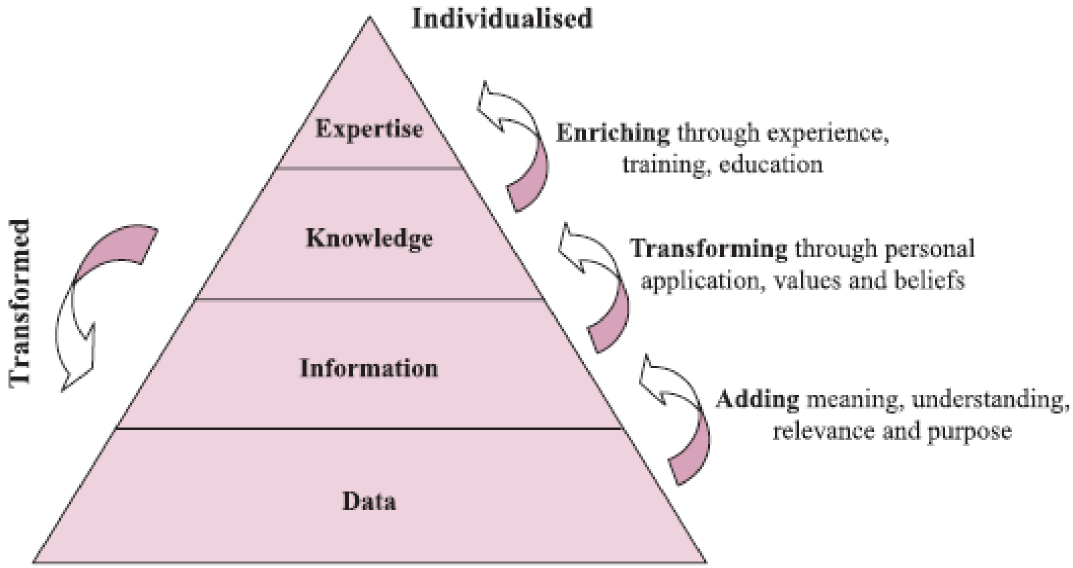

Figure 2-2: Knowledge Hierarchy (Bender & Fish 2000)

2.2.2 Perspectives of knowledge

Different perspectives of knowledge have been discussed in literature. Liyanage et al. (2009) noted that different perspectives of knowledge have led to different views on knowledge management. Alavi and Leidner (2001) identified different perspectives on knowledge and how they affect knowledge management (KM) and knowledge management systems (KMS). Five perspectives of knowledge are identified, namely: state of mind, object, process, access to information, and capability. The first perspective views knowledge as a state of mind which means that knowledge management focuses on exposing individuals to potentially useful information so that they can assimilate it and apply to practical situations. Knowledge management systems in this case are focused on providing sources of knowledge and not the knowledge itself. The second perspective views knowledge as an object which means that knowledge can be stored and distributed. Knowledge management focus on building and managing knowledge stock and knowledge systems focus on codification and distribution of the knowledge.

In the third perspective, knowledge is viewed as a process and therefore it is a process of applying expertise. In this perspective, knowledge management is focused on ensuring knowledge flow, specifically the processes of sharing and distributing knowledge. The fourth perspective sees knowledge as access to information and knowledge management is focused on structured access and retrieval of content. In the fifth perspective, knowledge is viewed as a capability and knowledge, therefore, seen as a potential to influence action. In this perspective of knowledge as a process, knowledge management is concerned with building core competencies and understanding strategic know-how. The implications of these perspectives on knowledge management are summarized in Table 2-1.

Table 2-1: Knowledge perspectives and their implications for KMS (Alavi & Leidner 2001)

Perspective	***Implications for Knowledge Management Systems (KMS)***
State of mind – State of knowing and understanding	Impossible for KMS to provide knowledge, instead IT is used to provide sources of knowledge.
Object – can be stored and manipulated	KMS is useful for gathering, codification and storage of knowledge
Process – of applying expertise	IT is used in linking knowledge sources to enhance knowledge flow.
Access to information – condition of access to information	IT is used to provide mechanisms for searching and retrieval of information.
Capability – potential to influence action	IT is used to enhance intellectual capital by supporting capacity building at individual and organizational levels.

2.2.3 Types of knowledge

Two types of knowledge are discussed in literature, i.e. tacit and explicit knowledge. Tacit knowledge is ‘‘non-verbalised, intuitive and unarticulated knowledge’’ (Polanyi 1962). The knowledge resides in human brains and cannot be easily articulated, captured or codified (Nonaka & Takeuchi 1995; Wong & Radcliffe 2000). Diffusing and acquiring this kind of knowledge is therefore done through sharing experiences and by observation (Alwis & Hartmann 2008; Koulopoulos & Koulopoulos 1999). A definition that captures all these aspects of tacit knowledge is presented in (Zack 1999) where tacit knowledge is defined as knowledge that ‘is subconsciously understood and applied, difficult to articulate, developed from direct experience and action, and usually shared through highly interactive conversation, storytelling and shared experience”.

Explicit knowledge, on the other hand, is knowledge that can be documented and codified easily (Nonaka & Takeuchi 1995). Explicit knowledge can be expressed in some language and conveyed to others. Explicit knowledge is knowledge documented in books, manuals, databases, websites or any other media. Explicit knowledge is different from tacit knowledge in a number of ways one of them being that tacit knowledge is knowledge of experience while explicit knowledge is knowledge of rationality.

Alavi and Leidner (2001) outlined other types of knowledge identified based on different factors. Based on how the knowledge was created; they identified individual knowledge created by individuals and social knowledge created by a group and their collective actions. Based on the actions that lead to knowledge, they identified automatic and conscious knowledge. Automatic knowledge is the individual’s subconscious tacit knowledge such as chewing gum. Conscious knowledge is explicit knowledge that has been learnt by an individual. Based on factors that are neither explicit nor tacit they identified declarative knowledge, which is knowledge about something, for instance. What are the ingredients of a certain food? Procedural knowledge which is knowledge on how to do something, for instance, how to install an operating system. Causal knowledge which is knowledge on why some things happen the way they do or what will happen as a result of something. Conditional knowledge is knowledge on the “know-when”, for instance, knowing when to prescribe a given drug. Relational knowledge is knowledge on something in relation to another, for instance, knowing the consequences of planting one type of plant near another type. Other types of knowledge described by Alavi and Leinder (2001) include objectified knowledge, which is codified knowledge of some system such as organizational procedures, collective knowledge, which is the tacit knowledge known to people within a certain system, for example, organizational culture and pragmatic knowledge, which is knowledge that is currently useful to an organization, such as, best practices, market reports and performance contracts.

2.2.4 Knowledge creation process

The knowledge creation process is an important component of research in knowledge management, research and practice, and knowledge transfer. In Giddens (1984) structuration theory, humans are seen as role-taking and norm fulfilling beings who act according to their perceptions on what reality is, and treats all institutions and social practices as structures. The human agency and social structures are therefore intertwined, and both are important perspectives in understanding social action. Giddens identified two levels of consciousness from which we enact our actions: discursive consciousness and practical consciousness. Discursive consciousness refers to things that the actors can express or “all those things that actors can say, put into words, about the conditions of their action” (Giddens 1983) while practical consciousness refers to “what actors know, but cannot necessarily put into words, about how to go on in the multiplicity of contexts of social life" and "unconscious sources of cognition” (Giddens 1979).

Nonaka and Toyama (2003) linked the process of knowledge creation to the structuration theory by Giddens (1984) and argued that knowledge is created and enlarged through interaction between human agency and social structures. They (Nonaka & Toyama 2003) observed that our discursive consciousness could produce explicit knowledge while our practical consciousness could produce tacit knowledge. Knowledge is therefore created and enlarged through processes of conversion of tacit and explicit knowledge (Nonaka 1991; Nonaka et al. 1994; Nonaka & Takeuchi 1995). In Nonaka and Toyama (2003), a knowledge creation model is outlined consisting of four processes, namely: Socialization, Externalization, Combination and Internalization. The model is named using the initials of its constituent processes; SECI model and is diagrammatically illustrated as shown in Figure 2-3.

In the SECI model, knowledge creation is a spiral process that traverses through the four processes. Knowledge creation process begins with Socialization, which is a process that converts knowledge from tacit to tacit. Socialization entails sharing tacit knowledge through day-to-day interactions that lead to sharing of experiences among actors. Actors absorb knowledge by being situated in the environment they need to learn from and acquire knowledge through practical consciousness of the interactions and actions that take place in this environment. Externalization is the second process of knowledge creation and deals with conversion of knowledge from tacit to explicit. This process entails articulating of tacit knowledge and translating it to make it explicit. This is done through dialogue and reflection among actors. The third process of the SECI knowledge creation model is combination, which converts knowledge from explicit to explicit. The process includes gathering and integrating explicit knowledge, transferring and diffusing explicit knowledge and editing of the knowledge to suit the context it is intended for.

The fourth and final process of the SECI model is the internalization process which converts knowledge from explicit to tacit. The process is aimed at applying explicit knowledge to practical applications and could lead to change, possibly improvement, of procedures. The explicit knowledge has to be assimilated and used by individuals so that it becomes new tacit knowledge that is applied in practice. The internalization process can be done through reading documents, through trainings, and through simulation and experiments. The next process is the socialization process which takes place with the new knowledge just introduced from explicit knowledge, and the spiral continues again through the processes.

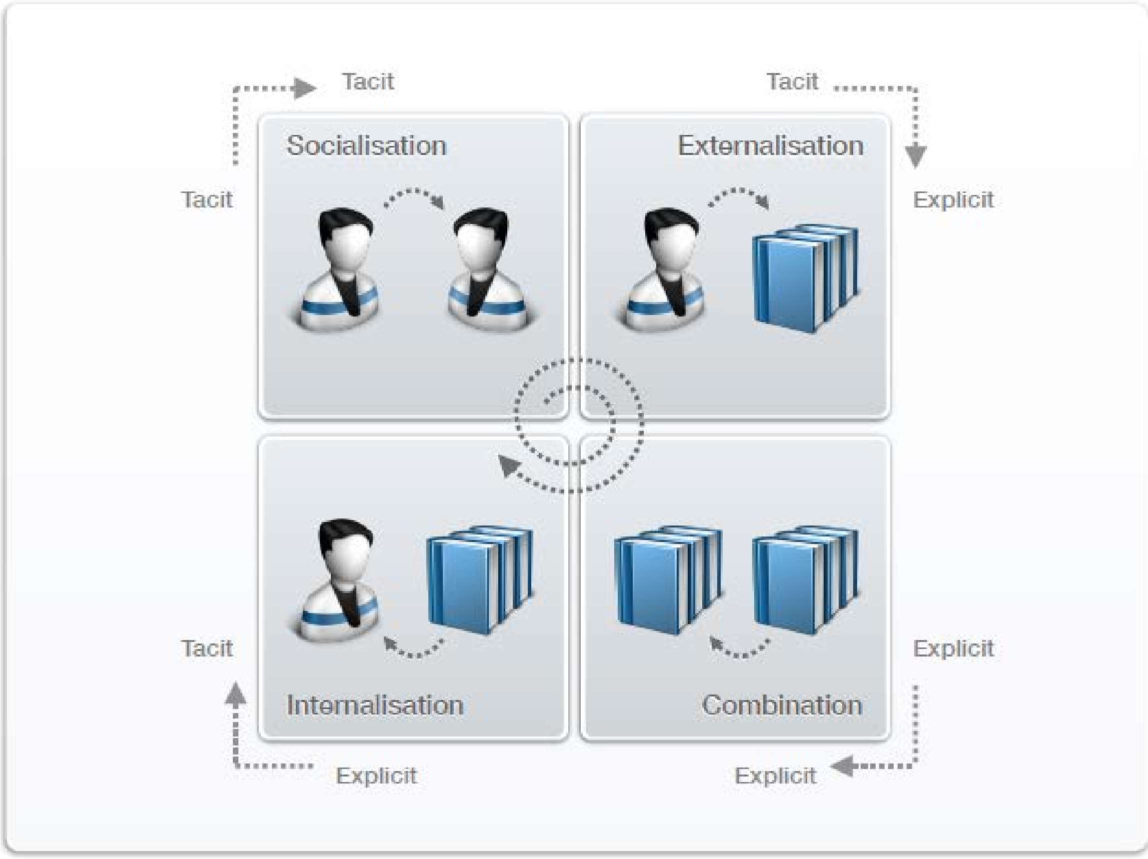

Figure 2-3: SECI model of knowledge creation (Nonaka & Toyama 2003)

2.3 KNOWLEDGE TRANSFER

In this section literature review on knowledge transfer is presented. The section begins with definition and background of knowledge transfer followed by research dimensions on knowledge transfer, knowledge transfer processes and concludes with mechanisms of knowledge transfer.

2.3.1 Definition of knowledge transfer

Knowledge transfer is the process by which one entity (e.g. person, group, department, and institution) is affected by the experience of another (Argote & Ingram 2000). It is the movement of knowledge from one group to another. In Carlile and Rebentisch (2003), knowledge transfer is defined as an area in knowledge management that is concerned with integration of knowledge across the boundaries created by specialized knowledge domains. Darr and Kurtzberg 2000) define knowledge transfer as an event through which one unit learns from another. Knowledge transfer is also defined as a process that involves either actively seeking to communicate to others what one knows, or actively consulting others in order to learn what they know (van den Hooff & De Ridder 2004). Another definition available in literature is "Knowledge transfer is about identifying (accessible) knowledge that already exists, acquiring it and subsequently applying this knowledge to develop new ideas or enhance the existing ideas to make a process/action faster, better or safer than they would have otherwise been. So, basically knowledge transfer is not only about exploiting accessible resources, i.e. knowledge, but also about how to acquire and absorb it well to make things more efficient and effective" (Liyanage et al. 2009).

Although different definitions of knowledge transfer have been proposed in literature, most researchers agree that the fundamental requirement for knowledge transfer is the presence of a knowledge source and knowledge receiver (Hendriks 1999; Kumar & Ganesh 2009; Major & Cordey-Hayes 2000; Liyanage et al. 2009). In Liyanage et al. (2009) and in Kumar and Ganesh (2009), simple models that capture key concepts of knowledge transfer are presented (see Figure 2-4). The models indicate that knowledge can be transferred from source to receiver by adopting some process model for knowledge transfer (Liyanage et al. 2009) or a knowledge transfer process (Kumar and Ganesh 2009). In the model presented by Kumar and Ganesh (2009) the possible agent types are listed, and they include: individual, team, unit, organization or cluster.

The term knowledge sharing is closely related to knowledge transfer, and some authors use the two terms interchangeably. Paulin and Suneson (2012) surveyed the use of these terms in literature and noted that in earlier writings, the two terms were used interchangeably but in more recent literature, notable separation between the contexts in which the two terms are used seems to be emerging.

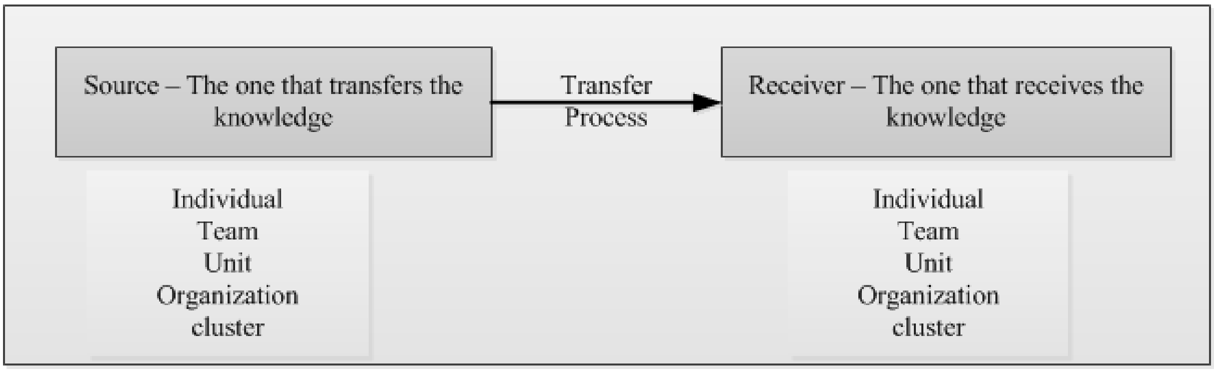

Figure 2-4: A simple model for Knowledge transfer (Kumar & Ganesh 2009)

Although the distinction between the two terms is not mutually exclusive, there is a pattern in literature to use the term knowledge transfer where groups, departments or organizations are involved and knowledge sharing where sharing between individuals is involved. It is, however, worth noting that some authors still use the term knowledge transfer where individuals are involved, for instance, Liyanage et al. (2009) and Kumar and Ganesh (2009) describe knowledge transfer between actors, and the actors could be individuals.

The factors that influence the success or failure of knowledge transfer have been discussed in literature, and they include: - the properties of the actors (source and recipient) such as their abilities to disseminate and to absorb the knowledge (Cohen & Levinthal 1990), their passion and perceptions (Sié & Yakhlef 2009); properties of the relationship between the parties involved (Argote et al. 2003; Joshi & Sarker 2007); and properties of the knowledge itself, such as the complexity of the knowledge, extent to which the knowledge is explicit or tacit (Nonaka et al. 1994), internal or external knowledge (Menon & Pfeffer 2003) and ambiguity of the knowledge (Szulanski 1996).

Success of knowledge transfer is not in replicating the knowledge of the source at the receiver, but rather, it is in contextualising the knowledge at the receiver's end so that it is useful and can therefore be utilized by the receiver (Foss & Pedersen 2004; Seaton 2002). Seaton (2002) explains the process of knowledge transfer as involving contextualizing at the receiver's end, and instead of saying, "this is what I know", the knowledge transfer process should say, "this is what my knowledge means for you". The process of knowledge transfer should therefore perform the necessary translation and transformation so that the knowledge is useful to the receiver.

For the purpose of the study presented in this thesis, the definition of knowledge transfer adopted is the definition presented by Liyanage et al. (2009) and knowledge transfer is defined as the 'process of identifying (accessible) knowledge that already exists, acquiring it and subsequently applying this knowledge to make a process/action faster, better or safer than they would have otherwise been'. The study assumed the view that success of knowledge transfer is measured by the availability of the knowledge for practical application among the targeted recipients of the knowledge (Seaton 2002).

2.3.2 Dimensions of knowledge transfer research

As stated in the introduction, research in knowledge transfer has been done in different dimensions, including study, knowledge, agents, flow, mechanism, contextual factor, geography, business context, policy, strategy and transfer process (Argote et al. 2003; Kumar & Ganesh 2009; Major & Cordey-Hayes 2000). The *study dimension* looks at the underlying design of the research. Most research in knowledge transfer adopted the theoretical, case study based, cross-sectional and longitudinal designs. The possible options identified under the study dimension include: theoretical (Tallman et al. 2004), case study based (Boh 2007), cross sectional (Reagans & McEvily 2003), longitudinal (Dyck et al. 2005) and experimental. Research on the *knowledge dimension* view knowledge transfer research from the knowledge type, i.e. explicit and tacit perspectives. Explicit knowledge is perceived to be easier to transfer since it can be documented and transmitted to interested parties while tacit is considered more challenging since knowledge receivers have to spend time with the source and observe in order to acquire it (Nonaka & Takeuchi 1995). Different research has been done to examine transfer of explicit as well as tacit knowledge, for example; transfer of explicit knowledge is studied in Gera (2012), transfer of tacit knowledge is examined in Louise Hamilton et al. (2014) and in McBeath (2012) transfer of both explicit and tacit knowledge is examined.

The dimension of *knowledge agents* deals with the participants in knowledge transfer, including the source and the receiver. Kumar and Ganesh (2009) describe it as the perspective that looks at "between whom does the knowledge transfer take place"? Possible categories of agents involved in knowledge transfer include individuals, teams, firms, diversified firms, novices and experts. Research adopting this dimension also looks at transfer across different combinations of agents. The flow of knowledge dimension investigates the direction of flow of knowledge depending on the "focal point" defined in the study. The *flow dimension* has two options, namely: internal inflow and outflow. Internal flow is where the transfer is within the focal entity, for example, in Joshi and Sarker (2007) the focal entity is Information Systems (IS) development teams and knowledge transfer is within the IS teams. Inflow is where knowledge is flowing from an external source to the focal point while outflow is flow from the focal point to an external receiver.

The *mechanism dimension* of knowledge transfer is concerned with answering the question of "how" knowledge is transferred (Kumar & Ganesh 2009). Research has been conducted on how movement of people, tools, tasks and networks are mechanisms to knowledge transfer (Argote & Ingram 2000; Berry 2006; Takii 2004; Winter & Szulanski 2001). Other sub dimensions studied under the mechanisms of knowledge transfer includes codification of knowledge, which results in virtual movement of knowledge (Watson & Hewett 2006) and personalization of knowledge, which involves connecting people and enabling them to learn from each other (Borgatti & Cross 2003). *Contextual factors* is another dimension that knowledge transfer has been studied, and they are believed to enable or inhibit knowledge transfer. In Kumar and Ganesh (2009), five categories of contextual factors are identified, namely: cognitive (Borgatti & Cross 2003), social-psychological (Bock et al. 2005), social (Collins & Smith 2006), structural (Gold et al. 2001) administrative (Lee & Choi 2003).

Cognitive factors include facets such as knowledge about knowledge, i.e. meta-knowledge, specifically where and with whom is the different kinds of knowledge; depth and breadth of the knowledge in the knowledge areas of interest; expertise available which focus on the know-how of various skills; nature of knowledge which looks into ability of individuals/firms to acquire, absorb and apply new knowledge and the learning orientation which studies the individual/firm intrinsic characteristic to continuously build a knowledge base by learning and generating new knowledge (Cohen & Levinthal 1990; Szulanski 1996; Gray & Meister 2004; Wasko & Faraj 2005). Social-psychological research in knowledge transfer focus on the social contexts that influence people's thoughts, feelings and causes of behaviour.

The social-psychological factors have a direct influence on people's decision to share or not to share knowledge (Bock et al. 2005; Bordia et al. 2006; Renzl 2008). Research in the social dimension of knowledge transfer look at the social contexts in which knowledge transfer is done, for instance, the interpersonal relationships between employees and nature of social networks among knowledge sharing units (Hansen 1999). The structural dimension includes research that look at how organizational structures and how knowledge management activities are arranged to influence knowledge transfer (Söderquist 2006). Such structures include physical structure, tools, systems, networks and knowledge repositories at the workplace (Borgatti & Cross 2003; Gold et al. 2001; Lee & Choi 2003; Watson & Hewett 2006). The last sub dimension of contextual factors is the influence of administrative factors in knowledge transfer. Administrative factors include organizational policies, procedures, organograms and definition of roles (Alavi et al. 2005).

The *geography dimension* of knowledge transfer constitutes research which has been done across defined geographical locations. Different kinds of knowledge transfer across geographical boundaries is seen in literature consisting of those that transfer knowledge in subsidiaries across country boundaries (Birkinshaw & Arvidsson 2007; Foss & Pedersen 2002; Gupta & Govindarajan 2000) and regional clusters (Tallman et al. 2004; Dahl & Pedersen 2004). Research that consider knowledge transfer within the business context dimension is available in literature. Kumar and Ganesh (2009) argue that it is possible to conceive knowledge transfer in any business context. Examples of business contexts include manufacturing (Appleyard 1996), R & D (Rothaermel & Thursby 2005), product development (Hoopes & Postrel 1999), software development (Joshi et al. 2007), innovation and retail and franchises (Darr et al. 1995).

Research on the strategy dimension of knowledge transfer is highly varied, for instance, evaluation of knowledge transfer as a strategic tool to improve an organization’s performance (Tsai 2001; McLaughlin 2010), seeking to achieve knowledge transfer using strategic alliances (Narteh 2002; Mowery et al. 1996) and review and development of knowledge transfer strategies (Gera 2012; Jacobson et al. 2005; Roux et al. 2006; Winter & Szulanski 2001) among others. Research that looks at the *knowledge transfer process* and focuses on the total process of knowledge transfer from source of the knowledge to the receiver (Graham et al. 2006; Major & Cordey-Hayes 2000; Martin et al. 2012; Liyanage et al. 2009). The outcome or research in this dimension is mainly frameworks or models that document the process that can be adopted to attain successful knowledge transfer.

In this study, the main focus is on the knowledge transfer process dimension, but it also includes different components from the other dimensions as outlined in Table 2-2. The knowledge transfer process and the mechanisms of transfer are discussed in the next section.

Table 2-2: Knowledge transfer dimensions for this research

Dimension	Study focus
Process	Whole process
Mechanisms	codification and personalization
Knowledge type	Explicit

Dimension	Study focus
Agents	Experts and citizens (novices)
Flow	Bi-directional

2.3.3 Knowledge transfer process

In this section a review of literature on the knowledge transfer process is presented. As stated earlier, knowledge transfer process has been described using frameworks and models (Major & Cordey-Hayes 2000). A knowledge transfer process is the set of steps taken to transfer knowledge from source to receiver. The focus of this section is on the model adopted in this study and is the knowledge transfer process model developed by Liyanage et al. (2009). The process model is based on two theories; the communication theory and the translation theory.

The Liyanage et al. 's model has five integral processes namely awareness, acquisition, transformation, association and application as shown in Figure 2-5 (Liyanage et al. 2009):

- The awareness process deals with identification of the suitable knowledge resources and its output is the required knowledge.
- The acquisition process is concerned with the acquisition of the required knowledge and requires cooperation and ability of both knowledge source and knowledge receiver. The output of the acquisition process is the data and information; and is the input to transformation process.
- The transformation process happens at receivers' end and deals with conversion of knowledge to a form usable at receiver's end. Transformation can be achieved through an activity such as translation, making it transformed knowledge. The transformed knowledge is then subjected to a process of association.
- The association process takes the transformed knowledge and links it with the receiver's context resulting in useful knowledge.
- The useful knowledge then becomes the input to practical application at the receiver's side completing the knowledge transfer process.

The model also includes a knowledge externalization and feedback process which deals with feedback to the knowledge source from the receiver.

Liyanage et al. (2009) identified four prerequisites on the source and receiver in the knowledge transfer process as outlined below: -

- Identifiable relevant knowledge source (Source)
- Willingness of the source to share knowledge(Source)

- Willingness of the receiver to receive knowledge (Receiver) and
- Absorptive capacity of the receiver (Receiver).

The demand for absorptive capacity on the side of the receiver is a major barrier to knowledge transfer and especially in biodiversity management. The receiver needs to be able to apply the knowledge in interpretation of their own situation in order to use it. A knowledge transfer model that can reduce absorptive capacity requirements is therefore more relevant in the field.

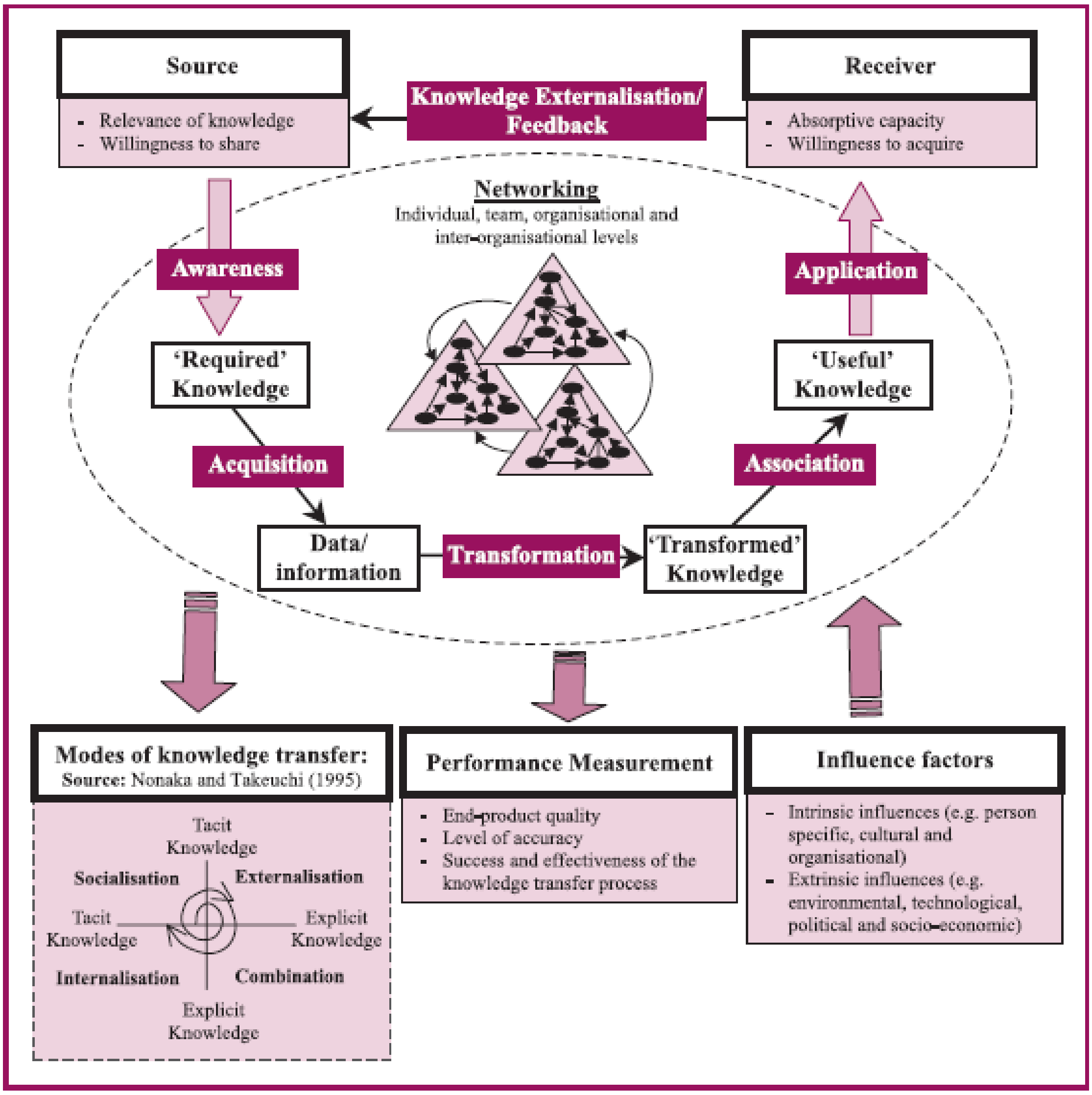

Figure 2-5: A process model for knowledge transfer (Liyanage et al. 2009)

2.3.4 Mechanisms of knowledge transfer

In this section, the review is on two dimensions of the knowledge transfer mechanisms, namely codification and personalization (Kumar & Ganesh 2009). Personalization is sometimes called tacitness (Schulz & Jobe 2001). Researchers in the knowledge management have had divergent opinions with respect to these two mechanisms as strategies of knowledge sharing with some pro codification (Gupta & Michailova 2004; Zack 1999) while others are pro personalization (Davenport & Prusak 1998; Liebowitz 2001). Others have taken a middle ground routing for combination of both approaches and argue that there is no right approach but rather choices should be made based on the context and specific project objectives (Hansen et al. 1999; Jasimuddin 2008; Tiwana 2000).

2.3.4.1 Codification

The Compact Oxford English Dictionary of Current English (Soanes & Hawker 2006) defines *to codify* as 1) to put (laws or rules) together as a code or system and 2) to put (things) in an orderly form. In the knowledge management domain, codification has been used to mean different things, and some examples are presented next. Cowan and Foray (1997) define codification as "the process of conversion of knowledge into messages, which can be then processed as information". Codification is seen as the process of structuring of knowledge into a set of identifiable rules and relationships that can be easily communicated (Kogut & Zander 1992). Schulz and Jobe (2001) view codification as a process of packaging organizational knowledge into formats that facilitate knowledge transfer. Argote and Ingram, (2000) have a similar perspective that codified knowledge is easier to transfer. Other authors also viewed codification as a vehicle through which knowledge becomes portable, transferable and re-usable (Ruggles 1997; Davenport & Prusak 1998). Codified knowledge that is stored in databases can easily be searched, accessed and used by recipients without the need to refer to the knowledge contributor (Hansen et al. 1999)

A common debate in knowledge codification is the role of Information Communication Technologies (ICTs) in codification of knowledge. Different views are presented in literature with some seeing knowledge codification as some kind of knowledge capture that exists outside the use of ICTs (Spender 1996; Tsoukas 1996; Tiwana 2000; Steinmueller 2000) while others present the views that meaningful codification happens with the use of ICTs and real benefits of codification are attainable with use of computers (Zuboff 1996; Hansen 1999).

The codified knowledge needs to be decodified for the recipient and different researchers therefore discuss the need to consider knowledge decoding when planning for codification (Steinmueller 2000; Hall 2006). Hall (2006) notes that a critical consideration in knowledge transfer is understanding how to generate the closest possible coalescence between the codification and de-codification processes. The importance of an end-to-end process in codification and de-codification is discussed in McLaughlin (2010). Another critical proposal is made by Cohendet and Steinmueller (2000) where they suggested the possibility to use collective efforts to define and use standards for knowledge codification.

In this thesis we take the view that the primary objective of knowledge codification is to allow ease of transfer between knowledge and practice communities (Argote & Ingram 2000; Cowan & Foray 1997; Kogut & Zander 1992; Schulz & Jobe 2001).

2.3.4.2 Personalization

Personalization mechanism assumes a direct person-to-person approach in transferring knowledge (Hansen et al. 1999; Richter & Stocker 2011). Personalization is implemented using different strategies, for instance, enabling individuals and teams to work together and therefore, exchange knowledge in the course of working; scheduling meetings and interaction sessions for individuals to exchange knowledge, including one-on-one mentoring; rewarding individuals and teams for direct sharing of knowledge; developing networks of people that facilitate flow of knowledge across the network; and investing in ICTs that foster person-to-person knowledge transfer rather than creating repositories for knowledge. The main purpose of ICTs in personalization mechanism is to help people communicate knowledge, not to store it as in the case of codification (Hansen et al. 1999). The focus is therefore not in standardizing formats of knowledge transfer and structuring the knowledge but rather in ensuring there is understanding between the source and receiver. ICTs support should focus on facilitating conversations, video conferencing, discussion forums and other tacit knowledge transfer technologies (Tiwana 2000).

As mentioned in the introduction of this section, the decision to adopt a pro-codification or pro-personalization approach is dependent on the organization's business model, objectives and priorities. Tiwana (2000) demonstrates that adopting a purely codification approach with no personalization is bound to fail. The question, therefore, is in the degree of use of each approach. In terms of the organization's business model, the codification approach is found useful for organizations that deal with similar problems that require similar decisions over and over while the personalization approach is suited for organizations that deal with unique problems each time and require creativity in solving each problem. In Tiwana (2000) a framework to guide the choice of approach between codification and personalization is presented; the need to find the right balance of both approaches is emphasised.

2.3.5 Computing technologies in knowledge transfer

As stated earlier, knowledge transfer process can adopt a pro-codification approach, pro-personalization approach or take a middle ground and combine the two approaches. This research study combines codification and personalization using selected computing technologies. The objective of codification of knowledge is to structure and package the knowledge in a format that can be easily communicated, transferred and re-used (Schulz & Jobe 2001; Davenport & Prusak 1998; Ruggles 1997; Kogut & Zander 1992). Use of computing technologies in codification has been found to provide great benefits since it allows easy analysis, retrieval and search of the knowledge. Personalization encourages person-to-person support in knowledge transfer through some form of interaction. As stated in Section 2.3, computing technologies used in personalization are those that support person-to-person interactions in the knowledge transfer process.

This research reviewed different technologies for codification and personalization mechanisms of knowledge transfer. A review of the technologies used is presented next followed by a review of codification of biodiversity management knowledge in Section 2.4 and in Section 2.5, a review of personalization technologies for biodiversity management knowledge.

2.4 TECHNOLOGIES FOR CODIFICATION OF BIODIVERSITY KNOWLEDGE

This study is concerned with three categories of knowledge as delimited in Section 1.6 namely taxonomic knowledge, knowledge about the relationships between organisms and knowledge of chemicals that can be used to control different organisms. In this section, a review on formats used to represent these kinds of knowledge is presented. Attempts to represent biodiversity knowledge in formats that can be processed by computers can be traced back to representation of taxonomic knowledge for purposes of supporting taxonomic services (organism identification and taxonomic revisions). The taxonomic applications were designed into two distinctive parts, the description of the taxon stored in standardized file formats, mostly matrices (Penev et al. 2009) and the software programmes that traverse the descriptions for identification or any other defined use. The focus of this section is on the data formats that could be used to store the knowledge.

2.4.1 DELTA data Format

The DELTA (DEscription Language for TAxonomy) standard was developed in 1980 with the primary drive being to facilitate data sharing across many applications, or simply put data re-use (Dallwitz 1980). Dallwitz observed that when taxonomic data is captured, the form of representation is largely driven by the requirements of the system being developed. Dallwitz noted that the potential advantages of automation, especially in connection with large groups of taxonomic data, cannot be realized if the data have to be manually restructured for every application. This motivated the development of the DELTA data standard which was primarily for use by people in recording data and not computer programmes, meaning that the format was used in capturing data even in cases where computer processing was not anticipated. The essential components of DELTA data format are normally the character list, the taxon or item descriptions, the character types, the implicit values, and the character dependencies (Dallwitz et al. 2013). Other information can be inferred from the above, but in programming cases it is preferred if stated explicitly. The catch in using the DELTA format is in ensuring the directives are properly coded for use by all systems. Although systems can skip directives that are meaningless to it, this presents the possibility of duplicating similar directives by using different naming for different systems

2.4.2 Lucid Interchange Format (LIF):

The LIF files are XML documents containing all the data (features, entity lists, item properties, and scores properties and media attachments) for a key. LIF format is the format used in the Lucid applications and has undergone revisions alongside the Lucid applications (Lucid2, Lucid3), with Lucid 3 being the latest version. Lucid 3 uses the SDD (See below) data standard. The main use of the Lucid application is for organism identification and its data formats are described and optimized for this purpose.

The most widely used descriptive format for taxonomic revisions data is DELTA, while Lucid is popular for creating keys (Pullan et al. 2005). These data formats are built based on a basic element of representation often referred to as a character. Notable differences, however, exist in the interpretation of character across the formats. Colless (1985) found nineteen different explicitly stated or clearly implied definitions of character. The other major challenge with the character-based standards is the variations introduced during the derivation of character concepts (Pullan et al. 2005) that are not logically interconnected. This is because, whereas the formats agree that the basic definition is the character, the process of derivation is largely open. This leaves a lot of room for variation, and yet the analysing programmes depend on these character descriptions to extract matching data sets.

From the overview above, it is clear that the data formats are tied to applications; with the DELTA data format being used in DELTA applications and Lucid Interchange Format (LIF) used in Lucid applications. The need to share data across platforms resulted in creating data porting applications making it possible to port data across the DELTA and Lucid applications (Penev et al. 2009; Smith 2000). The shortcomings of character based data formats is recognized by researchers, prompting efforts to look for better methods to represent taxonomic data. Among the alternatives that have captured researchers attention is the use of XML and semantic technologies. In the Sections 2.2.3 and 2.2.4 the XML based, SDD standard and ontologies as options for biodiversity knowledge codification are discussed.

2.4.3 Structured Descriptive Data (SDD) Formats

In 1998, the Taxonomic Databases Working Group (TWDG) initiated a process to develop a new interoperability standard for descriptive data. This new standard was to succeed existing program dependent, proprietary standards like DELTA, NEXUS, or XDF. The SDD standard borrows heavily from DELTA, and is done in XML. It is, however, not a conversion of DELTA to XML as it addresses the weaknesses of DELTA identified by DELTA users and the software-development teams as well (Dallwitz et al. 2007; Dallwitz 1980). The goal of the SDD standard is to allow capture, transport, caching and archiving of descriptive data using a platform & application independent, international standard (Hagedorn et al. 2005). This in return ensures the possibility of porting data across platforms and the analysis of data from federated data stores.

2.4.4 Ontologies

An ontology is a formal representation of some aspect of reality using a formal (machine readable) language, and this allows deductions/inferences to be made based on the represented facts (Guarino et al. 2009). Use of ontologies in representing knowledge has several advantages over the other forms of representation, for example: - the possibility for humans and machines to have a common understanding of represented knowledge, the possibility to use a reasoner (algorithm) to extract both explicit and non-explicit facts represented in the ontology and the possibility to have multiple annotations over the same underlying facts in the ontology (see Chapter 5 for detailed definition and discussion on ontologies). Codification of knowledge using ontologies in the area of biology and biodiversity, though still at explorative stages, is not entirely new. The field is characterized by different ontologies used to represent different aspects of biological and biodiversity knowledge.

Ontologies have been used to represent knowledge in almost the entire spectrum of biological and ecological sciences. For example, the Gene ontology (Ashburner et al. 2000) representing knowledge on molecular functions, biological processes and cell components, the Plant ontology (Avraham et al. 2008; Jaiswal et al.

2005), which links plant anatomy, morphology, growth and development to plant genomics data, Mouse gross anatomy ontology (Hayamizu et al. 2005) representing knowledge on the anatomy of adult mice, mapping ontologies (Bodenreider et al. 2005; Gross et al. 2011) that map different life sciences ontologies and HAO ontology (Yoder et al. 2010) which contains knowledge on the gross anatomy ontology for Hymenoptera. More biological ontologies are hosted at the OBO Foundry ontologies website (http://www.obofoundry.org/).

Biodiversity management efforts between experts and citizens mostly rely on external observable traits of different organisms. The nature of knowledge transfer, therefore, relies on such observable traits, and codification approaches must focus on traits of this nature. A search for traits ontologies in the in the OBO Foundry ontologies website found five ontologies that model traits knowledge: - Flora Phenotype Ontology (FLOPO) which contains knowledge on traits and phenotypes of flowering plants (Thessen et al. 2015); Ontology of Biological Attributes (OBA) which contains a collection of biological attributes covering all kingdoms of life (Dietze et al. 2014); Plant Trait Ontology (TO) which contains phenotypic traits of plants (Jaiswal et al. 2005); and Vertebrate Trait (VT) ontology which contains biological traits of vertebrates (Park et al. 2013). Another ontology that models morphological traits is the Afrotropical Bee Ontology which contains taxonomic knowledge on different species of afrotropical bees (Gerber et al. 2014).

Ontologies are either extensions of other ontologies or are independently created on their own. Depending on the kind of questions that the ontology is intended to answer, each ontology is done based on a model that allows representation of all the intended knowledge. The model can be adopted from existing models or developed if existing models do not satisfy the needs of the ontology being developed. This research examined the model structure of different traits ontologies with the intention to identify a modelling style that could be adopted for modelling biodiversity knowledge for citizen use (See Chapter 5 and Appendix II for review of different ontology models). The review found that the existing models were not sufficient for representation of biodiversity management knowledge and therefore, there was need to create a model for representing the different categories of traits knowledge.

2.5 TECHNOLOGIES FOR PERSONALIZATION OF BIODIVERSITY KNOWLEDGE

As stated in Section 2.3.4.2, a personalization strategy of knowledge transfer is concerned with creating opportunities for person-to-person interaction, which results in inter-personal knowledge transfer. A personalization strategy, therefore, does not invest heavily in technologies for creating knowledge repositories but rather in communication technologies and human resource. Technologies for personalization, therefore, focus on facilitating person-to-person communication and interaction, which result in the transfer of knowledge. Personalization technologies are not aimed at replacing the person, but rather, they are aimed at bridging spatial and temporal differences between participants in knowledge transfer. Personalization technologies include those that bring together communities of practice to engage and share knowledge (McMahon et al. 2004), for example, telephonic, emails, messaging, video conferencing and different forms of collaboration technologies. In this research, an emerging technology – crowd computing – is examined for use in the personalization of biodiversity knowledge transfer. In Section 2.5.1, the use of crowd computing in transfer of biodiversity management knowledge is reviewed.

2.5.1 Crowd computing

Crowd computing is an emerging computing paradigm and like many new concepts, it does not have a unified definition but rather different definitions exist from various authors (see Chapter 6 Section 6.2.1 for some definitions). In this research crowd computing is defined as a computing paradigm characterized by "participation by a crowd of humans, interaction with computing technology, activity that is predetermined by the initiator or application itself and the execution of tasks by the crowd utilizing innate human capabilities" (Parshotam 2013).

Different taxonomies for classifying crowd computing applications have emerged, for example: - crowd-task-based classification into micro-tasks and mega-task categories (Good & Su 2013); Yuen et al's (2011) crowd computing aspect-based categorization into application, algorithm, performance and dataset classes; and implementation model-based categorization consisting of web 2.0, social computing, crowdsourcing, human computation and crowd-computer interaction (Gomes et al. 2012; Parshotam 2013; Schneider et al. 2012). This study adopted the implementation model based categorization and the different forms of crowd computing (web 2.0, social computing, crowdsourcing, human computation and crowd-computer interaction) are described in Chapter 6, Section 6.2.2.

Although not under the banners of knowledge transfer or crowd computing, the different forms of crowd computing have been used in biodiversity-related research and practice. Web 2.0 has been used in different online citizen science projects to bring together scientists and citizens in biodiversity projects, for example, bird count project (Lebaron 2009), general species monitoring projects (Agrin et al. 2014) and digitization projects (Ellwood et al. 2015). Crowdsourcing has been used in the collection of species data (He & Wiggins 2015; Matheson 2014), annotation of species imagery (Welinder, S Branson, et al. 2010), and digitization of biological records (Ellwood et al. 2015). Social computing has been used in species monitoring (Agrin et al. 2014; Gardiner et al. 2012). Human computation has been used in digitization (Welinder, S Branson, et al. 2010; Ellwood et al. 2015). A detailed analysis on the use of crowd computing in biodiversity sciences is presented in Chapter 6 Section 6.4.1.

It can be noted that like other domains, use of crowd computing techniques in the area of biodiversity sciences has been introduced in an ad hoc and project specific manner (Yuen et al. 2011). The literature reviewed together with practical applications highlighted above indicates that use of the crowd computing techniques in the biodiversity domain is new and still at explorative stages. Also it can be noted that the application areas are mostly in citizen engagement in species monitoring and data cleaning. It can also be noted that some projects are a shift from traditional paper-based species monitoring citizen science to online environment (Sullivan et al. 2009; Lebaron 2009; Gardiner et al. 2012). Finally, it can be noted that the crowd computing technologies are mostly used to transfer ground knowledge from citizens to experts and not vice versa.

2.6 KNOWLEDGE TRANSFER IN BIODIVERSITY MANAGEMENT

2.6.1 Overview and Context

According to DeLong (1996), Biodiversity is an attribute of an area and more specifically refers to the variety within and among living organisms, assemblages of living organisms, biotic communities, and biotic processes, whether naturally occurring or modified by humans. Biodiversity can be observed and measured at any spatial scale ranging from micro-sites and habitat patches to the entire biosphere; that is local and global biodiversity. Biodiversity management has gained a lot of attention in the past decade, especially in the wake of climate change and its role in enhancing quality of human life through providing natural resources for ecosystem services and economic enterprises.

Effective management of biodiversity requires knowledge both at temporal and spatial scales. This means that data has to be collected for long time and across different spatial ranges (local and global). Achieving such a goal is a complex task and different researchers have pointed out the need to deliberately design systems to address this global knowledge need. Bisby (2000) points out a central goal in biodiversity informatics as the need to develop systems that permit interoperability and knowledge synthesis across wide arrays of local systems, and to embed them in global knowledge architectures. Thessen et al. (2012) discussed the requirement for a cyber-infrastructure that organizes an open pool of biological data for managing large amounts of heterogeneous data for this Big New Biology. If biodiversity data resources are organized and integrated well, the potential for such a knowledge fabric is enormous. Canhos et al. (2004) noted that such a fabric would facilitate ecological predictions of diverse species, prediction of infectious diseases vectors, prediction of invasive species and prediction of impact of different activities that affect biodiversity.

Management and conservation of biodiversity is done through coordination of international, regional and country organizations (Heller & Zavaleta 2009). For instance, globally, the United Nations' Convention on Biological Diversity (CBD) was established with the goals of ensuring conservation of biodiversity, sustainable use of natural resources and equitable sharing of benefits from genetic resources. Since its establishment, the CBD has been driving the biodiversity agenda through establishing international laws, measures for conservation, incentives for conservation, technical and scientific cooperation, impact assessments, capacity building, technology transfer, education, public sensitizations and awareness among other activities all aimed at biodiversity conservation. Besides the CBD, other environmental conservation efforts are continuously recognizing the importance of participatory approaches, where scientists and citizens are involved in conservation activities (Cooper et al. 2007; Reed 2008). The focus of this research is on the engagement of scientists and citizens in biodiversity management activities. The research looks at knowledge transfer between the two categories of actors in biodiversity management.

2.6.2 Mechanisms of knowledge transfer between experts and citizens in biodiversity management

It can be argued that knowledge transfer in biodiversity is an old age practice that can be traced back to when shamans and healers started teaching their offspring different names of plants and their uses and therefore, the only thing that has changed over time is the mechanisms (Heidorn 2011). The field of biodiversity management is characterized by vast knowledge both explicit and tacit. The focus of this research is on transfer of explicit knowledge, and the review in this section will therefore focus on transfer of explicit knowledge.

Biodiversity knowledge transfer from experts and citizens has been largely accomplished using simplified field guides and pamphlets that contain explicit knowledge packaged by experts for citizen use (Behler & King 1979; Hawthorne & Lawrence 2013; Little et al. 1997). These materials are provided in print form and also sometimes availed in an electronic form through different websites as web pages and downloadable documents. Taxonomic databases have existed since the 1970s and were created mainly for expert use in providing taxonomic services (Peterson et al. 2010). Technological advances have enabled publishing of these databases online through the web making them accessible to citizens as well. Some of the online databases, however, contain highly technical knowledge and therefore, not readily usable by citizens.

Transfer of ground knowledge on biodiversity status from citizens to experts has been done using traditional and emerging online citizen science projects (Conrad & Hilchey 2011; LeBaron et al. 2006; Schmeller et al. 2009). These projects use citizens to record occurrences of target species in standard templates that can then be combined to generate species distribution maps and other species occurrence reports. The emergence of Web 2.0 has led to rise in online recording of biodiversity data by citizens through citizen science websites and phone apps (Delaney et al. 2008; Sullivan et al. 2009; Wiersma 2008). Biodiversity data collected through online citizen science projects has, however, faced different challenges, especially that of data validation (Loos et al. 2015). Data collected through online citizen science projects has been found to be incomplete and not validated.

In terms of codification and personalization as mechanisms of knowledge transfer, it can be noted that transfer of biodiversity knowledge from experts to citizens through the web has adopted a pro-codification approach. As discussed above, expert knowledge is packaged into simplified documents that are then made accessible to citizens through print or electronic media. Likewise, citizen knowledge is transferred using predefined templates in print or electronic form. Web-based personalization mechanisms which involve person-to-person interactions are also emerging, and mechanisms such as social media networks and Web 2.0 platforms are being used (Matheson 2014).

2.7 MOTIVATION FOR THIS RESEARH STUDY

From the literature reviewed, it can be seen that use of computing technologies in management of biodiversity knowledge is an old phenomenon that was initially motivated by the need to provide support for taxonomic services. Taxonomy is characterized by huge amounts of species knowledge and codification of this knowledge using computing technologies introduced the much-needed efficiency in the provision of taxonomic services. Codified biodiversity knowledge for a long time was confined to institutional boundaries and could be accessed through inter-institutional lending. Emergence of network technologies, specifically the web technologies made it possible to share this knowledge online thus making it easily accessible to other institutions as well as the general public. Codified knowledge continue to characterize biodiversity knowledge as many repositories containing the knowledge are available online (Graham et al. 2004; Hardisty et al. 2013).

From the literature review, combination of codification and personalization mechanisms for knowledge transfer has been emphasized as a good strategy to knowledge transfer since it provides an opportunity to leverage on the strengths of both mechanisms. Moreover, explicit and tacit knowledge reinforce each other and therefore, transfer of explicit knowledge for practical use is best accompanied by some tacit knowledge (Edwards et al. 2003; Jasimuddin 2008). The transfer of biodiversity knowledge would significantly benefit from the combination of both mechanisms since the knowledge involved is enormous and complex; high volume of knowledge needs to be codified for effective transfer and retrieval, and complex knowledge needs to be personalized so as to foster understanding between the actors (experts and citizens).

As stated in Section 2.3.3, knowledge transfer process has largely been represented using models and frameworks. The existing models are silent on the medium used in the transfer process. This makes the models still highly abstract and inadequate for use in designing knowledge transfer computer systems. A more focussed model that can guide development of knowledge transfer applications is necessary where computing technologies need to be used as a medium for knowledge transfer. Review of computing technologies used in codification and personalization of biodiversity knowledge resulted in identification of two technologies that this research explored: ontologies for codification and crowd computing for personalization. The main shortcoming that this study sought to address is the lack of adequate knowledge transfer models that combine ontologies and crowd computing technologies for the transfer of biodiversity management knowledge. The literature review revealed that the ontology models for representation of biodiversity knowledge are not adequate, specifically where different kinds of traits knowledge need to be combined to answer biodiversity management questions. This is the second limitation that this research identified. Citizen engagement require combination of different kinds of knowledge and in order to codify and de-codify this knowledge for citizen use, a model that allows combination of different traits was necessary. Different crowd computing technologies have been used to support person to person interactions (Luther et al. 2009; Matheson 2014; Parr et al. 2014; Sullivan et al. 2009). Crowd computing has been used mainly in species monitoring projects, which is essentially transfer of ground knowledge to experts. From the literature review, these projects are either evolved from the existing citizen science species monitoring projects or ad hoc developments to address ad-hoc researchers' needs. A model to guide use of crowd computing technologies for transfer of biodiversity knowledge is lacking and this is the third limitation this research sought to address.

2.8 SUMMARY

This chapter presented the relevant background literature to this research study and culminated in identification of the lack of knowledge the study sought to address. The literature review commenced with a general introduction to knowledge consisting of what knowledge is, different perceptions of knowledge, the two types of knowledge (tacit and explicit) and how knowledge is created. The SECI model of knowledge creation was adopted as a reference point for knowledge creation (Nonaka & Takeuchi 1995). The introduction to knowledge was followed by the literature review on knowledge transfer, starting with definitions of knowledge transfer followed by the different dimensions from which knowledge transfer has been studied including agents involved in knowledge transfer, directions of knowledge flow, knowledge transfer process, mechanisms of knowledge transfer, contextual factors, geography, policy, business contexts and policy. The dimensions studied in this research included the knowledge transfer process and mechanisms for knowledge transfer. The knowledge transfer process was reviewed in detail, culminating in an outline of the knowledge transfer model that was adopted in this study. The model by Liyanage et al. (2009) was adopted, and an overview of the model is presented. A detailed discussion of the mechanism dimension followed since this study was focused on the use of computing technologies as mechanism for knowledge transfer. Two mechanisms of codification and personalization are reviewed in detail followed by the computing technologies used to achieve them.

Review on computing technologies for codification and personalization mechanisms of knowledge transfer is presented starting with an overview of different technologies used in each mechanism followed by a more detailed description of the computing technologies selected for this research. For codification, ontological modelling was selected and an overview of the models used in representation of biodiversity knowledge is provided. An in-depth review of ontological modelling is provided as part of Chapter 5 which deals with ontological model for biodiversity management knowledge transfer. For personalization mechanism, crowd computing was used, and this was introduced in this chapter, and a detailed review is provided in Chapter 6.

Lastly, a review of literature on knowledge transfer mechanisms between experts and citizens in the biodiversity management domain was presented. The section also highlighted the state of technology use in knowledge transfer between the two categories of actors and the nature of solutions that characterise the domain. The characteristics of knowledge transfer in the domain together with opportunity provided by advancements in computing technologies necessitate a knowledge transfer model to guide development of knowledge transfer systems. The lack of such a model forms the basis of this research. The chapter concludes with an outline of the knowledge shortcomings that the research study aims to address.

Chapter 3 - Research Design and Methodology

3.1 INTRODUCTION

In this chapter, the research design and methodology used in the study, is presented. The research design and methodology adopted are demarcated by presenting different concepts of research, namely philosophical views, research strategy, research methods and data collection. This is followed by the research plan that was adopted for the study and an outline of the research process that was used to answer the research questions of the study.

3.2 PHILOSOPHICAL PERSPECTIVES

Research execution is based on underlying assumptions about what constitutes valid research and which research methods are appropriate for answering the particular research question (Seyppel 1953; Myers 2011). At the broadest level is the philosophical assumptions or the worldview, perspective(s) and beliefs that the researcher adopts to guide their inquiry (Creswell 2014). The word 'paradigm view' is often used to describe the worldview and is defined as the set of common beliefs, theories, models and agreements shared between researchers about how problems of a certain type should be understood and solved (Kuhn 1970; Soanes & Hawker 2006). Various authors have proposed different worldview options, some extensions of others and others completely contrasting previous views.

Different paradigms adopt certain stances on the different philosophical dimensions used to describe the world. Chua (1986) outlines three sets of beliefs that represent the dimensions of viewing and researching the world namely: 1) beliefs about the phenomenon of study; 2) beliefs about the notion of knowledge, and 3) beliefs about the relationship between knowledge and empirical world. Creswell and Clark (2011) discuss the worldviews as having common elements, and each view having certain stances on these elements. The elements are ontology, epistemology, axiology and methodology. Ontology describes what is considered to be the nature of reality and differentiates what is real from what is not. Epistemology deals with how we can be certain of what we know and epistemology relate to the origin, validity and boundaries of knowledge. Axiology has to do with the role of values or the values that individuals hold and why. Axiology also covers the effect of the researcher’s values in the execution of the research. Methodology has to do with the research process.

Different paradigm views applicable to research were developed over the years. Guba and Lincoln (1994) suggested four research paradigms namely positivism, post-positivism, critical theory, and constructivism. Borrowing from Chua (1986), Orlikowski and Baroudi (1991) present three paradigms in IS context -positivist, interpretive, and critical. In more recent developments a dynamic paradigm that is essentially pragmatic namely design science research, has become increasingly relevant in IS (Fallman 2003; Niederman & March 2012; Peffers et al. 2007; Stolterman 2008; Vaishnavi & Kuechler 2007). An overview of each of these views is outlined next and in Table 3-1 a summarized comparison of the different views is presented using the philosophical dimensions of ontology, epistemology, axiology and methodology (Creswell & Clark 2011; Vaishnavi & Kuechler 2007).

Positivist research assumes that knowledge is objective and that fixed relationships between objects of study exist, as well as that it is possible to measure these relationships objectively (Orlikowski & Baroudi 1991). The positivist paradigm assumes the existence of an objective social reality that is stable and can be measured objectively. The focus in positivist research is mainly on testable propositions (Myers 2011) in the form of hypotheses, which are either proven or disproven.

Interpretive research is premised on the assumption that the social reality is constructed (such as shared language, consciousness, and meanings) and the truth therefore lies in how the subjects influence each other. As people interact a social reality is woven and therefore the interpretive view seeks to understand a continuously moving target (Klein & Myers 1999; Orlikowski & Baroudi 1991; Myers 2011). The focus in interpretive research is to understand the world from the point of view of those living it (Walsham 1995; Andrade 2009).

Critical research, similar to interpretive research, believes in reality as being socially constructed and that knowledge is grounded in social and historical practices. The focus in critical research is to critique those realities and seeks to eliminate the causes of alienation and domination. Simply put, research enquiries adopting the critical view are of the form 'beyond what is, beyond verification, to what could be' (Orlikowski & Baroudi 1991).

Pragmatism is a research paradigm that is concerned with change through interventions. Pragmatism is premised in problem solving and views the world as capable of change through introduction of new better solutions to problems. The role of the researcher is to introduce change through action, intervention and constructive knowledge (Goldkuhl 2012). Pragmatism has been accepted in the recent years as a philosophical underpinning for design science research in Information Systems (Goldkuhl 2012).

Table 3-1: Research paradigms and philosophical views (Adebesin et al. 2011; Creswell & Clark 2011; Vaishnavi & Kuechler 2007)

Dimension	Positivism	Interpretive	Critical	Pragmatism
Ontology (What is the nature of reality?)	Singular reality (Researcher rejects or fails to reject hypotheses)	Multiple realities (Researcher illustrates the different perspectives)	Political reality (Findings negotiated with participants)	Singular and multiple realities (researchers tests hypotheses and provide multiple perspectives)

Dimension	Positivism	Interpretive	Critical	Pragmatism
Epistemology (Relationship between researcher and the being researched)	Detached observer (Researchers objectively collect data using selected instruments)	Closeness (Researcher visit participants to collect data or immerse themselves in the social context)	Collaborative, political, suspicions (Researcher actively involve participants as collaborators)	Practicality (Researchers collect data by "what works" to address research question)
Axiology (Role of values)	Unbiased (Researcher uses controls to eliminate bias)	Biased (Researchers talk actively about their biases and interpretations)	Researchers values affect the study (Researchers negotiate their biases with participants)	Multiple stances (Researchers include biased and unbiased perspectives)
Methodology (Process of research)	Deductive (Researcher tests a proposed theory)	Inductive (Researcher starts with participant views and builds up to patterns, theories and generalization)	Participatory (Researchers involve participants in all stages of research)	Mixed methods (Researchers intervene by implementing rigorous and relevant interventions)

3.2.1 Paradigm views in IS

Research communities generally have what is considered to be universal agreements on themes of investigation and the methods of investigating it. Vaishnavi and Kuechler (2004) identify two broad types of research communities; paradigmatic communities have universal agreements and multi-paradigmatic (sometimes termed pre-paradigmatic) communities who have overlaps in themes of interests and methods of inquiry. Information Systems is a multi-paradigmatic community.

The multi-paradigmatic nature of IS has attracted significant attention among researchers, with some proposing for a push for single paradigm claiming it will unify and strengthen the field while others have argued that the embracing of multiple paradigms will strengthen the field by broadening it and ensuring relevance (Gallupe 2007; I Benbasat & Weber 1996; Izak Benbasat & Weber 1996). Surveys on paradigms adopted in the IS field over the years indicates a move towards a diversity of paradigms (Orlikowski & Baroudi 1991; Walsham 1995; Izak Benbasat & Weber 1996), and thus efforts towards a unified paradigm have taken a back stage. Researchers are focusing more and more on adapting the different paradigms for IS, and developing guidelines, principles, methods on the paradigms to ensure that quality research is conducted in the discipline (Gregor &

Jones 2007; Hevner et al. 2004; Jones & Karsten 2008; Klein & Myers 1999; Walls et al. 1992; Walls et al. 2004).

3.3 RESEARCH METHODS

A research method is the approach that moves the research effort from the fundamental philosophical beliefs to research design and data collection. It is imperative therefore that the choice of method guides the way data will be collected and analysed. There are two broad categories of research methods namely qualitative and quantitative methods (Olivier 2009; Creswell 2014).

3.3.1 Quantitative research

Quantitative research is based on measurement and makes use of external standards against which all observations can be measured objectively. Research in this category aims at measuring relationships between subjects of study with the aim of understanding or predicting the future. Quantitative research places the emphasis on measurement when collecting and analysing data. Research is defined, not just by its use of numerical measures but also that it generally follows a natural science model of the research process measurement to establish objective knowledge (that is, knowledge that exists independently of the views and values of the people involved) (Olivier 2009; Creswell 2014; Creswell & Clark 2011). Quantitative methods are mostly used in research that assume the positivist paradigm view. Some of the quantitative research methods are outlined in Table 3-2.

Table 3-2: Quantitative research method (Smuts 2011)

Research method	**Research method description**
Observation studies	Focus on a particular aspect of behaviour that is quantified in some way.
Correlational research	Examines the extent to which differences in one variable relate to differences in one or more other variables.
Developmental designs	Study of how particular characteristics that can me measured change over time.
Survey research	Involves acquiring information about one or more groups of people by asking them questions that can be numerically analysed and tabulating their answers. Depending on the survey design, surveys can also be used in qualitative research.

3.3.2 Qualitative research

Qualitative research originated from the social science discipline and was driven by the need to study social and cultural phenomena (Myers 1997). Qualitative research emphasizes meanings (such as often represented in words) rather than frequencies and distributions (numbers) when collecting and analysing data. Kaplan and Maxwell (2005) argue that when focus is placed on creating numbers out of textual data, the goal of understanding a phenomenon in its natural settings is lost. Qualitative research is generally inductive rather than deductive in its approach, that is, it generates theory from interpretation of the evidence, albeit against a theoretical background. There are various methods that support conducting qualitative research. Myers (1997) discusses four methods namely: action research, case study research, ethnography and grounded theory. Table 3-3 provides a highlight of some of the qualitative research methods used in IS (Hunter 2004; Myers 1997; Olivier 2009).

Table 3-3: Qualitative research methods (Smuts 2011)

Research method	**Research method description**
Appreciative inquiry	Researcher acts as facilitator with technique that can be used to improve a wider range of contexts. *Discovery* – an "appreciation" of what already exists. *Dream* – what it could be. *Design* – formulates vision and strategy. *Delivery* – implementation plans.
Design science research	Involves the analysis of the use and performance of designed artefacts in order to comprehend, explain and improve the behaviour of aspects of information systems.
Action research	Involves determining current situation of interest and then designing an intervention. Contributes to both research and practice.
Case study	Explores a single entity or phenomenon bounded by time and activity. Collects detailed information using a variety of data collection methods over a sustained period of time.
Focus group	Stimulates thinking and creativity through the dynamics of interaction in the context of a small group.
Ethnography and participant observation	An intact group of individuals in their natural setting is studied over a long period of time through observation.

Research method	Research method description
Grounded theory	Seeks to develop theory that is grounded in data systematically gathered and analysed. Rigorous and detailed method.
Hermeneutics	Theory of interpretation of meaning. Primarily concerned with the meaning of text or text-analogue.
Semiotics	Study of signs. By nature inherently interpretive.
Narrative inquiry	Entails documentation and analysis of individuals' stories and personal accounts.
Survey research	Involves acquiring information about one or more groups of people by asking open-ended questions that can, for instance, be thematically analysed.

Qualitative and quantitative methods are not mutually exclusive and some studies require a combination of methods to cover the whole enquiry (Olivier 2009; Creswell & Clark 2011). Combination is done either through triangulation, where one method is used to confirm or develop holistic outcomes of another method, or mixed methods where a research uses both qualitative and quantitative methods to answer different sub-questions within the same research (Jick 1979; Creswell & Clark 2011).

3.4 DESIGN SCIENCE RESEARCH

Design science research (DSR) is a research approach within the pragmatist worldview that is concerned with design of man-made objects (artefacts) aimed at meeting certain desired objectives (Kuechler & Vaishnavi 2008). Nunamaker et al. (1991) compares the benefits design science researchers realise from construction and evaluation of an innovative idea to those behavioural scientist experience from field studies. The construction and evaluation of innovations help the scientist to get directly involved thus understanding the problem domain better and therefore theorise the phenomena better. At a broad level, design science research process involves two categories of activities namely the activities involved in the building process and the activities involved in the knowledge generation process. Owen (1998) presents a general model for generating knowledge in design science (see Figure 3-1). The model is composed of doing something (work) and then judging the results. Knowledge and work have a cyclic relationship where knowledge is used to create work and work is judged to create knowledge. In the work process, existing knowledge is used to enhance the artefact being created while in the knowledge building process, reflection and abstraction is carried out to create new knowledge.

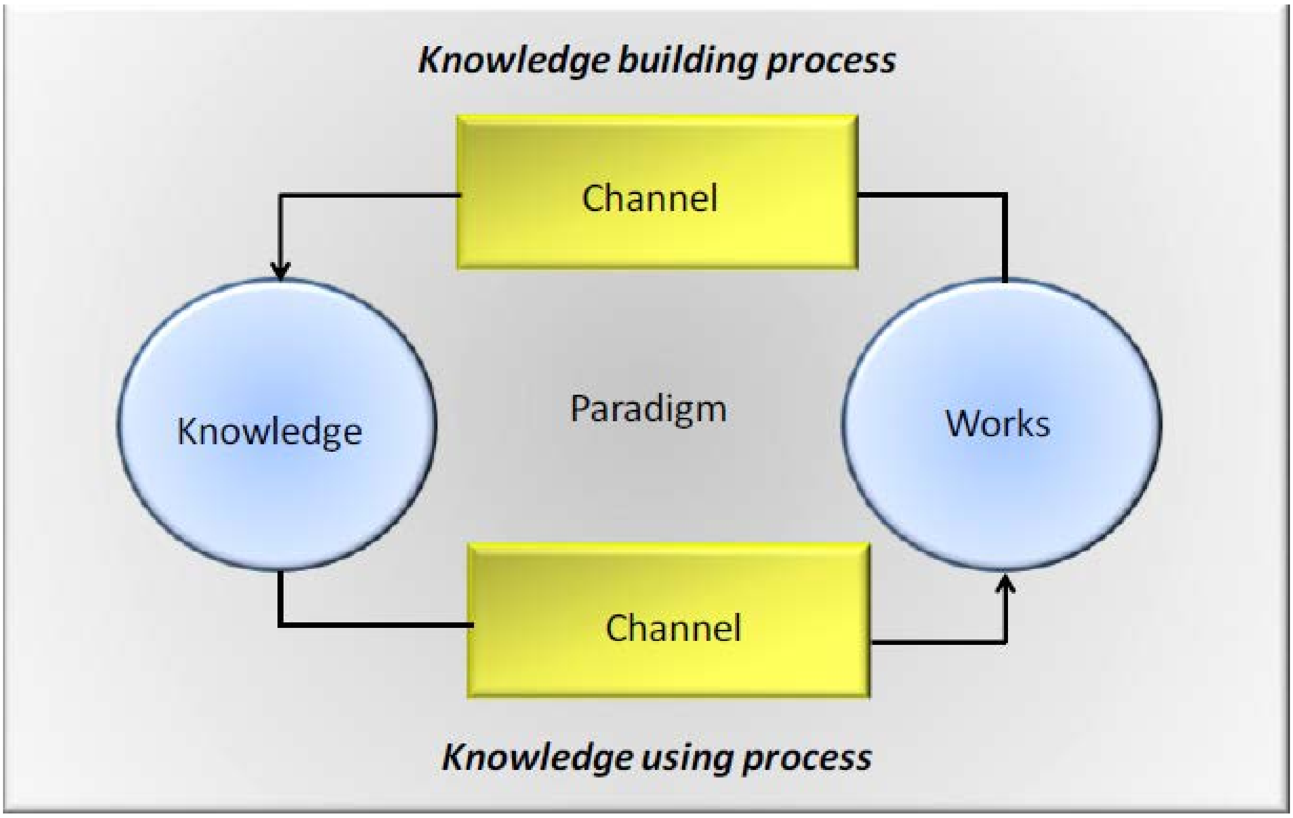

Figure 3-1: A general model for generating and accumulating knowledge (Owen 1998).

3.4.1 DSR research framework

As discussed in the previous section, the DSR research framework is characterized by two broad categories of activities - construction and evaluation. A fundamental requirement of DSR is positioning the building and evaluation in the practical context while making reference to the existing knowledge base (Hevner et al. 2004; Niederman & March 2012; Hevner 2007). The DSR framework therefore consists of construction and evaluation activities that are carried out with constant reference to the problem domain (to ensure relevance) and the domain knowledge (to ensure rigor). The construction activities involve iterative steps of development or building of theories and artefacts, and then assessment is carried out by justification and evaluation activities, which inform further refinement of the theories and artefacts. The iteration is repeated until satisfactory outcomes are attained. The justification and evaluation activities could be executed through analytical or case studies, experiments, field studies or simulations.

Figure 3-2 presents a conceptualization of DSR research in the context of the targeted environment and knowledge base. This illustration (Figure 3-2) elucidates the position of IS research in relation to the practical environment and the knowledge base. DSR is expected to contribute to both the practical environment and the theoretical knowledge base. The contribution to the practical world is in the form of artefacts such as information systems and system architectures whilst contributions to the knowledge base is in the form of theoretical foundations including constructs, models, methods and instantiations.

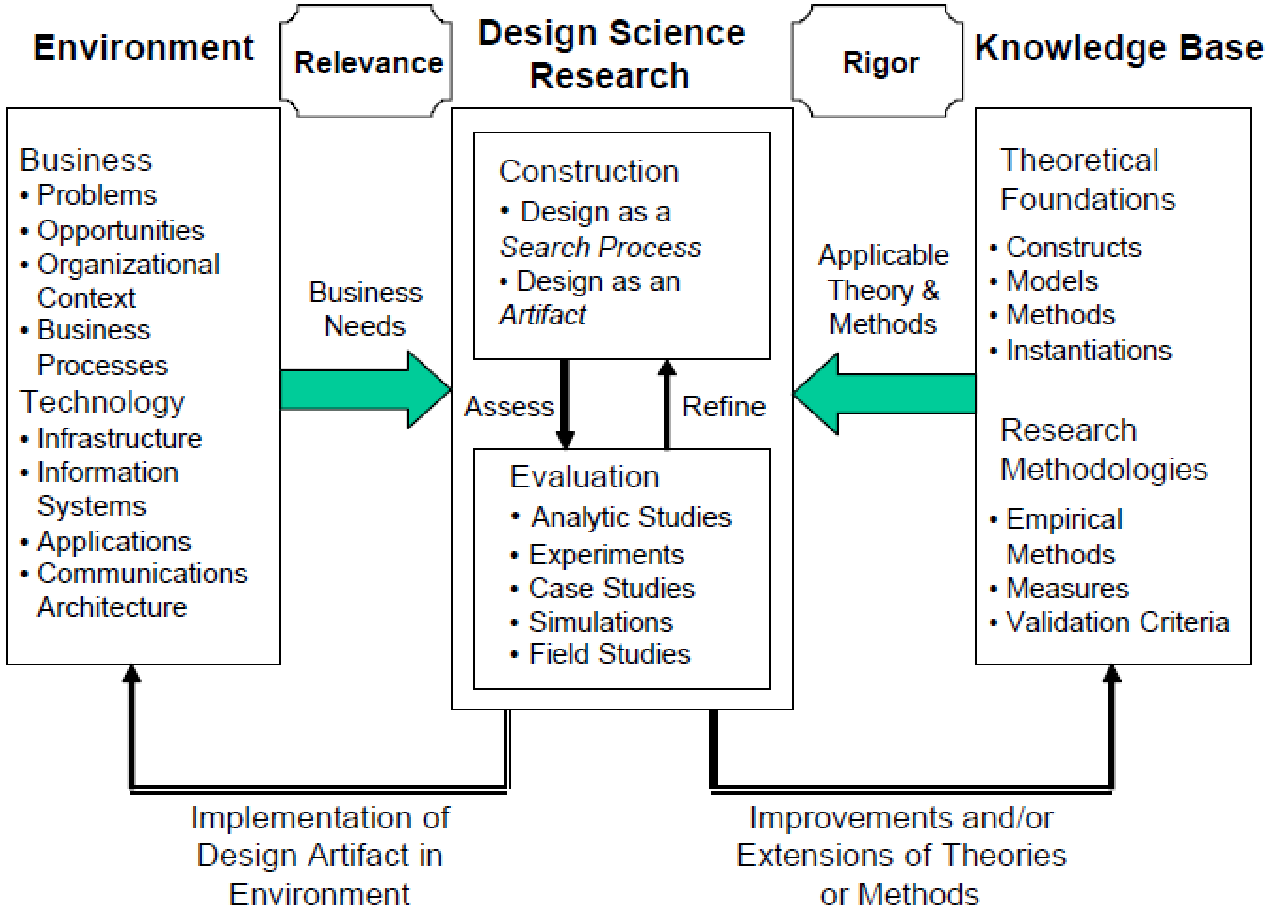

Figure 3-2: DSR Research Framework (Hevner et al. 2004)

3.4.2 DSR research guidelines

Due to the tendency to confuse ordinary routine design with DSR, several researchers have worked on guidelines for DSR research to ensure that researchers, editors and reviewers are guided on key issues. Hevner et al. (2004) developed seven guidelines on different aspects of the DSR in information systems, namely:

1 Design as an artefact
2 Problem relevance
3 Design evaluation
4 Research contributions
5 Research rigour
6 Design as a search process
7 Communication of research

Hevner et. al. (2004) emphasises that the DSR guidelines are not meant to suppress the creative skills of researcher and individuals therefore have the lee-way to apply the guidelines in an adaptive way and as and when necessary. The guidelines are described in detail in Section 3.4.2.1 to Section 3.4.2.7 below.

3.4.2.1 Guideline 1: Design as an artefact

One of the key outcomes of the design science research (DSR) in information systems is a distinctive purposeful IT artefact in the form of a construct, a model, a method, or an instantiation. Once the artefact has been constructed, it has to be represented and presented in a way that it lends itself for comparison with other artefacts in a similar category (Hevner et al. 2004). Representing the artefact is a key component of DSR and must be done clearly. Simon (1996) emphasizes the importance of representation by equating problem solving with that of representing it well so that the solution is clear.

3.4.2.2 Guideline 2: Problem relevance

The primary objectives of DSR in information systems include to introduce technological solutions to relevant problems in the real world (Hevner et al. 2004). The problem is defined as the gap between what it is and what it could be (Simon 1996) and the objective of DSR is to bridge this gap with appropriate solutions. The relevance of the problem is determined by the constituent community whose problem is being addressed and in IS, the constituent community is thus the community of practitioners whose problem is being addressed. This constituent community own the procedures that are targeted by the new interventions. Working closely with the communities is therefore essential to ensure relevance as required by DSR. The resulting artefact should be implementable in the environment of practice and demonstrate that it is solving unsolved problem (Vaishnavi & Kuechler 2007; Hevner et al. 2004).

Finding solutions to routine day-to-day problems is not DSR. The problem must therefore be relevant in DSR contexts. The nature of problems addressed should be non-routine but rather be the so-called “wicked problems” (Brooks 1987; Rittel & Webber 1984). Wicked problems are characterised by unstable requirements, complex relationship between components, changing design processes and artefact functionality, dependence on human cognitive abilities and dependence on human social contexts. Finally, the focus of DSR is on the creation of artefacts that provide solution to a class of problems (Baskerville et al. 2009; Gregor & Hevner 2013). This focus means that the problems being solved should result in solutions that can be generalised to address related problems and not just be solutions that address the needs of a specific case.

3.4.2.3 Guideline 3: Design evaluation

Evaluation in DSR is a central step in the construction of the artefact (see Figure 3-2). DSR evaluation has two components; rigor and relevance (Hevner et al. 2004). Evaluation methods should therefore be carefully selected to ensure the designed artefact is rigorously evaluated in terms of utility, quality and efficacy. Niederman and March (2012) emphasize the importance of evaluating built artefacts in a behavioural context. Evaluating using the knowledgebase of research methodologies is important to ensure there is rigor (Hevner et al. 2004). Design is a creative process that is bound to introduce desirable aesthetic and functional features that are improvements from the old artefacts. Evaluation should therefore include assessment of additional aesthetics and inherent creativity. Hevner et al. (2004) proposed some methods for evaluation of artefacts in IS research, outlined in Table 3-4 below:

Table 3-4: Artefact evaluation methods (Hevner et al. 2004)

1. Observational	Case study – study artefact in depth in business environment Field study – monitor use of artefact in multiple projects
2. Analytical	Static analysis – examine structure of artefact for specific qualities (e.g., complexity) Architecture analysis – study fit of artefact into technical IS architecture Dynamic analysis – study artefact in use for dynamic qualities (e.g., performance)
3. Experimental	Controlled experiment – study artefact in controlled environment for qualities (e.g., usability) Simulation – Execute artefact with Artificial Data
4. Testing	Functional (black box) testing – execute artefact interfaces to discover failures and identify defects Structural (white box) testing – perform coverage testing of all execution paths in the artefact

3.4.2.4 Guideline 4: Research contributions

The objective of all research is to contribute towards the body of knowledge. Contributions made when the DSR approach is adopted in IS are generally twofold: theoretical contribution and practical contribution. Hevner et al. (2004) identified three areas of contributions from design science research in IS: - design artefact, theoretical foundations, and evaluation contributions. The *design artefact* is the new construct, model, method, or instantiation. The artefact is a practical solution to the problem that the research sought to solve. The *theoretical foundations* is the creative use of the artefacts to make contribution to the theoretical body of knowledge. The *evaluation contribution* is the outcome of evaluation results made from evaluating the use of an artefact.

3.4.2.5 Guideline 5: Research rigor

Rigor in DSR deals with the way research is conducted with an emphasis on the use of existing knowledge bases (Hevner et al. 2004). Even though rigour is emphasised in DSR, it has been observed that excessive focus on rigor can reduce relevance and creativity, but the importance of both relevance and rigor has been emphasised as an inevitable and attainable requirement for design science research (Applegate 1999). Rigor has been found relevant in two aspects of the DSR framework; construction and evaluation. Construction require use of appropriate theoretical knowledge in the subject area and this is done through selecting appropriate theories through literature reviews.

Rigor is ensured in DSR through the use of existing design theories including models, constructs and methods (see Figure 3-2). Selection of theory and theoretical foundations should not be based simply on researcher preferences but rather on objective selection criteria. Use of methods such as a systematic literature review ensures that new knowledge is built upon objectively selected theoretical foundations from the literature. In Section Part 1 -3.4.2.5.1 below, a description of the systematic literature review used in this study is presented. Furthermore, evaluation as specified by DSR ensures rigor. The evaluation step often requires the use of some mathematical formalism or empirical work for evaluation. Artefacts such as constructs, models, methods, and instantiations should be evaluated using simulations, field studies, experiments or case studies. Emphasis on rigor during evaluation is the key point on this guideline, more guidelines on evaluation are provided in Section 3.4.2.3.

3.4.2.5.1 Systematic Literature Review

A systematic literature review could provide an important theoretical foundation for any research. Systematic literature review is an established research method that involves the use of literature, including retrieving, appraising and summarizing available knowledge on a specific subject in order to answer a specific question (Booth et al. 2016; Kitchenham 2007; Webster & Watson 2010; White & Schmidt 2005).

Prior to the definition of systematic literature review (SLR) as a systematic method, researchers could select sources that supported their views and this often led to biases on the research findings. The systematic literature review (SLR) method was therefore designed to ensure that undue biases are removed from the literature review process thus accomplishing more objective results. The research process of a systematic review follows a well-defined sequence of methodological steps, developed in priori (Biolchini et al. 2005; Booth et al. 2012). The systematic literature review process is characterised by five steps (Khan et al. 2003; White & Schmidt 2005; Biolchini et al. 2005), described below:

Step 1: **Frame questions for a review:** The research questions / objectives of the review should be stated clearly and without any ambiguity before beginning the review work. The objectives can be split into sub objectives if that will enhance clarity.

Step 2: **Identify relevant work**: Identify the relevant work from both print and electronic sources. The search criteria for the literature should be directly derived from the questions and clearly defined in advance and adhered to during the review. Language should not be a barrier, and where necessary, services of interpreters should be sought.

Step 3: **Extract the relevant data:** Extract relevant data using a predefined criteria. For instance, study authors, methods used, outcomes, etc. After extracting relevant data, further assess the quality and validity of the studies. ***Assess the quality of studies:*** Quality of the review should be accessed. Both the questions for review and literature sources should be subjected to some form of appraisal. A more specific criteria should be defined for assessment of the relevant work. ***Asses the validity of the studies:*** Develop criteria for accessing validity, for instance the sample size, the domain addressed, etc.

Step 4: **Summarise the evidence**: Synthesise the findings using a clearly defined structure. Tabulation of data can be used to synthesize the findings where possible. In some qualitative cases, tabulation may not be possible, but a criteria for synthesis needs to be developed so as to ensure results are synthesised using a clearly defined structure.

Step 5: **Interpret the findings**: Present the findings including the strengths and weaknesses of the review. Interpret the evidence and implications both for both theory and practice. The results are easy to present if the work reviewed are homogeneous, but highly varied work can be normalised to make them comparable.

3.4.2.6 Guideline 6: Design as a search Process

Design is basically a search for the most effective way to develop a solution to a problem. Simon (1996) described problem solving as utilizing available means to solve a problem while observing the laws in that domain. DSR requires knowledge both in the problem domain and the technical domain (Hevner et al. 2004). The requirement of knowledge in two domains often result in DSR in Information Systems being complex and therefore DSR researchers often choose to focus on a small aspect of the problem or fragment the problem into small sub-problems with solutions that can be integrated at a later stage to solve the bigger problem. This approach is not necessarily the best, and may reduce the overall impact in the problem domain, but such an approach is often a good starting point. The search process in DSR is mostly intractable and heuristic search approaches are often used until a solution that works is arrived at (Peffers et al. 2006; Hevner & Chatterjee 2010; Hevner et al. 2004).

3.4.2.7 Guideline 7: Communication of research

Communication of the research findings: Research findings must be communicated effectively to technical audience - IT specialist - and also non-technical audience who are usually problem domain audience. Explanation to non-technical audience must be simplified and demonstrate how the artefact is going to solve their problem in a better way than earlier solutions (Hevner et al. 2004).

3.4.3 DSR research process

Several researchers have proposed general models to guide the DSR research process (Gregg et al. 2001; March & Smith 1995; Nunamaker et al. 1991; Peffers et al. 2007; Purao et al. 2002). We discuss these phases using the model presented by Hevner et al. (2004) consisting of five circumscriptive steps, namely awareness of the problem, suggestion, development, evaluation and conclusion (see Figure 3-3). The important guideline is that a researcher should remain cognisant of in the research process, is the primary objective of knowledge contribution and therefore that the phases are not executed in a waterfall fashion, from one phase to another, but rather in circumscriptions of build and evaluate (Hevner 2007; Kuechler & Vaishnavi 2008; Niederman & March 2012; Kuechler & Vaishnavi 2012).

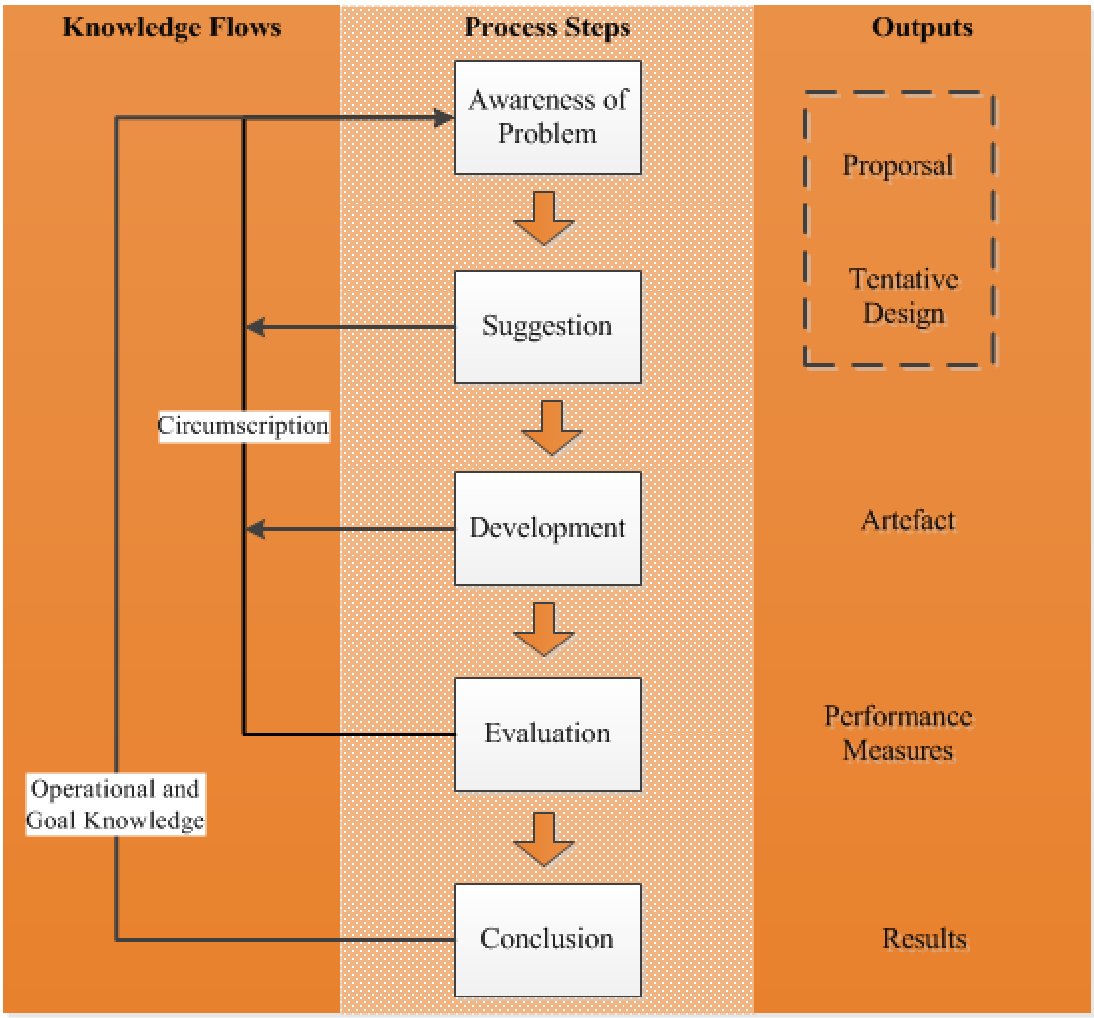

Figure 3-3: DSR research process (Vaishnavi & Kuechler 2007)

The DSR research process according to Vaishnave & Kuechler (2007) consists of five circumscriptive steps as depicted in Figure 3-3 namely:

Step 1: ***Awareness of the problem:*** Interesting problems come from multiple sources; could be from new developments in the domain, exploring solutions of one domain in a completely different, or any other source. These problems have to be sufficiently studied and documented to produce a proposal, which is the primary output of this phase.

Step 2: ***Suggestion phase:*** Involves proposing a solution to the problem. It is closely tied to proposal phase. This phase is a creative step utilizing cognitive skills to propose where new possibilities. The evaluation criteria for the suggested artefact must be prescribed at this stage.

Step 3: ***Development:*** The suggestion is further developed in this phase. The techniques used will depend on the suggestion. The choice of technique will be informed by the knowledge base. The focus is more on the novelty of the suggested design and not on the construction in the case of software related artefacts.

Step 4: ***Evaluation:*** This involves assessment of the developed artefact using the criteria developed during the proposal stage. Deviations from expectations have to be explained. The outcomes of this phase are compiled and taken back to inform an improved suggestion, until a desired result is attained. This is illustrated in Figure 3-3 through the circumscription arrow.

Step 5: ***Conclusion:*** This is the end of the research cycle and is usually arrived at when the results are deemed as 'good enough'. The knowledge gained through the process can either be categorized as “firm” or “loose ends”; firm means the facts have been established and can be repeatedly invoked while loose ends means “anomalous behaviour that defies explanation and may well serve as the subject of further research” (Kuechler & Vaishnavi 2012). The research findings documentation (write-up) is an important output of this phase since it will contain the knowledge contribution.

3.5 DATA COLLECTION AND ANALYSIS

Any research study should clearly explain the data collection methods and analysis used for the research (Creswell 2014; Welman et al. 2005; Oates 2006). The data collection process used should be explained, including how researcher gained access to subjects, the data collection techniques used, data collection dates and settings of data gathering. The data analysis approaches used must also be describes, including rationale behind selection of analysis procedures and the actual procedures (Mouton 2001). The data that a researcher collects may be quantitative or qualitative (Olivier 2009) and different data collection techniques are used to collect it. Depending on the source, two categories of data are distinguished, i.e. primary and secondary data (Hofstee 2006). Primary data is that which is collected directly from the source by the researcher for the study being conducted while secondary data involves examining second-hand accounts of people as written by others and includes data that has previously been published (Creswell 2014; Myers 1997). Different data collection methods were used in this study namely interviews, document analysis, systematic literature review and online experiments, which will be discussed in the sections that follow.

3.5.1 Interviews

Data collection using interview is a process where “knowledge is constructed in the interaction between the interviewer and the interviewee” (Kvale 2008). The objective on interviews is to obtain “descriptions of the life world of the interviewee in order to interpret the meaning of the described phenomena” (Brinkmann 2014). Interview method is often employed as a pilot approach to gather preliminary knowledge before other approaches are employed.

Different kinds of interviews are available in literature e.g. semi-structured interviews, structured interviews, unstructured and in-depth interviews (Kvale 2008; Qu & Dumay 2011; Rowley 2012). Like all data collection methods, use of interviews present advantages and disadvantages. One advantage of using interviews is the possibility to get richer data set through open communication between researcher and interviewee and disadvantages include possibility of interviewee to digress away from the topic and the fact that interviews can be expensive and time consuming.

3.5.2 Document Analysis

Document analysis is defined as "a systematic procedure for reviewing or evaluating documents—both printed and electronic (computer-based and Internet-transmitted) material" . Documents as a source of qualitative data is a source that requires a systematic approach in order to retrieve important data for a study. The process involves finding, selecting, appraising (making sense of), and synthesising data contained in documents. Systematic document analysis yields data that is then organised into themes, categories and examples for analysis and processing according to the research objectives. Document analysis as a source of data has both advantages and disadvantages; the pros include: - efficient, readily available, cost effective, not reactive /obstructive, is stable, exactness and wide and deep coverage; and the cons include: - insufficient details, retrieval challenges and inherent biases in writing.

3.5.3 Online data collection

Online data have become a popular avenue for collecting data social and technical research. Online data collection is done through surveys, online experiments, case based longitudinal studies and netnography (Analysis 2016) . In computing and information systems online research is done using mainly online experiments and surveys (Oates 2006). Formal experiment data collection involves observing, making measurements of the data variables and recording changes. Use of internet based experiments, particularly websites has made it possible to conduct experiments without the need to invite participants to a computer laboratory environment (Field & Hole 2002; Sacks et al. 1989; Zendler et al. 2001). Usually, websites that collect the data are carefully designed to ensure they can gather the required data and users are invited to visit the web page and carry out the prescribed activities. Depending on the objectives of the research, the data collected includes direct responses from the users or other information collected using cookies. Either way, participants must be aware that the data is being collected for research purposes and failure to do so could mean non-compliance with ethical requirements.

3.5.4 Systematic literature review

Systematic literature review entails an objective review of different literature sources in order to arrive at a conclusion with minimal bias. The process of systematic literature review is presented in detail in Section 3.4.2.5.1.

3.6 ETHICAL CONSIDERATIONS

Ethical issues are present in any research and should be considered at each stage during the research process. Ethical issues pertain to doing good and avoiding harm (Oates 2006). The research process is often faced with the tension between the aims of research to make generalizations for the good of others, and the rights of participants to be protected. Ethical principles governing research are fundamentally the same across disciplines. Orbn et al. (2001) identified three ethical principles, namely: autonomy, beneficence and justice. The principle of autonomy provides for participants' rights to willingly participate in research and the right to withdraw their participation anytime. The principle of beneficence is to do with doing good for others and preventing harm. The specific research situation and objectives will guide the researcher to use creative ways to achieve beneficence. The principle of justice ensures equal share and fairness. The justice principle is intended to protect participants from exploitation and all forms of abuse that they could be exposed to as a result of participating in the research.

Honouring the various ethical principles is done by using different tools. It is upon the researcher to choose appropriate ethical consideration tools depending on the research objectives and context. Autonomy, for instance, could be honoured using documents that record participant's informed consent signed by a participant. Beneficence could be honoured in different ways, including in participant selection, by making participants anonymous, keeping their individual contributions confidential and by restricting circulation of research findings depending on the consequences of a wider circulation. The principle of justice requires very customised approaches based on contextual factors. Ensuring justice may require constant discussions and negotiations with participants in order to ensure fairness. Ethical consideration measures are becoming increasingly broad in IS due to the need to incorporate ethical practices in the field that technology is applied to, e.g. information science, health informatics among others (Gupta et al. 2003; Koskinen et al. 2012; Lipinski & Britz 2000). Commonly used approaches to ethical issues in IS include informed consent, participant privacy and protection from harm (Leedy & Ormrod 2002; Welman et al. 2005).

3.7 RESEARCH PLAN AND DESIGN FOR THIS STUDY

In this section, the details of the specific research methodology and plan applied for this study is presented. In order to effectively present the research plan and design, the section begins with the research questions and objectives in Section 3.7.1. The selection of the philosophical view adopted is presented in Section 3.7.2, followed by the research approach taken in Section 3.7.3. In Section 3.7.5, the research design used in the study is presented followed by the data collection methods and selection of participants in Section 3.7.5. In Section 3.7.6, the ethics and user protection options adopted for this study are presented.

3.7.1 Research questions and objectives

The research question and objective for this study are defined in Chapter 1 and are recast in Table 3-5 below.

Table 3-5: Research questions and objectives

	Main question (MQ) and Sub-Questions (SQ)		Main Objective (MQ) and Sub-Objectives (SQ)
MQ	What are the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management?	MO	To identify the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management.

	Main question (MQ) and Sub-Questions (SQ)		Main Objective (MQ) and Sub-Objectives (SQ)
SQ 1	Which knowledge transfer model is applicable for expert-citizen knowledge transfer in biodiversity management?	SO 1	To identify a knowledge transfer model applicable for expert-citizen knowledge transfer in biodiversity management.
SQ 2	How can ontologies be used to capture biodiversity management expert knowledge?	SO 2	To establish how ontologies can be used to capture biodiversity management expert knowledge.
SQ 3	How can crowd computing technologies be used to support biodiversity management knowledge transfer?	SO 3	To establish how crowd computing technologies can be used to support biodiversity management knowledge transfer.

3.7.2 Research philosophy

The IS field is a multi-paradigmatic field as discussed in Section 3.2.1. Therefore, it is upon the researcher to choose a paradigm view that a study adopts. The goal of this research is "To identify the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management". To select philosophical view adopted for this study, the philosophical assumptions of each view were considered vis-à-vis the research objective of the study, and applicable believes highlighted as shown in Table 3-6.

Table 3-6: Comparison of the research objective of this study with research paradigm view and associated philosophical assumption summary

	Philosophical assumption			
	Ontology	**Epistemology**	**Axiology**	**Methodology**
Positivist	▪ Single stable reality ▪ Law-like	▪ Objective ▪ Detached observer	▪ Truth (objective) ▪ Prediction	▪ Experimental ▪ Quantitative ▪ Hypothesis testing
Interpretive	▪ Multiple realities ▪ Socially constructed	▪ Empathetic ▪ Observer subjectivity	▪ Contextual understanding	▪ Interactional ▪ Interpretation ▪ Qualitative

Philosophical assumption				
	Ontology	**Epistemology**	**Axiology**	**Methodology**
Critical	▪ Socially constructed reality ▪ Discourse ▪ Power	▪ Suspicious ▪ Political ▪ Observer constructing versions	▪ Inquiry is value bound ▪ Contextual understanding ▪ Researcher's values affect the study	▪ Deconstruction ▪ Textual analysis ▪ Discourse analysis
Pragmatist	▪ Multiple, contextually situated realities ▪ Reality can be influenced through new interventions	▪ Knowing through making ▪ Context-based	▪ Contextual Understanding ▪ Control ▪ Creation	▪ Developmental ▪ Impact analysis of artefact ▪ Solving of new problems

Ontologically, this research holds the view that a new reality can be created through introduction of new artefacts, and the goal in this research is to create knowledge through creation of such an artefact. The pragmatist view holds the belief that reality can be socio-technologically constituted and therefore, this view supports the ontological beliefs of this research.

Epistemologically, interaction between researchers and participants can lead to the emergence of new knowledge. In this case, the epistemologies of the interpretive view and pragmatism view are in support of the belief of this research.

Considering the *axiology* dimension, the positivist view believes in an objective truth and prediction, while the interpretive, critical and pragmatism belief environments are value bound and contextual understanding is necessary. This inquiry was influenced by the context and therefore, the views that supported the value of the context were found appropriate, and they included the interpretive, critical and pragmatism.

In terms of *methodology*, the positivist view characterized by observation and quantitative analysis; the interpretive is participatory and qualitative in nature; the critical view involves discourse analysis; pragmatism is developmental and is concerned with changing through introduction of new solutions to problems.

For this research study, the possible methodologies were interpretive and pragmatism as the other two were not applicable. Based on this analysis of the research question against the different world views, the philosophical assumptions that would suit this study are highlighted as shown in Table 3-6. From this analysis, the pragmatist paradigm was identified as the appropriate philosophical view for the research problem investigated in this thesis.

3.7.3 Research approach selection

In this section, the selection of the approach for conducting the research is presented. The pragmatism view as described above is concerned with action and change and the interplay between knowledge and action

(Goldkuhl 2012). Introduction of new artefacts can be done using both quantitative and qualitative methods (Hevner et al. 2004). The subject of investigation in this thesis, however, is concerned with enabling the transfer of knowledge between actors using technology and qualitative methods are more suited. The qualitative methods were examined in order to select appropriate research method for this research.

Table 3-7: Research methods applicable to the study

Research method	**Research method description**
Appreciative inquiry	Researcher acts as facilitator with technique that can be used to improve a wider range of contexts *Discovery* – an “appreciation” of what already exists , *Dream* – what could be , *Design* – formulates vision and strategy , *Delivery* – implementation plans
Design research	Involves the analysis of the use and performance of designed artefacts in order to comprehend, explain and improve the behaviour of aspects of information systems
Action research	Iterative method for determining current situation of interest and then designing an intervention , Researcher collaborates with practitioners and deliberately intervenes , Contributes to both research and practice
Case study	Explores a single entity or phenomenon bounded by time and activity , Collects detailed information using a variety of data collection methods over a sustained period of time
Focus group	Stimulates thinking and creativity through the dynamics of interaction in the context of a small group
Ethnography and participant observation	Researcher studies an intact group of individuals in a natural setting over a specific period of time , Observes what people are doing as well as what they say they are doing – participant observer
Grounded theory	Seeks to develop theory that is grounded in data systematically gathered and analysed , Rigorous and detailed method
Hermeneutics	Theory of interpretation of meaning , Primarily concerned with the meaning of text or text-analogue
Semiotics	Study of signs , By nature inherently interpretive
Narrative inquiry	Entails documentation and analysis of individuals’ stories and personal accounts

Investigating the different methods for qualitative studies in IS, three methods were considered as possibly suitable for use, namely: action research, case study and design science research as highlighted in Table 3-7. The three are further elaborated upon and the selection of the method used in this research is justified in Section 3.7.3.4.

3.7.3.1 Action research

One of the most widely cited definitions of Action research is that of Rapoport (1970) stating "Action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework" (Rapoport 1970). Two key concepts underline this method namely collaborative aspects and the possible ethical dilemmas which arise from its use. Action research is often confused with applied social science, but the distinguishing feature is that of action research is concerned with enlarging the stock of knowledge of the social science community while applied social science focus is simply on application of social scientific knowledge but not to add to the body of knowledge (Myers 1997). Action research has been used in the field of social sciences as a research strategy that combines theory and practice since the 1940s (Baskerville & Myers 2004; Lau 1997); In IS its popularity started growing towards the end of the 1990s (Baskerville 1999), and in 2004 MIS Quarterly journal published a special issue on action research (Baskerville & Myers 2004).

The premise of action research is that of solving the current practical problem while generating scientific knowledge, and it involves strong collaboration between researcher and subjects. The process for action research is characterized by a set of stages that can be executed by iterating within a stage or across several stages (Papas et al. 2012).

3.7.3.2 Case Study Research

The term "case study" in research has multiple meanings. Some researchers use it to describe a unit of analysis (e.g. a case study of a particular institution) while others use it to describe a research method (Myers 1997). Here, we are concerned with the use of the case study as a research method. Case study research is the most common method for qualitative study in IS (Alavi & Carlson 1992; Orlikowski & Baroudi 1991). Myers (1997) points out that case study empirical studies investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident. According to Benbasat et al. (1987), the popularity of case study approach in the IS discipline is no surprise since the focus in IS often shifts from technical issues to the organization. The case study approach can be used in positivist, interpretive and critical research (Myers 1997).

3.7.3.3 Design science Research (DSR)

Design Science Research (DSR) is a fundamentally concerned with problem solving, and has its roots in engineering and the sciences of artificial (Hevner 2007). Research in DSR is conducted by building and evaluating artefacts designed to address an identified problem; it generates understanding/knowledge that can only be gained from the specific act of construction. DSR is characterized by an iterative process of mainly building and evaluating with knowledge generation resulting from the execution of the two broad sets of activities.

3.7.3.4 Motivation for selecting DSR

The objective of the study presented in this thesis is to contribute a prescriptive theory as solution to an identified problem, and this means that the problem domain must be studied with an open mind with the intention of establishing how best to capture the domain knowledge. This can only be achieved through a qualitative approach since there are no propositions to test, but rather solutions that are expected to emerge during the process of the study.

Action research as described concerns itself with enlarging the stock of knowledge of the community. The problem in this study does not match this goal of action research since a product does not already exist. So although in some aspects – e.g. involving the community - action research may seem appropriate, it was found not the most suitable for this research.

Case study research method has properties that this research may find attractive. It is, however, not ideal since this work does not target a specific institution. Although a case is used in the evaluation of this research, the case is not as a method but as a unit of analysis. This distinction is necessary at this stage and it is important to note this clarification as it can easily cause confusion as stated by Myers (1997).

The DSR approach is concerned with knowledge creation through building of artefacts and this method was found the most suited for the research goals of this study, and therefore, it is the method that this research adopted. In Section 3.4, this approach is discussed in greater detail.

3.7.4 Research Design

The study adopted the Design Science Research (DSR) approach as justified above. DSR creates knowledge through construction and evaluation of artefacts (see Section 3.4). This section describes how this study was designed in line with this approach.

The research was designed into a main cycle and three sub-cycles. The main research question was designed as the main cycle and the sub questions were designed as the three sub-cycles within the main cycle as illustrated in Figure 3-4. The research process in the main cycle, the second and the third sub-cycles were designed in line with the DSR research process consisting of five steps, namely: - awareness, suggestion, development, evaluation and conclusion (Vaishnavi & Kuechler 2007) as described in section 3.7.4.1, Section 3.7.4.3 and Section 3.7.4.4 respectively. The research process for the first sub-cycle was the systematic literature review and the application of it in answering the first sub-question is presented in Section 3.7.4.2.

3.7.4.1 Main Research Cycle

The details of the steps in the main cycle are described below:

Main cycle-Awareness: The awareness of this cycle is linked to the main question of the research. To fit in the DSR terminologies, the main question was paraphrased as an awareness of the existing gap. Thus the awareness was phrased as: *Lack of adequate knowledge transfer model for transfer of biodiversity knowledge between experts and citizens*

Main cycle-Suggestion: The suggestion step was concerned with proposing how a selected knowledge transfer model can be enhanced using ontological modelling and crowd computing techniques. The suggestion was: *Identify a knowledge transfer model that can be adopted for biodiversity management knowledge transfer and propose enhancements using ontological modelling and crowdsourcing techniques.* Identification of a knowledge transfer model to adopt was done through a sub-cycle, *Sub-cycle 1* described in Section 3.7.4.2.

Main cycle-Development: Development stage consisted of combining outcomes to two sub-cycles, *sub-cycle 2* and *sub-cycle 3* to create a knowledge transfer model that combines ontological modelling and crowd computing to facilitate knowledge transfer. The details of the two sub-cycles, *sub-cycle 2* and *sub-cycle 3* are presented in Section 3.7.4.3 and Section 3.7.4.4 respectively. The development step was: *Develop the model by enhancing the output of suggestion step with the findings in the two sub-cycles*

Main cycle-Evaluation: Evaluate the model by using it to build a platform for biodiversity knowledge transfer. Use a specific application case that involves knowledge transfer between experts and citizens.

Main cycle-Conclusion: The research was concluded by reporting the main outcome and the other outcomes of the main-cycles. The outcomes are both theoretical and practical (artefacts) in nature.

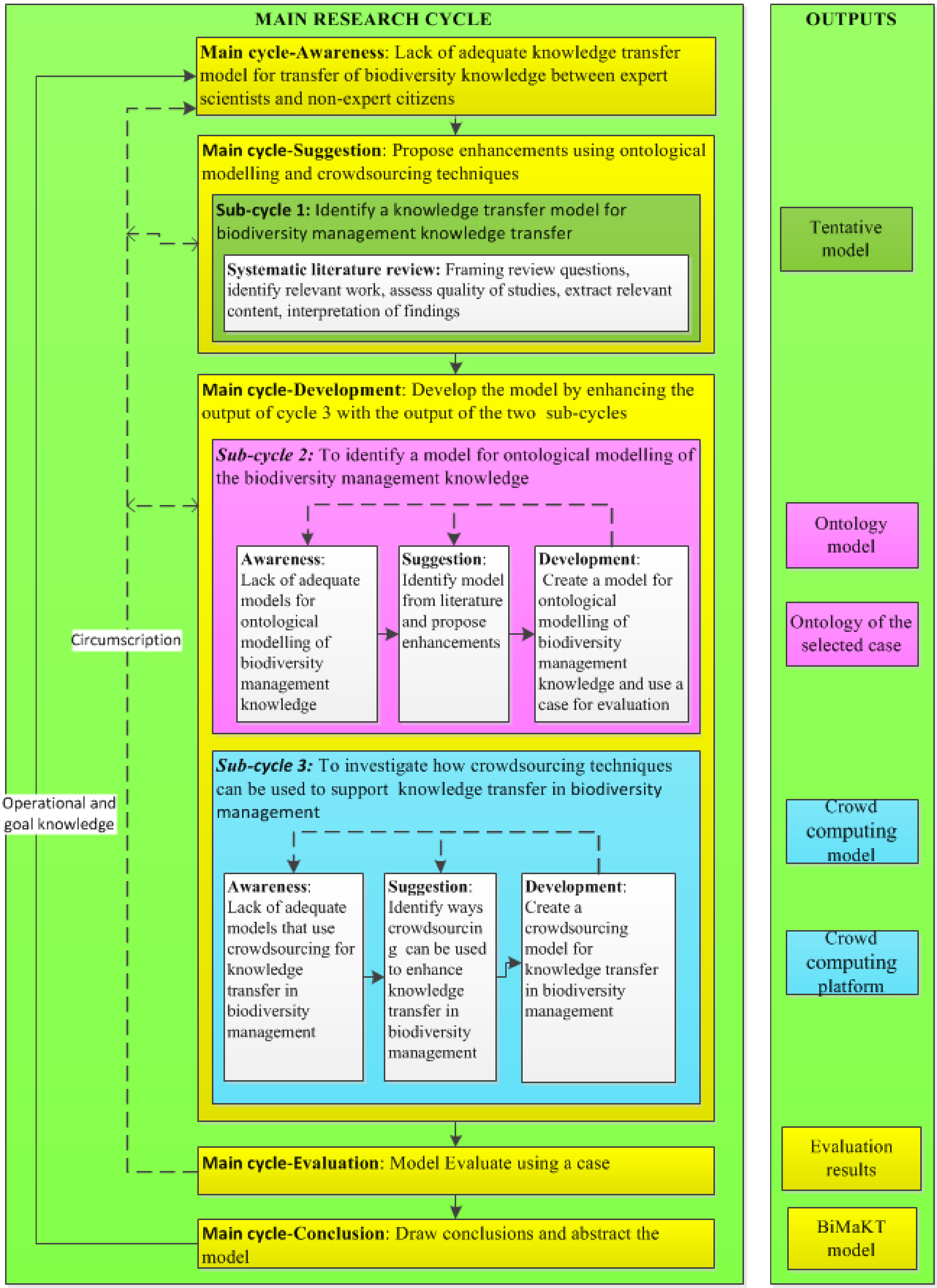

Figure 3-4: Research cycles in the study.

3.7.4.2 Sub-cycle 1

The sub-cycle 1 was designed to answer the first sub-question of this study "Which knowledge transfer model is applicable for online expert-citizen knowledge transfer in biodiversity management?" The sub-cycle was done using systematic literature review approach described in Section 3.4.2.5.1. The steps taken included: - framing questions for a review, identifying relevant work, extracting the relevant content and interpretation of findings adapted from (Booth et al. 2012). The review process steps are described below: -

Sub-cycle 1 - Step 1. *Framing questions for a review:* The questions for review were derived from the first sub-question of the research questions in this study "Which knowledge transfer model is applicable for online expert-citizen knowledge transfer in biodiversity management?" Because of the limited literature focusing specifically in biodiversity management knowledge transfer, the question was expanded to "Which knowledge transfer models are available in literature?" and "Which knowledge transfer model is applicable for expert-citizen knowledge transfer?" This provided opportunity to include models which are domain independent and also from other domains and could possibly be adopted for biodiversity management domain.

Sub-cycle 1 - Step 2. *Identifying relevant work:* This was done through extensive search for literature relevant to the question of literature review. The literature searched included both print and electronic sources. As stated above, knowledge transfer has been studied in non-homogeneous way and therefore, different terminologies must be used in order to find the available resources on the topic. Phrases selected for literature search included "knowledge transfer in biodiversity management", "knowledge transfer models", "knowledge transfer architectures", "knowledge transfer frameworks", "expert-citizen knowledge transfer models", "explicit knowledge transfer models", "knowledge sharing", "Knowledge exchange". The abstracts of retrieved resources were reviewed in order to identify relevance. Finally, resources in specific journals were sifted through and works of specific authors in the knowledge transfer topic were also examined.

Sub-cycle 1 - Step 3. *Assessing the quality of studies:* The quality of literature reviewed gives value to research since work based on good-quality works is more relevant. The quality of the relevant work was assessed by establishing the level of acceptance of the work through the number of times it is cited. Furthermore, the reputation of journals and conferences published in were considered.

Sub-cycle 1 - Step 4. *Extracting the relevant content:* Extracting the relevant models was done by creating a criterion for comparing the studies under consideration. The criterion for comparison considered several factors including: - target of the knowledge transfer process, actors involved in transfer process (e.g. source and receiver), directions of knowledge transfer and contexts used

Sub-cycle 1 - Step 5. *Interpretation of findings:* After extracting the relevant models, this step involved identification of the appropriate model based on the biodiversity management needs. In this step, the justification for the selected model is given.

The outcome of this cycle is a knowledge transfer model that could be adapted for knowledge transfer between experts and citizens in biodiversity management.

3.7.4.3 Sub-cycle 2

The sub-cycle 2 was designed to answer the second sub-question of this study "How can ontologies be used to capture biodiversity management expert knowledge?"

Sub-cycle 2 - Awareness: Lack of adequate models for ontological modelling of biodiversity management knowledge.

Sub-cycle 2 - Suggestion: Create a model for ontological modelling of biodiversity management knowledge.

Sub-cycle 2 - Development: Using a case, develop a model for representing biodiversity management knowledge.

Sub-cycle 2 - Evaluation: Evaluate using the selected case, evaluate correctness of ontology.

Sub-cycle 2 - Conclusion: Abstract from the case and report output.

3.7.4.4 Sub-cycle 3

The sub-cycle 3 was designed to answer the third sub-question of this study "How can crowd computing technologies be used to support biodiversity management knowledge transfer?"

Sub-cycle 3 - Awareness: Inadequate models that use crowd computing for biodiversity management knowledge transfer.

Sub-cycle 3 - Suggestion: Create a crowd computing model for biodiversity management knowledge transfer.

Sub-cycle 3 - Development: Develop a model for biodiversity management knowledge transfer.

Sub-cycle 3 - Evaluation: Evaluate the model by creating a platform using the model.

Sub-cycle 3 - Conclusion: Abstraction from the case and report results.

3.7.5 Data collection and participant selection

Since this research adopted the DSR approach, different techniques for collecting data were utilized depending on the research cycle. The data collection methods used in the different cycles are discussed in the sub-sections below:

3.7.5.1 Sub-cycle 1 Data collection

This sub-cycle was concerned with identification of a knowledge transfer model that could be adopted for biodiversity management knowledge transfer. The systematic literature review was used for collection and analysis of data on existing models.

3.7.5.2 Sub-cycle 2 Data collection

The sub-cycle 2 explored ontological modelling of biodiversity knowledge. The data collection method used in this cycle was document review to identify the nature of biodiversity knowledge to be modelled and transferred. The documentations reviewed included field guides and pamphlets used to transfer knowledge from experts to citizens.

3.7.5.3 Sub-cycle 3 Data collection

This sub-cycle examined how the different forms of crowd computing should be used to support the knowledge transfer processes. The data collection method used was systematic literature review of crowd computing literature.

3.7.5.4 Main cycle Data collection

The main cycle used interviews and web experiment to collect data. Interviews were used to get guidance from experts on knowledge transfer approaches used. A web experiment was used in the evaluation phase of the main model. The experiment was designed to allow participants to execute different activities online resulting in the collection of data for evaluation of the model.

Participants in this research were identified using purposive and convenience sampling techniques. Purposive sampling involves selecting participants based on their certain characteristic (Olivier 2009).Convenience sampling does not identify a representative subset of a population, but rather research participants who “are readily available” (Leedy & Ormrod 2002; Whitman & Woszcynski 2004; Ruttenberg et al. 2009).

Purposive sampling was used in the selection of experts, and fruit fly researchers from the African Fruit Fly Programme based in ICIPE, Nairobi Kenya were engaged. Convenience sampling was used in selection of the crowd participants as anyone who was willing to participate could do so.

3.7.6 Ethics and research participants protection

All participants in the research were protected, specifically the following ethical considerations were made to ensure autonomy, to protect participants from harm and ensure their privacy:

- Informed consent was made in writing or through acceptance of terms and conditions of participation.
- No names of participants were used or published at any stage of the research.

3.8 SUMMARY

In this chapter, the research methodology of the study was presented. The chapter commenced with a discussion on philosophical views as well as the assumptions associated with each view. An overview of research methods was furthermore presented, with an outline of the two categories of research methods; quantitative and qualitative research. The research methods within each category were identified and described. This research being qualitative, more details were provided on three qualitative research approaches namely action research, case study and design science research.

The design science research (DSR) approach was discussed in detail in Section 3.4 giving details on the research framework, the research process and guiding principles for this approach. The DSR framework was described as being located between knowledge building process and knowledge using process. This means that DSR research is conducted with elements of rigor and relevance, with rigor coming from the existing knowledge and theories and relevance coming from practical application to the relevant domain.

Data collection approaches were discussed with focus on the approaches used in this research; interviews, the systematic literature review and online data collection through online experiment. The topic of ethical considerations was discussed and its role in research.

The research design was presented in the final section of this chapter. The research design described how this study was conducted using the concepts from the introductory sections. Section 3.2 formed a basis for identification of the philosophical view that was taken in this research. The philosophical view was identified through a systematic process of using the paradigm views of different dimensions (ontology, epistemology, methodology, and axiology) of the philosophical views to examine the research objective of this study. The identification process resulted in selection of the pragmatism view as the appropriate philosophical view for this study. Within the pragmatism view, the design science research approach was found appropriate for this research. The rest of the research design section describes how the study was conducted using the DSR approach. The study was designed into research cycles consisting of a main research cycle whose output answers the main question and three sub-cycles whose output answers the three sub-questions. The chapter concludes with ethical considerations considered for the research.

Part II - Awareness and suggestion

In this part, the findings of the second phase of the main research cycle are presented. The part II is contextualised within the entire research phases as shown in Figure II-I. The part has one chapter, chapter 4 and presents the findings of the awareness and suggestion phase of the main research cycle.

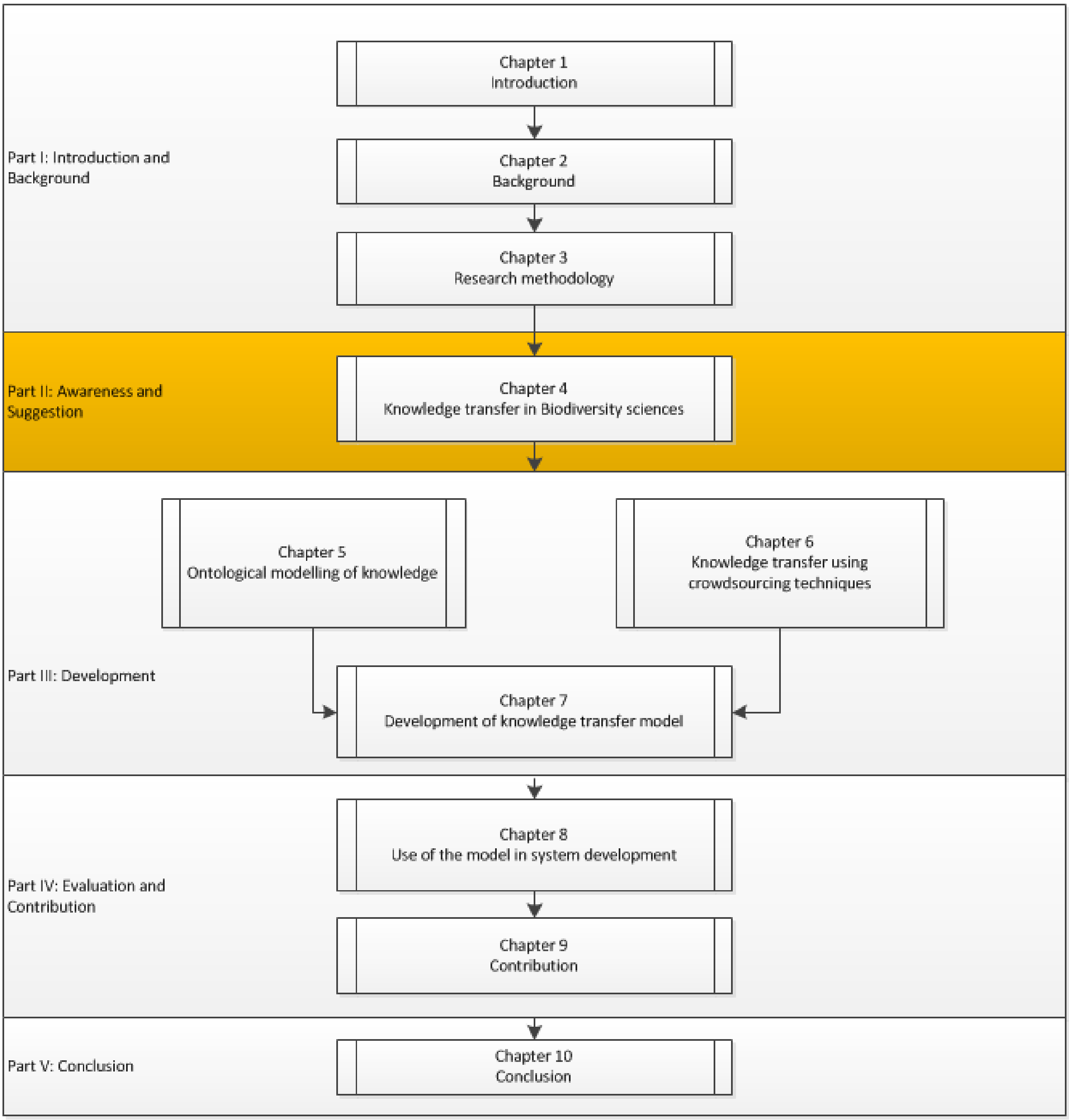

Figure II-1 - Part II Outline

Chapter 4 - Knowledge transfer in Biodiversity Management

4.1 INTRODUCTION

In this chapter, the results from the awareness and suggestion phases of the study are presented. The awareness phase was developed from the main research question and was re-phrased as:

"*Lack of adequate knowledge transfer models for transfer of biodiversity management knowledge between experts and citizens*"

The suggestion phase is closely related and was concerned with proposing how a selected model can be enhanced for knowledge transfer in the biodiversity management domain. The suggestion was phrased as:

"*Identify a knowledge transfer model that should be adopted for biodiversity management and enhance using ontological modelling and crowd computing technologies*"

This research in this phase was designed as a process that included one cycle, sub-cycle 1 that answer the first sub-question of the study. The first sub-question - highlighted below - was concerned with the identification of a knowledge transfer model that can be adopted for biodiversity management knowledge transfer.

SQ 1) Which knowledge transfer model is applicable for expert-citizen knowledge transfer in biodiversity management?

Research for the awareness phase was done through executing the research design of the first sub-cycle presented in Chapter 3, Section 3.7. The systematic literature review approach was used, and the process involved systematic review of knowledge transfer literature and identification of a model that should be applied in the context of biodiversity management knowledge transfer between experts and citizens. The results of the first sub-cycle were used as input to the subsequent suggestion phase which used conceptualization to propose possible enhancements to the model. The awareness and suggestion phases are presented next: -

4.2 AWARENESS

4.2.1 Knowledge transfer process models

In this section, a background on knowledge transfer process models is presented in order to give the chapter a grounding. As stated in Chapter 2, knowledge transfer has been studied in many dimensions (Kumar & Ganesh 2009). The knowledge transfer process is one of the dimensions from which knowledge transfer has been studied. Knowledge transfer process involves linking potential knowledge users to appropriate knowledge. The process of knowledge transfer can therefore be achieved through creating environments for knowledge source and receiver to interact and the knowledge transfer to happen in the process or through deliberately creating actions that facilitate the transfer of knowledge. In this study, the focus is on deliberate knowledge transfer process that relies on a set of steps taken to ensure knowledge is transferred from a knowledge source to a knowledge receiver (Major & Cordey-Hayes 2000; Gilbert & Cordey-Hayes 1996).

4.2.2 Method

The identification of a suitable knowledge transfer process was done through systematic literature review described in Section 3.7.4.2. The review began with framing the review objective which was “To identify a knowledge transfer process model suitable for biodiversity management knowledge transfer between experts and citizens”.

The second step was to identify relevant work through literature search. The literature search included both print and electronic sources. The search targeted processes that transfer explicit knowledge into action. The literature was found under diverse topics, including transfer of knowledge into action, theory to practice and research to practice. Different search engines were used including Google Scholar and search services available within the identified journals. Snowballing techniques (reference of references) were also employed in the identification of literature sources.

The step that followed was that of filtering the identified literature in order to arrive at a smaller set from which to consider. Literature in knowledge transfer process span across different domains and in the final stages it was necessary to consider domain needs as part of the critical criteria in deciding on the model to adopt. The final step was concerned with selecting one model and examining how the model would suit the biodiversity domain knowledge transfer needs.

In summary, the approach taken was divided into four stages: literature search; article selection for detailed reading; identifying recurring themes from selected articles; and selection of the suitable model for the knowledge transfer process. The review process is outlined in Figure 4-1 and the details of each review stage are described in Section 4.2.2.1 to Section 4.2.2.5 below.

4.2.2.1 Literature search

Knowledge transfer literature is scattered across different topics, and different terms are used to describe the same thing. Terms used in this search for literature reviewed for this research were identified through an initial search for “Knowledge transfer models” in Google Scholar, Science Direct, Scopus, Web Science, Springer Link and ACM digital library. The results of this initial research and snowballing techniques were used to identify a set of terms that this research used to search different databases for literature to review. The phrases that were used to conduct the literature search included: -“knowledge transfer models”, “knowledge sharing models”, “research to practice models”, “theory to practice”, “knowledge to action models”, “knowledge transfer process”, “knowledge transfer frameworks”, “knowledge translation models”, knowledge communication models” and “transfer of knowledge into action models”.

Using these phrases, different sources were searched including: - Google Scholar, Science Direct, Scopus, Web Science, Springer Link, ACM digital library, Emerald Insight, CiteseerX and EbscoHost. Specific journals were also searched including: - The Electronic Journal of Knowledge Management (EJKM), International Journal of Knowledge Management Studies (IJKMS), and International Journal of Knowledge Management (IJKM). Papers that discussed the theme of knowledge transfer were selected based on the title and a quick scan of the abstracts. The search process resulted in selection of three hundred and seventeen (317) papers. The selected papers were published between 1978 and 2016.

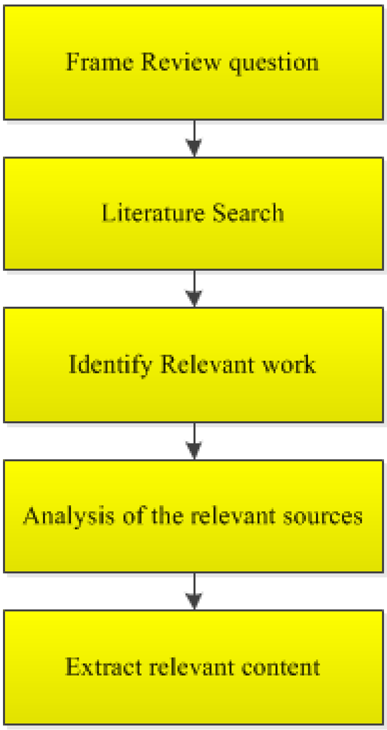

Figure 4-1: Systematic literature review process

4.2.2.2 Identification of relevant work

The review proceeded with detailed reading of abstracts and results of each paper. The articles discussing part or all of the knowledge transfer process were selected for detailed review. Papers that discuss other dimensions of knowledge transfer, such as contextual factors, theoretical analysis, impact assessments of knowledge transfer and other dimensions not pertaining to actual proactive transfer process were omitted. Since literature in knowledge transfer spans across different fields such as health care, sociology, political studies and education, sources from knowledge management and transfer of scientific knowledge domains were selected. The process of identification of relevant work resulted in selection of forty nine (49) papers.

4.2.2.3 Analysis of models

The selected papers were subjected to a detailed review. During this review, the papers were further rated as discussing specific steps of the knowledge transfer process to presenting generalised conceptualizations. The discipline the model was created under was also identified and the popularity of the model through the number of references that quote the paper as shown in Appendix I.

4.2.2.4 Extracting relevant content

During this stage of the review, the elements of knowledge transfer process were identified from the various sources and described.

4.2.2.5 Selection of model

After the analysis, the process elements considered necessary for biodiversity management knowledge transfer are identified. The process model that contains these elements in the logical order applicable to biodiversity management knowledge transfer is selected for further enhancement.

4.2.3 Results

In this section, the results from the systemtic literature review are presented. As stated above, the literature searched using the identified keywords resulted in 317 sources for review. The sources were subjected to a finer process of abstract and results review resulting in a further refinement of relevant sources to 49 papers. The 49 papers focussing on the knowledge transfer process were further analysed and detailed results are available in Appendix I. Summarized results on the discipline of knowledge transfer, the level of detail and the process steps of the model are presented in Sections 4.2.3.1 to 4.2.3.3 below.

4.2.3.1 Discipline

It has been observed that research in knowledge transfer is dispersed across diverse disciplines (Curran et al. 2011). The sources reviewed were therefore from different disciplines and numbers from the different disciplines identified in this research were as follows: -

- Biodiversity management (n=3)
- Construction (n=2)
- Education (n=3)
- Health (n=9)
- Knowledge management (n=7)
- Management Science (n=9)
- Multidisciplinary (n=1)
- Science (n=3)
- Strategic management/ Policy (n=4)
- Technology (n=7)

4.2.3.2 Level of detail

The models presented had different levels of detail; some had detailed descriptions that could directly be implemented while others are conceptualizations and abstractions that provide general guidelines. The models in the different sources were ranked in a scale of 1 to 4, with 1 being detailed enough for practical implementation and 4 being highly abstract. The results were as shown in Table 4-1 below.

Table 4-1: Number of knowledge transfer models per levels of details scale

Scale	1	2	3	4
Number of models (n)	4	3	10	30

4.2.3.3 Steps of knowledge transfer

The models that were classified as detailed in Section 4.2.3.2 above were studied further. These models were rated as 1 and 2 and are highlighted in Appendix I. The knowledge transfer process steps of each model are summarized in Table 4-2

Table 4-2: Knowledge transfer processes

Source	Knowledge Transfer Processes
1. (Cohen & Levinthal 1990) Absorptive Capacity: A New Perspective on Learning and Innovation Wesley	*Process 1*: Recognition *Process 2*: Assimilation *Process 3*: Application
2. (Horton 1999) A simple guide to successful foresight	*Process 1*: Collection *Process 2*: Collation / Summarization *Process 3*: Translation / Interpretation *Process 4*: Assimilation *Process 5*: Commitment
3. (Major & Cordey-Hayes 2000) Knowledge translation: a new perspective on knowledge transfer and foresight	*Process 1*: Codification *Process 2*:Translation *Process 3*:Contextualizaton
4. (Trott et al. 1995) Inward technology transfer as an interactive process	*Process 1*: Awareness *Process 2*: Association *Process 3*: Assimilation *Process 4*: Application
5. (Carlile & Rebentisch 2003) Into the Black Box: The Knowledge Transformation Cycle (Knowledge transformation cycle)	*Process 1*: Storage *Process 2*: Retrieval *Process 3*: Transformation

Source	Knowledge Transfer Processes
6. (Narteh 2002) Knowledge transfer in developed-developing country interfirm collaborations: a conceptual framework	*Process 1*: Conversion *Process 2*: Routing *Process 3*: Dissemination *Process 4*: Application
7. (Liyanage et al. 2009) Knowledge communication and translation – a knowledge transfer model	*Process 1*: Awareness *Process 2*: Acquisition *Process 3*: Transformation *Process 4*: Association *Process 5*: Application *Process 6*:Externalization

It was confirmed from the analysis that the different process models for knowledge transfer though developed in different contexts do have similarities. From Table 4-2, the process models have varying number of elements describing the knowledge transfer process. The models presented in Carlile and Rebentisch (2003) and Major and Cordey-Hayes (2000) focus specifically on knowledge translation and not the knowledge transfer process in total. A description of different knowledge transfer processes in the models are outlined next.

Recognition / Awareness Knowledge Transfer Process

The awareness process of knowledge transfer is concerned with identification of the valuable knowledge sources. To identify the valuable sources, one has to be aware of the problem and existence of knowledge that can solve the problem. This process is listed in two models; Cohen & Levinthal (1990) and Liyanage et al. (2009)

Collection / Acquisition Knowledge Transfer Process

The acquisition process of knowledge transfer involves collecting the relevant knowledge from different sources. Horton (1999) described collection as getting broad information on a future theme when describing the process of foresight. Liyanage et al. (2009) describe the process as getting the knowledge from available sources as long as both receiver and source are willing.

Collation / Summarization Knowledge Transfer Process

The collation process of knowledge transfer is used in Horton (1999) as part of foresight process and is aimed at summarizing the knowledge that was collected in order to give it structure and form.

Translation / Interpretation Knowledge Transfer Process

The translation process of knowledge transfer is aimed at ensuring clarity of the knowledge by removing technical jargon thus making it plain and simple to understand, but retaining the organizational flavours (Horton 1999).

Transformation Knowledge Transfer Process

Transformation is concerned with converting the knowledge to a useful form at the receivers' end (Liyanage et al. 2009). This means that the knowledge at the receivers' end must be known and well-grounded so as to build the new knowledge on top of it. A transformation cycle is described in Carlile & Rebentisch (2003).

Conversion Knowledge Transfer Process

Conversion is described as an element of knowledge transfer process in Narteh (2008) model and stems from (Nonaka & Takeuchi 1995) which describes knowledge as being converted from one type (explicit/tacit) to another.

Association Knowledge Transfer Process

Association is part of making the knowledge relevant at receivers end and is concerned with linking the new knowledge with the specific areas in the receivers' context (Trott et al. 1995; Liyanage et al. 2009).

Assimilation Knowledge Transfer Process

Assimilation is adoption of the new knowledge at receivers' end (Cohen & Levinthal 1990; Trott et al. 1995).

Commitment / Application Knowledge Transfer Process

Application is the last element of most of the models and describes the practical use of the new knowledge at the receivers' end (Cohen & Levinthal 1990; Narteh 2002; Trott et al. 1995; Liyanage et al. 2009).

Externalization Knowledge Transfer Process

Most process models provide one way transfer of knowledge and silent on flow of knowledge from the receiver back to the source. Externalization is the feedback that loops back with feedback from the receiver to the source (Liyanage et al. 2009).

4.3 SUGGESTION

4.3.1 Model Selection

In order to select the model, the different models are appraised against the elements considered relevant for biodiversity management knowledge transfer. As discussed in the introduction, biodiversity management requires transfer of knowledge to address specific needs. The awareness process is therefore, necessary so that the knowledge transferred is geared towards achieving the desired change. Three models have the awareness process, namely Cohen & Levinthal (1990), Trott et al. (1995) and Liyanage et al. (2009). Biodiversity management requires transfer of knowledge from expert scientists to citizens who are not knowledgeable in scientific jargon. The absorptive capacity of the receiver is therefore, different from that of the source. Transformation and association are therefore, important processes so that the knowledge is made usable in the receivers' context. The models that have transformation and association processes include Horton (1999) and Liyanage et al. (2009). Finally, biodiversity management requires flow of knowledge from experts to citizens and also from citizens to experts. A feedback loop is therefore a requirement and the model by Liyanage et al. (2009)is the only model that discusses a feedback loop.

From this consideration of the models against biodiversity management knowledge transfer requirements, the model by Liyanage et al. (2009) was found appropriate for extension in this research. The model elements are relevant for biodiversity knowledge transfer and can be extended and enhanced for transfer of knowledge using ontological modelling and crowd computing technologies.

4.3.2 Knowledge transfer model enhancement suggestions

In this section, the knowledge transfer model is described with the suggestions on improvement using the two web technologies considered in this research are made. The knowledge transfer model developed by Liyanage et al. (2009) is characterized by six processes of Awareness, Acquisition, Transformation, Association, Application and Externalization, all described in Section 4.2.3.3. Besides these linked processes, the model provides further requirements for successful knowledge transfer, which includes: - a suitable knowledge source, willingness of source to share knowledge, willingness of the receiver to acquire the knowledge and absorptive capacity of the receiver. As discussed earlier, enhancing the model will ensure maximum benefits from the use of computing technologies in knowledge transfer to biodiversity management stakeholders. The enhancements that were suggested considering ontological modelling and crowd computing techniques are presented in the next sections.

4.3.2.1 Ontological modelling

The expert knowledge that needs to be transferred to citizens must be represented in some format. As stated in the introduction, experts in biodiversity management publish actionable knowledge through field guides, pamphlets, books and websites, which can then be accessed by citizens for action. In this research, it was suggested that the expert knowledge be represented using ontological modelling techniques so as to enable software support in accessing the knowledge (Guarino et al. 2009).

In this research, it was suggested that appropriate models for ontologically modelling of biodiversity expert knowledge be identified and enhanced as necessary. The model identified should support and complement the knowledge trancfer processes that make the knowledge relevant to the receiver (transformation, association). A model that also ensures the requirement for high absorptive capacity among receiver is reduced as much as possible from hindering knowledge transfer was considered ideal. Liyanage et al. (2009) identify absorptive capacity of the receiver as a requirement for knowledge transfer, but the ontological model adopted should aid in reducing it to a minimum. Although the impact of absorptive capacity is difficult to measure (Cohen & Levinthal 1990), knowledge modelling process should treat citizens' abilities to understand complex scientific knowledge as minimal and therefore, endeavour to make it accessible.

In summary, it was suggested that the model for representing expert knowledge should have the following features: -

- Accurately represented expert knowledge.
- Support transformation of knowledge to forms understandable in citizen contexts
- Provide for association with citizen knowledge
- Accommodate varying absorptive capacities among citizens

It is acknowledged in literature that development and evaluation of domain ontologies is still a craft, and no single methodology is applicable (Jones et al. 1998). For this research, it was suggested that evaluation of the model proposed be done by checking for the ontology correctness in answering domain questions. Also evaluation in answering citizen questions must be evaluated.

4.3.2.2 Use of crowd computing techniques

As stated in Chapter 2, crowd computing is a set of computing technologies that are characterized by “participation by a crowd of humans, interaction with computing technology, activity that is predetermined by the initiator or application itself and the execution of tasks by the crowd utilizing innate human capabilities” (Parshotam 2013). Different flavours of crowd computing implementation models have been identified including: - web 2.0, social computing, crowdsourcing, human computation and crowd-computer interaction (Gomes et al. 2012; Schneider et al. 2012; Parshotam 2013).

In this section, the suggestions on how crowd computing could be used to support the knowledge transfer process, are presented. It is suggested that the research should look at how the different steps of knowledge transfer would be supported using the different types of crowd computing. For instance, the first step in in the selected model is “awareness”. The suggestion phase of the research explored how the awareness phase could be supported by the different crowd computing approaches and made recommendations based on findings.

The phase also recommended evaluation of proposed approaches through evidence from literature on use of the approaches in addressing similar processes. In cases where evaluations are lacking in literature, the research performed an evaluation through experiments to validate the suggestions.

4.4 SUMMARY

In this chapter, the awareness and suggestion phase of the main research cycle is documented. This cycle was concerned with putting into perspective the existing models of knowledge transfer and selecting one for enhancement for ontological modelling and crowd computing based knowledge transfer in biodiversity management. The awareness was done through review of knowledge transfer models. It was found that the models have varying degree of detail, with some being conceptualizations and highly abstract while others are detailed and document the actual process of knowledge transfer. Although the abstract models were necessary in understanding the big picture of knowledge transfer, this research was concerned with the identification of a model that could be operationalised through adoption for practical knowledge transfer. A detailed review was therefore made on models that address the practical process of knowledge transfer from source to receiver.

Seven knowledge transfer models (Cohen & Levinthal 1990; Horton 1999; Major & Cordey-Hayes 2000; Carlile & Rebentisch 2003; Narteh 2002; Trott et al. 1995; Liyanage et al. 2009) were found relevant in this research, and a detailed review was made on the models. Selection of the model to adopt was done by considering the requirements of biodiversity management knowledge transfer against the properties of the different models. The model by Liyanage et al. (2009) was found suitable for biodiversity management knowledge transfer and was thus selected.

The chapter concludes with a suggestion section that presents the enhancements that are suggested for the enhancement on the model. The suggestions are based on two technologies; ontological modelling and crowd computing. The enhancements that could be made using each technology are proposed together with evaluation methods to be used as required in DSR.

Part III - Development

Part 3 of this study deals with the development phase of the main cycle. In this phase, the development of the suggestions made in the previous part, part 2, is done. Part 3 consists of three chapters; chapter 5 which documents ontological modelling of expert knowledge, chapter 6 presents how crowd computing techniques can be used to support knowledge transfer in biodiversity management and chapter 7 documents the development of an ontology and crowd computing technologies-based model for knowledge transfer in biodiversity management. The part is contextualised within the study as shown in Figure III-1 below.

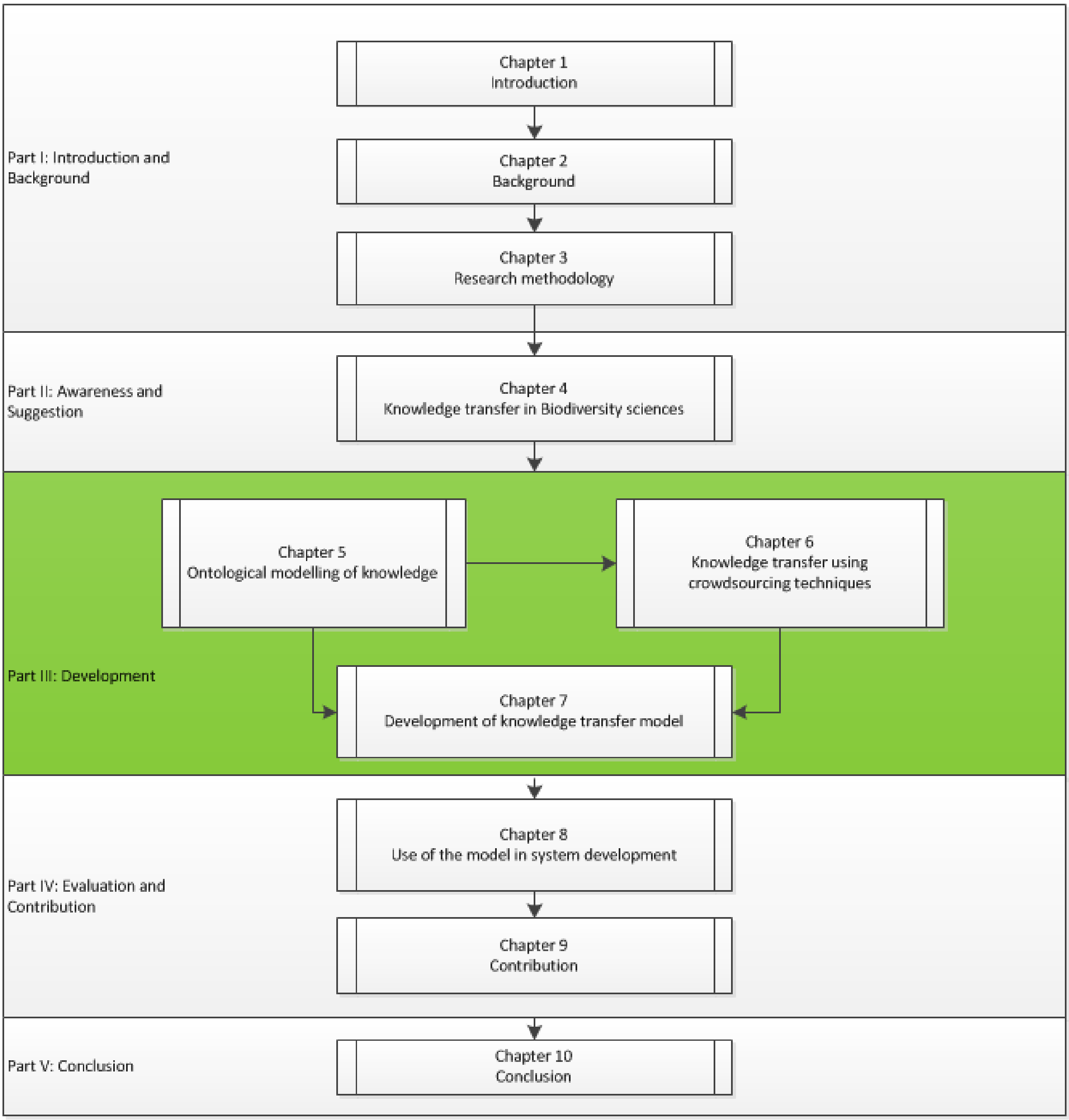

Figure III-1: Part III outline

Chapter 5 - Ontological modelling of biodiversity management knowledge

5.1 INTRODUCTION

In this chapter, the focus is on the second research question (SQ 2), which is concerned with ontological modelling of biodiversity knowledge.

SQ 4) How can ontologies be used to capture biodiversity management expert knowledge?

The type of biodiversity knowledge focused on were of three categories as stated in Chapter 1: - organism identification knowledge (taxonomic knowledge), relationship with other organisms and chemicals that can be used to control different species. The contents of this chapter are outlined in Figure 5-1 below.

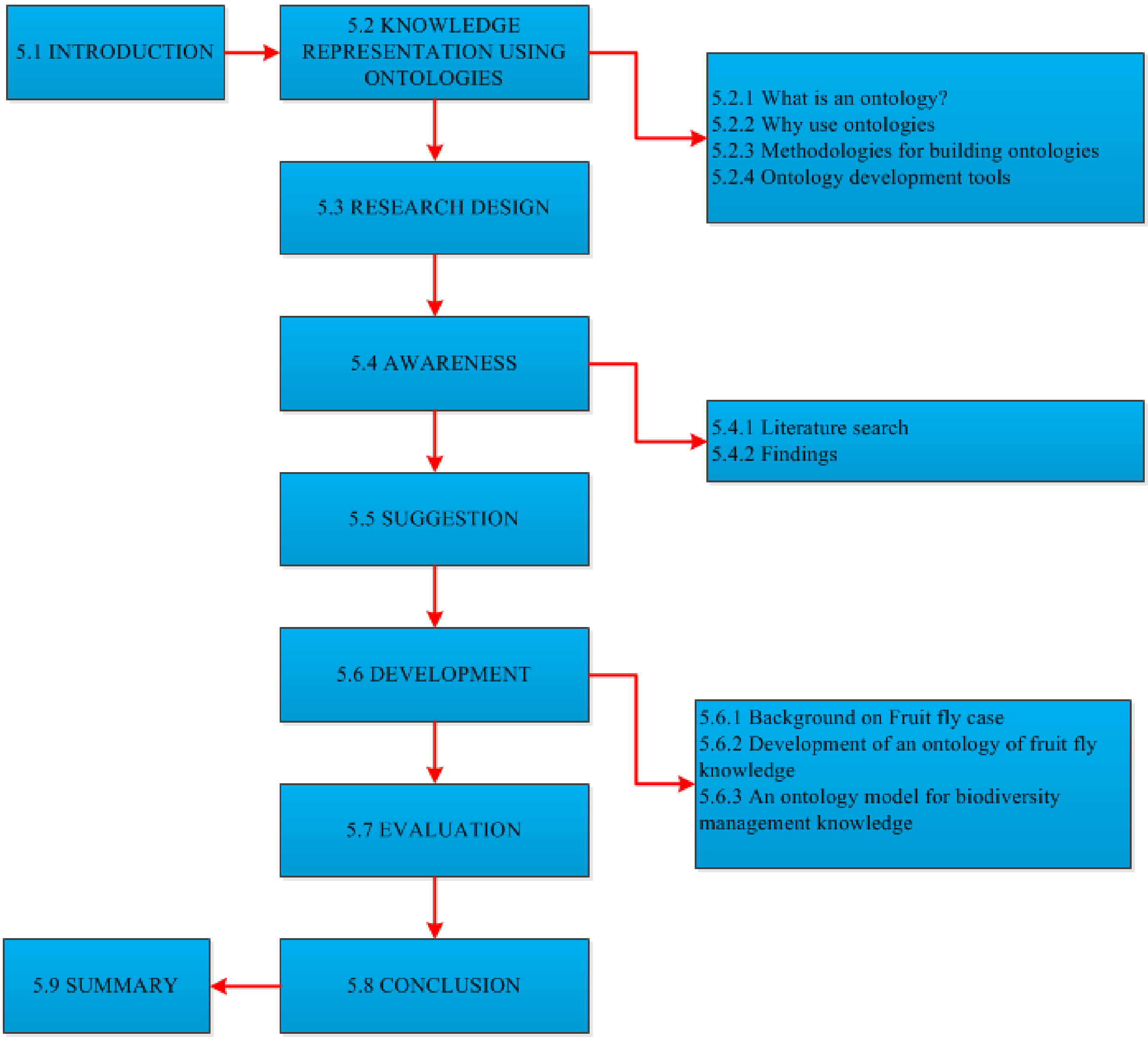

Figure 5-1: Chapter 5 outline

The chapter begins with a literature review on ontologies in Section 5.2. The review covers the definition of what an ontology is, why they are used, methodologies for building ontologies and tools used in the development of ontologies. In Section 5.3 the research design used in addressing this question is presented. In the subsequent sections, the results of the different DSR cycles are presented: - 5.4 the awareness, 5.5 the suggestion, 5.6 the development, 5.7 the evaluation and 5.8 the conclusion. Section 5.9 is a summary of the chapter.

5.2 LITERATURE REVIEW

In this section, a review of literature on ontologies is presented, including what they are, advantages of using ontologies over other forms of knowledge codification, methodologies for developing ontologies and tools for building ontologies.

5.2.1 What is an ontology?

The term ontology has its origin in philosophy where it is a sub discipline of Metaphysics that deals with the "study of being" (Schuwey & Smith 1985). In Metaphysics, an Ontology defined as the science of "*being qua being*," i.e., the study of attributes that belong to things because of their very nature (Guarino et al. 2009). The term has become common in computer science and information systems with varying definitions. The most cited definition of ontology is that of Gruber (1993) which define an ontology as "*a formal, explicit specification of a shared conceptualization*", where *formal* means the specifications are encoded in a well-understood language, usually logic-based language; explicit *specification* means concepts are given explicit names and definitions, *shared* means the knowledge in the ontology can be shared and re-used by different groups that subscribe to it; conceptualization means the way people think in a given domain (Uschold & Gruninger 2004; Guarino et al. 2009; Corcho et al. 2006).

Other definitions of ontology have been proposed by other authors, for example: - "An ontology is an explicit account or representation of a conceptualization" (Uschold & Gruninger 1996); "Ontologies are content theories about the sorts of objects, properties of objects, and relations between objects that are possible in a specified domain of knowledge" (Chandrasekaran & Josephson 1999); "An ontology defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary" (Neches et al. 1991); "An ontology is something used to embody the structure of a system" (Guarino et al. 2009); An ontology is a "human intelligible and machine interpretable representations of some portions and aspects of a domain" (Baclawski et al. 2013); and "An ontology is a formalized representation of knowledge consisting of classes, properties and individuals" (Horridge et al. 2009).

Depending on the objectives of creating an ontology, different degrees of expressiveness are necessary. The expressiveness of an ontology depends on the expressiveness of the language adopted. Languages for modelling ontologies can be organised into a continuum ranging from highly informal to rigorously formal languages as shown in Figure 5-2 (Guarino et al. 2009; Uschold & Gruninger 1996; Torre 2009). Starting at the informal end, is a list of terms that have no specifications, and towards the formal end, the level of specification increases with all terms formally defined using logical languages such as description logics and modal logics. The implications of the variation across the continuum is that ambiguity reduces as one moves from the informal towards formal, support for automated reasoning increases as the degree of formality increases and complexity in creating and evaluating ontologies increases as level of formality is increased.

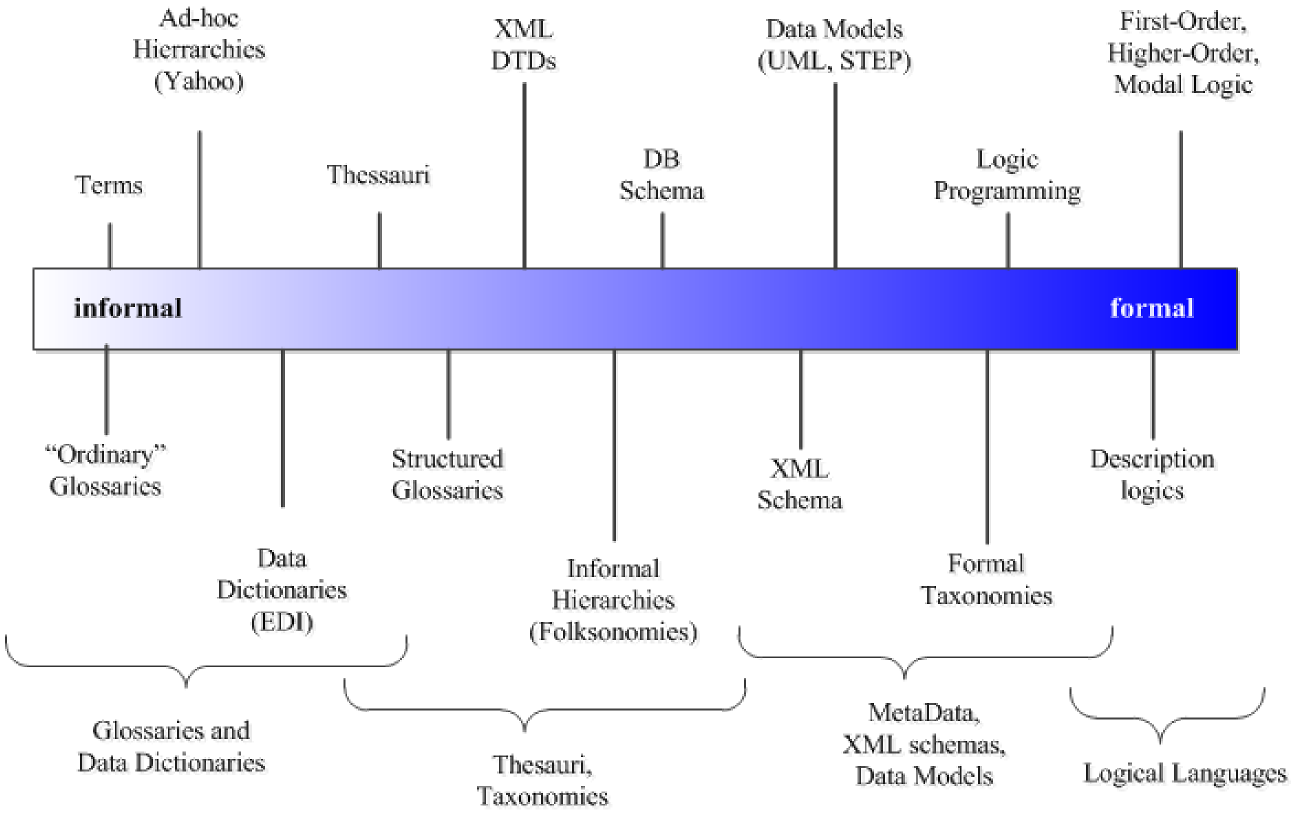

Figure 5-2: Ontology languages (Guarino et al. 2009)

On the formal end, *logical languages* support reasoning, but within these languages, a trade-off between *expressiveness* and *efficiency* is often encountered (Guarino et al. 2009; Torre 2009). Highly expressive logical languages are not efficient as they do not allow for complete reasoning within practical timelines, and when they do the reasoning is not tractable. Examples of formal logic languages include: - Predicate logic such as First Order Logic (FOL), Second Order Logic, Modal Logic and higher order logic; Description Logics (DL); and Frame-based Logic (Corcho & Gómez-pérez 2000; Su & Ilebrekke 2002).

Description Logics (DL) is a widely used in ontological modelling and is one of the main languages that is the foundation to Web Ontology Language (OWL). OWL 2 (OWL version 2) was accepted by the World Wide Web Consortium (W3C) as standard and OWL 2 is thus one of the ontology languages with significant adoption in ICT. DLs allow representation of knowledge using formal semantics that can be shared by both humans and computers without ambiguity thus allowing incorporation of reasoning to infer more assertions from the represented facts (Krötzsch et al. 2012). DL languages are designed to ensure expressiveness and efficiency of the reasoning algorithms. Because of this trade-off, different DL languages have been developed with different strengths and weaknesses with respect to expressiveness and algorithm performance. Examples of DL languages include: - Attributive language (AL), Frame based description language (FL), Existential language (EL),SHIQ, SROIQ, SHOIN and SHIF (Baader et al. 2005; Krötzsch et al. 2012; Rudolph 2011)

5.2.2 Why use ontologies

Several reasons motivate the development and use of ontologies for knowledge representation, key amongst them includes the need to share common understanding of the structure of information among people or software agents, to enable domain knowledge reuse, to make domain assumptions explicit, to separate domain knowledge from the operational knowledge and to analyse and reason upon domain knowledge (Gruber 1993; McGuinness & Wright 1998; McGuinness et al. 2000).

Circumstances where ontologies are considered relevant have also been identified in relation to other data storage techniques, for instance, Horrocks (2008) outlined three instances when it is recommended to use ontologies as opposed to databases: 1) when the dataset is very large, with complex relationships and inferences need to be made at query time; 2) when it is not possible to assume completeness of information; and 3) when one is willing to pay performance costs.

5.2.3 Methodologies for building ontologies

Over the years different methodologies have been proposed and in this section a few methodologies are reviewed. Review of ontology development methodologies has been done from different dimensions, for example: - a review on maturity of methodologies based on the IEEE standard was done by Fernández-López (1999); a survey of methodologies was conducted by (Jones et al. 1998); and chronological analysis and comparison of methodologies based on a defined criterion was done by Iqbal et al. (2013).

Different methodologies have been developed over the years, some based on specific project experience and others tied to ontology development tools. Methodologies that emerged from specific project experiences were common in the 1990s. Examples include: - TOVE (*TOronto Virtual Enterprise)* methodology derived from development of an enterprise ontology (Uschold & King 1995); Methodology by Grüninger and Fox (1995) , which builds on TOVE methodology and provide framework for evaluation of the ontologies; KACTUS methodology derived from building an ontology in the electrical networks domain (KACTUS Consortium 1996); METHONTOLOGY was developed in an artificial intelligence lab (Fernández-López et al. 1997; Gómez-Pérez & Benjamins 1999; Fernández-López 1999); SENSUS-based methodology derived from the SENSUS project developed by the Information Science Institute to provide a conceptual framework for machine translation of natural language (Knight & Luk 1994; Knight et al. 1995).

Methodologies that are tool-based became more popular from year 2000. For instance: methodology proposed by Noy and McGuinness (2001), provides an ontology development methodology based on Protégé - 2000 (Protege 2000) for explication, as well as the methodology by Horridge et al. (2009), which describes how to build OWL ontologies and use Protégé to provide a step by step process of building an ontology. Other methodologies include a methodology for development of small enterprises ontologies (Ohgren & Sandkuhl 2005); a methodology for product family ontology development using OWL (Nanda et al. 2006). Until the period around the year 2010, there was general consensus in literature that ontology development was still a craft skill without scientifically proven engineering methodologies to guide the development (Noy & McGuinness 2001; Jones et al. 1998; Fernández-López 1999; Bergman 2010).To build ontologies, researchers in many cases therefore adapted some methodology or used components from different methodologies.

More recently, new methodologies and guidelines for building ontologies are on the rise (Baclawski et al. 2013; Suárez-Figueroa et al. 2012). Baclawski et al. (2013) proposed an ontology development life cycle model detailing how an ontology should be conceived, specified, developed, adapted, deployed, used, and maintained. Emphasis is placed on evaluation at each phase to ensure the requirements are met at all times and guidelines for evaluation of each phase are provided in the model. Baclawski et al. (2013) also provide a high-level guideline for the overall evaluation of an ontology. The guideline looks at five characteristics of the ontology namely:

1. Intelligibility - Can humans understand the ontology correctly?
2. Fidelity - Does the ontology accurately represent its domain?
3. Craftsmanship - Is the ontology well-built and are design decisions followed consistently?
4. Fitness - Does the representation of the domain fit the requirements for its intended use?
5. Deployability - Does the deployed ontology meet the requirements of the information system of which it is part?

Suárez-Figueroa et al. (2012) proposed the NeOn methodology. The NeOn methodology suggests a number of pathways for ontology development. Four facets of the methodology are:

1. The NeOn Glossary defining the potential processes and activities for ontology construction
2. Nine scenarios for building ontologies and ontology networks detailing how each scenario is decomposed into processes and activities
3. Two ontology network lifecycle models detailing how to organise processes and activities into phases
4. Methodological guidelines for processes and activities

Another more recent methodology for ontology development is the UPON methodology that was developed from Unified Development Process (De Nicola et al. 2005; De Nicola et al. 2009; De Nicola & Missikoff 2016). UPON is based on software development Unified Process (UP) modelling and uses the UML notations for documentation of ontology development blue prints.

5.2.4 Ontology development tools

Creation of ontologies requires careful modelling to ensure the specifications are sufficient, accurate and consistent in representing the desired world. To achieve this, there is need for a formal language for modelling. One such family of modelling languages that is prominent for knowledge representation modelling is the Description Logics (DL) (Krötzsch et al. 2012; Baader et al. 2005). The power of DL is in the capability to infer additional knowledge based on explicitly stated facts. Technologies for ontology development have been a subject of research, and useful tools are starting to materialise. One such milestone is the development of the Web Ontology Language (OWL) which is based on expressive DLs and tools such as Protégé ontology editor (Protege 2000) that together with integrated reasoner aid modelling and generation of ontologies in the OWL syntax (Horridge et al. 2011).

5.3 RESEARCH DESIGN

The objective of this section is to present the research design used to answer the research question addressed in this chapter, "How can ontologies be used to capture biodiversity management expert knowledge?" The DSR approach was used, and in Figure 5-3, this research question is fitted into the DSR research phases of awareness, suggestion, development, evaluation and conclusion.

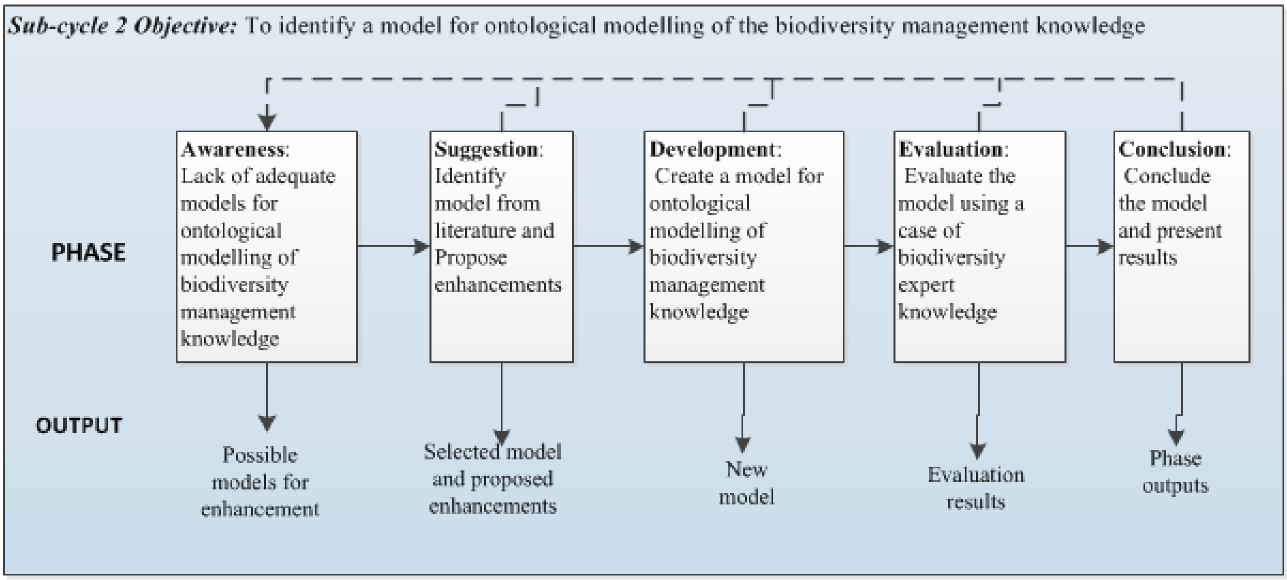

Figure 5-3: Research Design of the Sub-cycle 2

The awareness phase was conducted through narrative research review, which is sometimes called literature review and involves getting relevant literature from different sources and combining it into a whole. The objective of this review is to survey the state of ontological models in order select a suitable one for biodiversity management knowledge representation. The suggestion phase was done through conceptualization and reflection from current work. The development and evaluation phase was done through adopting guidelines from different ontology development methodologies (Noy & McGuinness 2001). The details of the research design and outcome of each phase is presented within the phases in Section 5.4 to Section 5.8 below.

5.4 AWARENESS

The objectives of this phase was to identify and establish the suitability of existing ontology models for representation of biodiversity management knowledge, specifically, the type of knowledge delimited for consideration in this research. To identify ontology models for representation of biodiversity management knowledge, the narrative literature review approach was used. Narrative literature review can be used to survey the state of knowledge in a selected area (Baumeister & Leary 1997) and this is in line with one of the objectives of this phase. The review process included: - searching the literature and gathering relevant work, reading and analysing the literature and writing the review (Cronin et al. 2008).

5.4.1 Literature Search

The identification of relevant literature was done using keywords search, snowballing techniques from sources found relevant and searching of biological ontologies websites. Biological ontologies websites searched include: - Open Biological Ontologies (OBO) foundry (Smith et al. 2007); BioPortal (Whetzel et al. 2011) and The National Center for Biomedical Ontology, NCBO (Musen et al. 2012) . As stated in Section 5.1, the type of knowledge considered for representation included taxonomic knowledge, relationship with other organisms and chemicals used in the control and management of different species. These knowledge types were grouped into two categories for purposes of identification of relevant sources: - anatomy knowledge and traits knowledge. The search keyword used was "biological ontologies" and the results were scanned through to pick, anatomy and traits ontologies sources.

5.4.2 Findings

The search resulted in hundreds of results that were analysed to identify the ontologies that focused on anatomy and traits knowledge. The definitions of the two kinds of ontologies are: Anatomy ontologies (AOs) are representations of the parts of an organism and the structural relationships that hold between them (Mungall et al. 2012) while Traits ontologies (TOs) represent any measurable or observable characteristic pertaining to an organism or any of its substructures (Park et al. 2013). From the definitions, the two categories of ontologies are encompassing for the kind of knowledge considered in this study. The review examined how the different ontologies modelled these kinds of knowledge with the aim of identifying modelling approaches that could be adopted for this research. A summary description of the analysed ontologies is presented in Appendix II consisting of the ontology and a description.

The review found that there are many sources on anatomy ontologies compared to traits and phenotype ontologies. A simple count of ontologies in the Open Biological Ontologies (OBO) foundry (Smith et al. 2007) website found 19 ontologies focused on anatomy knowledge while 4 focused on traits knowledge. The anatomy ontologies range from top level ontologies such as the Common Anatomy Reference Ontology (CARO) (Haendel et al. 2008) to ontologies representing gross anatomy knowledge such as the gross anatomy of Hymenoptera (Yoder et al. 2010). An in-depth study of anatomy ontologies shows that most of them adopt the CARO ontology to define the top-level concepts, and use of three object properties ("is_a", "part_of" and "develops_From") to define relationships between anatomical components, is common across sampled ontologies. The trait ontologies showed variations in modelling and no common ontology is adopted in the traits ontologies.

The widely reference anatomy ontology is the CARO ontology was modelled for purposes of promoting interoperability between anatomy ontologies (Haendel et al. 2008). The ontology provides high level definitions and relations for high level anatomical components. The components defined include : anatomical entity, immaterial anatomical entity, anatomical line, anatomical point, anatomical space, cell space, anatomical surface, anatomical group, anatomical cluster, anatomical system, compound organ, solid compound organ among others. A complete list of definitions is available in Haendel et al. (2008). It is recommended by OBO that the CARO ontology is adopted when defining high level terms in anatomical ontologies so as to ensure interoperability between ontologies. Relationships between concepts is modelled using "is_a", "develop_from" and "part_of" object properties.

As stated above, the number of ontologies representing traits knowledge are still relatively few compared to anatomy ontologies. An example of trait ontology is the animal trait ontology (Hughes et al. 2008) which represents traits knowledge on three domesticated farm animals: - pigs, cows and chicken. The ontology distinguishes six sub-categories of traits namely: - development traits, exterior traits, immune function traits, product quality traits, production traits and reproduction traits. Another example of traits ontology is the Plant Trait Ontology (PTO) reference model (Arnaud et al. 2012). In this PTO model, the trait is defined as an entity with an attribute (Trait=Entity+Attribute). The model presented in (Gerber et al. 2014) is another example of trait knowledge representation where the diagnostic features used in multi entry key can be seen as traits that are associated with different afro tropical bees taxonomic groupings. The diagnostic features are modelled as anatomical body parts with some feature, i. e. Diagnostic feature= anatomic part + feature. The Diagnostic features are associated with taxonomic groupings as documented in taxonomic key being modelled. More anatomy and traits ontologies are described in Appendix II.

The anatomy and traits ontology describe knowledge on selected taxonomic groupings. This is attributed to the fact that anatomy and traits knowledge are common across closely related clusters of organisms and therefore it is natural to model knowledge on closely related groups for some purpose such as analysis of existing datasets or linking to other knowledge bases such as genomic data (Dahdul et al. 2010). Motivations of developing otologies is defined in each project and from the reviewed cases, the motivations are diverse and includes the need to be able to standadize datasets from disparate sources (Maglia et al. 2007), the need to analyse data from multiple species (Mungall et al. 2012), the needs to simplify querrying acrosss databases (Segerdell et al. 2008) among others. Ontologies that model morphology knowledge together with traits knowledge for joint querrying are missing in the literature. Morphology and traits knowledge are important knowledge for knowledge transfer to citizens in biodiversity management since identification needs are mostly met through observable morphological features and traits. Ontologies that enable experts and citizens to share knowledge were not found in the literature search conducted in this research yet it is an important component of citizen engagement in biodiversity management.

5.5 SUGGESTION

This section presents the suggestion phase of the sub-cycle 2 of this study. From the awareness phase in Section 5.4 above, it was established that models for representing morphological and traits knowledge so that they can be jointly analysed are lacking. Jointly analysing this kind of knowledge is necessary in answering different biodiversity management questions and therefore, in this research it was suggested that a model to represent morphologies and traits knowledge be created.

Biological ontologies need to adhere to certain guidelines in order for the resulting ontologies to contribute to the overall requirements of modelling biological knowledge. These requirements include: - the need to model biological knowledge in a way that can be linked to other knowledge bases and the need to model the knowledge in a way that it can be jointly analysed with other sources of knowledge. It is therefore suggested that the proposed model should adhere to guidelines provided for the modelling of the different knowledge types.

The suggestion phase proposed the creation of a new model for ontological modelling of biodiversity management knowledge that meets the following requirements: -

- Models morphology and traits knowledge
- Allows joint analysis of the knowledge to answer questions without the need to use multiple queries.
- Adhere to guidelines of modelling the two kinds of biological knowledge.

5.6 DEVELOPMENT

In this section, the results from the development phase of sub-cycle 2 are presented. The objective of this phase was to develop a model for ontological representation of biodiversity management knowledge focussing on morphological and traits knowledge that meets the requirements outlined in the suggestion phase, Section 5.5 above. In order to develop the model, a case that required modelling of morphological and traits knowledge was selected for use in the development. The research selected a case of fruit fly control and management knowledge for use in the development of the ontology model. This section commences with a brief background on the case in Section 5.6.1 followed by the development of the ontology in Section 5.6.2 and concludes with the model created through abstraction from the case to create an ontology model in Section 5.6.3.

5.6.1 Background on Fruit fly control and management

Tephritid fruit flies in Africa have been the subject of research for scientists resulting in generation of different kinds of knowledge, including: - the biology, ecology and control and management knowledge. Three categories of knowledge are core in the control and management of the fruit flies; identification and taxonomic knowledge, knowledge regarding lures that attract different species and host plants of the different fruit fly species.

Simplified taxonomic keys of the economically important species have been developed for use in field identification. One such taxonomic key is Billah et al. (2007) available in print form. Research has shown that different species of the flies are attracted to different lures (Manrakhan 2007; Billah & Ekesi 2007; Nagaraja et al. 2014). The knowledge on attractants is useful in deciding on the lures to use on fly traps for the trapping of different species of the flies. Finally, different fruit species are host to different species of the fruit flies (Billah & Ekesi 2007; Rwomushana et al. 2009; Ekesi & Muchugu 2007). Because host status is a dynamic phenomenon, cataloguing the host status of the various species is crucial for management and predicting infestation patterns based on preferred hosts knowledge. Knowledge on host preference also aids in prioritization of fly-host investigation of non-commercial fruits.

This case was selected because it was found suitable for investigating the research questions of the study presented in this thesis. It involves the transfer of biodiversity management knowledge between experts and citizens. The other motivation for selection of the case was the interests and willingness of fruit fly researchers to participate and provide necessary documentation in order to explore technology mediated knowledge transfer to solve the fruit fly challenges. Finally, the case was also selected because of my personal interests to contribute to control, and management problem faced by many subsistence growers who cannot easily access useful scientific knowledge from ongoing fruit fly research.

5.6.2 Development of an ontology of fruit fly knowledge

The development of the fruit fly ontology followed the ontology development guidelines and methodologies proposed by Grüninger and Fox (1995), Horridge et al. (2009) and Noy and McGuinness (2001). The approach was borrowed from the development of the Afro-tropical bee ontology presented in Gerber et al. (2014). The Afro-tropical bee ontology models morphology knowledge and this research models morphology knowledge of the fruit fly together with other traits knowledge. This research therefore adopted the same approach in the development of the fruit fly ontology. The overall approach used was defining the scope of the ontology, search of existing ontologies for re-use, ontology modelling and evaluation.

5.6.2.1 Scope of the ontology

The scope of the ontology defines the nature of knowledge that needs to be represented together with the level of detail required. In this research, the scope was defined through definition of competency questions that the ontology must answer as prescribed in (Noy & McGuinness 2001). The competency questions that the fruit fly ontology must answer are outlined in Table 5-1 below. The questions were structured into generic questions which outlines a class of questions based on different categories of knowledge and an example specific question for each generic competency question.

Table 5-1: Fruit fly ontology competency questions

Generic question	Specific questions
(1) Which species have a given set of taxonomic features	Which species have patterned wings, dark brown femora and three black spots on the scutellum?
(2) Which set of host plants can a given species attack	Which hosts can be attacked by Bactrocera latifrons (Hendel)?
(3) Which set of species can a given lure attract?	Which species are attracted by Trimedlure?
(4) Which set of species has a selected morphological feature, is hosted by a selected host and is lured to a given attract?	Which species have three dots on scutellum, is attracted to protein bait and can be hosted by Anacardium *Occidentale* (cashew nut)

The competency questions are also useful at the evaluation stage since they are used to check if the ontology correctly answers the domain questions it was intended to answer.

5.6.2.2 Identify existing ontologies for re-use

Creation of ontologies is expensive and where possible, existing ontologies must be re-used. Re-use of existing ontologies may be done through using an existing ontology as it is if it meets the requirements of a new application, extending an existing ontology to incorporate non-met requirements if the existing ontology partially meets current requirements or for interfacing if the ontology needs to interact with other ontologies that have committed to a certain vocabulary (Noy & McGuinness 2001; Horridge et al. 2009).

In this research, the TAXARANK ontology (Phenoscape 2010) was re-used. The TAXARANK ontology contains a vocabulary of biological taxa and all terms are directly descending from the term 'taxonomic rank'. The TAXARANK ontology was found suitable for the association of our taxonomic groupings with the biological taxon information. The use of the TAXARANK ontology is demonstrated in the next section of ontology modelling.

5.6.2.3 Ontology modelling

The modelling of the ontology involved anchoring the ontology within the biological context and representing all the knowledge categories that needed to be captured in the ontology. Modelling of the various categories of knowledge is presented in the sub-sections below.

5.6.2.3.1 Top level structure and biological taxon

Development of the ontology was done using Protege (2000). In this section, the structure of top level classes and object properties are presented. Two top level classes were created under the Thing class; taxonomic_rank and DomainConcept. The taxonomic_rank is the TAXARANK ontology which was imported together with its subclasses. The DomainConcept class was created as a subclass of the Thing class and four subclasses created under it; BodyPart, DiagnosticFeature, Feature and Organism as shown in Figure 5-2 below. The BodyPart class contains all the body segments identified and named in the ontology. A BodyPart can contain other

BodyPart and the hasPart object property is used to model the relationship between BodyPart. DiagnosticFeature has three subclasses; morphologyDiagnosticFeature, attractantDiagnosticFeature and HostDiagnosticFeature and their modelling are explained in the next sections. The organism class has two subclasses, the hostPlantOrganism and tephritidaeOrganism. As the names suggests, details on host plants and the fruit flies is modelled under them. The feature class is used to model generic features not related to any body part. Features include things such as colour, texture and pattern.

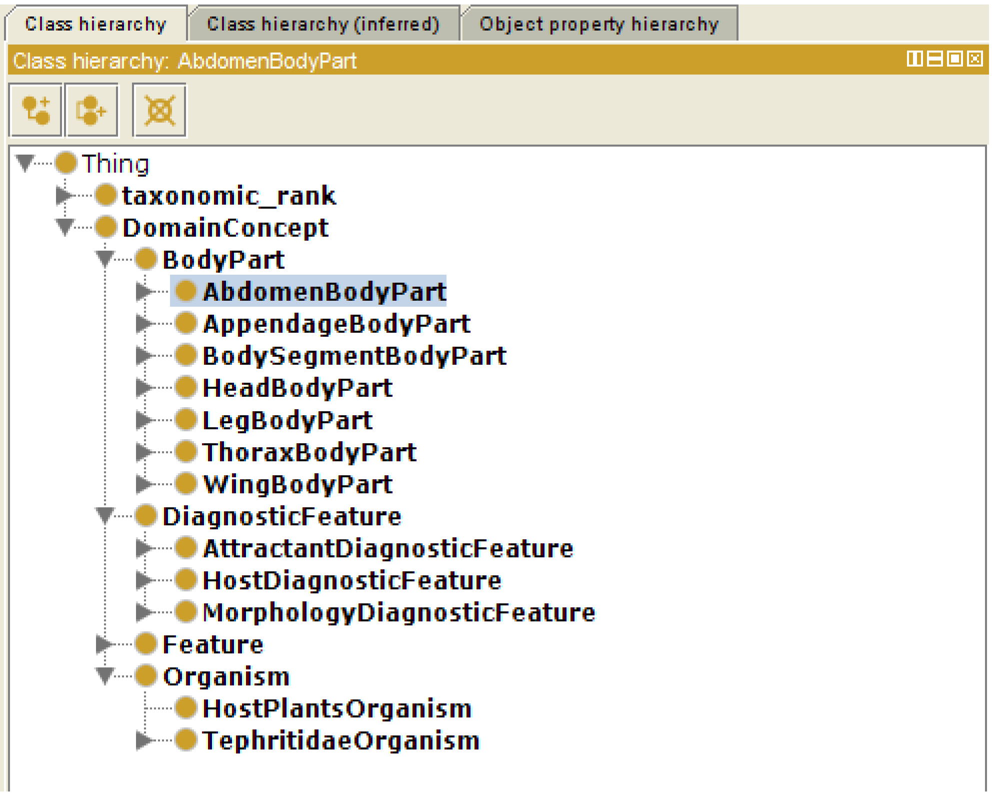

Figure 5-4: Fruit fly ontology class hierarchy

The object properties defined for this ontology included four top object properties, namely: - hasDiagnosticFeature, hasFeature, hasPart and hasTaxaRank as shown in Figure 5-5 below. Use of the different object properties is demonstrated within the specific knowledge modelling sections below.

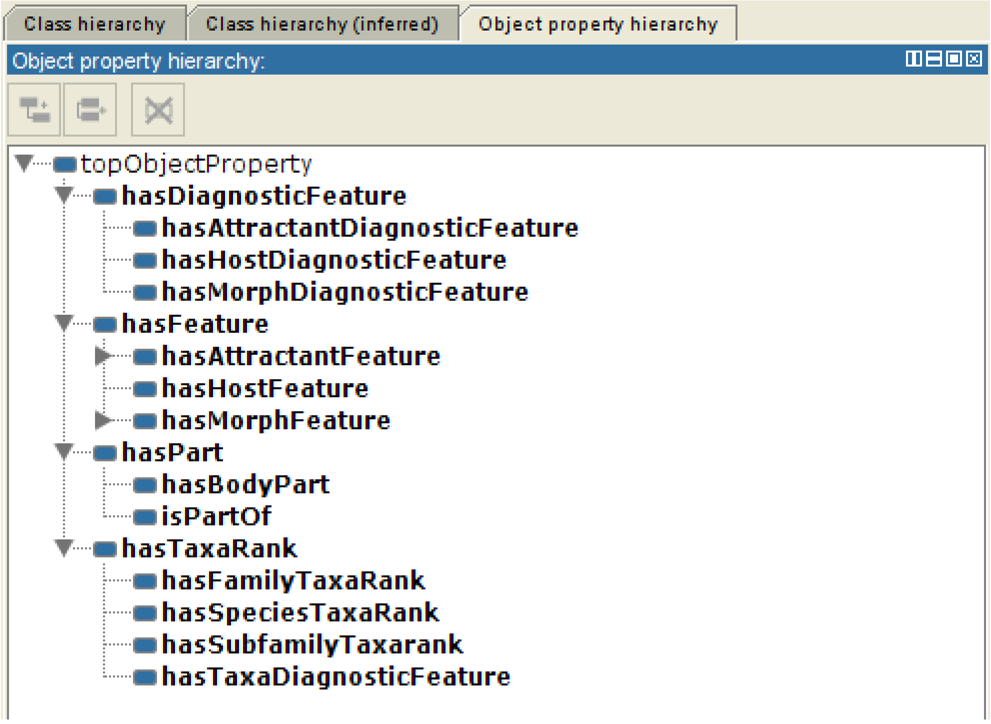

Figure 5-5: Fruit fly ontology object properties

5.6.2.3.2 Morphology Knowledge

Modelling of the morphology knowledge was done through modelling the diagnostic features first then associating the diagnostic features with taxonomic groupings. A diagnostic feature was represented using the model presented in Gerber et al. (2014) where a diagnostic feature is a body part with feature. Body parts are defined as subclasses in the BodyPart class and features are defined as subclasses of the Feature class. A morphologyDiagnosticFeature is therefore modelled as BodyPart and hasFeature Feature as shown in Figure 5-6 below.

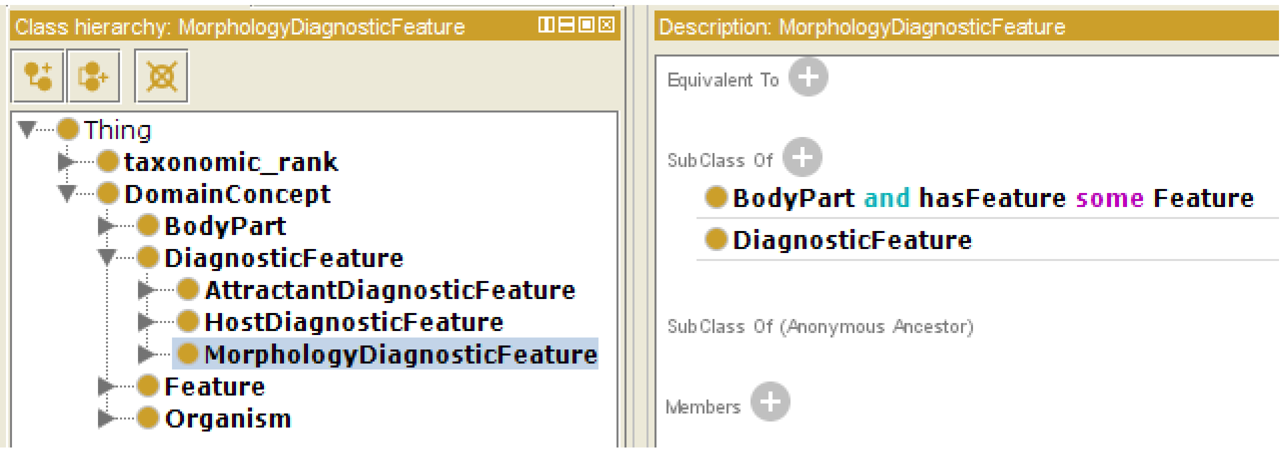

Figure 5-6: Morphology diagnostic feature model

To complete the modelling of morphological features of the different taxonomic groupings, the morphological diagnostic features are linked to the different taxonomic groupings using the hasMorphDiagnosticFeature object property. For example to model the Bactrocera sub family as having the diagnostic feature of yellow scutellum, the hasMorphDiagnosticFeature is used as shown in Figure 5-7.

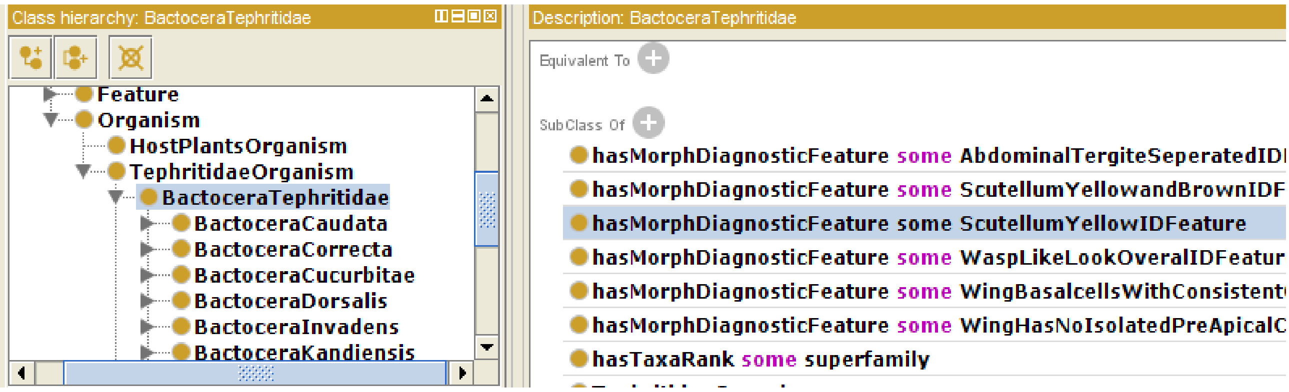

Figure 5-7: Example of linking a taxonomic grouping to a morphological feature

5.6.2.3.3 Host knowledge

The host plant diagnostic features were modelled as subclasses of HostDiagnosticFeature. To associate the host with a fruit fly taxonomic grouping, the hasHostDiagnosticFeature object property was used. For example, association of Bactrocera *Invadens* with different hosts is modelled as highlighted in Figure 5-8 below.

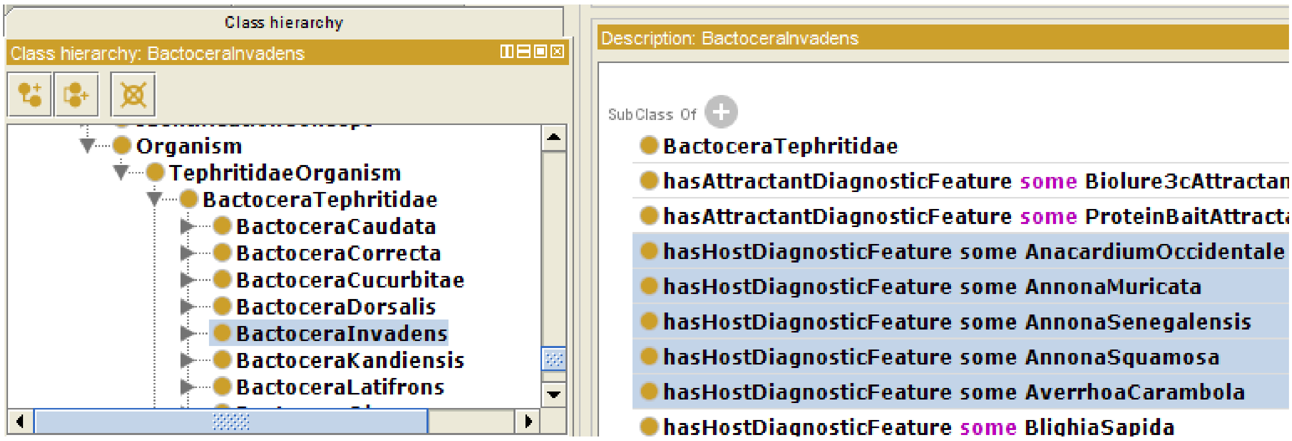

Figure 5-8: Example of linking a fruit fly taxonomic grouping (species) to host plants

5.6.2.3.4 Attractants knowledge

The attractant diagnostic features were modelled as subclasses of AttractantDiagnosticFeature. To link the fruit fly taxonomic groupings with the different attractants, the hasAttractantDiagnosticFeature object property was used. For example, to model the fact that of Bactrocera *Cucurbitae* is attracted to Biolure3 and protein bait is done as highlighted in Figure 5-9 below.

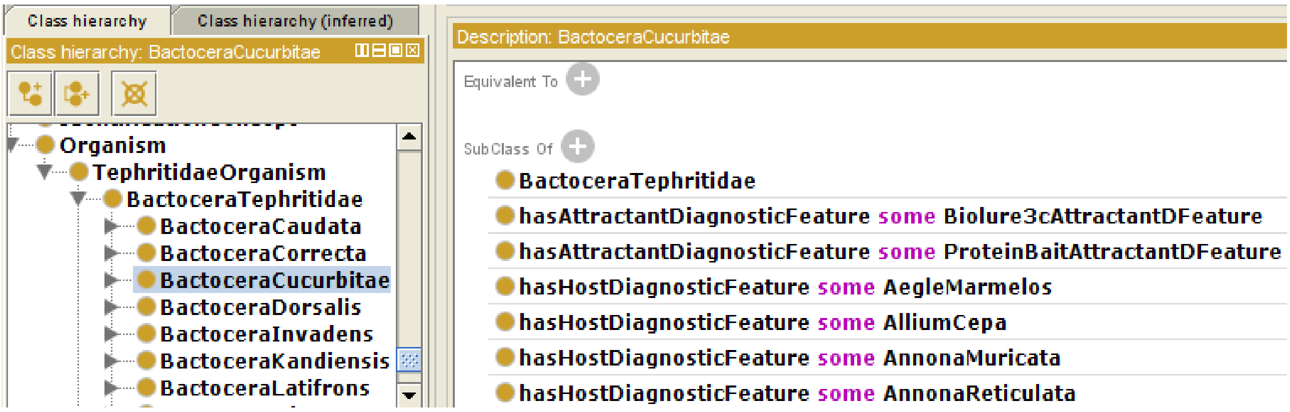

Figure 5-9: Example of linking fruit fly taxonomic grouping (species) to attractant

5.6.2.3.5 Taxa rank knowledge

As mentioned earlier, the biological taxonomic ranking knowledge was imported in the TAXARANK ontology. Therefore, the only modelling required in the fruit fly ontology was to link the different taxonomic groupings to the taxonomic rank classes defined in TAXARANK. The hasTaxaRank object property was used to represent this association as shown in Figure 5-10 below.

Figure 5-10: Example of linking of fruit fly taxonomic grouping to taxa in TAXARANK ontology

5.6.2.4 Evaluation of the fruit fly ontology

Evaluation of the ontology was done through discussions with fruit fly experts and by evaluating against the knowledge source that was provided by the experts. The competency questions used to define the scope of the ontology were used to evaluate if the ontology consistently gave correct answers. Two approaches were used in the evaluation; using DL queries within Protégé with an integrated Fact++ reasoner and by using the ontology in the development of the application it was designed for.

5.6.2.4.1 Evaluation using DL queries

Evaluation using the competency questions with DL query tool in protégé was found to give correct answers. For example, the DL query of the last competency question “Which species have three dots on scutellum, is attracted to protein bait and can be hosted by Anacardium *Occidentale* (cashew nut)?" gave the result shown in below. The answers given in the evaluation is based on the knowledge that was modelled and is not exhaustive since all the knowledge on fruit flies has not been captured in the ontology.

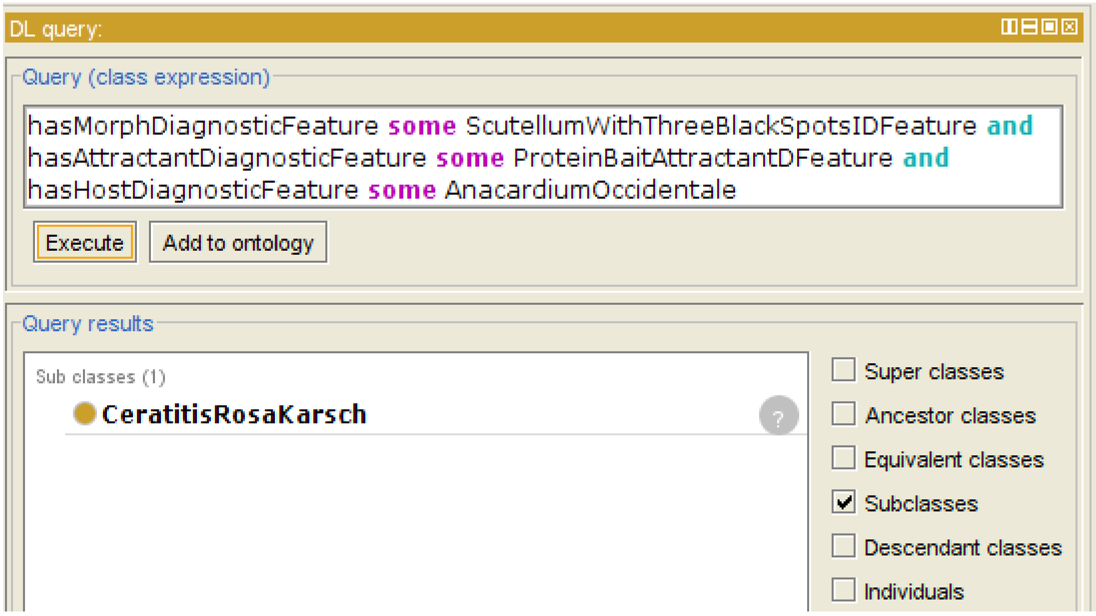

Figure 5-11: Example of ontology evaluation using DL query

5.6.2.4.2 Evaluation using an application

The fruit fly ontology was further evaluated through integration into an application that was aimed at enabling users to get answers to fruit fly questions based on the ontology knowledge. The application presented different tools including a multi-entry taxonomic key and interfaces for querying the other forms of knowledge. In an example of querying the possible species attracted to Capilure attractant is shown in Figure 5-12 below.

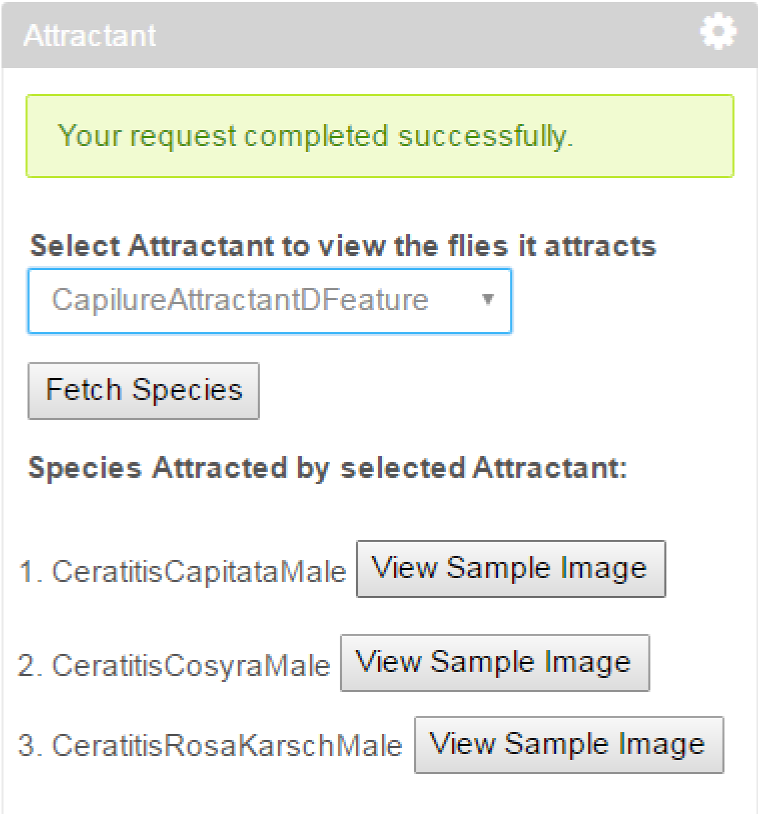

Figure 5-12: Example of ontology use in application

The development of the fruit fly ontology is published in Kiptoo et al. (2016).

5.6.3 An ontology Model for biodiversity management knowledge: Morphology and traits knowledge

In this section a model for representing the biodiversity management knowledge is presented. The model was abstracted from the fruit fly case and the objective of this abstraction was to create a reference model for representing morphology and traits knowledge using ontologies. Representing morphology knowledge requires representation of anatomy knowledge, and it was found that the different kinds of knowledge could be represented as follows: -

5.6.3.1 Anatomy Knowledge

The CARO ontology (Haendel et al. 2008) should be used as the top-level ontology and the anatomical components represented as classes underneath the appropriate subclasses leading to an "is_a" hierarchy. The relationships between the anatomical components should be represented using the object properties defined in CARO, including "part_of" and "overlaps". For example, if you have anatomical entities *AE1*, *AE2,……AEn* and *AE1* is part of *AE2*, then the representation will be as follows: -

- Represent the anatomical entities as subclasses under relevant entity
- Represent the property using the "part_of" object property as shown below: -

  AE1 *and part_of some* AE2

5.6.3.2 Morphological knowledge

Morphological knowledge consists of properties of body structures. In this model the structure proposed in Gerber et al. (2014) was adopted, and morphological features are modelled as an anatomical entity with feature. Given a set of features (e.g. colour, texture, pattern, shape) defined as F1, F2,….Fn, a morphological Feature MF1 that describes anatomical entity AE1 having feature F1, and object property *hasFeature*, then this is represented as:

- MF1 = AE1 and hasFeature F1

5.6.3.3 Traits knowledge

Representation of traits knowledge is still at infancy and depending on the needs; this knowledge can be represented in many ways. For instance, if the interest is just to represent traits with the need to further break it down for deeper analysis, then the traits can be represented as classes under appropriate subclass. In the fruit fly case, it was sufficient to only represent the hosts as classes of plant names without further breaking it down. If there was a need was to model the specific anatomical entity within the host plant on which the fruit fly is hosted, then it would require an anatomy ontology of the host plants as well so as to associate the hosting relationship with the specific body part of the host plant. Similarly, it was found sufficient to model the lures knowledge as subclasses of the lures class.

5.6.3.4 Associating traits with species

Associating the traits defined with the different species should be done using the applicable property under *hasDiagnosticFeature*. The traits may have been imported from other ontologies such as the TAXARANK ontology (Phenoscape 2010), or defined within the ontology being developed. Different sub properties need to be defined for associating different categories of traits with the species. For instance, in the fruit fly case, the objective was to represent that a given fly species (FS) is hosted by a given plant species (PS). To represent this, we used a sub property of hasDiagnosticFeature called, hasHostDiagnosticFeature to relate the trait to the species as follows:

- FS and hasHostDiagnosticFeature some PS.

Associating the morphology and attractant trait was done using the hasMorphDiagnosticFeature and hasAttractantDiagnosticFeature respectively.

5.7 EVALUATION

The evaluation of the model was done within the development of the fruit fly ontology described in Section 5.6.2. One of the widely recommended method to evaluate an ontology is the evaluation of correctness (if it gives correct answers to questions it was expected to answer) and if serves the purpose it was created for(Noy & McGuinness 2001; Grüninger & Fox 1995). The following results were found in the evaluation: -

- The ontology gives correct answers to questions asked. This was done using DL queries in Protégé with its built in reasoner.

- A single query could be used to answer questions that require the use of the three categories of knowledge modelled in the ontology.
- The ontology was used to develop a simple application that answered questions it was intended to answer, and this showed that the ontology could meet the purpose it was developed for.

Evaluation of the fruit fly ontology was done using both DL queries and a prototype platform that utilized the ontology as documented in Section 5.6.2.4 and also in Kiptoo et al. (2016). The evaluation gave correct answers as expected in both cases.

5.8 CONCLUSION

In this section, the conclusion of the sub-cycle 2 is presented. The sub-cycle was aimed at investigating how biodiversity management knowledge should be modelled so that it can be used to answer citizen questions with respect to biodiversity management. Citizens do not see biodiversity knowledge as a compartmentalised discipline but rather as a continuous whole. The questions they would have can therefore, span across different kinds of knowledge. In this sub cycle, a model for representing three categories of knowledge was created, and it was demonstrated that it is possible to answer questions that cut across different knowledge categories. This kind of ontology is necessary in facilitating expert and citizen knowledge transfer since it cushions citizens from the need to know the categories that each kind of knowledge belongs to. In the model, it has been demonstrated that it is possible to query the knowledge using single queries to answer questions making it efficient and not resource intensive since ontologies require more resources to process queries compared to other methods of representation (Horrocks 2008)

5.9 SUMMARY

In this chapter, the results of the sub-question 2 (SQ2) of this study were presented. The chapter presented an overview on ontologies, what they are, the methodologies and tools for development. Biological ontologies were examined in great detail since this research falls in this domain. Different ontologies were examined, specifically those that focus on modelling anatomical and traits knowledge. It was found that models that represent anatomical knowledge alongside traits knowledge were inadequate and the focus of this chapter was to develop a model that could be used for representing different kinds of traits knowledge.

The research approaches used was first narrative literature review, which was aimed at establishing what has been done with respect with modelling biodiversity management knowledge. This review identified the gap that the models for representing morphology and traits knowledge for citizen use were inadequate. This gap was the basis of the rest of the research which sought to introduce such a model. The creation of the ontology model was done using a case of fruit fly control and management knowledge. This case presented the opportunity to model three knowledge categories; fruit fly identification knowledge based on morphological features, preferred host plants to different fruit fly species and lures that can be used in fly traps to attract different species of the flies. Using this case an ontology was developed combining all the knowledge categories in one ontology. Evaluation of the ontology was done using DL query tool found within Protégé and through a prototype, application developed that use the ontology and both gave satisfactory results. This case was abstracted to provide a guiding reference model for developing ontologies containing biodiversity management knowledge.

Chapter 6 - Knowledge transfer using crowd computing techniques

6.1 INTRODUCTION

In this chapter, the results of the third sub-objective (SO 3) are presented. The aim of this sub-objective was to identify the approaches that can be used to facilitate knowledge transfer using crowd computing techniques.

SQ 3) How can crowd computing techniques be used to facilitate biodiversity management knowledge transfer?

The chapter is organised as follows: - In Section 6.2 a literature review of what crowd computing is, the different forms of crowd computing techniques and approaches used in aggregation of crowd results is presented. In Section 6.3 the research design used to achieve the objective which was to develop a crowd computing model for biodiversity management knowledge transfer is presented. Section 6.4 details the results of the research outcome and is structured using the DSR phases of awareness, suggestion and development. Section 6.5 is a summary of the chapter. A graphical outline of the chapter is shown in Figure 6-1.

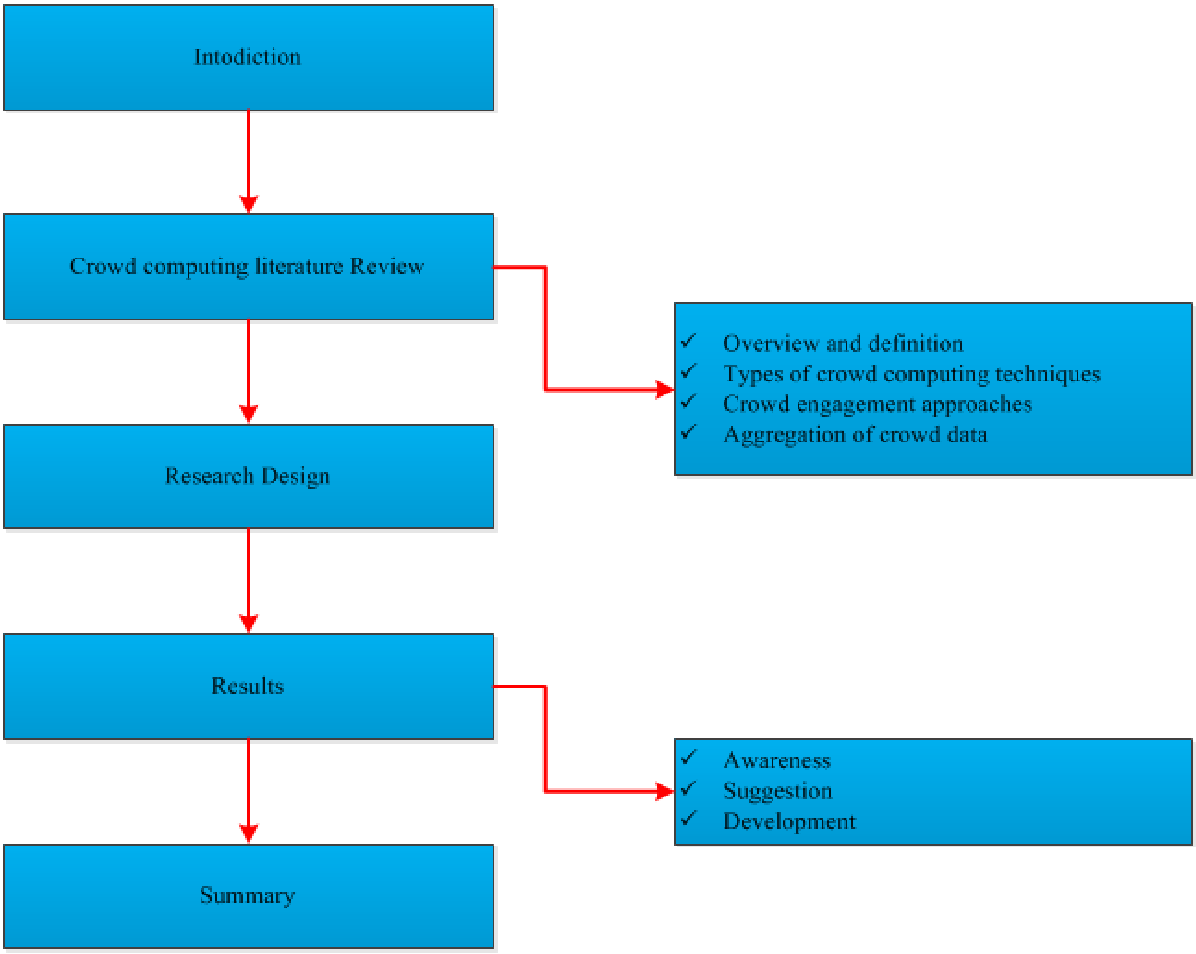

Figure 6-1: Outline of chapter 6

6.2 CROWD COMPUTING LITERATURE REVIEW

6.2.1 Overview and Definition

Crowd computing emerged as a major problem-solving and data gathering paradigm on the web (Doan et al. 2011). Other terms that are used to describe crowd computing related research include peer production, crowd wisdom, social search, collective intelligence, crowdsourcing, smart mobs, human computation, user powered systems, user-generated content, collaborative systems, community systems, social media, social systems, wikinomics, citizen science and mass collaboration.

With all these terminologies it has been observed that use of different labels to describe the same thing can lead to disarray in existing literature and further research. According to Pozzi (2001) a clear definition is part of important delimitation from others and a key requirement of any inquiry. Different researchers expressed the need to have succinct definition of these terms and provide distinctions and relationships between them in order to prevent these confusions (Bessis et al. 2010). The focus of this research is in crowd computing, so a few definitions from different authors are examined. Cooke and Gillam (2011) define crowd computing as "the use of a number of people who are offering human intellect and their computers to solve problems, which are at present unsuitable for computational approaches. This definition does not mention predefined nature of task to be carried out by the crowd. Bernstein (2013) while describing crowd powered systems, define crowd computing as systems that "combine computation with human intelligence, drawn from large groups of people connecting and coordinating online". Several authors have used the term as synonyms with other related concepts, for example, treating crowd computing as synonyms with crowdsourcing and data collection from distributed sources using citizen science (Bessis et al. 2010; Asimakopoulou & Bessis 2011), description of crowd computing as a form of outsourcing a task to crowds thus tapping into their collective intelligence (Kucherbaev et al. 2013) and treating crowd computing as a form of social computing that involves human interaction for a task and sharing implemented through web 2.0 technologies (Lima et al. 2012).

In this research, the definition by Parshotam (2013) was adopted, and crowd computing is defined through outlining the core characteristics as including "participation by a crowd of humans, interaction with computing technology, activity that is predetermined by the initiator or application itself and the execution of tasks by the crowd utilising innate human capabilities". Parshotam (2013) argued that, although the concepts of wisdom of the crowds and collective intelligence are widely discussed in literature, they are not prerequisites to crowd computing and therefore do not qualify as defining characteristics.

Popular examples of crowd computing applications include general-purpose platforms such as Yahoo! Answers, Wikipedia, YouTube, Mechanical Turk-based applications, Flicker, oDesk, Freelancer, Crowdflower, MobileWorks, ESP game, Fix my street and ManPower; and specialist platforms such as: - 99Designs,Innovation Jam, Linux, TopCoder, uTest, and other Open source software (OSS) (Kittur et al. 20131; Doan et al. 2011; Weber 2004; Parshotam 2013)

6.2.2 Taxonomy of crowd computing

The rapid evolution of crowd computing research and the diverse application areas has prompted researchers to develop ways of classifying the different types of crowd computing research. Based on the nature of tasks design, Good and Su (2013) identified two types of crowdsourcing systems: ‘microtasks’ crowdsourcing where a task is split into small puzzles whose results are combined to solve the main puzzle and ‘megatasks’ crowd computing where a task is solved in its main form. Yuen et al. (2011) identified four broad categories that literature in crowdsourcing research can be grouped into; application, algorithm, performance and dataset as shown in Figure 6-2.

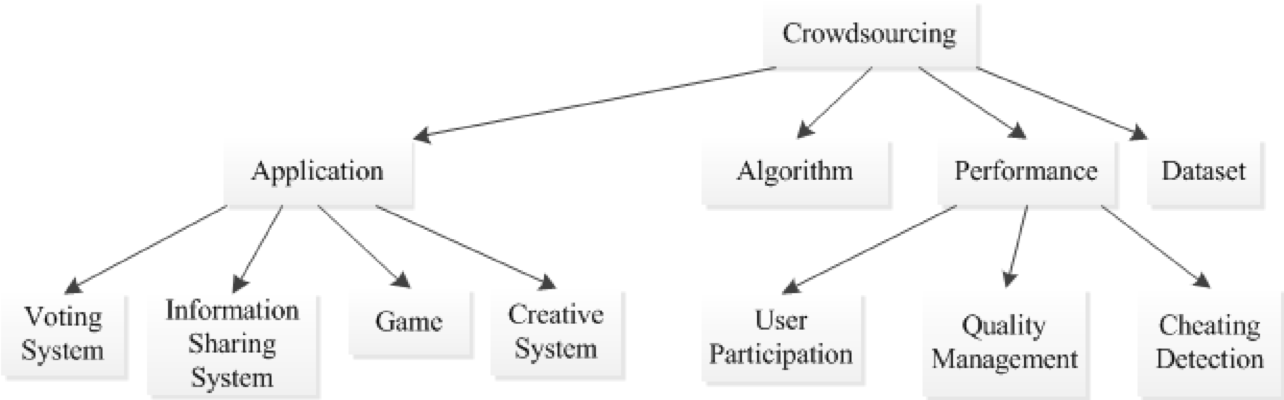

Figure 6-2: Crowdsourcing taxonomy (Yuen et al. 2011)

Geiger et al. (2012) developed a typology based on four system types: rating, creation, processing and solving. A six-dimensional classification system for human computation systems is proposed in Quinn and Bederson (2011). The six dimensions are: - motivation, quality control, aggregation, human skill, process order, and task-request cardinality. Another taxonomy based on three broad categories of parameters, namely: requestor, campaign and contributor is proposed in AlShehry and Ferguson (2015). The requestor category has two sub categories of type and purpose; the campaign category has platform, duration, data, sensitivity and channel sub categories, and the contributor category has relationship and motivation sub categories, all as shown in Figure 6-3.

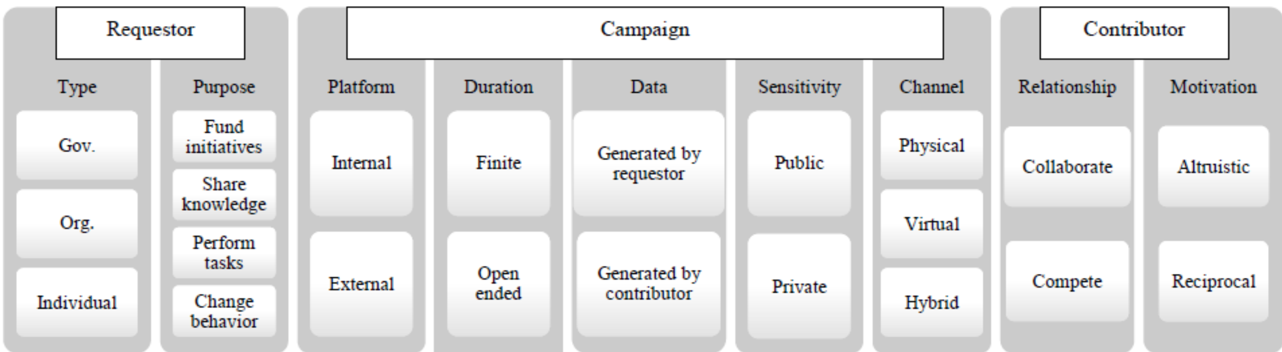

Figure 6-3: Taxonomy of crowdsourcing campaigns (AlShehry & Ferguson 2015)

More generic taxonomies that clarify the relationship between concepts commonly related to crowd computing are presented in Gomes et al. (2012) and Schneider et al. (2012). The two taxonomies distinguishes five classes of crowd computing applications: Web 2.0, social computing, crowdsourcing, human computation and audience/crowd computer interaction. This research found this classification relevant since it also clarrifies the terminological confusion that characterise these terminologies in the crowd computing research domain as they are often used as synonyms. The classes are described in more detail in Sections 6.2.2.1 to 6.2.2.5 below.

6.2.2.1 Web 2.0

Web 2.0 contains a set of technologies that emerged as an improvement to the traditional web and shifted the mode of operation from an information dissemination tool to an interactive tool thereby enabling co-creation of content. Web 2.0 transitioned from fixed packaged software to scalable services, dynamic data storage, collaborative development and engagement of users as co-developers of content, dynamic interfaces, software operating across devices, light weight programming and business models re-engineering for the web (O'Reilly 2007). Co-creating and collective intelligence are key features of Web 2.0.

6.2.2.2 Social computing

Social computing is closely related to Web 2.0 but has broader concepts. Although the driving infrastructure is more less the same, social computing has additional distinguishing features, including networking, highly interactive, entertaining, more compelling usability and very light weight. The main driving force behind social computing is to support inherent human social behaviours which include interacting with others, sharing feelings, supporting each other and any other undertakings by individuals and communities. Social computing can be seen as utilizing Web 2.0 technologies to create applications that focus on social interaction around diverse topics. Examples include wikis, blogs, social networking platforms, folksonomies, photo sharing applications, bookmarking and diverse online profiles (Lima et al. 2012; Schneider et al. 2012; Gration & Miah 2012; Jensen & Mehlhorn 2009; Gomes et al. 2012)

6.2.2.3 Crowdsourcing

The term crowdsourcing was popularised by Howe, in June 2006 issue of wired magazine (Brabham 2008). Howe defined crowdsourcing as the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call. This can take the form of peer-production (when the job is performed collaboratively), but is also often undertaken by sole individuals. The crucial prerequisite is the use of the open call format and the large network of potential labourers. Since then, several researchers attemped to give crowdsourcing a refined definition. Yuen et al. (2011) defined crowdsourcing as "tapping into the collective intelligence of the public to complete a task." while Estellés-Arolas and González-Ladrón-de-Guevara (2012) defined it as "A type of participative online activity in which an individual, an institution, a non-profit organization, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task". Several attributes (stated and implied) of crowdsourcing can be detected in these definitions namely: a crowd of problem solvers; varying knowledge of the crowd; open call; voluntary participation; distributed participants; as well as collective problem solving. Examples include: Threadless.com - a web-based t-shirt company that crowdsources the design process for their shirts through an ongoing online competition, iStockphoto.com - web-based company that sells royalty-free stock photography, animations, and video clips, InnoCentive.com ‘enables scientists to receive professional recognition and financial award for solving R&D challenges’ and simultaneously ‘enables companies to tap into the talents of a global scientific community for innovative solutions and tough R&D problems’ (Brabham 2008).

Although many crowdsourcing literature cite computer use in crowdsourcing (Schneider et al. 2012) , crowdsourcing does not automatically imply computer use, and this can be seen from Howe’s definition and other discussions in literature (Erickson 2011; Parshotam 2013) .

6.2.2.4 Human computation

The concept of human computation is used in the artificial intelligence context to describe utilization of humans to perform activities that cannot be solved by computers alone (Von Ahn 2009). Such problems could be programmed into tasks that humans can execute and their results incorporated into solving the main problem. Human computation has been seen as a form of interesting reversed roles between humans and computers, and instead of humans using computers to solve problems, computers use humans to solve computational problems (Schneider et al. 2012; Gomes et al. 2012).It has been observed that human computation is related to social computing in that humans can be used for computation where their motivation is socializing but Quinn & Bederson (2011) clarify that in social computing, humans are playing social role facilitated by computing, but in human computation, they play a computational role.

6.2.2.5 Audience/crowd computer interaction

Audience / crowd computer interaction is a class of crowd computing where a known crowd is participating in an activity through some computing media. The known crowd could be the audience of a specific event, students in an institution, visitors to a given park and other sets of known audience (Schneider et al. 2012; Gomes et al. 2012). The idea behind this category of crowd computing is to structure crowd tasks around activities of interest to the crowd and tasks can be done competitively or through cooperation and include tasks such as voting, opinion polls, games and raffles. (Maynes-aminzade et al. 2002; Medeiros et al. 2012; Lima et al. 2012). Audience/crowd computer interaction overlaps with other crowd computing, specifically, social computing and crowdsourcing.

Parshotam (2013) compared the different classes of crowd computing as summarized in Table 6-1 below: -

Table 6-1: Characteristics of crowd computing application classes (Parshotam 2013)

Application class	Crowd	Computing platform	Predetermined purpose	Human capabilities	Collective intelligence
Web 2.0	Yes, online	Yes, mostly Internet	Sometimes, may be used just for sharing.	Yes, creativity	Sometimes

Application class	Crowd	Computing platform	Predetermined purpose	Human capabilities	Collective intelligence
social computing	Yes, online	Yes, Internet, mobile	Social activity	Yes, social behaviour	Sometimes
Crowdsourcing	Yes, mostly online	Mostly, Internet, but can involve no technology	Yes, includes creation, problem-solving, idea generation	Yes, various	Yes
Human computation	Mostly, but can involve individuals	Yes, mostly Internet	Yes, performing tasks, e.g. problem solving	Yes, various	Sometimes
Audience/crowd computer interaction	Yes, online and physical	Yes, can include mobile, sensors, other	Yes, typically for engagement	Yes, social behaviour, coordination Collective	Sometimes

The taxonomies are based on some criteria and a research study could include different groupings depending on whether it meets the criteria for that grouping or not. It is worth noting that the different classes of crowd computing applications have overlapping properties and classifying an application as belonging to one class against another, will largely depend on the properties being considered and in most cases, an application will belong to multiple classes.

6.2.3 Approaches to crowd engagement

Crowd computing has been achieved through different approaches of engaging crowds. The important requirement of any approach is to incentivise participants to execute the crowd tasks as accurately as possible and for them to remain motivated (Good & Su 2013; Geiger et al. 2011). In this section, different approaches are presented, detailing a description of the approach, the incentives used and examples of research that utilize these approaches.

6.2.3.1 Volunteer

The traditional method to get a large number of people to participate in research projects is to seek volunteers. This approach has been used long before the computing era, for example, the Christmas bird count (Cohn 2008), and continues to be a viable approach in crowd computing projects as well. Research that use volunteers seek to tap into willing communities that wish to contribute to a given cause. Incentivising participants in this approach involves making them aware of the cause they are contributing to. Though not a prerequisite, recognition of volunteer efforts has also been found to motivate participation among the volunteers. Examples of projects that have successfully used volunteers include: Galaxy zoo, Zooniverse Project (Lintott et al. 2008), which uses online volunteers for morphological classification of galaxies; Cell slider project, which used volunteers to analyse tissue samples donated by cancer patients treated on clinical trials (Candido dos Reis et al. 2015); the Whale FM project that used volunteer citizen scientists to analyse audio signals recorded from whale audio sensors (Shamir et al. 2014); and the use of volunteers and a Random Encounter Model to estimate lion density from camera traps in the Serengeti (Cusack et al. 2015).

6.2.3.2 Games

There has been a more recent shift in crowd computing to try to incentivise participants with fun. Games use fun games to woo participants to participate in crowd activities use of games has been studied, and most of its literature is available under Human Computation Games, HCGs (Goh & Lee 2011) and Games With a Purpose, GWAP (Good & Su 2011; von Ahn & Dabbish 2004). A typology for classifying human computation games has been proposed based on three Meta categories; Game play mode, game structure and data (Pe-Than et al. 2015). Two categories of games are identified namely casual games and hard games.

In casual games the crowd tasks are designed into a game that participants play to have fun, and in the process of playing the participants solve the crowd computation problem. Casual games are often designed into simple decision clicks that allow participants to earn points at every click and the desire to accumulate points motivates participation. Casual games are usually used in microtasks kind of crowd computing and are often played by individuals (Good & Su 2013). Examples of casual games is the ESP game whose aim is to use a game to label images on the web to improve image search (von Ahn & Dabbish 2004) and the Malaria parasite game whose aim is to spot malaria parasites in images of potentially infected lab slides (Mavandadi et al. 2012).

Hard games design the problem into a complex puzzle that needs to be solved by an individual or closely collaborating teams. The hard games are often time-consuming to play and require time and serious thinking to be able to solve the puzzle (Schrope 2013). Examples of hard games are the foldIT protein folding game, which uses gamers to find the 3D formation of a given protein structure that results in the lowest calculated free energy (Cooper et al. 2010; Rohl et al. 2004; Khatib et al. 2011; Eiben et al. 2012); as well as EteRNA, which uses weekly design contests games where gamers are supposed to design a RNA structure that folds into a predefined shape (Koerner 2012).

6.2.3.3 Crowd markets

Crowd markets are platforms where participants are paid to perform whatever tasks they are recruited to perform. The tasks in crowd markets are normally very easy to perform and participants are paid a small token for every task they execute. Crowd markets have been found effective in annotation tasks, both image and text annotations, giving good results at very minimal costs. Ethical issues have been raised with regards to compensation of crowd workers and discussions on compensation of crowd workers are active (Kittur et al. 20131; Fort et al. 2011; Whitla 2009; Gupta et al. 2012; Norcie 2011; Ross et al. 2010). Different platforms that support crowd working have become popular, examples include Mechanical Turk, Click worker, Micro workers and Crowdflower (Schmidt & Jettinghoff 2016).

6.2.3.4 Forced labour

Forced labour literally means forcing crowds to work. This is often done through tying a service that a crowd is interested in to a task that needs to be done. The ReCAPTCHA security project (Von Ahn et al. 2008) is the widely cited example that uses forced labour. In the ReCAPTCHA project crowds are forced to retype a scanned image that needs to be digitized as part of the security access to a system. The user is often asked to prove that they are human and not a computer program trying to gain access to the system. The forced labor approach has also been used to create a clinical knowledge base by linking ailments to drugs (McCoy et al. 2012).

6.2.3.5 Open innovation contests

Open innovation contests are contests that invite the general public to submit a solution or ideas for solving a specified problem. The winning solutions usually get monetary rewards. The motivation for crowds to participate in open innovation contests is the monetary reward and the prestige associated with winning such contests. An example of open contests is the TopCoder project that invites people to write algorithms to solve different software problems (Lakhani et al. 2010).

6.2.3.6 Education

Incorporation of research activities into education systems is another approach that has gained popularity in the recent past. Use of learners to perform crowdsourcing tasks as part of their learning has been found to yield good results since the activities can be checked by their educators. The motivation is to learn and specifically to achieve the learning goals on the part of the learner. Examples include the genome annotation, which has been incorporated into bioinformatics education (Hingamp et al. 2008; Brister et al. 2012) and the DuoLingo project that uses students learning a language to create translations between two languages (Garcia 2013).

6.2.4 Aggregation of crowd data

Aggregation of data collected from crowds into one answer is a technical challenge that every crowd computation project has to address. In this section, the approaches used to aggregate crowd data to answer crowd computation problems, are presented. The focus is on solving problems that have a single answer, but this answer is not known beforehand. In Hung et al. (2013), an evaluation of different aggregation techniques is presented and classified into two categories namely non-iterative techniques and iterative techniques. As the names suggests, non-iterative techniques arrives at decision in one cycle, while iterative techniques are characterized by multiple cycles and results of one cycle are used in the next. The aggregation techniques are presented next.

6.2.4.1 Majority Decision (MD)

Majority decision is a non-iterative technique that simple uses the majority vote to decide how to aggregate crowd data. The unique labels for each question are counted and the label with the highest votes becomes the answer. The MD approach is an easy straightforward approach and is ideal where there are no spammers, and good quality workers. The approach can, however, be problematic where the quality of workers is substantially varied and where the platform is prone to many spammers (Kuncheva et al. 2003).

6.2.4.2 Honeypot (HP)

Honeypot uses an extra processing step to filter out spammers. Questions whose answers are known are used intermittently to filter out spammers. Workers who don't meet a set threshold on the trapping questions are filtered out, and the rest of the results are processed using the majority decision approach. The weakness in this approach is that genuine workers can be filtered out if difficult questions are used as trapping questions (Lee et al. 2010; Hung et al. 2013).

6.2.4.3 Expert Label Injected Crowd Estimation (ELICE)

The Expert Label Injected Crowd Estimation method uses trapping questions like the Honeypot approach, but instead of filtering out the workers, it uses the worker performance on the known questions to inject an expertise level of each worker. It also considers the difficulty of each question based on the workers' performance. The answer is then weighted based on both the worker performance and the question difficulty (Khattak & Salleb-Aouissi 2011).

6.2.4.4 Expectation Maximization (EM)

Expectation Maximization is an iterative approach with two cycles, first of expectation and second that of maximization. In the expectation cycle, the label probability is estimated based on the worker's current estimates of their expertise. In the maximization cycle the estimation is done based on the re-estimated expertise of workers (Dawid & Skene 1979; Ipeirotis et al. 2010). The cycles are repeated until stable probabilities are arrived at. A notable weakness with the EM algorithm is the computation time since the computation cycles can be many.

6.2.4.5 Supervised Learning from Multiple Experts (SLME)

The Supervised Learning from Multiple Experts is an approach for analysing binary data and uses statistical sensitivity and specificity to characterise workers. It then uses the EM approach to compute the crowd results (Raykar et al. 2009).

6.2.4.6 Generative model of Labels, Abilities, and Difficulties (GLAD)

The Generative model of Labels, Abilities, and Difficulties (GLAD) is an extension of EM and takes into account two scenarios; when a question is answered by many workers, the worker with high performance has higher probability of being correct and when a worker answers many questions, the probability of being correct is low (Whitehill et al. 2009; Hung et al. 2013).

6.2.4.7 Iterative Learning (ITER)

ITER is based on standard believe propagation and computes the reliability of each answer separately and not the reliability of a worker having one value as is the case with the other iterative models. The difficulty level of each question is computed individually for each worker and not combined value for everyone. The reliability of a worker is then computed based on the two values; the reliability of each answer and the individual's difficulty of each question. The ITER approach also splits the questions into sets and computes results for each set of questions making it possible for a user to have different levels of expertise at different times, making it more realistic (Karger et al. 2011).

In conclusion, the aggregation techniques applicable to crowd computing results have been developed in different contexts and targeted at solving diverse kind of problems. It is therefore not possible to objectively compare them and decide on a best and worst technique. Selection of a technique to adopt is mostly dependent on the project at hand and crowd dynamics.

6.3 RESEARCH DESIGN

In this section, the research design used for answering the question of this chapter is presented. The design science research (DSR) approach was adopted. The objective of this chapter was to establish how crowd computing techniques could be used to facilitate biodiversity management knowledge transfer. This was achieved through creation of a model that outlines how crowd computing could be used to aid in knowledge transfer between citizen and experts in the biodiversity management domain. In this chapter, the objective was to address the developmental phase of the model and therefore, three phases of the DSR were used; awareness, suggestion and development as outlined in the research process in Figure 6-4. Evaluation is not included in this chapter because the evaluation is done in part 4 of this thesis (evaluation and contribution).

The awareness was done through literature review, focussing on how crowd computing has been used in the biodiversity management domain. The awareness is followed by suggestions on how crowd computing can be used to enhance knowledge transfer. The suggestion was done through the use on crowd computing knowledge and conceptual thinking. The outcome of the suggestion phase formed the basis for development of a model on how crowd computing could be used to enhance the transfer of biodiversity management knowledge between experts and citizens.

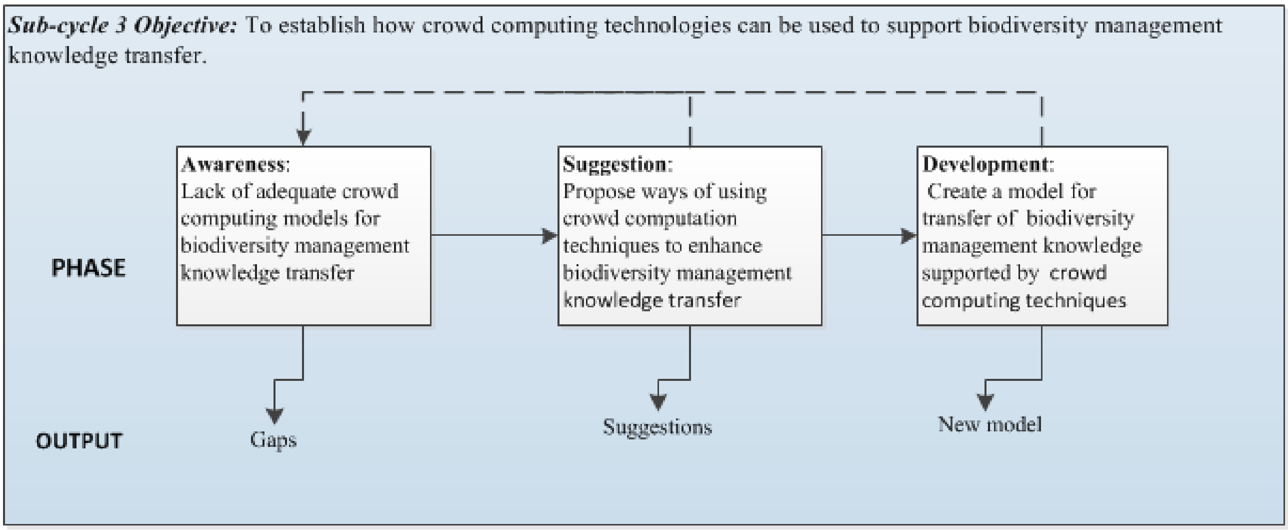

Figure 6-4: Sub-cycle 3 research process

6.4 RESULTS

In this Section, the research results are presented. The findings are presented in line with the research design. In Section 6.4.1 the results of the awareness phase done through literature review. In Section 6.4.2 the suggestion phase is done through a process of conceptualization and the results are presented. In Section 6.4.3 the development phase done through conceptualization and application of crowd computing knowledge is presented.

6.4.1 Awareness

This phase was concerned with establishing how crowd computing has been used in the biodiversity management domain. The research was done through narrative literature review (Baumeister & Leary 1997). The review process involved searching for literature using selected keywords and gathering relevant work, reading and analysing the literature and writing the review (Cronin et al. 2008). The search was conducted using different search engines including: - Google scholar, Elsevier journals, Science direct, Springer link and ACM digital library. The following key words were used in the search for literature sources: - "crowd computing in biodiversity management", "citizen science in biodiversity management" and "crowdsourcing in biodiversity management". The searches resulted in diverse sources ranging from works that use amateurs in carrying out scientific work without the use of any computing technologies to sources that are based on computing technologies. Nature and biodiversity studies has traditionally been studied through collaborative relationship between experts and citizens, and studies of this nature are mostly published under the citizen science and crowdsourcing umbrellas. Cohn (2008) categorized citizen science projects into five typologies: - Action, Conservation, Investigation, Virtual and Education. Action projects engage volunteers through encouraging them to participate in local concerns. Conservation projects are concerned with management of natural resources to ensure protection and sustainable use. Investigation projects support scientific research goals in a physical setting. Virtual projects are the ICT mediated projects and cut across the other types, but most are investigation. Education projects have education and outreach as their primary goals. In this research, our focus was on the sources that use computing technologies to enable and support engagement of non-experts in scientific research.

The sources that use computing technologies address challenges in different areas of biodiversity management activities, including: primary data collection activities, which include going out to nature and recording organism observations in databases (mostly online); digitization activities, which generally involve transcribing of information from digital images into dedicated databases; data cleaning activities, which deal with support for data collection and digitization to ensure well standardized data; and infrastructure development activities, which deal with developing the required databases and software systems to support biodiversity data collection and data management (Curtis 2015).

Different projects were studied to establish how crowd computing is used to support the biodiversity management objectives and to establish the extent to which these projects utilize crowd computing approaches. The evaluation framework created by Parshotam (2013) was used to evaluate the projects for crowd computing properties. The crowd computing application classes considered include those identified by Gomes et al. (2012) and Schneider et al. (2012) as described in Section 6.2.2 and include Web 2.0 and social computing, crowdsourcing, human computation, and audience/crowd computer interaction. In Table 6-1, the analysis of different projects is presented.

Table 6-2: Analysis of biodiversity crowd computing projects using the Parshotam (2013) framework.

Project	Description	Application class	Crowd	Computing platform	Purpose	Human capabilities	Collective intelligence
Bird count project - The Great Backyard Bird Count (Sullivan et al. 2009; Lebaron 2009; Wiersma 2008)	Create a real-time snapshot of bird populations' by asking participants 'to count birds periodically' and to 'report their sightings online. The duration for counting can be as little as 15 minutes. Audubon society runs many bird count projects including Christmas bird count. Web address: http://www.audubon.org/	Crowdsourcing Web 2.0	Online volunteers, Members work independently	Internet - based	Data collection	-Observation skills - Bird identification knowledge or Ability to use bird guides - Camera skills - Location mapping	Not applicable

Project	Description	Application class	Crowd	Computing platform	Purpose	Human capabilities	Collective intelligence
California Academy of Sciences inaturalist project (Matheson 2014; Agrin et al. 2014; He & Wiggins 2015)	Record any species in online portal through taking photos, videos or sounds, short description and the location it was observed. Assignment of scientific names to recorded data is done through crowdsourcing from other members Web address: http://www.inaturalist.org	Crowdsourcing Web 2.0 Social computing	-Online members with interests to manage their records, to contribute to different projects by recording or identifying -members work independently	Internet-based	Data collection	-Camera and recording skills -Identification skills for those participating in identification	Implied
Encyclopaedia of Life (Parr et al. 2014)	Receive data from other infrastructures in order to bring it into a meaningful whole through a standardized process of categorization Web address: http://eol.org/	Crowdsourcing Web 2.0	-members work independently or in collaboration with others	Internet-based	Gather, organise and share species data	Species knowledge	Yes

Project	Description	Application class	Crowd	Computing platform	Purpose	Human capabilities	Collective intelligence
Caltech-UCSD Birds 200 (Welinder, S Branson, et al. 2010; Welinder, Steve Branson, et al. 2010)	Image dataset with photos of over 200 North American bird species annotated through crowdsourcing. The annotation include: - a bounding box, rough segmentation and attributes. The objective was to create a dataset for object recognition and computer vision Web address: http://www.vision.caltech.edu/visipedia/CUB-200.html	Crowdsourcing Human computation	independent working	Internet based- Mechanical Turk	Image analysis	Annotation skills	Not applicable
CitSci.org (Dickinson et al. 2012; Suomela 2014)	Provides infrastructure for researchers to create their projects and data capture interfaces to suit their needs. The projects focuses on include species and other ecological data. Web address: www.citsci.org	Web 2.0	Independent project owners Project contributors	Internet-based	Infrastructure support to research	Project design	Not applicable

Project	**Description**	**Application class**	**Crowd**	**Computing platform**	**Purpose**	**Human capabilities**	**Collective intelligence**
Spot A Ladybug (Gardiner et al. 2012)	Aimed at recording ladybugs at different regions in order to perform comparative studies. Web address: http://scistarter.com/	web 2.0 , Social computing	Work independently	Internet-based	To record lady bug observations and images	Camera use and recording	Not applicable
Integrated Digitized Biocollections (iDigBio) (Ellwood et al. 2015)	Project aimed at digitization of biodiversity collections. Images of biological specimens are availed online for volunteers to participate in digitizing. Web address: https://www.idigbio.org	Crowdsourcing Human computation Web 2.0	Work independently Work in collaborations	Internet-based Crowdflower	To digitize museum collections	Tagging, transcribing, cataloguing, translation, linking, georeferencing, commenting, contextualizing	Implied

The analysed projects are by no means an exhaustive list of the projects that use crowd computing techniques in biodiversity management, but rather representative of the concepts and patterns of current implementations. From these cases, a number of observations can be made.

- Firstly, many projects focus on collection of occurrence data. It can be noted that although the projects look at different species, the main theme is the collection of occurrence data, with experts engaging citizens in species monitoring activities.
- Secondly, it can be observed that the projects equip citizens with the necessary identification tools so that they can record data with scientific identification of the occurrences. The bird count project (Lebaron 2009), for instance, provides field guides for the citizens which they can use in identification of their observations. The citizens are therefore expected to learn to use these resources in order to effectively participate.
- The third observation is that in cases where the citizens are not able to scientifically identify samples, some projects provide alternatives for recording without full identifications (e.g. inaturalist). The recordings without identification are later identified by experts or crowd members who have knowledge on the scientific names of the organisms.
- The fourth observation is on the activity design. Whereas most projects have designed activities in line with traditional offline roles where citizens perform citizen roles and experts, expert roles, some projects have ventured into re-engineering of activities so as to reduce human capability requirements and therefore, expand participants. The digitization project, for instance, has broken down the digitization process into small tasks that can be executed by the crowd and the total of which leads to completion of the process. This kind of process re-engineering is necessary if the spectrum of participants is to be expanded and involve more people.

In terms of the research objective in this thesis, which is knowledge transfer between experts and citizens focussing on traits knowledge, it can be observed that crowd computing approaches have not been used to directly address knowledge transfer from experts to citizens, but have been used in transfer of ground knowledge from citizens to experts. The species occurrence data collection and other ecological monitoring information are a form of knowledge transfer from citizens to experts since they constitute ground knowledge.

6.4.2 Suggestion

In this section, results of the suggestions made on how crowd computing could be used to support knowledge transfer between experts and citizens, are presented. The suggestions were made in line with the model selected for adoption for this research, the knowledge transfer process model in (Liyanage et al. 2009) and conceptualization based on the different types of crowd computing. In the model, the knowledge transfer process between the source and receiver is made up of five processes, namely: Awareness, acquisition, transformation, association and application then a knowledge externalization and feedback process from the receiver back to source. It was suggested that different forms of crowd computing be used to support the different steps of the knowledge transfer process.

Awareness is concerned with identification of valuable knowledge and in the context of this study, it is a process that is done by both experts and citizens in close consultation. It was suggested that awareness could be supported by Web 2.0 and social computing classes of crowd computing. Acquisition deals with assembling the knowledge as long as the source and receiver are willing. Web 2.0 is applicable for the knowledge acquisition stage since a customised structure is necessary so that the knowledge is complete and re-usable. Transformation is a process of making knowledge useful to receiver and could include adding or removing some details or translation to a language understandable by the receiver. It was suggested that this process could be supported by Web 2.0 and crowdsourcing, especially for translation services. Association is also part of making the knowledge useful and involves relating the transformed knowledge to the needs of the receiver. This process could be supported by crowdsourcing assuming that the needs of the receiver are succinctly defined then crowdsourcing presents the necessary strengths for relating the two. Application is the use of useful knowledge by the receiver and may not require any support.

Social computing could be used where necessary to support the social needs of the receiver while utilizing the knowledge and could probably create awareness across communities. Knowledge externalization and feedback is concerned with giving feedback on new knowledge created by the receiver to the source. This process could be supported by Web 2.0 and crowdsourcing. Web 2.0 provides an opportunity to create necessary structures for transmitting feedback. In the event that the receiver is not able to give feedback that meets the standards required in the discipline, as is often the case with biodiversity management, crowdsourcing could be used to standardize the feedback.

6.4.3 Development

In this section, the results of the development phase are presented. The main objective of this phase was to create a conceptualization of how crowd computing could be used to support knowledge transfer in biodiversity management. Detailed description of how the different crowd computing approaches could be used to support the different phases of the knowledge transfer process is presented in the sections below.

6.4.3.1 Crowd computing approaches for knowledge transfer processes

From the suggestion phase above, different classes of crowd computing are suggested for the different phases of the knowledge transfer process as summarized in Table 6-3.

Table 6-3: Crowd computing approaches for the different phases of knowledge transfer

Knowledge transfer Phase	**Crowd computing class**
Awareness	Web 2.0 Social computing
Acquisition	Web 2.0

Knowledge transfer Phase	**Crowd computing class**
Transformation	Web 2.0 Crowdsourcing
Association	Web 2.0 Crowdsourcing
Application	Social computing
Knowledge externalization and feedback	Web 2.0 Crowdsourcing

Support of the different knowledge transfer activities outlined above using crowd computing approaches is described in greater detail in the sections below.

6.4.3.1.1 Awareness

The awareness process is concerned with recognition of knowledge needs and the identification of appropriate or valuable knowledge to meet this needs. This is a process that needs cooperation between the source and receiver and in the case of this research, the experts and citizens. Two classes of crowd computing approaches were found appropriate for supporting this process, namely the social computing and web 2.0. Social computing as described in Section 6.2.2.2 is computing that takes advantage of intrinsic social behaviour of humans. This class of crowd computing approach was considered suitable for the awareness process since people can easily share their needs and experiences that can then be compiled to generate needs and knowledge sources. Although the information may be highly unstructured, the awareness process can greatly benefit from social computing. Web 2.0 was found appropriate for a structured approach to the awareness process. Web 2.0 techniques provide opportunity for creating a clearly structured process where experts and citizens can work together to identify knowledge needs and knowledge sources. Use of web 2.0 provides opportunity to create tailor made tools for the awareness phase.

6.4.3.1.2 Acquisition

The acquisition process deals with the gathering the knowledge from the identified sources. Web 2.0 was found ideal for this process since it requires the willingness of both source and receiver. This means that they would be able to work in a structured way, and Web 2.0 provides an opportunity for this. There is also no requirement to have other motivating factors such as meeting social needs as in social computing. In the biodiversity management setting, this role is largely played by experts.

6.4.3.1.3 Transformation

Transformation deals with making the knowledge useful to the intended receiver. It may include acts of translations, illustrations or elaboration. The Web 2.0 again lends itself as a useful crowd computing approach for transformation of knowledge. Crowdsourcing approaches were also found viable for transformation activities. Examples of use of crowdsourcing techniques in translation include mobile translation of images for travellers (Liu et al. 2010) and translation of messages for emergency response during the Haiti earthquake (Munro 2010).

6.4.3.1.4 Association

Association process deals with linking the new knowledge with the needs of the receiver. Two classes of crowd computing were found relevant for this task, Web 2.0 and crowd computing.

6.4.3.1.5 Application

Application is concerned with the utilization of new knowledge. Although this phase is concerned with practical application thus concluding knowledge transfer from source to receive, social computing was found appropriate so as to enable the knowledge recipient to share experiences from using new knowledge thus supporting the process with useful feedback that could enhance the knowledge transfer process as a whole. The social computing will tap into the inherent human desire to share experiences with others.

6.4.3.1.6 Knowledge externalization and feedback

Knowledge externalization and feedback is a process of giving feedback on the use of new knowledge. In biodiversity management, this process has the potential of being complex due to the nature of knowledge and the disparity in levels of understanding between experts and citizens. Three crowd computing approaches were found relevant: - Web 2.0 where structures for providing feedback can be created to provide a structured way of giving feedback, social computing where knowledge receivers in the process of using knowledge can give feedback on their experiences. These experiences can be analysed to extract feedback. Finally, crowdsourcing could be incorporated into Web 2.0 for purposes of structuring feedback to suit some standards making it analysable.

6.4.3.2 Actors in the Knowledge transfer process

Traditionally, the knowledge transfer process has two categories of actors: - the source and receiver as described in Chapter 4. In a crowd computing environment, a new category of actor is introduced, the crowd. Introduction of the crowd further introduces two other categories of actors: - source-crowd and receiver-crowd. The source is in line with traditional source and represents the knowledge source. The receiver is also a traditional role and is the targeted recipient of the knowledge. The crowds are people who participate in crowd computing activities and could also be members of the source or receiver groups. The source-crowd are people who are members of the knowledge source but choose or are forced to participate in crowd tasks. The receiver-crowd are the targeted receivers of knowledge and also choose or are forced to participate in crowd computing activities. The actors in a crowd computing knowledge transfer environment can be represented in a continuum from source to receiver as shown in Figure 6-5.

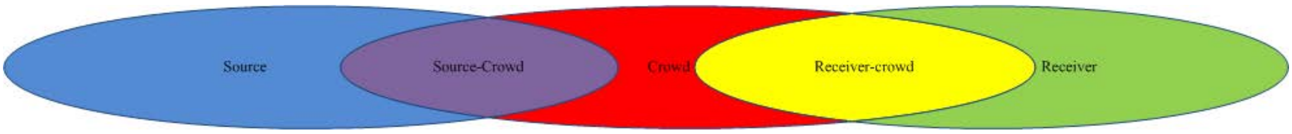

Figure 6-5: Actors in crowd computing knowledge transfer environment

6.4.3.3 Conceptualization of crowd computing in a knowledge transfer process

In Section 6.4.3.1 and 6.4.3.2 the possible crowd computing approaches for the knowledge transfer process and the actors were described. In this section, the two are combined to create a conceptualization of the different actors and the crowd computing approaches for supporting the processes of knowledge transfer. The conceptualization illustrated the contextual location of the actors in relation to the different crowd computing approaches proposed for use in supporting the different phases of the knowledge transfer processes is as shown in Figure 6-6.

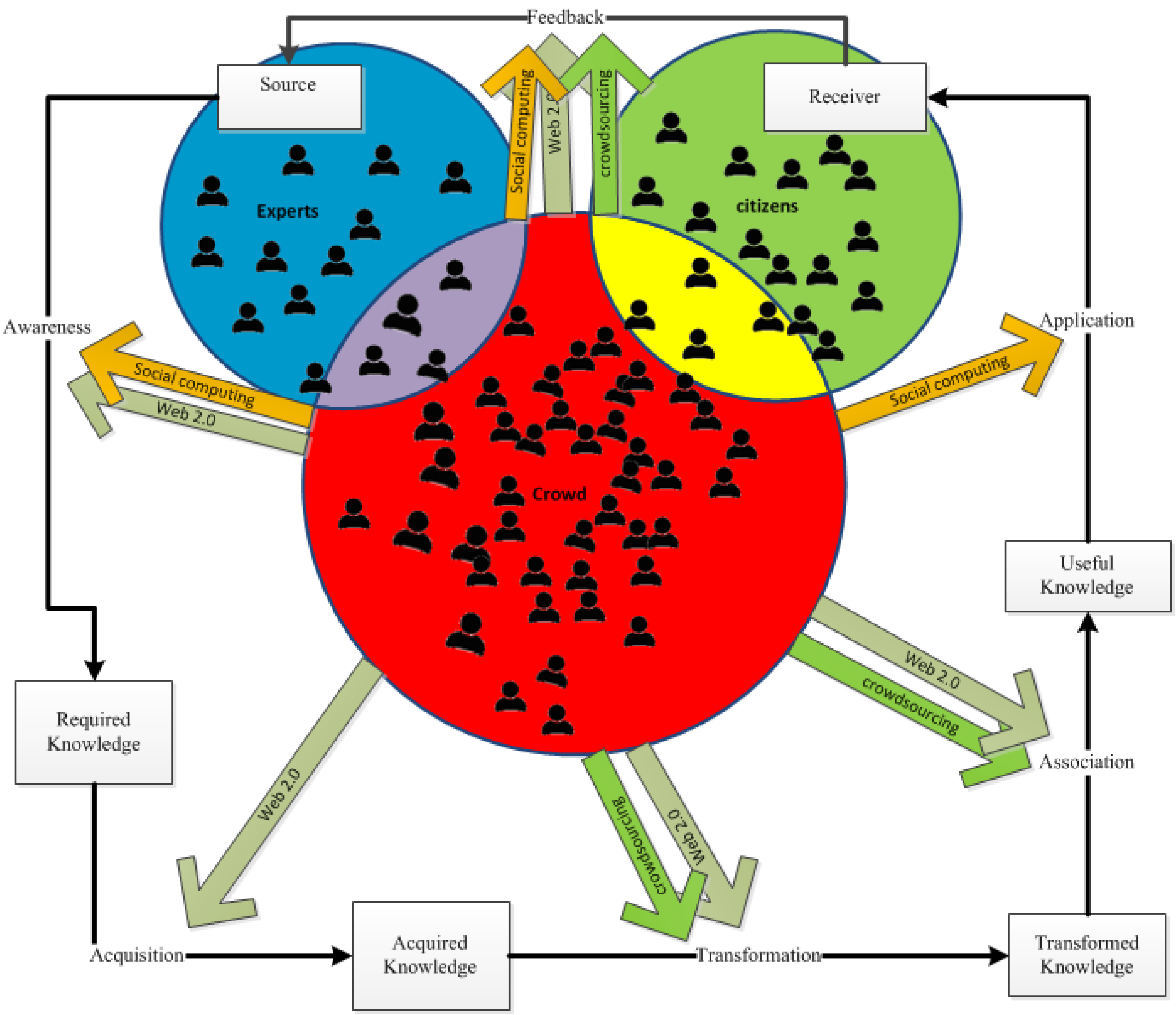

Figure 6-6: Conceptual model of crowd computing types for supporting different knowledge transfer processes.

6.5 SUMMARY

In this chapter, the results of sub-cycle 3 were presented. The objective of this cycle was to answer the third sub question “To establish how crowd computing technologies can be used to support biodiversity management knowledge transfer.” The chapter commences with a background literature review on crowd computing where a definition of crowd computing is provided together with classifications of crowd computing applications and distinction from related concepts of social computing, crowdsourcing, human computation and Web 2.0. The approaches to crowd computing are also outlined followed by models of aggregating data gathered from crowd computing. After the background, the research design used in answering the research question is presented, and DSR was selected. Three steps of the DSR research process were used, namely: awareness, suggestion and development. The awareness was done through literature review where the use of crowd computing in biodiversity management was reviewed. The awareness phase demonstrated that crowd computation has been used in the area of biodiversity management, mainly for collection of primary biodiversity data, digitization of museum specimens and other ecological monitoring activities. Use of crowd computing in knowledge transfer was not found though biodiversity monitoring activities were seen as transfer of ground knowledge from citizens to experts. The awareness section set the stage for suggestions on how crowd computation could be used to support the knowledge transfer process. The chapter concludes with development of a conceptual knowledge detailing how crowd computing techniques could be used to support knowledge transfer in biodiversity management.

Chapter 7 - Development of knowledge transfer model

7.1 INTRODUCTION

In this chapter, the objective is to explore how the results of ontological modelling of biodiversity knowledge in Chapter 5 together with crowd computing techniques (Chapter 6) can be combined to create a biodiversity management knowledge transfer model. The findings in Chapter 5 and Chapter 6 were inputs into the development of the model presented in this chapter.

In Chapter 5, representation of biodiversity management knowledge, using ontologies was examined. It was found that many ontologies representing biological and biodiversity knowledge continue to emerge. It was also found that use of ontologies is becoming the preferred option for representing the biological knowledge fabric due to the advantages that come with representing knowledge using ontologies. In the recent years, tools that support web-based creation and manipulation of ontologies have made it possible to enable collaborative construction and maintenance of ontologies by stakeholders in different geographical locations.

In Chapter 6, use of crowd computing techniques to support the knowledge transfer process was examined. A detailed analysis of the knowledge transfer processes was done with an aim of identifying suitable crowd computing approaches that could be used to support the different processes. It was proposed that different forms of crowd computing could be used to support different processes of knowledge transfer. A continuum of actors in the knowledge transfer process was also identified ranging from source on one end to a receiver on the other end. The contextualization of actors and crowd computing types identified for use in the different knowledge transfer processes is presented in Chapter 6.

This chapter commences by establishing how ontologies can be used to support the different stages of the knowledge transfer process in Section 7.2. In Section 7.3 the use of ontologies and crowd computing to support the knowledge transfer process are combined to create a single high level application model. In Section 7.4 detailed models of each process of knowledge transfer are presented, and Section 7.5 is the chapter summary. The chapter outline is summarized in Figure 7-1.

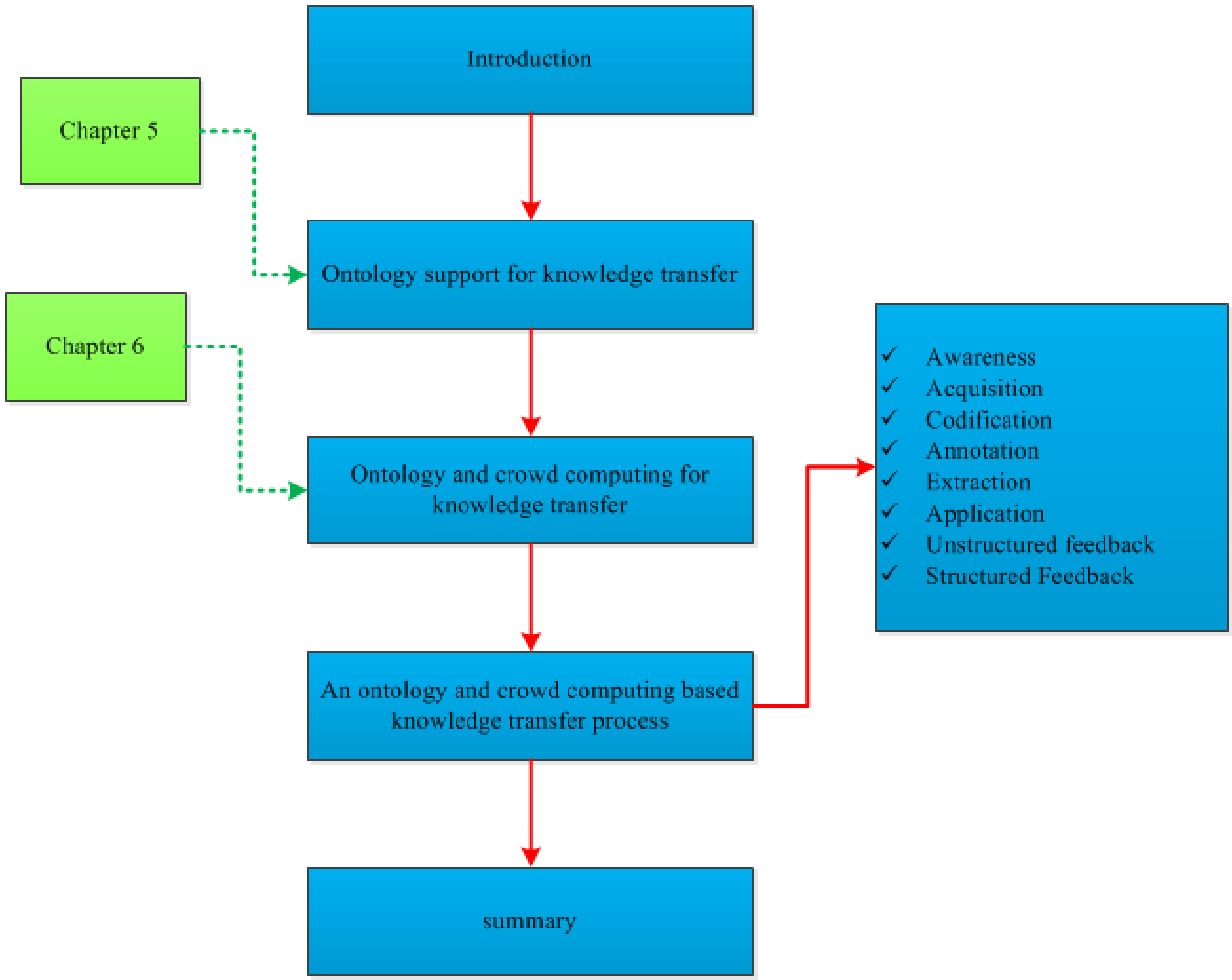

Figure 7-1: Outline of chapter 7

7.2 ONTOLOGY SUPPORT FOR KNOWLEDGE TRANSFER

The knowledge transfer model adopted for this research is the Liyanage et al.'s (2009) process model consisting of five process steps (awareness, acquisition, transformation, association and application) between source and receiver, and one step of feedback from a receiver to the source. In this section, the different steps were examined to establish how ontologies could be used to support the knowledge transfer process. This was done by analysis of the process steps and proposing how ontologies could be used to support the different process steps. It is worth noting that ontologies are not suitable for every software application needs (Horrocks 2013) and use of ontologies is uncalled for in every situation. Moreover, creation of ontologies is expensive and an ontology should only be done if it is necessary in achieving the project's goals.

7.2.1 Awareness

The awareness process deals with identification of appropriate knowledge and it was found that use of ontologies was not necessary.

7.2.2 Acquisition

Acquisition process deals with getting the knowledge from identified sources. In biodiversity management, this knowledge could be in books, scientific literature, pamphlets, user guides, technical reports or other documentations. The sources could be in print or different formats of electronic formats. Use of ontologies to support this process was also found to be unnecessary.

7.2.3 Transformation

Transformation is part of a process of making the knowledge useful to the receiver. Use of ontologies is necessary for this process since with ontologies knowledge can be logically represented in a form that can answer questions based on the represented knowledge. Traits knowledge in biodiversity management has many dimensions and combining different traits knowledge to answer questions is complex and use of ontologies was found appropriate for the transformation process. Use of ontologies will enable incorporation of a reasoner in answering questions. Search for existing ontologies for re-use should be the starting point for this process. Transformation in some projects includes translation activities, and ontology development tools readily support this requirement.

7.2.4 Association

The association process is concerned with mapping the new knowledge to the receiver's knowledge. Use of ontologies was found appropriate for this process, and the ontology from the previous process could be extended with the receiver's knowledge.

7.2.5 Application

Application process involves the practical use of the newly acquired knowledge by the receiver. Use of ontologies in this process was considered unnecessary.

7.2.6 Feedback

The feedback process deals with externalization of new knowledge back to the source. Ontologies were found useful for this process for purposes of structuring feedback. In biodiversity management, especially, feedback from citizens to experts is expected to be highly unstructured and varied due to different levels of abilities and communication. Ontologies can be used to either structure the feedback process or to clean the unstructured feedback depending on implementation choices made in a project.

The recommended use of ontologies to support different knowledge transfer processes is as summarized in Table 7-1.

Table 7-1: Ontology use for knowledge transfer processes

Process	Ontologies use required?
Awareness	No
Acquisition	No
Transformation	Yes

Process	Ontologies use required?
Association	Yes
Application	No
Feedback	Yes

7.3 ONTOLOGY AND CROWD COMPUTING SUPPORT FOR KNOWLEDGE TRANSFER

In this section, a high level software model of the knowledge transfer process between expert and citizen supported by both ontologies and crowd computing technologies is presented. In Chapter 6, different crowd computing approaches that can be used to support the knowledge transfer process steps were identified. Development of the software model presented in this section was done through combining the results of chapter 6 and the use of ontologies to support the knowledge transfer process presented in Section 7.2 above.

Table 7-2: Ontology and crowd computing to support knowledge transfer process

Process	Ontologies use required?	Crowd computing approaches
Awareness	No	Web 2.0, Social computing
Acquisition	No	Web 2.0
Transformation	Yes	Web 2.0, Crowdsourcing
Association	Yes	Web 2.0, Crowdsourcing
Application	No	Social computing
Feedback	Yes	Web 2.0, Crowdsourcing, Social computing

The development of the software model resulted in revision of the knowledge transfer process in order to take advantage of the strengths of the two computing paradigms and to generate a model that can translate to practical implementation, a fundamental reason for creating models and a key requirement of model driven software development (Acuña & Ferré 2001; Gonzalez-Perez & Henderson-Sellers 2007). The revised model of knowledge transfer has the following process steps: awareness, acquisition, codification, annotation, extraction, application, feedback structuring and feedback.

The awareness step is concerned with recorgnition of a knowledge need and possible knowledge sources and the step is adopted as it is from the Liyanage et al. (2009) model. The acquisition step is also adopted as it is and deals with collating the knowledge from the identified sources. The codification step replaced the transformation step. Where as transformation is concerned with conversion of knowledge to a form usable at receivers end, the codification step deals with transformation of knowledge into machine and human understandable form. The term codification was used to harmonize with the lingo in knowledge representation. Unlike transformation which happens at receivers end, the codification step happens at the source end. Annotation step replaces the association step. Like association, the annotation step labels the knowledge with terminologies relevant to receiver. The term was also selected to harmonize with the lingo used in the ontological modelling domain.

The fifth step, the extraction is a new step that does not exist in Liyanage et al. (2009). The Liyanage et al.'s assumes that once knowledge is in a form that can be understood by the receiver then it can be applied. This is not always true since some knowledge require certain technical skills to be useful. For example, taxonomic identification require application of knowledge in a certain way to arrive at identifications. The extraction step was therefore introduced to mitigate against such challenges as it provides the avenue to extract specific knowledge for receiver based on their specific needs. The application step is the same as in Liyanage et al.'s model. The feedback step is split into two, structured and unstructured feedback. The structured feedback is expected to be in a format prescribed by the feedback receiver (knowledge source). In some situations structuring the feedback to fit the prescribed format can again be highly complex to receivers so, the unstructured feedback is provided so that additional technologies can be applied to structure it.

The use of ontologies and crowd computing techniques is as summarized in Table 7-3 and illustrated on the high level model in Figure 7-1. In Section 7.4, a description of each process is provided.

Table 7-3: Ontology and crowd computing use to support the revised knowledge transfer process

Process	Ontologies use	Crowd computing approaches
Awareness	No	Web 2.0, Social computing
Acquisition	No	Web 2.0
Codification	Yes	Web 2.0
Annotation	Yes	Web 2.0, Crowdsourcing
Extraction	Yes	Web 2.0, Crowdsourcing
Application	No	Social computing
Unstructured Feedback	Yes	Web 2.0, Crowdsourcing, Social computing
Structured Feedback	Yes	Web 2.0

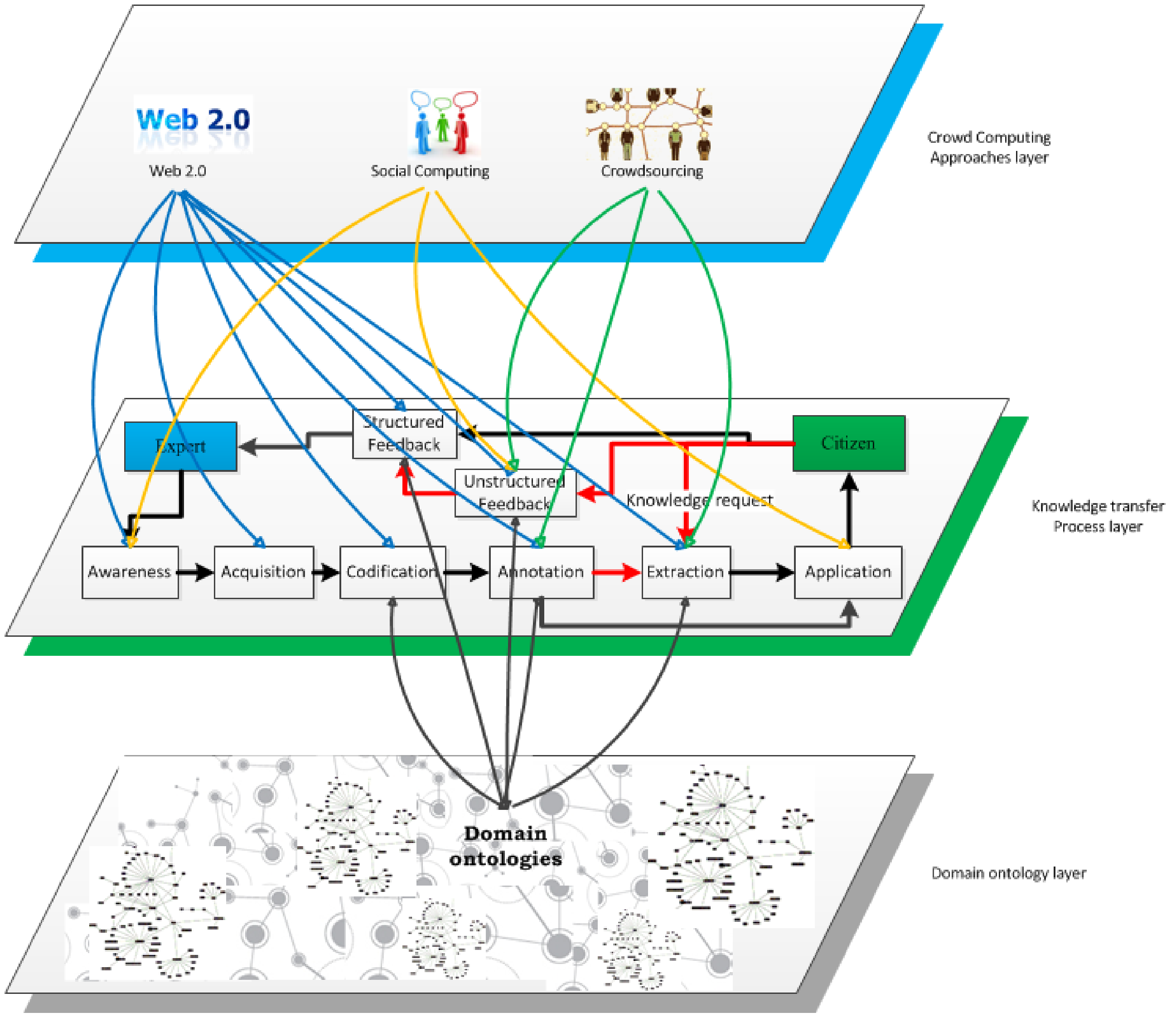

Figure 7-2: Knowledge transfer process supported by ontologies and crowd computing

7.4 THE KNOWLEDGE TRANSFER PROCESS

In this section, description of the knowledge transfer process steps and a general model of the knowledge transfer processes are presented. The ontological modelling is presented using OWL notations while the crowd computing modelling is presented using UML notations specifically use case diagrams so as to illustrate the roles of the different actors. The models are presented next using notations from the two modelling techniques.

7.4.1 Awareness

The awareness process deals with identification of knowledge needs and appropriate sources of the knowledge. The process requires both the experts and the citizens to work together. This research proposed that the awareness process can be supported by web 2.0 and social computing technologies as shown in Figure 7-2 and described in bullets (a) and (b) below.

a) Web 2.0

Web 2.0 can be used to create tools that allow citizens to record their knowledge needs and experts to identify knowledge sources for addressing those needs. Because it is assumed that both receiver and sender must be willing participants, then providing interfaces that support the required functionalities would be enough as no external motivation is required. The awareness process does not necessarily have to start with receiver requesting based on needs since in some instances, the expert is aware of specific knowledge that needs to be transferred to citizens. The generic use case diagram illustrating the receiver and source roles is shown in Figure 7-2 (a) and (b) respectively.

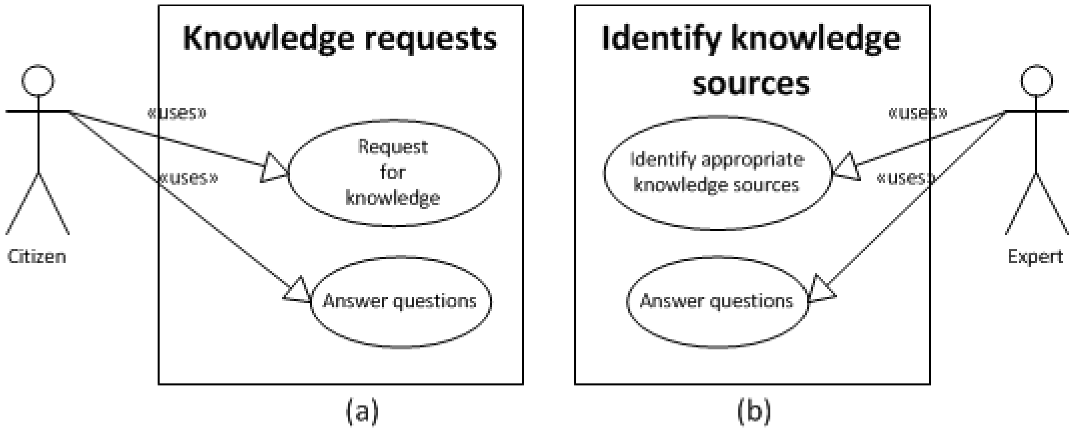

Figure 7-3: Use case models of the awareness process

b) Social Computing

Social computing can be used to support the awareness process through identifying biodiversity management-related challenges shared by citizens. Also some researchers and different interest groups working on biodiversity management-related programmes have used social media to discuss different topics and help each other identify and solve problems.

7.4.2 Acquisition

This process deals with acquiring the knowledge from the identified sources. In biodiversity management setting, experts can collaborate to source for the knowledge from the identified sources. The output of this process is the knowledge to be transferred and could be in an electronic or print format.

a) Web 2.0

Web 2.0 could be used to create the necessary tools to support this process. The use of web 2.0 could be purely to support the process but not to convert or format the knowledge to electronic forms.

7.4.3 Codification

Codification is the process of converting the knowledge acquired in the acquisition stage to a format that can be transferred in the subsequent knowledge transfer process steps.

a) Ontology modelling

The use of ontologies to represent the knowledge was found ideal for representing the traits knowledge in biodiversity management. Organisms have different types of traits that are used to describe them, for example, morphological traits, behavioural traits, product traits, reproduction trait and functional traits. This research proposed a model that can be adopted in modelling the traits knowledge as follows:

Given an organism with O with different traits as shown in Box 7-1

```
trait type A – trait A1, A2, A3 …..An

trait type B – trait B1, B2, B3 …..Bn
.
.
.
trait type N – trait N1, N2, A3 …..Nn
```

Box 7-1: Organism traits

Given also that different types of object properties are defined as shown in Box 7-2

```
hasTraitA

hasTraitB
.
.
.
hasTraitN
```

Box 7-2: Object Properties

The modelling should be as shown in Box 7-3

O and (*hasTraitA* some TraitA_1) and (*hasTraitA* some TraitA_2) …and (*hasTraitA* some TraitA_n) and

(*hasTraitB* some TraitB_1) and (*hasTraitB* some TraitB_2) …and (*hasTraitB* some TraitB_n) and

(*hasTraitN* some TraitN_1) and (*hasTraitN* some TraitN_2) …and (*hasTraitN* some TraitN_n)

Box 7-3: Traits model

The modelling of the traits using Protégé is presented next. The traits should be modelled as sub-classes of the different trait types defined as classes as shown in Figure 7-4.

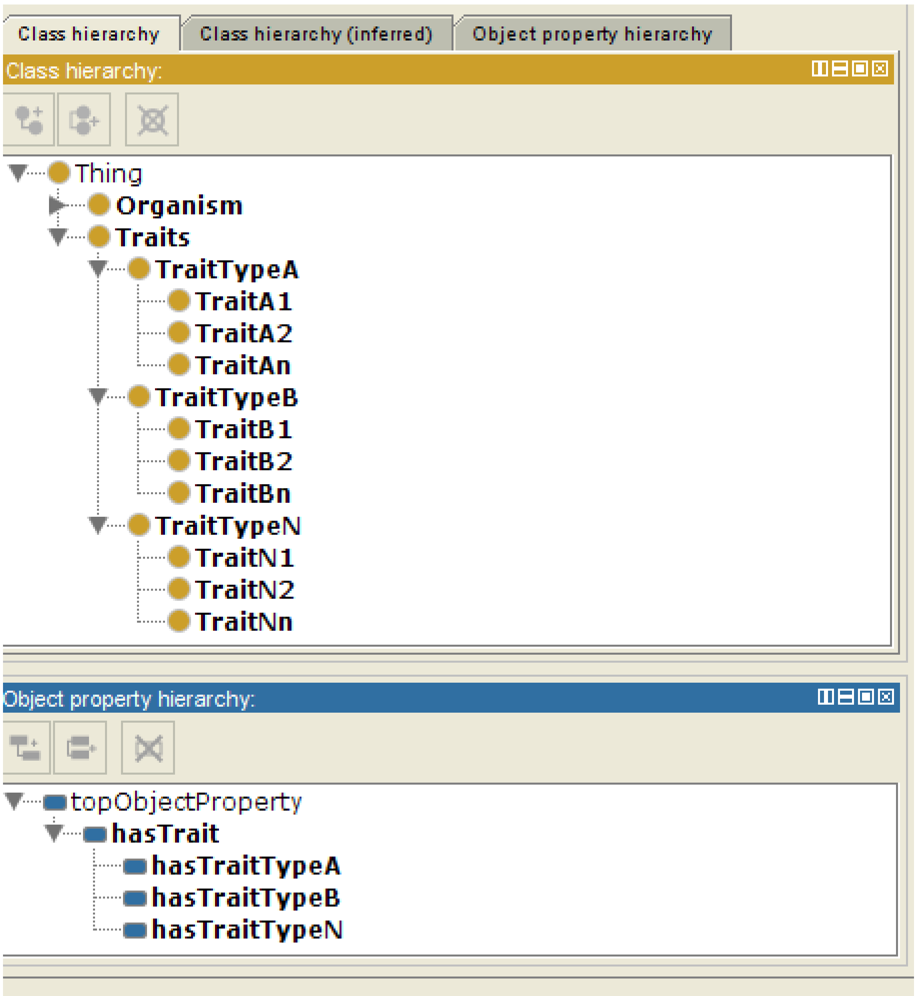

Figure 7-4: Traits and traits object property model

The object properties for associating the organism with the different trait types should also be modelled as sub-properties of the `hasTrait` object property as shown in Figure 7-4.

Modelling the organism groupings should be done as sub-classes of the organism class. The organism groupings can also have hierarchies of different levels depending on the properties as long as a sub-class has all the properties (traits) of the superclass. For purposes of this illustration, the organism groupings are all modelled as subclasses of the organism class without further sub-classes as shown in Figure 7-4.

Association of the traits with the different organisms should be done using the applicable object property to link the trait. Modelling of an organism grouping `OrganismA` that has three traits, `TraitA1, TraitB2` and `TraitN1` is as shown in Figure 7-4 and the equivalent view is shown in Figure 7-4.

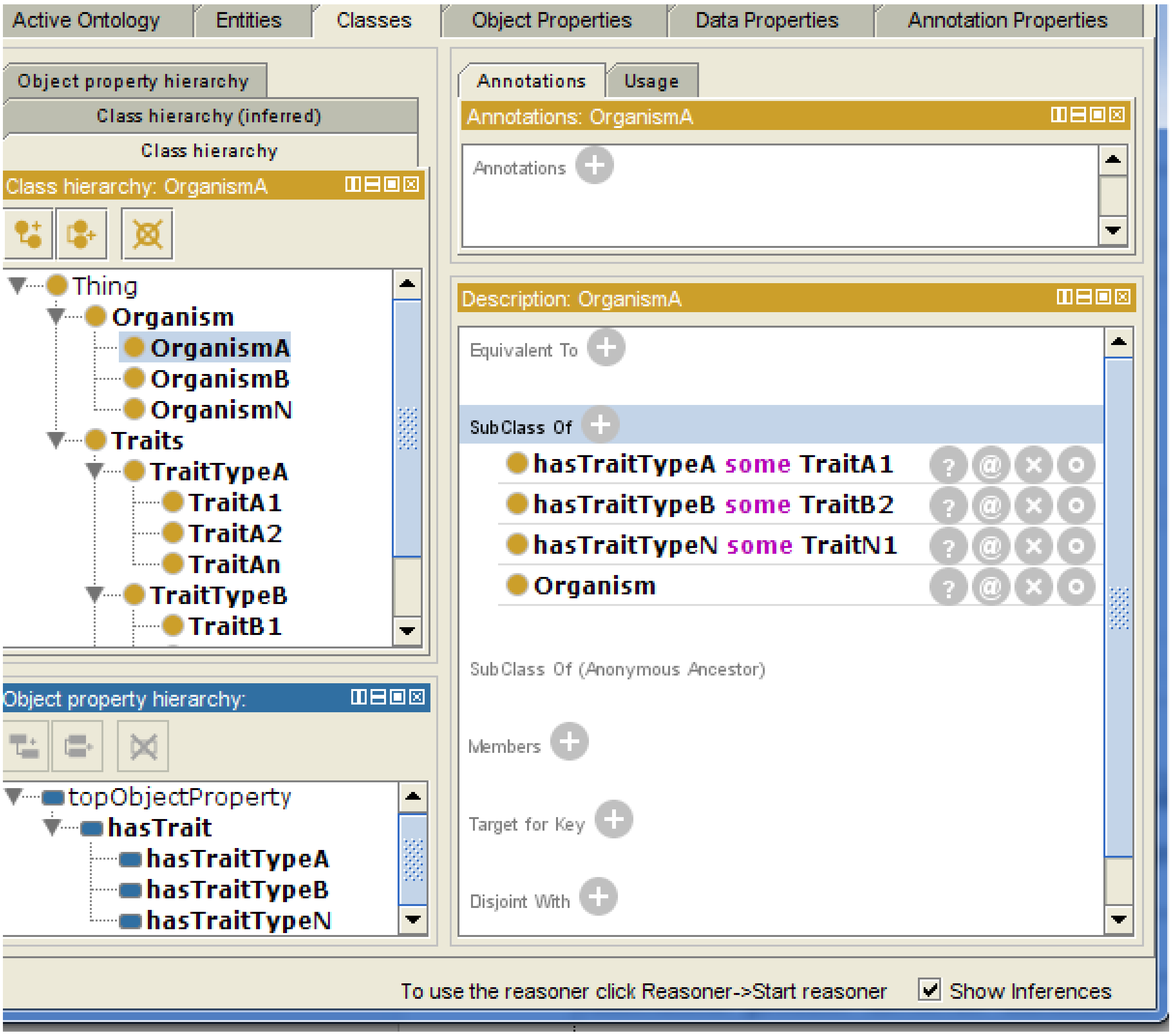

Figure 7-5: Organism traits model

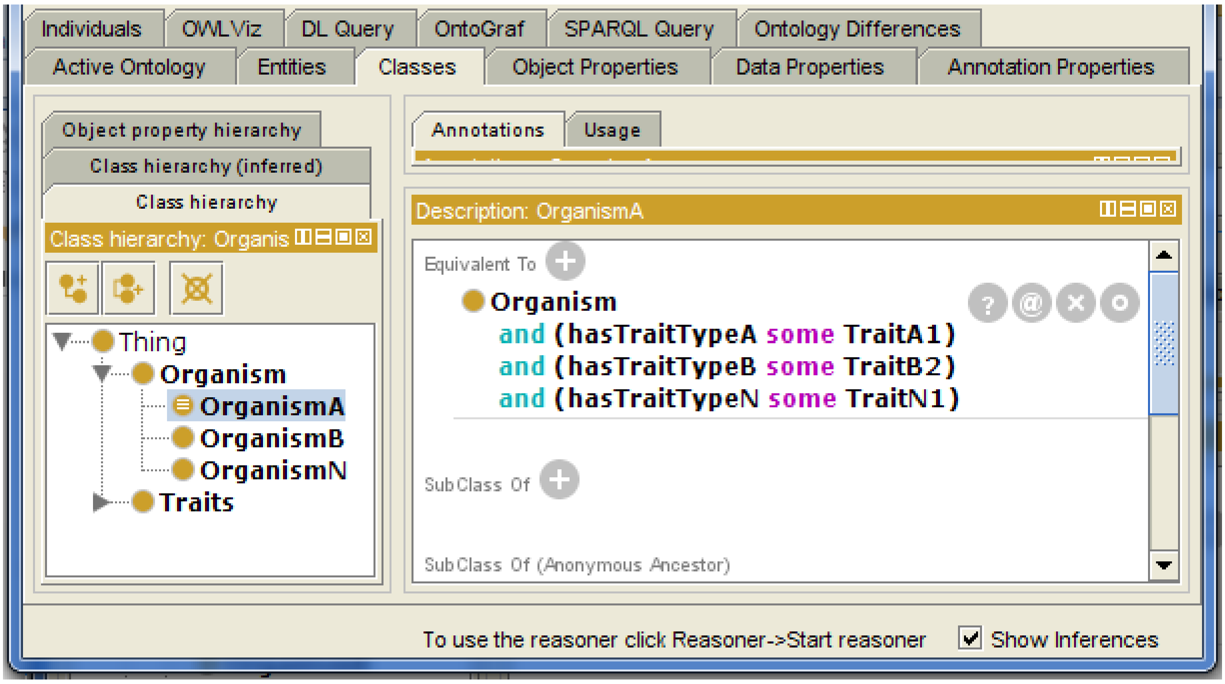

Figure 7-6: Traits model organism equivalent view

Details and development of the model proposed for representation of the traits knowledge are available in Chapter 5.

7.4.4 Annotation

Annotation process involves enrichment of the knowledge represented in the ontology concepts with terminologies from the user domain. This allows for enrichment of the ontology without altering its logical structure. Annotation enables the ontology users to interact with the ontology using their terminologies and still benefit from reasoning based on the underlying logical structure.

a) Ontology modelling

Annotation of the ontology is part of the ontology modelling process. Annotations is what is finally readable to humans and proper annotation of all ontology concepts is necessary. Tools for building ontologies come with features for annotation.

b) Web 2.0

Customised Web 2.0 based tools can be created to facilitate annotation of ontologies without the need to learn the ontology development software. For instance, if the ontology is to be annotated in a different language, then tools that display concepts in the existing language can be created, and translators can annotate in a new language without the need for them to understand the ontology's logical structure.

c) Crowdsourcing

Crowdsourcing techniques can be used for ontology annotation or support annotation process (Sarasua et al. 2012; Mortensen et al. 2013). This can be done through design of simple tasks (micro tasks) that can be performed by the crowd, and the crowd annotations combined to derive acceptable annotations.

7.4.5 Extraction

Extraction process is concerned with aiding citizens to extract the exact knowledge they need for specific questions. Biodiversity management is characterised by complex knowledge and translating it to forms useful to citizen does not guarantee access and use since it can be complex to extract what is useful. In some cases, some specialised skills are required to access the knowledge, for example, taxonomic identification skills. Providing a simplified taxonomic key does not guarantee identification of organisms by all citizens. This process is therefore aimed at extracting specific knowledge based on requests.

a) Ontology use

The knowledge represented in the ontology is input to this process. The ontology is used to interpret the citizen's request thus enabling access to appropriate knowledge.

b) Web 2.0

Web 2.0 could be used to design specific interfaces where citizens can ask questions that can be answered by other citizens of experts. A general use case diagram for this task is shown in Figure 7-4.

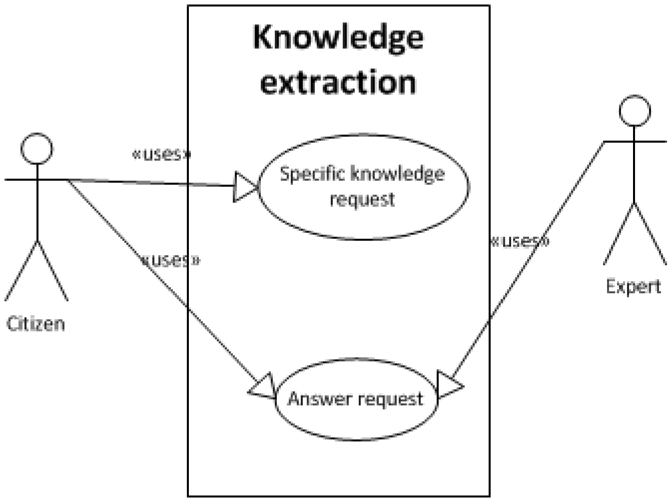

Figure 7-7: Knowledge extraction using Web 2.0

c) Crowdsourcing

Crowdsourcing techniques could be used to design activities that can be performed by the crowds, and the results combined using aggregation algorithms to provide answers. The ontology could be used in designing these activities making them more structured and ensuring more accurate results are achieved. A Generic model for knowledge extraction using crowdsourcing is presented in Figure 7-4.

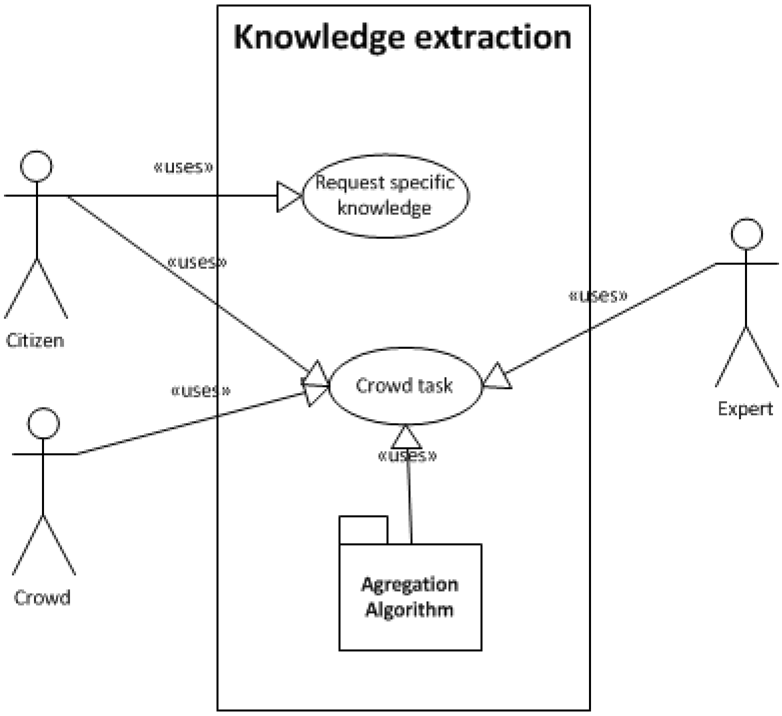

Figure 7-8: Knowledge extraction using crowdsourcing

7.4.6 Application

Application is the practical application of new knowledge by citizens.

a) Social Computing

Citizens may share their experiences using social media out of their social need/desire to do so.

7.4.7 Unstructured feedback

This process deals with unstructured feedback from citizens to experts. Forcing citizens to structure feedback could lead to "no feedback" since the processes of structuring feedback can be demanding. Different crowd computing techniques could be used to solicit and structure this feedback as described below:

a) Social Computing

This is similar to the use of social computing in the application phase. Citizens could be encouraged to share their feedback using social media and specific social computing pages created for the knowledge transfer case at hand.

b) Web 2.0

Web 2.0 interfaces could be created where the citizens can provide their feedback in a structured manner.

c) Ontology use

Ontologies could be used in structuring the feedback outside the feedback process.

d) Crowdsourcing

Crowdsourcing techniques can be used to structure the feedback provided by citizens. The generic process of structuring feedback is illustrated in Figure 7-4. Feedback structuring could be designed into simple crowd tasks that can be executed by citizens. The tasks could be supported by the ontology resulting in more accurate data.

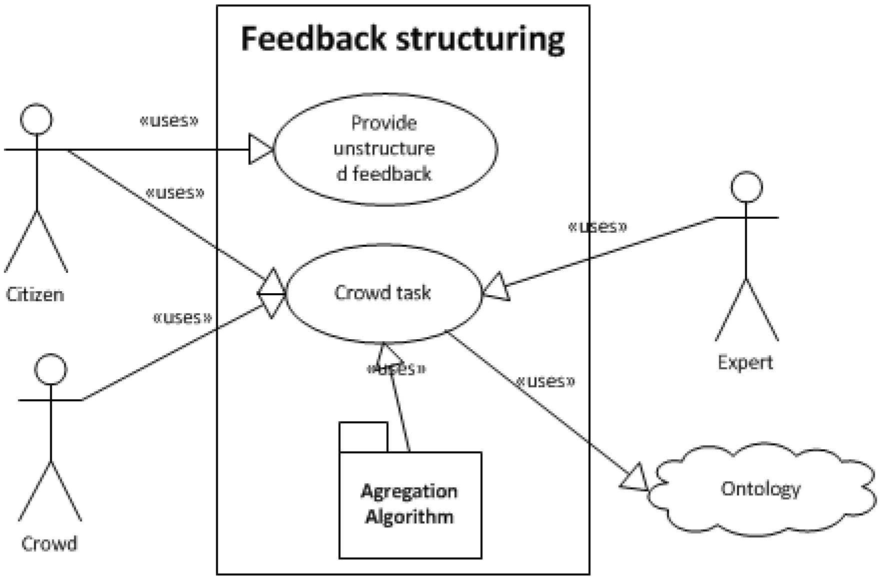

Figure 7-9: Feedback structuring using crowdsourcing

7.4.8 Structured Feedback

a) Ontology use

Ontology could be used to structure interfaces used in collecting structured feedback. This will ensure that the feedback received is valid data that can be used for scientific purposes.

b) Web 2.0

This involves providing carefully designed feedback interfaces where citizens can use to provide feedback. Web 2.0 could be used together with ontologies to ensure feedback provided by citizen is structured and useful to scientists.

7.5 SUMMARY

In this chapter, the development of a knowledge transfer model supported by ontologies and crowd computing technologies, is presented. The development of the model used the outputs of Chapter 5, ontological modelling of biodiversity management knowledge and Chapter 6, crowd computing approaches for supporting knowledge transfer process and combined them to create a model that uses both technologies to support the process of knowledge transfer between experts and citizens in biodiversity management. The outcome of the combination is a knowledge transfer process model consisting of eight processes, namely: awareness, acquisition, codification, annotation, extraction, application, feedback structuring and feedback. The use of ontological modelling and crowd computing techniques to support this process is presented (Section 7.3) and illustrated in a knowledge transfer model presented in Figure 7-2.The chapter also presents a description and general models of the process steps of the knowledge transfer in Section 7.4.

Part IV - Evaluation and contribution

In this part, the results of the fourth phase of the main research cycle are presented. The part has two chapters: chapter 8 which deals with the evaluation and chapter 9 presenting the contributions of the study. The part and its chapters are contextualised within the rest of the study as shown in Figure IV-1 below.

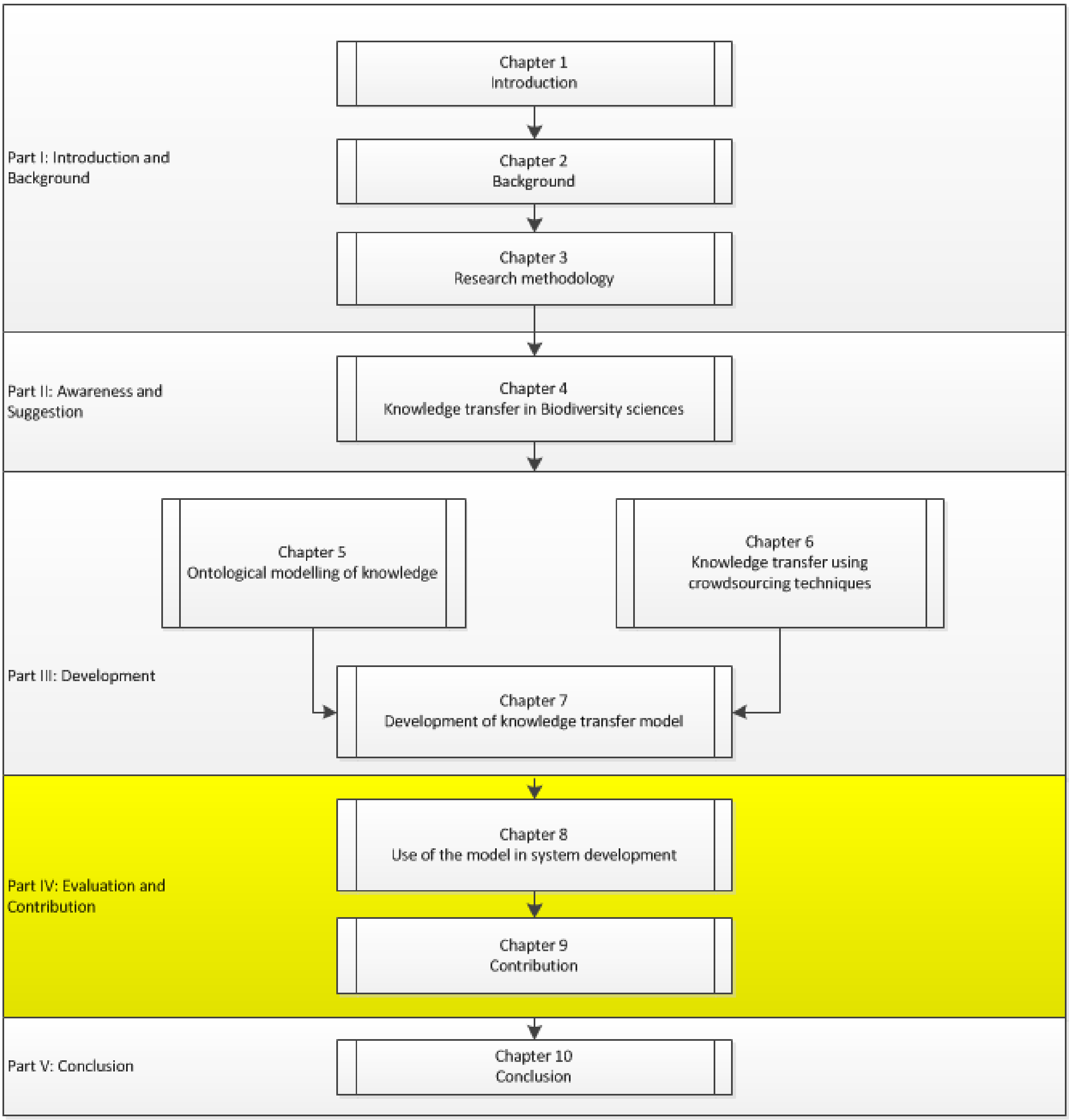

Figure IV-1 - Part IV outline

Chapter 8 - Application Case: Using the Knowledge Transfer model in system development

8.1 INTRODUCTION

The objective of this chapter is to apply the knowledge transfer model developed in Chapter 7 in the development of a system aimed at knowledge transfer between experts and citizens in the biodiversity management domain. The chapter is structured as follows: Section 8.2 contains a description of the case used in the research; Section 8.3 describes the nature of knowledge transferred between the experts and citizens; Section 8.4 entails the requirements of the system; Section 8.5 presents the development of the system; Section 8.6 presents the evaluation using a case of knowledge transfer; and Section 8.7 concludes the chapter. The chapter outline is shown in **Error! Reference source not found.**.

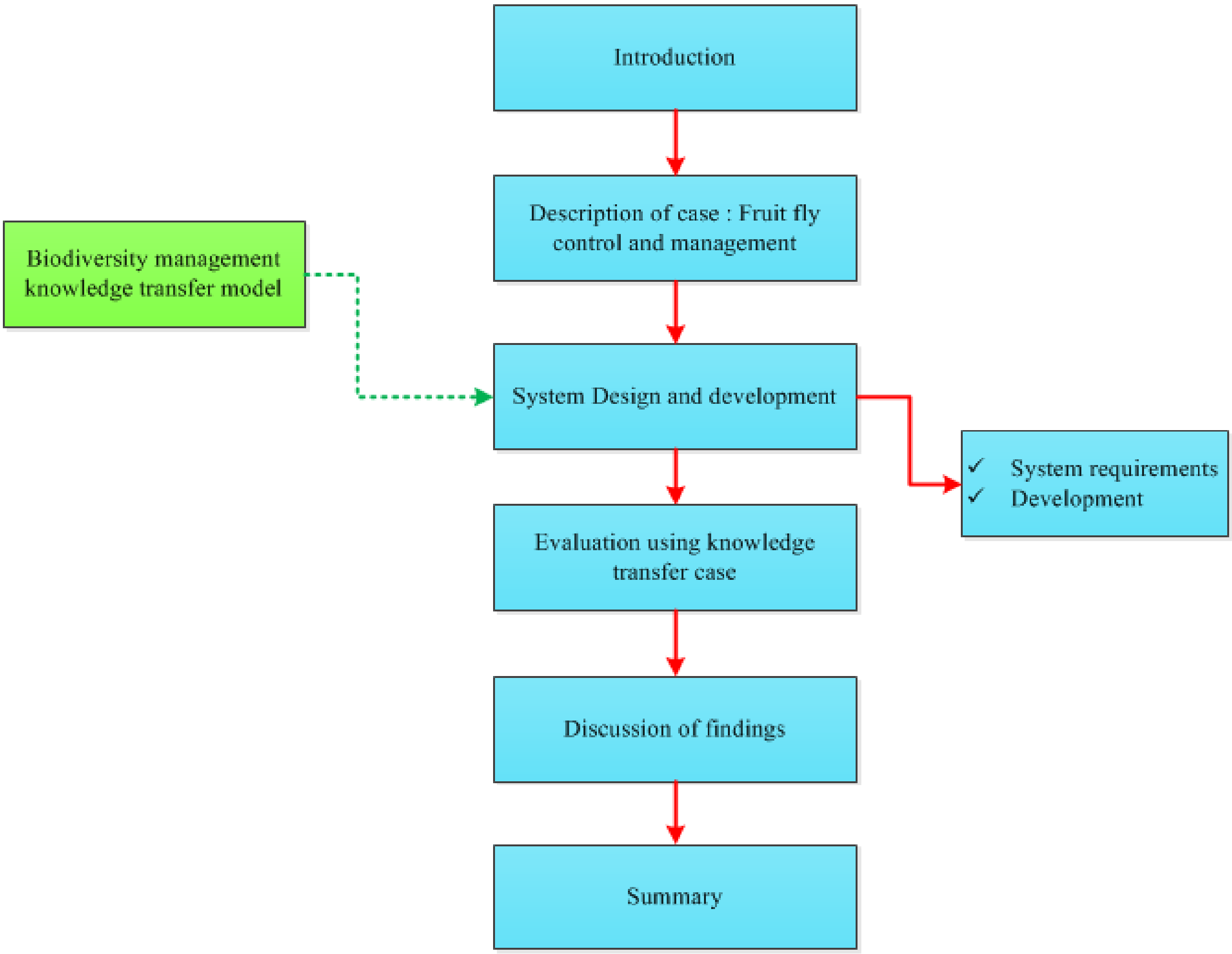

Figure 8-1: Outline of chapter 8

8.2 APPLICATION CASE

8.2.1 Overview of the case

An application case involving the transfer of biodiversity management knowledge between experts and citizens was selected for use in the evaluation of this research. The application case used was that of the transfer of biodiversity management knowledge on the control and management of fruit flies (Diptera: Tephritidae), a widespread pest that affects the horticulture industry. Fruit flies are pests to both fruits and vegetable and causes damage through the females laying eggs on fruits and the soft tissue of vegetables. As the eggs develop to larvae (maggots), they cause the fruit to rot and fall to the ground. The maggots crawl on the ground and burry themselves in soil where they develop into pupae stage. On completion of the pupae stage, a fly emerges and crawls out of the soil and when they are mature, they start mating and laying eggs again, thus starting another cycle (Ekesi & Muchugu 2007). A generalised life cycle of the fruit flies is shown in Figure 8-2. The fruit flies are therefore, most destructive at the egg-laying stage by the females since that is when they cause harm to produce.

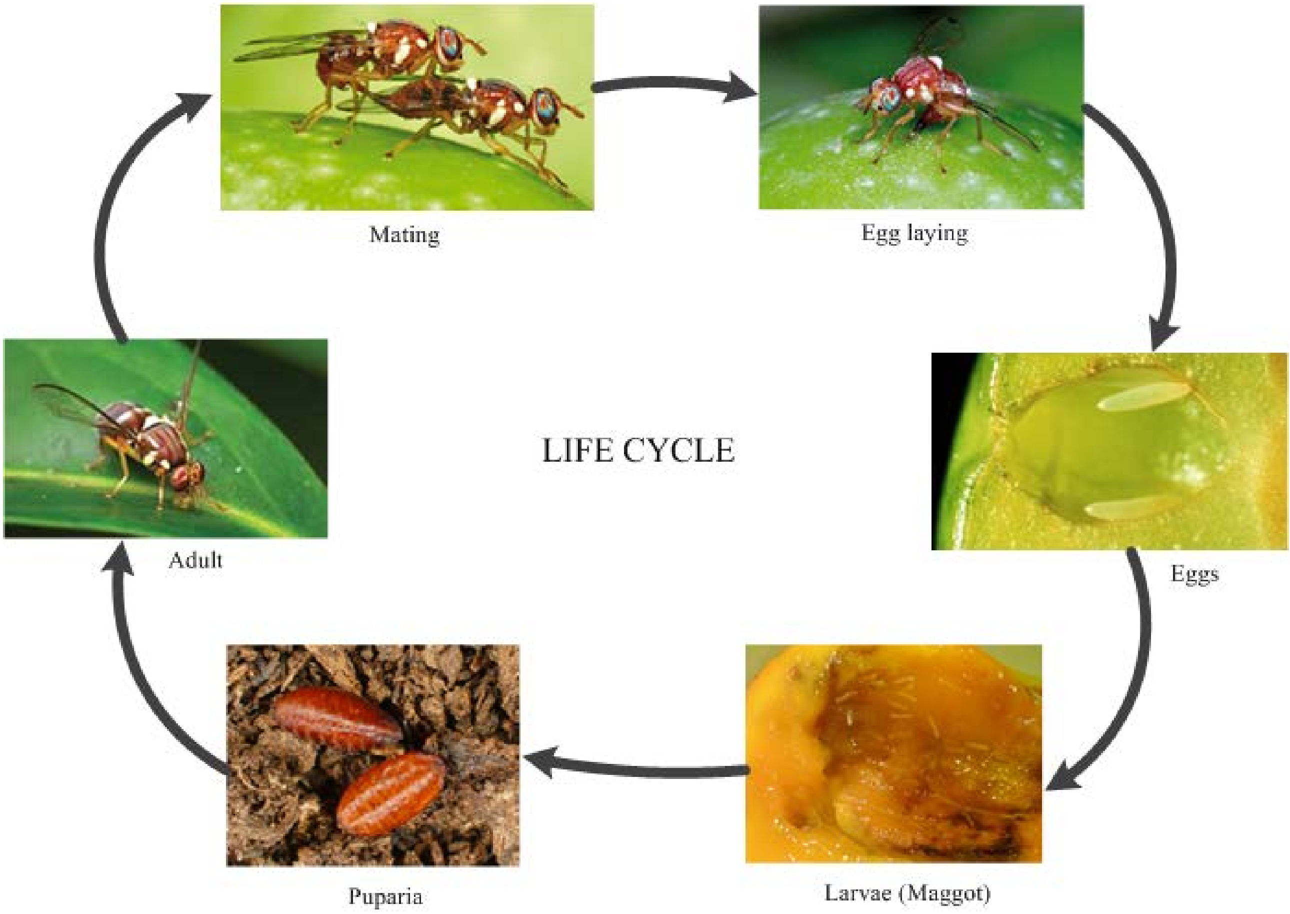

Figure 8-2: Generalised life cycle of fruit flies

Horticulture is regarded as among the fastest-growing agricultural sectors in Africa, providing both economic, dietary and health benefits to growers, traders and consumers in general. Fruit flies remain a major threat to this industry and if not contained could bring down the industry (Billah & Ekesi 2007). Excessive use of pesticides to contain the flies is not a solution since many pesticides leaves a toxic residue in the produce thus reducing its quality and suitability for international markets. In Kenya, for instance, loss due to fruit flies is experienced from three fronts; first is the direct damage to produce due to infestation of orchards and farms by the flies, second is the loss of market due to imposition of strict quarantine measures by importing countries and third is the loss of market due to exceeding of maximum residue levels (MRL) requirements by importing countries.

To mitigate against these challenges, different stake holders, including growers' associations, government agencies and border control bodies came together to develop strategies to counter the flies and ensure the produce meets the requirements of local and international markets. In 1998, the International Center of Insect Physiology and Ecology (ICIPE) created the African Fruit Fly Initiative (AFFI) and among its mandate was to develop biodiversity friendly, scientific and cost effective practical methods of combating the fruit flies as well as carry out capacity-building initiatives to ensure support for growers (Lux et al. 2003). Since then, the programme has created and packaged diverse kinds of scientific knowledge for use in monitoring, control and management of the flies. The nature of knowledge considered in this research is presented in the Section 8.2.2.

The practical control and management of the fruit flies is done through the transfer of relevant expert knowledge to citizens who apply the knowledge thus improving the yield of their horticultural produce. The different approaches currently used to transfer the knowledge is discussed in Section 8.2.3.

8.2.2 Nature of knowledge

As stated above, experts generate different kinds of knowledge on the control and management of fruit flies. Some of this knowledge has been packaged for practical application by growers in order to safeguard their produce from damage by the flies. In this research, three kinds of knowledge were considered namely knowledge on species identification, knowledge on the host plants preferred by the different fly species and knowledge on the attractants that can be used to lure different species of the fruit flies.

Identification knowledge constitutes the taxonomic knowledge required in order to establish the taxonomic identification of fruit flies being targeted. Control and management knowledge is organised around the scientific identification of the flies being targeted so the identification knowledge is of paramount importance in the access of all other types of knowledge. Biodiversity knowledge in general is organised around the species being targeted making species identification using taxonomic key a very important step in order to access relevant knowledge (Mace 2004). Simplified taxonomic keys for the fruit flies have been created for use in field identification, for example, a simplified key of twenty nine species considered to be of economic importance in Africa is available in Billah et al. (2007).

It has been established through research that different species of fruit flies are hosted by different sets of host plants (Rwomushana et al. 2009; Ekesi & Muchugu 2007). This knowledge is important in developing more customised intervention measures depending on the fly species and host plants that could be affected by that species. This knowledge can be used to compliment identification knowledge since it is possible to know the likely species depending on the host plant that is affected.

The final category of knowledge considered in this research is that of the attractants that can be used to lure the different species of flies. Research has shown that different species of the fruit flies are lured by different attractants used in monitoring and suppression fly traps (Manrakhan 2007; Ekesi & Lux 2007). Like knowledge on host plants, the knowledge on attractants can also compliment identification knowledge. The primary use of this knowledge, however, is for monitoring and control. After identification of the fly species present in an area, the appropriate attractant can be used in the fly traps. Also monitoring of different species is done using the attractants applicable for that species.

8.2.3 Transfer of fruit fly knowledge

In this section, the methods used and the challenges faced in the transfer and exchange of fruit fly knowledge between scientists, and other stakeholders are discussed. The research community face different challenges that hinder the transfer of knowledge across the diverse categories of stakeholders (Cugala et al. 2011).

- The first challenge was that of inadequate institution structures to facilitate transfer and exchange of knowledge. Control and management of fruit flies require inter-organizational and inter-sectoral collaboration and the structures for sharing knowledge are insufficient.
- The second challenge is that of weak link between research and extension services. Extension services are often used in the agricultural sector to transfer research output for practical application in the farms. The weak extension services, therefore, mean that a lot of research output does not reach targeted growers, and subsequent feedback not received thereby slowing down the control and management efforts.
- The third challenge is the weak linkages with producers. Producers are the final recipients of the knowledge and are responsible for applying it. To achieve good results, strong ties that support transfer of knowledge to producers and feedback systems are necessary.

Over the years, different strategies have been developed and adopted for use in fostering communication and transfer of knowledge among the stakeholders. The approaches that have been proposed and used to transfer knowledge include: - extension services, training workshops, formal publications, informal publications, websites, radio and television programmes (Ekesi et al. 2016; Cugala et al. 2011). Extension services as stated above are provided by persons equipped with the necessary skills to support farmers in introduction of new farming techniques or provide technical support to farmers, most are trained in agriculture or related fields. They provide the much-needed link between farmers and researchers. Extension service officers are usually employed by government and assigned an area where their role is to provide farmer support services in that area. Training workshops are organised from time to time with different themes, including presentation of new intervention programmes. The workshops are mainly organised for experts and also extension officers to equip them with new skills. Formal publications are done through different journals in entomology, agriculture and other related disciplines. Informal publications are made through fruit fly specific newsletters such as the Fruit Fly News, a quarterly newsletter published by Fruitfly Africa, or as inserts in daily newspapers. Radio and TV agricultural programmes are also used to disseminate fruit fly knowledge from time to time. Websites have also been used to share fruit fly knowledge. Some projects created websites where some control and management knowledge is published. Examples include the organic farmer (http://theorganicfarmer.org), Biovision (http://www.biovision.ch) and Kenya Biologics (http://www.kenyabiologics.com).

Despite these efforts to avail fruit fly control and management knowledge to growers, there are still many small-scale growers that have not been reached (Ekesi et al. 2016). It can be noted that transfer of fruit fly knowledge is not adequately supported by computing technologies. The websites that provide some control knowledge do so using static pages containing some information. In this research it is argued that the knowledge transfer process could benefit greatly from knowledge technologies and crowd computing techniques. In the next sections, the BiMaKT knowledge transfer model created in this study and presented in Chapter 7 of this thesis is used to guide development of a platform that supports transfer of fruit fly knowledge between experts and citizens.

8.3 SYSTEM DESIGN AND DEVELOPMENT

In this section the application case that involved the development of the fruit fly knowledge transfer platform using the BiMaKT model, is presented. In Section 8.3.1, the systems requirements are presented and in Section 8.3.2, the development is discussed commencing with the selection of a development methodology, followed by the development itself.

8.3.1 System requirements

The starting point of any system development is identifying, modelling, communicating and documenting the requirements for the system, and the contexts in which the system will be used. This process is often called Requirements Engineering (RE) (Paetsch et al. 2003). RE is the branch of software engineering that deals with the real-world goals for, functions of, and constraints on software applications. Shukla et al. (2015) outline different kinds of requirements that can be categorised into functional and non-functional requirements. Functional requirements specify system functionality and capabilities that should be implemented in order to deliver the solution and failure to address these usually imply that the system has failed to deliver the desired result. Non-functional requirements are other requirements that are value adding to the solution even though absence of them the solution will still be valid. In this research study, the evaluation is an application case and the focus is thus mostly on functional requirements but a few non-functional requirements were included.

The approach for collecting requirements for the system developed in this study was not straightforward since the research was exploratory in nature and use of routine RE approaches were not sufficient. Design of information systems that support scientific processes is not clearly documented and adoption of business application development approaches has been found to fail in the scientific arena (Vitale 1983; Strebel et al. 1994). The failure has been attributed to requirements of scientific applications not being known *a priori*. The process of requirements elicitation, therefore, did not take the approaches of business systems but rather adopted principles and guidelines that have been developed for exploratory and scientific applications. A few principles and guidelines were reviewed, and practices considered sufficient for this research adopted. The review was not in any way exhaustive since the objective of this section was not to go into detailed requirements engineering, but rather to identify basic requirements to use in evaluation of the BiMaKT model.

Strebel and Meeson (1994) proposed a framework for the development of scientific information systems based on what they identified as the four key components of a successful scientific information system namely management and organization, science requirements, data flow and resources. The conceptual framework principles for meeting the requirements of each component are identified. The principles of management and organization requirements emphasize the importance of flexibility, partnership between IS team and scientific team and the focus of the system should be service delivery to scientific needs. The principles of science requirements include the need for science requirements to drive the IS and not to be a held hostage by IS, start with basic requirements rather than attempt to be exhaustive for exploratory research; the focus should be on iterative development and the need to incorporate some peer review requirements to ensure scientific quality control. The data flow component emphasizes the need to appreciate data maturity as it flows through the different stages of the IS.

A three-staged requirements elicitation process for web-based information systems is presented in Yang and Tang (2003). In this model, elicitation of web applications requirements is noted to have several difficulties, including the diversity of users, difficulty to identify users, volatile requirements, conventional requirements elicitation processes being impractical, as well as expectations of the user-base that grow over time. To overcome these difficulties, a three stage process is proposed with the first phase entailing development of initial requirements and the second and third steps being enhancement of the requirements based on usage feedback collected online from users and frequent users respectively. The initial requirements are generated through interviews, focused groups and questionnaires to stakeholders and developers. Use of similar web information systems as a prototype for requirements elicitation is also recommended.

Holbrook (1990) proposed a scenario-based requirements engineering (SBRE) methodology for requirements elicitation. Holbrook defined scenarios as “stories that illustrate how a perceived system will satisfy a user's needs” and through the stories “we are able to have events brought before our minds”. In the scenario-based methodology, a scenario is “an idealized but detailed description of a specific instance of a human-computer interaction”. SBRE consists of four sets of information that are captured and manipulated during the requirements elicitation process. The information includes the goal, scenario, design set and issue set with a high level architecture as shown in Figure 8-3. The goal describes what the system must do and the means of doing it. The design set is a plan of how the system can be realised. The scenario set is the designer visualization of how the goals will be translated into a design and the issue set constitutes the problems or questions that are relevant to the project.

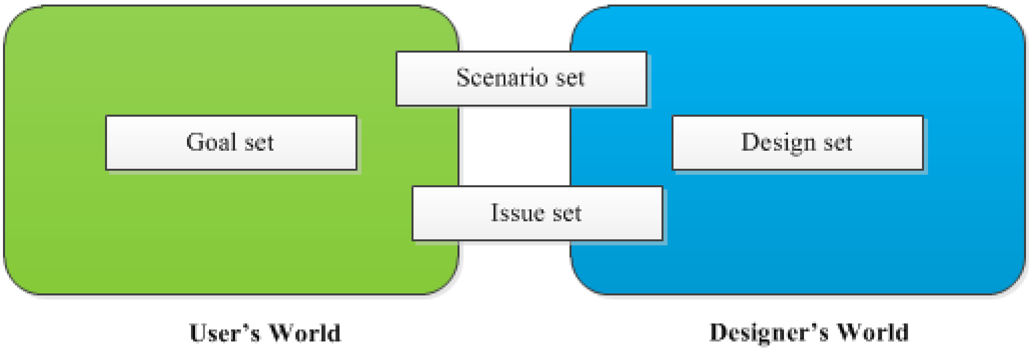

Figure 8-3: High level view of SBRE architecture

An enhancement of the inquiry-based approach to requirements engineering using scenario analysis is presented in Potts et al. (1994). The inquiry-based approach consists of three intertwined processes of: proposing or writing requirements, challenging or discussing them, and refining or improving them. The scenarios are defined based on the anticipated activities/events when using the system.

This research study adopted components from the different methodologies discussed above. The following principles were adopted:

- Start with basic requirements and don't aim to be exhaustive at exploratory stages (Strebel et al. 1994).
- Involve scientists since the system is aimed at providing service to process that supports scientific research (Strebel et al. 1994).
- Use existing similar systems as a prototype (Yang & Tang 2003)

The process of requirements elicitation was done using a combination of techniques from the three-stage requirements elicitation model (Yang & Tang 2003) and scenario based approaches (Potts et al. 1994; Holbrook III 1990). The first stage of the three-staged model was adopted, and since the research was exploratory in nature and an application case that served as a proof of concept, the subsequent stages were considered unnecessary. The first-stage suggests participation of stakeholders and developers through interview, focused group, questionnaires and use of similar web information systems as a prototype. The scenario-based approaches involves using "stories" to elicit what the system should do. The two approaches were combined, and the stakeholders of the system were grouped into three, namely experts, citizens and online crowds. The requirement elicitation high level model is summarized in Figure 8-4. The experts were consulted through interviews and discussions and scenario-based analysis of the requirements be conducted. The crowd and citizen requirements are difficult to collect since a clear audience is not demarcated from the onset. For these two categories of stakeholders, the initial requirements were creatively generated by developer using scenario-based approaches, review of existing literature and review of similar systems. Once a prototype was created, it was used to provoke for detailed requirements from the crowd and citizens.

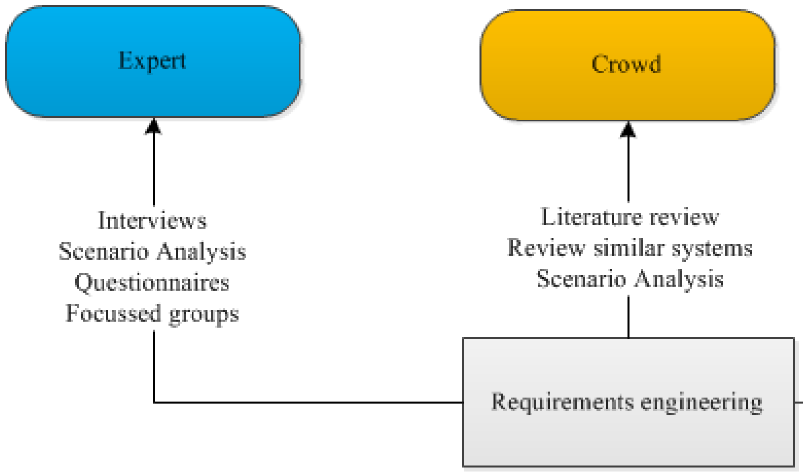

Figure 8-4: Requirements Engineering high level model

Using the requirements elicitation model described above the following basic requirements were identified:

- User Registration
- Create knowledge repositories
- Access and use taxonomic key
- Request species identification services
- Access lures for different species
- Access host plants for different species
- Access identification results
- Recording of occurrences from camera traps by citizens

8.3.2 Development

In this section, the development of the platform is presented. The agile methodology was used and in Section 8.3.2.1, an overview of the methodology is presented. Adoption of the methodology for the fruit fly project is presented in Section 8.3.2.2.

8.3.2.1 Agile methodology

As stated above, the development of the platform adopted the agile methodology. An agile methodology is founded on the philosophy of the need to respond to unpredictable change rather than planning to prevent it. The agile methodology is a collection of methodologies that subscribes to a number of principles, including the emphasis of individuals and interactions over processes and tools; focusing on a working software over comprehensive documentation; valuing customer collaboration over contract negotiation; and responding to change over following a plan (Fowler & Highsmith 2001). Compared to traditional methodologies, the agile methodology differs from traditional approaches in two ways namely:

1) Agile methodologies are adaptive and not predictive. Agile methodologies do not make detailed planning but rather make 'good enough' plans that can be adapted as the project progresses while traditional methodologies are characterized by long-term plans intended to last the entire project.
2) Agile methodologies are people oriented while traditional approaches are process oriented. The agile methodology relies on people and their interactions to produce high-quality software, unlike traditional approaches that rely on documentation and processes (Paetsch et al. 2003).

The common agile methodologies include Scrum, eXtreme Programming (XP), Agile Modelling (AM), Feature Driven Development (FDD), Adaptive Software Development (ASD), Lean Development (LD) and Dynamic System Development Method (DSDM). Some methodologies address the entire system development process while others address only some component/phase of system development. An overview of the different methodologies is provided next.

8.3.2.1.1 Scrum

Scrum methodology deals with management of a software project to ensure that changing requirements are accommodated during the software development cycle. Scrum manages the software development process using a prioritised list of features, bugs, functions and enhancements. The list is reviewed and priorities amended accordingly at the end of every sprint, which is a development iteration. No changes are allowed in the priority list during a sprint (Abrahamsson et al. 2002; Schwaber & Beedle 2001).

8.3.2.1.2 eXtreme Programming (XP)

XP brings together customers and developers to discuss what is required in open ended communication and programmers to implement what has been discussed and agreed upon. XP uses story cards to discuss requirements, which once agreed upon is translated to code. Once the agreed-upon requirements are implemented, a release of a new version is made. XP is therefore characterized by multiple version releases with different improvements on subsequent iterations(Beck & Anders 1999).

8.3.2.1.3 Agile Modelling (AM)

Agile modelling is a methodology of creating models to guide and resolve development problems. The emphasis is on building models without over-building them. AM recognizes two kinds of models; informal models that are aimed at guiding discussions and are often disposed upon conclusion of discussions, and formal models, which are well structured and are normally retained and included in documentations (Ambler 2001; Ambler 2002).

8.3.2.1.4 Feature Driven Development (FDD)

The Feature-Driven Development (FDD) methodology is characterized by short cycles of developing features/functionality and reviewing them frequently. At the initial stage, a detailed design is created by a team of domain experts and developers. The requirements of the system form the basis of the initial design and in this design, the classes, properties and methods are defined. The initial design forms the basis of the features which can then be amended and prioritised at every review as necessary(Paetsch et al. 2003; Abrahamsson et al. 2002).

8.3.2.1.5 Adaptive Software Development (ASD)

ASD methodology is premised on the fact that requirements are dynamic and constant involvement of customer is necessary for software success. The methodology proposes short development cycles and review with customers after every cycle. Initial requirements and development cycle need not be elaborate so that customers are involved in development from the onset and during each iteration (Highsmith 2013).

8.3.2.1.6 Dynamic System Development Method (DSDM)

The Dynamic System Development Method (DSDM) is characterized by two phases of feasibility study and business study. From these studies, the initial requirements are developed, and as they are implemented and tested, new requirements emerge (Paetsch et al. 2003; Stapleton 1997). The methodology emphasizes the use of prototyping and testing, which are carried out incrementally.

8.3.2.2 Development using the Feature Driven Development methodology

Development of the fruit fly knowledge transfer platform adopted the Feature-Driven Development (FDD) methodology. As highlighted above, the methodology is based on developing simple well defined features. The approach emanated from building a complex lending system and is therefore, ideal in development of complex systems whose full requirements are hard to conceptualize in simplified perspectives (Highsmith 2002a; Cohen et al. 2003). The development is broken down into features that drive iterative development cycles until the final system is attained. Highsmith (2002b) stated that “Projects may have a relatively clear mission, but the specific requirements can be volatile and evolving as customers and development teams alike explore the unknown”. This is true, especially for complex projects exploring novel computing approaches.

The process of the FDD methodology consists of five steps, namely development of an overall model, build a features list, plan by feature, design by feature and build by feature as shown in Figure 8-5.

- The first step, the development of the overall model, is a process aimed at creating the structure of the initial version of a system and is done through close consultations between development team and domain experts.
- The second step is that of building a features list which involves stating the features that the system to be developed must have. The features list should be developed from the ‘eyes’ of the client and should be clear and succinct. Where the features are complex, they should be broken down into sub features.

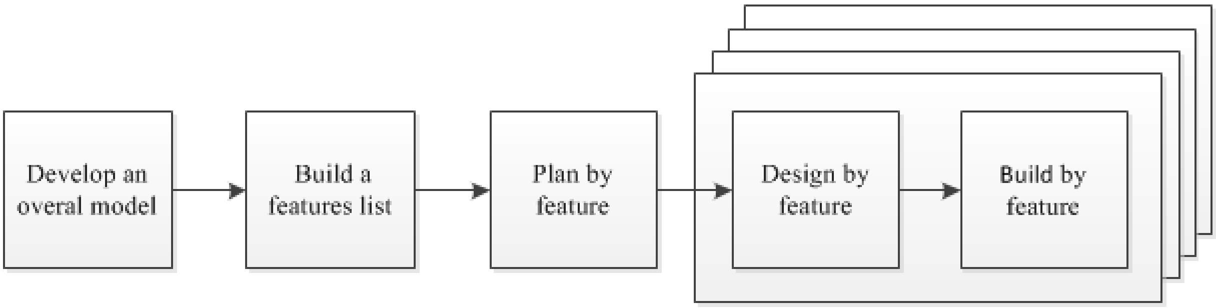

Figure 8-5: Feature Driven Development (Cohen et al. 2003; Rychlý & Tichá 2008)

- The third step of planning by feature is a plan of how each feature will be realised and also prioritization of the features. This step is done by someone from the systems development team. The fourth step design by feature involves a detailed design of a specific feature. The detailed design goes to the next step of development, which implements according to design.
- Steps four and five are closely related and several iterations and discussion with the client may be necessary before a feature is complete. Once the feature is accepted by the client, it is integrated into the system, and the same follows for other features. Review and prioritization of the remaining features is done before moving to design and development of the next feature. The feature list is therefore altered frequently during the development process since it is like the living requirements and must be adjusted according to changing needs and priorities.

The BiMaKT model developed in this research was incorporated into the FDD methodology and used in the development of the Fruitfly management knowledge transfer platform. The model was incorporated as input in the development of an initial model as shown in Figure 8-6.

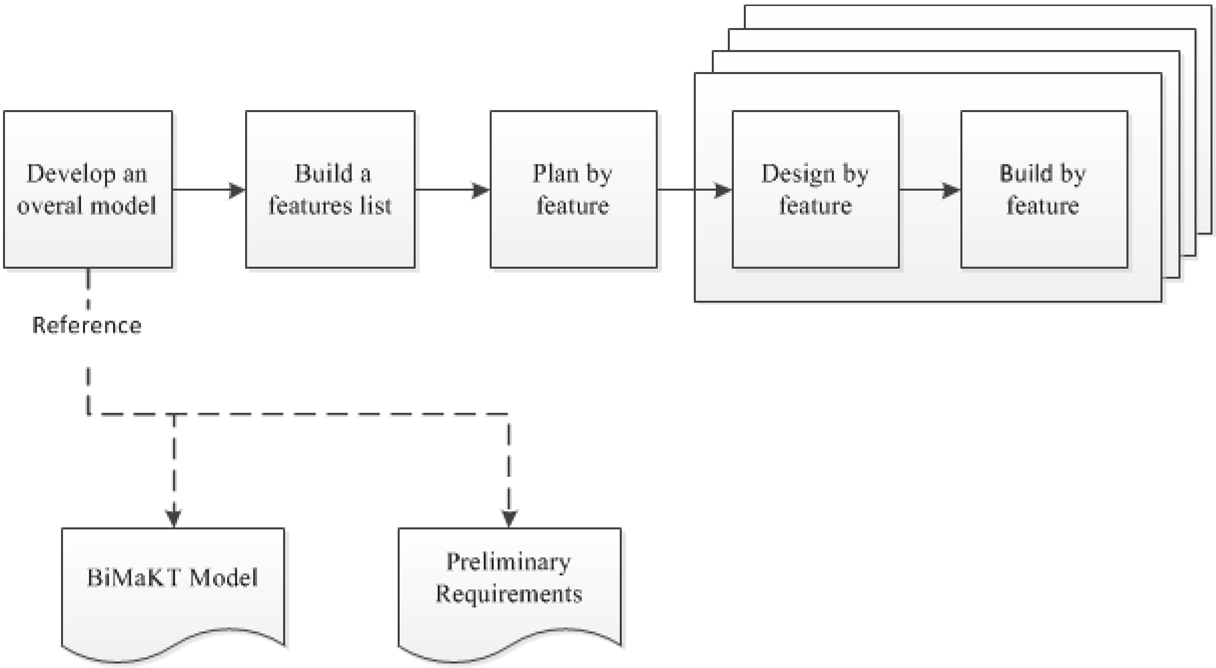

Figure 8-6: Incorporation of the BiMaKT model in the FDD methodology

The adapted methodology was applied in the development of the Fruitfly management knowledge transfer platform. The development of the platform in line with the FDD model is presented next.

8.3.2.2.1 Overall Model

As outlined in the FDD methodology, the first step was to develop overall models of the platform. The development of the models was done based on the preliminary requirements identified in Section 8.3.1 and the BiMaKT model. The models created at this stage were high level models and were defined using the UML notations. Three models were used to conceptualize the platform, namely: a high level use-case diagram, an information model and a deployment model.

The use-case diagram was created based on the knowledge transfer activities and user categories of the BiMaKT model – citizens, crowd and experts. Figure 8-7 shows an overall use-case model. The use-case model at this stage was still high level and was broken down during the modelling of specific use-cases in the subsequent stages of the FDD methodology, the design by feature phase.

The BiMaKT model has the necessary structures to meet these requirements so its processes are sufficient in guiding development of applications with requirements of this nature. The BiMaKT model proposes eight processes of knowledge transfer between experts and citizens, namely: - awareness, acquisition, codification, annotation, extraction, application, structured feedback and unstructured feedback. From the use case diagram, an Information Model (IM) was created and is shown in Figure 8-8. The model depicts the relationships between different classes and objects and aids in making clear the structure of the system. The user categories are represented as different classes but in implementation, they should be treated as one class and roles assigned dynamically.

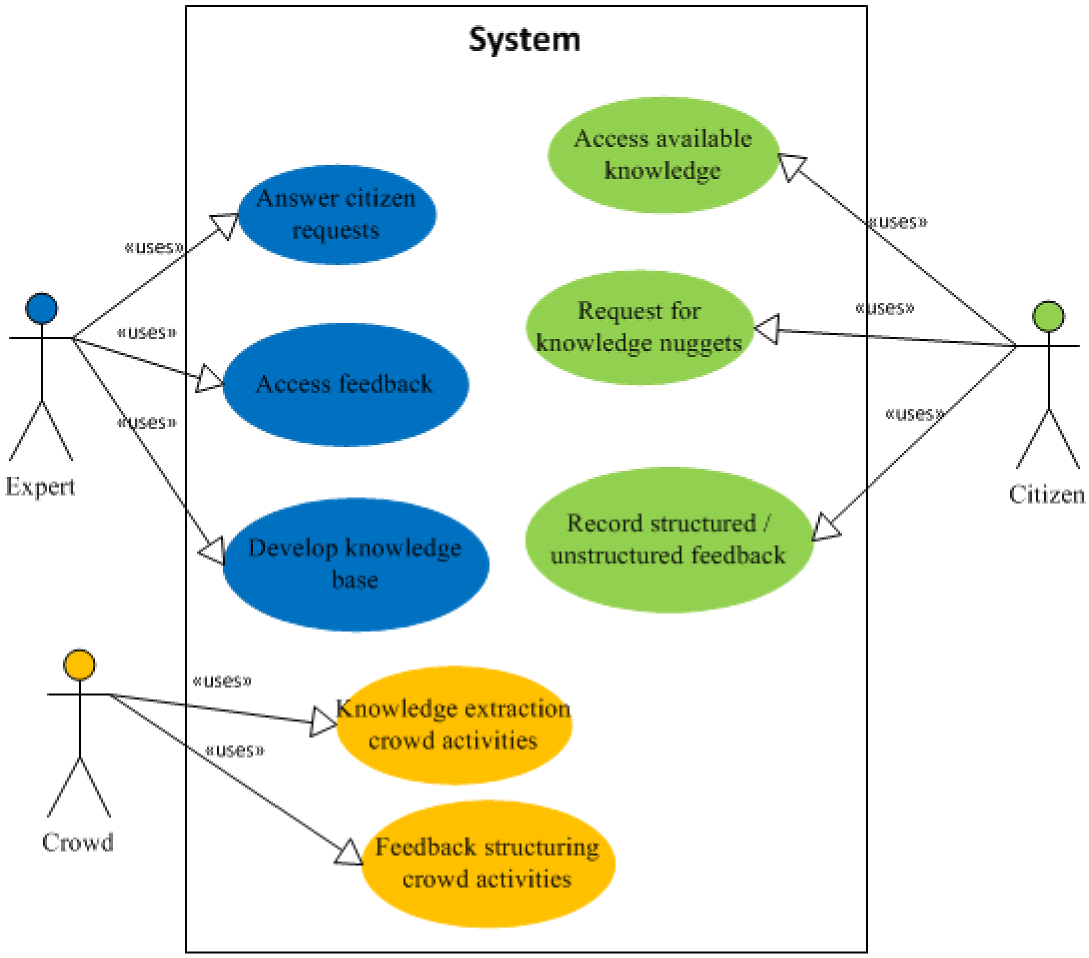

Figure 8-7: Overall use-case model of the fruit fly knowledge transfer platform.

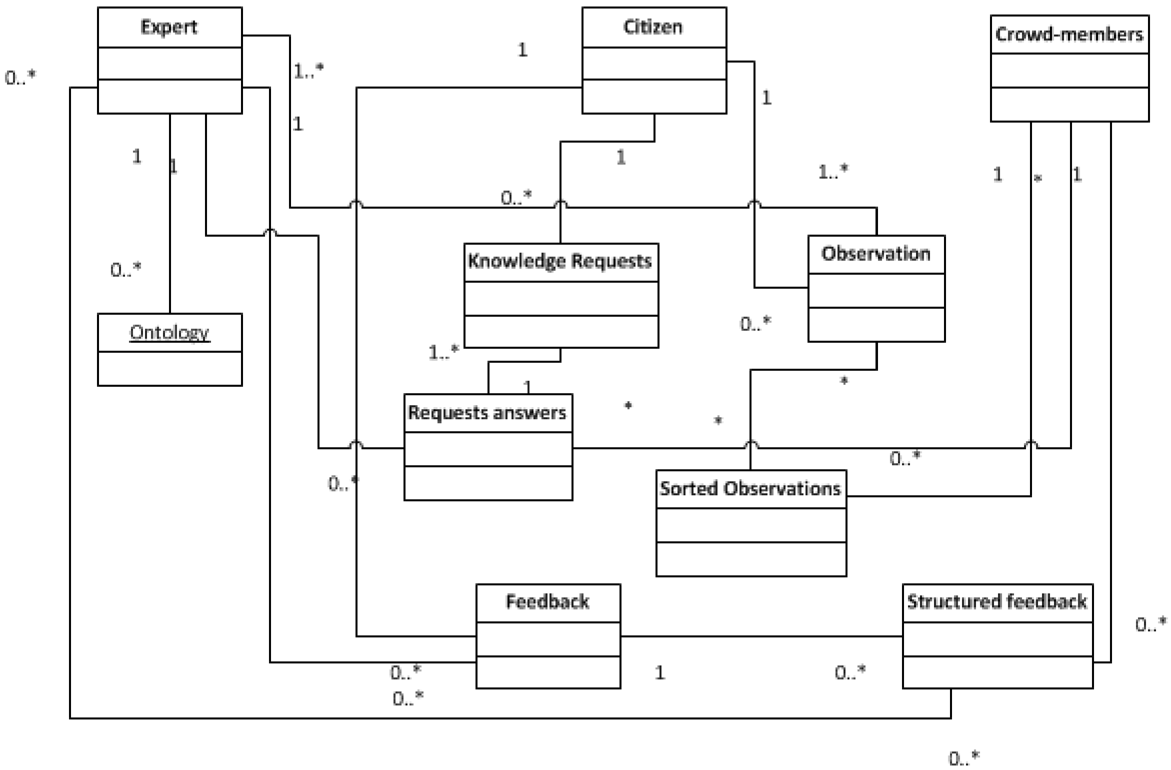

Figure 8-8: High level Informational Model

The final overall model was the deployment model. The deployment model shows the relationship between the different components and nodes of the system. The platform required an ontology of the biodiversity management knowledge, a database to store the platform operational data / knowledge and platform interfaces programmed to provide the necessary user interfaces for accessing the knowledge. The deployment architecture of the system is presented in Figure 8-9 below.

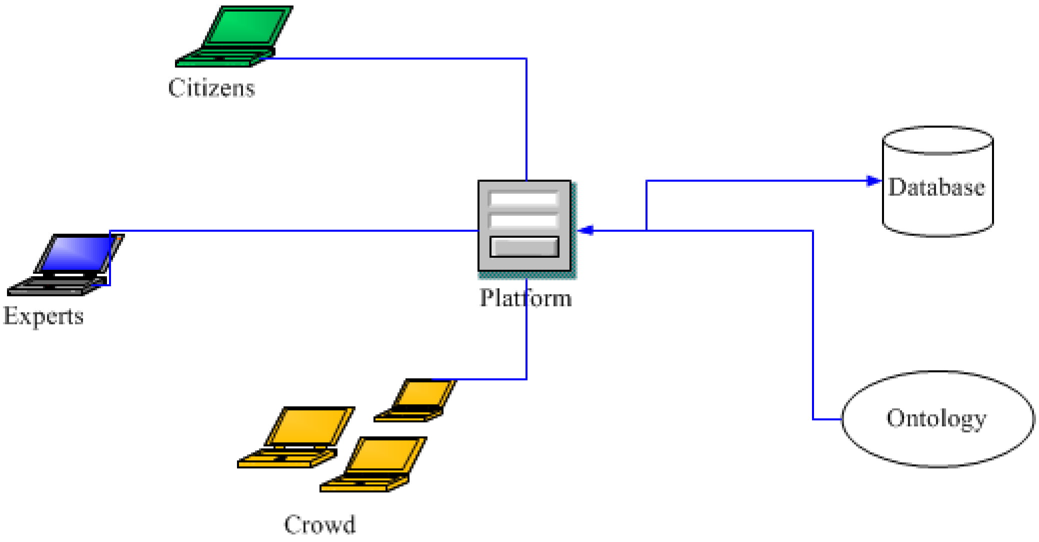

Figure 8-9: System Components Architecture

The ontology used in the platform was developed as part of this research and is presented Chapter 5. A basic design of the database was created and extended as required by additional features. The data stored in the database include that on the users of all categories, the occurrences recorded by participants, the identification assigned to different occurrences by users, the features spotted on the occurrences by the users and the final identification of the occurrences. The final design of the database used in the platform is shown in the ER diagram in Figure 8-10.

The phase concluded with identification of the tools necessary for the development of the platform, and they included:

- Java programming language for programming of necessary tools and interfaces
- MySQL RDBMS for database data storage
- Liferay framework which provides general features for user and portal development. The Liferay framework is an open source Java Enterprise portal solution that comes in two editions, Standard Edition (SE), which is free and Enterprise Edition (EE) which is commercial. Liferay is a portal server, and allows bringing together portlets with different functionalities into one interface where a user can access them all (Sezov 2009; Yuan 2010).

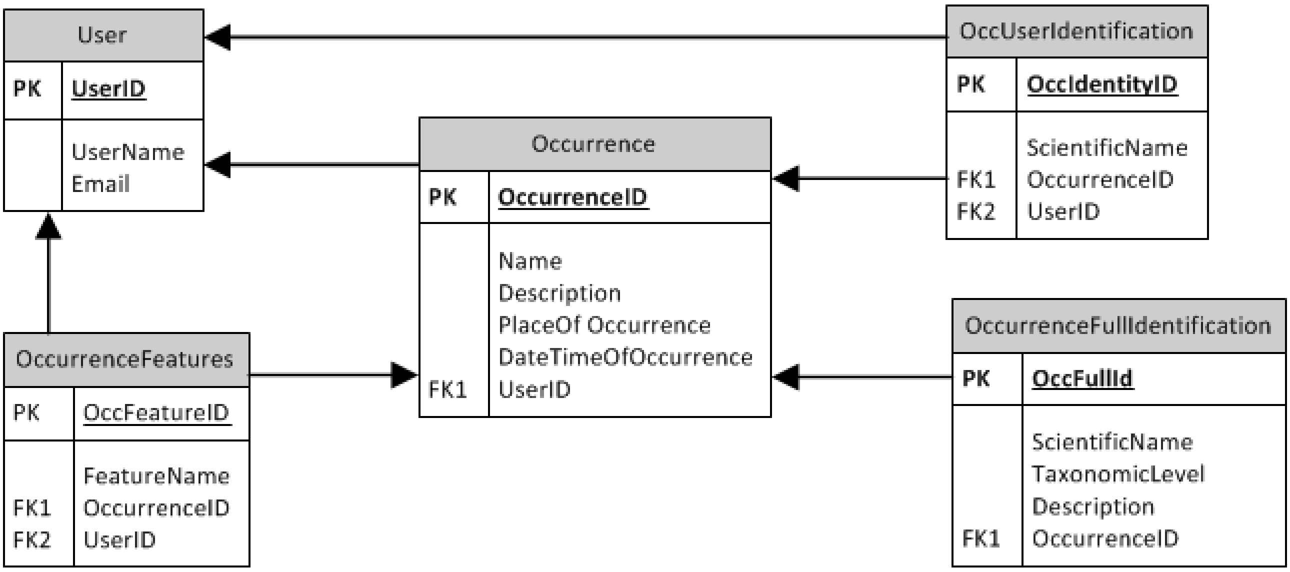

Figure 8-10: Fruit fly portal database design

8.3.2.2.2 Feature list

The initial feature list was created and fitted into the BiMaKT model. The features of platform included:

a) General Features
   - User registration

b) Awareness, Acquisition, Codification, Annotation
   - Create knowledge repositories

c) Extract knowledge
   - Identify samples using expert knowledge
   - Query host plants for any species
   - Query attractants per species

d) Application

e) Structured Feedback
   - Record identified occurrences

f) Unstructured Feedback
   - Record occurrences
   - Identify occurrences
   - Access identification results

8.3.2.2.3 Plan by Feature

This phase involved prioritizing the different features. Creation of user profile and login was the starting point, followed by access interfaces for citizen use. The creation of crowdsourcing interfaces were scheduled last.

8.3.2.2.4 Design & Develop by Feature

In this section, the design and development of the different features is presented. The design was done using UML diagrams, and development was done using the tools described above.

8.3.2.2.4.1 User registration and management

The user registration and management features were inherited from the Liferay framework which was selected as the development framework as described above. The framework comes with user account creation, login, roles and management that were sufficient for the fruit fly platform.

8.3.2.2.4.2 Awareness

The awareness phase included the recognition that citizens need expert knowledge in order to effectively control and manage the effects of fruit flies in their produce. This recognition that fruit fly control and management knowledge needs to be transferred to growers is widely acknowledged among stakeholders in the horticulture industry and is documented in section 8.2.1. The awareness phase was therefore already done outside this application development.

8.3.2.2.4.3 Acquisition

The acquisition phase was also already done outside this development. As stated in Chapter 7, the acquisition phase deals with gathering the knowledge that needs to be transferred. At this stage, the knowledge was already gathered by experts and documented in different pamphlets and books such as the "Field guide to Economically Important Fruit Flies of Africa". Different experts have worked together to gather this knowledge and this is evident by the different contributors to these publications. The process of collating this material can be supported by a publication management tool and Web 2.0 technologies could be used to support this process.

8.3.2.2.4.4 Codification

Codification of the fruit fly knowledge was done through representing the key knowledge in an ontology and is presented in Chapter 5. The ontology development was done using Protégé (Protege 2000)

8.3.2.2.4.5 Annotation

Annotation of the knowledge included enriching the knowledge with terminologies understandable to the receiver. The fruit fly ontology knowledge was sourced from field guides published for citizen use. The annotations used were from the same source and was in simple English language. The annotation was done using the annotation feature available within Protégé and was done as part of ontology development in Chapter 5.

8.3.2.2.4.6 Knowledge extraction

The knowledge extraction phase of the knowledge transfer process is concerned with extracting knowledge from the knowledge base. As shown in BiMaKT model, the process use ontology as input and two forms of crowd computing could be used, web 2.0 and crowdsourcing. Different tools were developed to enable citizen's access and use expert knowledge modelled in the ontology.

Multi-entry taxonomic key

The multi-entry taxonomic key is a biological tool for identifying organisms based on multiple features. The features expected from the key is to allow the user to select any set of features and query for the organism that has those features. The design of this feature is presented using an activity diagram as shown in Figure 8-11. This tool provided the opportunity to use the identification knowledge to identify fruit flies into the appropriate taxonomic groups. The tool is easy to use and can be used by non-experts to identify the flies.

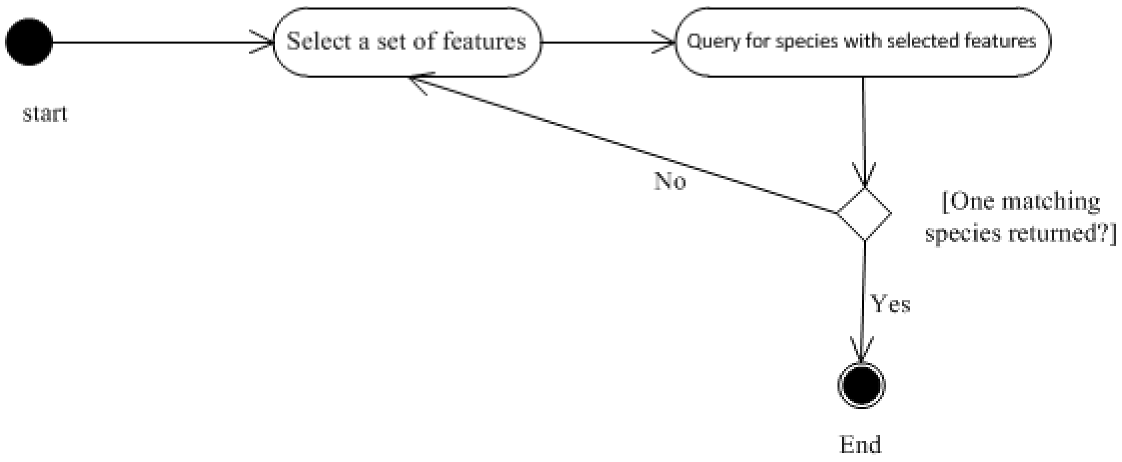

Figure 8-11: Taxonomic key activity diagram

The development of this feature used the Fruitfly ontology as the source of knowledge and Java programming language to create the interface. A screen shot of the taxonomic key feature is as shown in Figure 8-12.

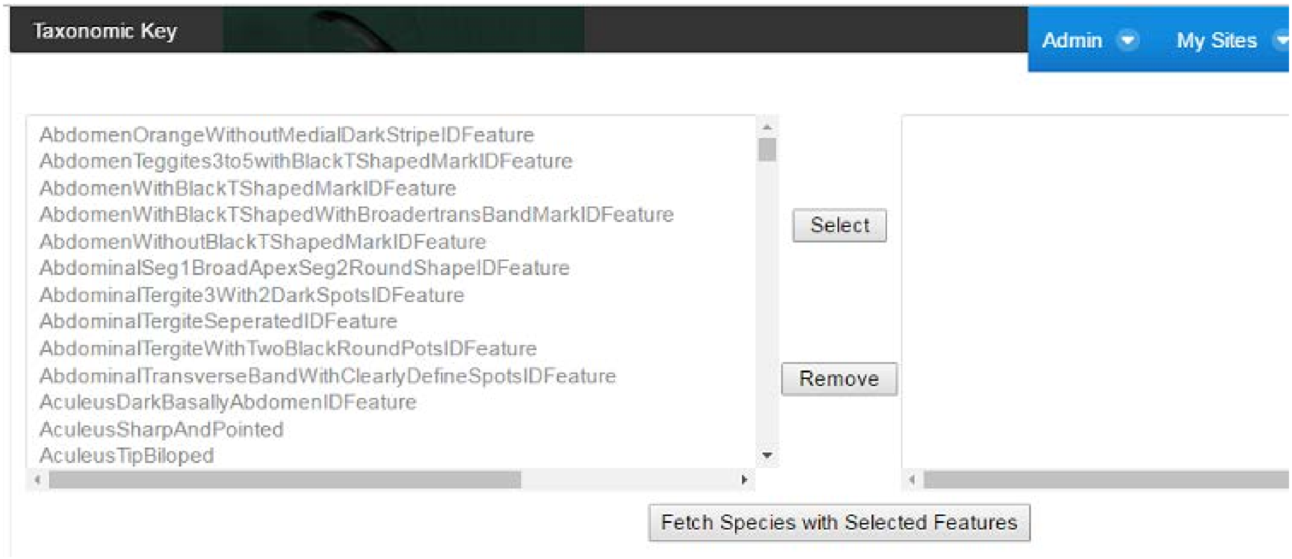

Figure 8-12: Multi-entry taxonomic key

Query host plants and attractants for different species

This feature involves selecting either a host plant or attractant then querying for the species that it can host or be attracted to respectively. The design and development of the two functionalities are similar. A functionality for selecting the host plant or attractant and viewing associated species. The design using an activity diagram is as shown in Figure 8-13.

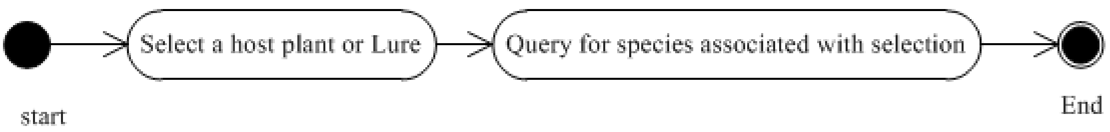

Figure 8-13: Search for species associated with a host plant or attractant.

The development of this feature relied on the knowledge modelled in the ontology. A screen shot is species that can be hosted by a select host plant is shown in Figure 8-14 below.

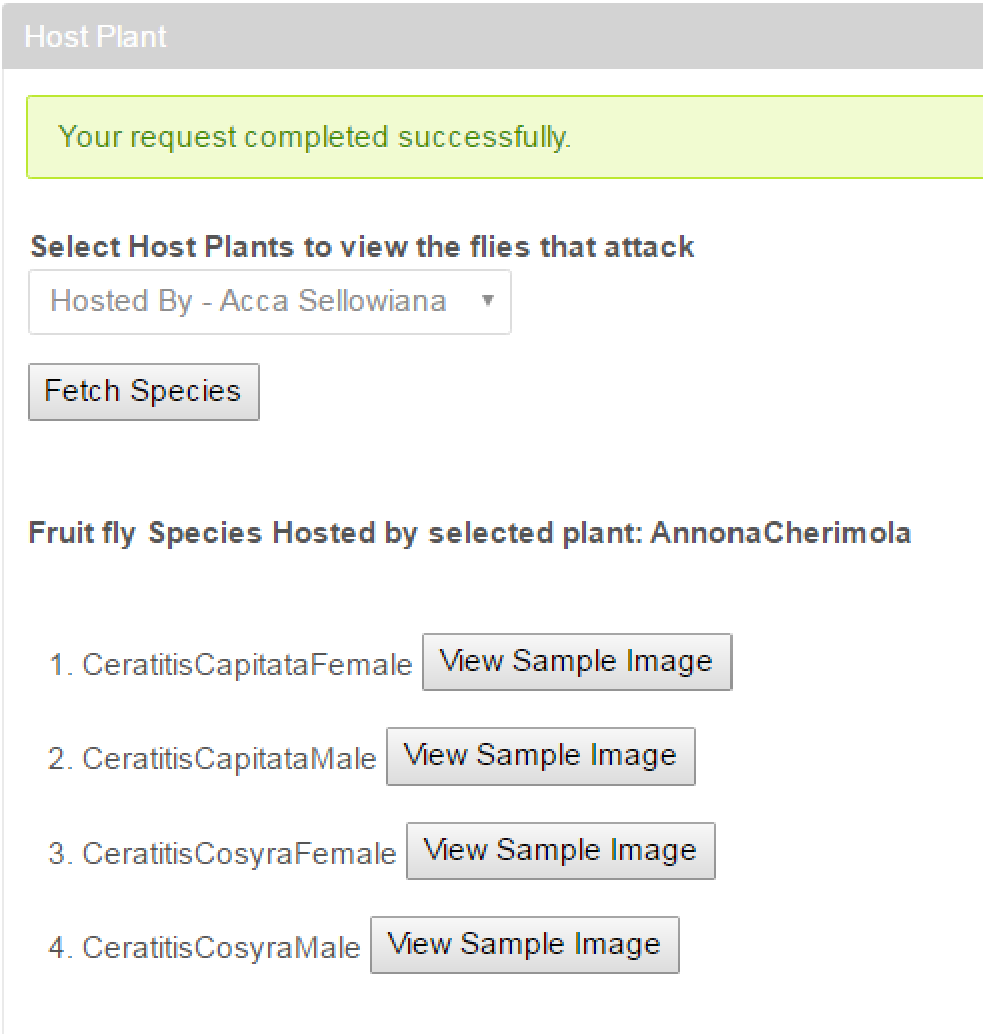

Figure 8-14: Species hosted by selected attractant

Full identification of occurrences

This feature provides an opportunity for members to identify occurrences recorded by citizens with the help of the taxonomic key. The occurrence images are provided alongside the taxonomic key, and the user can select the features they see on the occurrences until they identify that occurrences. See Figure 8-15 for a screenshot of this feature.

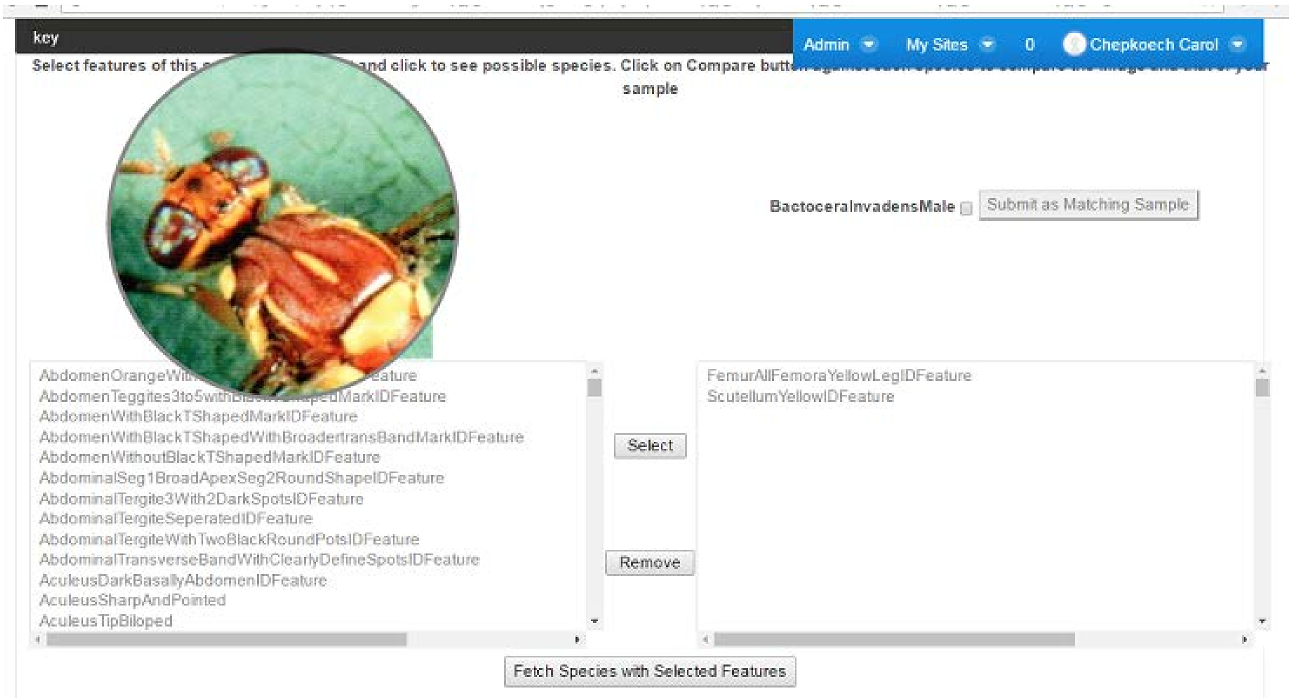

Figure 8-15: Identify Occurrences

The identification from different citizens is aggregated to arrive at the species of the occurrences. These identifications constitute preliminary results that need confirmation by experts.

Crowd identification of occurrences

This feature allows online crowds to participate in identification services without the need to fully identify samples. This feature was explorative in nature, and the objective was to allow participants to tag occurrences with features from the ontology. The aggregate features are then processed to arrive at identification. The screen shot for tagging features is shown in Figure 8-16 and evaluation of this feature was done during the empirical evaluation of the model in Section 8.4.

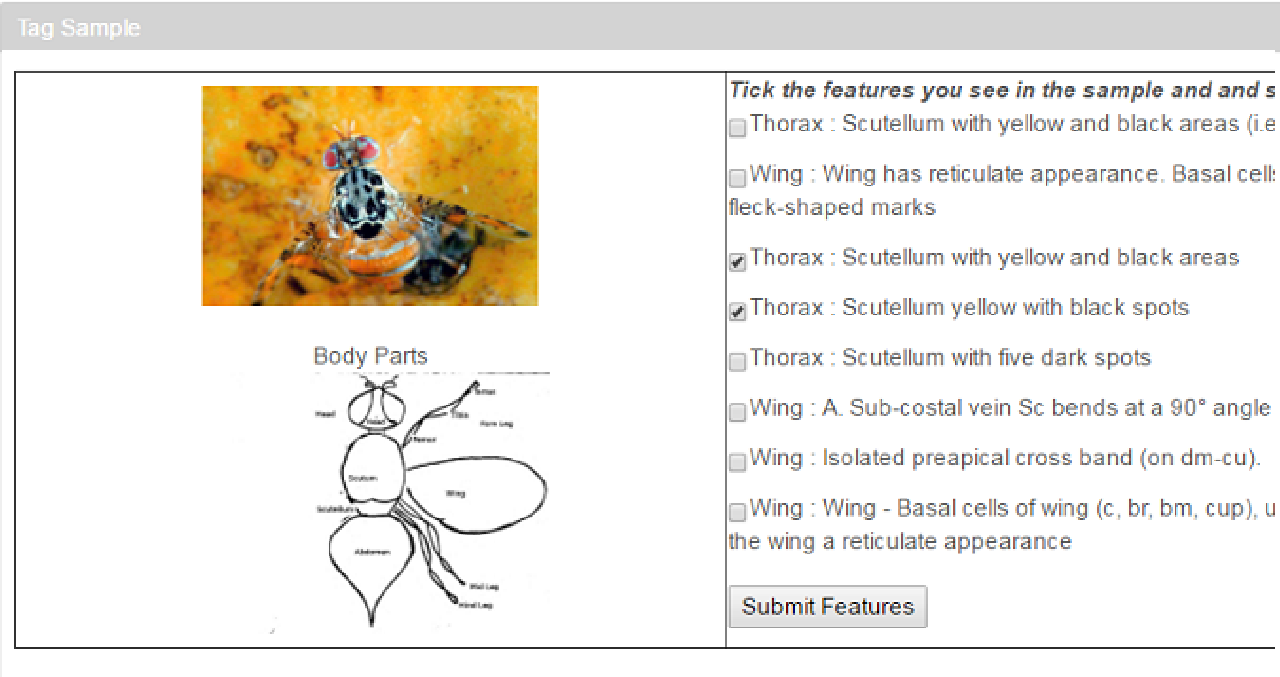

Figure 8-16: Tag features

8.3.2.2.4.7 Structured and Unstructured Feedback

Record occurrences

This feature is a data entry form that the citizens use to record occurrences online. The form is a simple form that allows entry of a description, images of the occurrences, time and place it was observed, and species name if citizens can fully identify the occurrence. The citizen is not expected to give a scientific name since they are likely not to know it. The recordings are later identified through crowdsourcing or by experts. The occurrences recorded by citizens could be subjected to the same web 2.0 and crowdsourcing identification processes above thus achieving full identifications.

Access identification results

Every user is provided with an interface where they can be able to view the scientific identifications assigned to the occurrences recorded in the platform.

8.4 EMPIRICAL EVALUATION

An empirical evaluation was done through an experiment that enabled knowledge transfer based on the BiMaKT model. The experiment was done using the fruit fly case where the platform presented in Section 8.3 above was used to transfer the expert knowledge to citizens and the crowd harnessed to facilitate transfer of the knowledge to citizens. The result of transfer are presented in line with the BiMaKT process steps in the sub-sections below.

8.4.1 Awareness, acquisition, codification and annotation

Awareness of the knowledge need, acquisition of the knowledge, codification and annotation were done as part of ontological modelling of expert knowledge in Chapter 5. The experiment, therefore, used the fruit fly knowledge already represented in the ontology and focused on the evaluation of knowledge transfer using the platform. The experiment evaluated knowledge extraction and feedback.

8.4.2 Extraction

As discussed in the development of the knowledge transfer platform in Section 8.3, biodiversity knowledge is organised around the identity of the organism. Similarly, in the fruit fly case, control and management knowledge is organised around the species being targeted. Identification of samples being targeted is therefore central to accessing any knowledge. Identification also requires use of taxonomic knowledge to perform identification samples. The experiment evaluated the performance of a crowd in the identification of fruit fly samples using the ontology based tools available in the application developed.

8.4.2.1 Experiment overview

The experiment was aimed at evaluating the knowledge extraction using crowdsourcing. The crowd identification tool was used in the experiment where a crowd was harnessed to provide identification services. The experiment recruited a total of 75 volunteers to participate and used 25 samples to evaluate the level to which crowds could identify them. The samples were coded S1 to S25. The experiment asked participants to tag samples with features from an ontology based features list. The images for each participant were randomly generated and the participant could tag as many images as they wished.

8.4.2.2 Experiment Results

At the end of the experiment, over 8700 tags were made on the images. The tags were then analysed to establish the crowd ability in the identification task. The least tagged sample had 27 annotations while the most tagged had 531 annotations. Because the samples were identified by experts, it was possible to know whether a feature is present in a sample or not. The overall correctness of the features tagged was analysed and out of the total 8728 tags made, 6286 were correct and 2442 were incorrect translating to 72% and 28% respectively.

The performance of the individual members of crowd participants yielded a normal distribution curve as shown in Figure 8-17. The performance was measured using the percentage of correct tags out of total tags made by the individual.

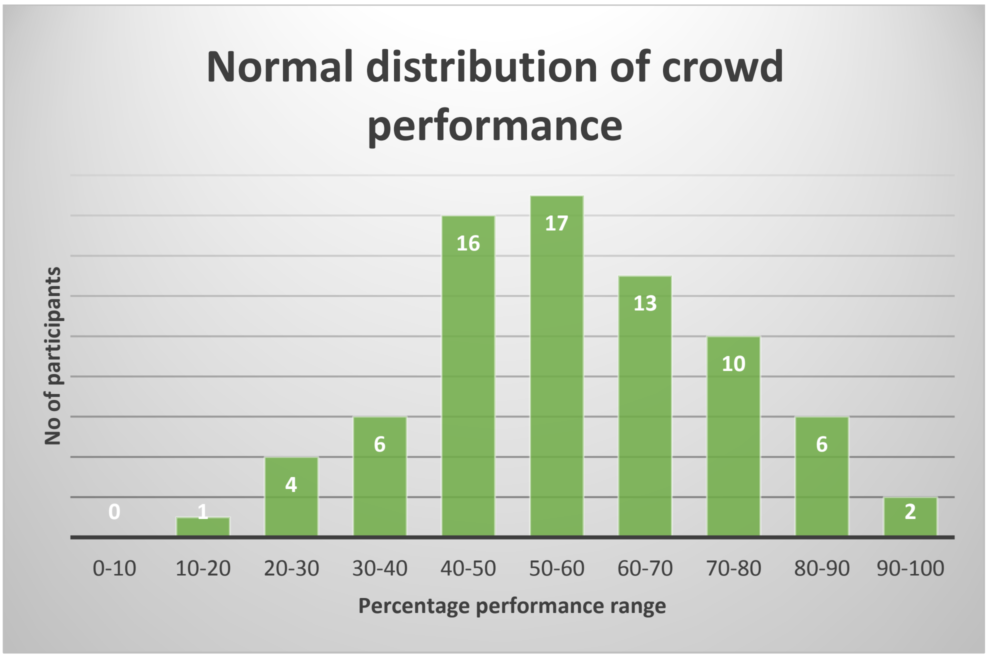

Figure 8-17: Crowd performance in image annotation task

The crowd performance in the identification of samples was analysed and it was found that the crowd could correctly identify eighteen (18) samples to species level, four (4) samples to sub-family level, two (2) sample to family level and one (1) sample not sufficiently tagged due to error in image display. The identification results are summarised in Table 8-1 below.

Table 8-1: Level of sample identification by the crowd experiment results

Sample	Expert identification	Crowd identification	Interpretation
S1	*Ceratitis anonae*	*1 Ceratitis anonae graham* *2 Ceratitis colae silvestri* *3 Ceratitis ditissima* *4 Ceratitis faciventris bezzi* *5 Ceratitis punctata* *6 Ceratitis rosa karsch*	Identified to sub-family level and six possible species listed
S2	*Bactocera invadens*	*Bactocera invadens*	Fully identified to species level
S3	*Bactocera olae*	*BactoceraTephritidae* *DacusTephritidae*	Two possible subfamilies identified, so identification to family level is correct
S4	*Ceratitis fesciventris-Bezzi*		Error – insufficient tags
S5	*Dacus vertebratus bezzi*	*Dacus vertebratus bezzi*	Fully identified to species level

Sample	Expert identification	Crowd identification	Interpretation
S6	*Ceratitis capitata*	*Ceratitis capitate*	Fully identified to species level
S7	*Ceratitis cosyra female*	*Ceratitis cosyra*	Fully identified to species level
S8	*Ceratitis cosyra Male*	*Ceratitis cosyra*	Fully identified to species level
S9	*Ceratitis discussa female*	*Ceratitis discussa female*	Fully identified to species level
S10	*Ceratitis ditissima female*	*Ceratitis ditissima female*	Fully identified to species level
S11	*Ceratitis faciventris bezzi*	*Ceratitis faciventris bezzi*	Fully identified to species level
S12	*Bactocera cucurbitae*	*Bactocera cucurbitae*	Fully identified to species level
S13	*Ceratitis faciventris bezzi female*	*Ceratitis faciventris bezzi*	Fully identified to species level
S14	*Ceratitis faciventris bezzi male*	*Ceratitis faciventris bezzi*	Fully identified to species level
S15	*Ceratitis fesciventris-bezzi*	*Ceratitis fesciventris-bezzi*	Fully identified to species level
S16	*Ceratitis quinaria*	*Ceratitis quinaria*	Fully identified to species level
S17	*Ceratitis rosa karsch female*	*Ceratitis*	Identified to sub family level
S18	*Ceratitis rosa karsch male*	*Ceratitis*	Identified to sub family level
S19	*Trihithrum nigerrimum*	*1 Trihithrum coffae bezzi* *2 Trihithrum nigerrimum*	Identified to sub family level and indicates two possible species
S20	*Dacus bivittatus female*	*Dacus bivittatus*	Fully identified to species level
S21	*Dacus ciliatus loew*	*Dacus ciliatus loew*	Fully identified to species level
S22	*Dacus ciliatus loew male*	*Dacus ciliatus loew*	Fully identified to species level
S23	*Dacus frontalis beccker*	*Dacus frontalis beccker*	Fully identified to species level
S24	*Dacus frontalis beccker male*	*Dacus frontalis beccker male*	Fully identified to species level
S25	*Dacus lounsburyii coquillet female*	*BactoceraTephritidae* *DacusTephritidae*	Two possible sub families identifies

From the results it can be seen that the online crowd with the support of the ontology identified 72% of the samples to species level.

8.4.2.3 Limitations of the experiment

Each sample in the experiment had one sample and in some cases the images were not very clear. In a fully practical situation, each observation will need to record several images from different dimensions so that all the features can be reliably observed.

8.4.2.4 Conclusion from the experiment

The objective of the experiment was to asses the performance of non-expert crowds in perfoming online tasks leading to identification of fruit flies, a task that is ordinarily performed by experts in taxonomy. Despite the limitations of the experiment described above, the online crowd with the support of an ontology was able to accurately identify three quatre of the samples to species. The performance of the crowd is significantly high considering the experiment limitations. From the results, it can be concluded that this approach to identification if enhanced can be adopted to compliment online species identification services provided by taxonomists.

8.4.3 Application

Application is the practical use of the knowledge by citizens.

8.4.4 Structured feedback

Structured feedback was not evaluated since it is useful where the citizen knows the full identification of the organism and the feature would involve recording it using provided Web 2.0 forms.

8.4.5 Unstructured feedback

As stated in the application development in section 8.3, the unstructured feedback can assume the same format as knowledge extraction. If the objective is to give feedback on the species affecting different farmers, the images uploaded by the farmers can be sorted using the same identification methods used in knowledge extraction. This will enable crowd participation is sorting the data and structuring the feedback for expert use.

8.5 DISCUSSION OF FINDINGS

The platform was developed as a proof of concept and as an application case to demonstrate how the BiMaKT model can be used to guide development of biodiversity management knowledge transfer applications. In the fruit fly case, identification of the Fruitfly species is key to accessing the control and management knowledge. Like most biological sciences discipline, knowledge is organised around the species name. So if one wants to, for instance, know which plants will be affected in case of an outbreak, one must know the species name of the fruit flies first, and only, then is it possible to identify the possible host plants. The tools developed therefore focused on identification services and after identification, the subsequent stage is to access the relevant knowledge which is a mouse click away since it is linked to the species.

To transfer the knowledge relevant in the control and management of fruit flies, different processes need to be carried out as shown in the BiMaKT model in Chapter 7. The processes include *awareness*, *acquisition*, *codification, annotation, extraction, application* and feedback from citizens to experts who could either be in *a structured or unstructured form*.

- The awareness and acquisition phases in the fruit fly case were not part of this research since the need for the knowledge has been justified through ongoing activities and substantial sources have been compiled and documented through the initiatives described in Chapter 5.
- The codification using ontological modelling techniques was done as part of this research in Chapter 5 and together with the creation of the fruit fly ontology. This ontology is the engine that drives access to different kinds of knowledge since all knowledge based services are guided using the ontology.
- The annotation was done together with ontological modelling in Chapter 5. Annotation of the knowledge represented in the ontology was done using protégé.
- Extraction of knowledge for citizen is based on identification of species being targeted. Three approaches to identification were implemented in the fruit fly platform, first is expert identification using taxonomic key which basically used Web 2.0, second is crowdsourcing for full identification by crowd members after which the identifications are aggregated and third is a feature level crowdsourcing for identification where crowds are asked to identify features in samples that can then be aggregated to fully identify samples. Crowd identification is discussed and evaluated using an experiment and is presented in Section 8.4.
- Application of knowledge into practical could be shared by citizens using social media and evaluation of this was not part of this research. Creating social avenues for sharing this kind of knowledge is conceptually possible.
- Structured feedback could be given using forms designed using Web 2.0 technologies. This kind of feedback can be provided by citizens who fully understand the knowledge required and are able to submit it in required formats.
- Finally unstructured feedback from citizens can also be structured using the same crowd sourcing techniques. Structuring of feedback also means properly identifying them, and the same identification techniques could be used.

8.6 SUMMARY

In this chapter, the development of a fruit fly portal for knowledge transfer is presented. The development of the platform is based on the Biodiversity Management Knowledge Transfer (BiMaKT) model presented in Chapter 7. The model provides the crowd computing approaches that can be used to support the different processes of knowledge transfer. It also provides the relationship the different processes has with the knowledge modelled in the ontology.

The development of the model adopted the agile approach, which is an approach that is flexible and allows for requirements to change during the project development lifetime when necessary. The development of the platform was explorative in nature and there were no clear requirements a priori, so an approach that allowed continuous change was required. Different methodologies of the agile approach were considered and the Feature Driven Development (FDD) methodology was adopted for the development.

The FDD is characterised by five development steps of creating an overall model, creating a feature list, plan per feature, design by feature and develop by feature as described in Section 8.3.2.2. . The FDD incorporated BiMaKT into the creation of the overall model and developing the list of features. The list of features formed the basis of design and development. The design was described and illustrated using different UML diagrams. The development was done using the OWL ontology created in Chapter 4, Java programming language, MySQL database and the Liferay framework.

Chapter 9 - Contributions

9.1 INTRODUCTION

In this chapter, the contributions of this research are presented consisting of the main contributions, secondary contributions and other contributions. The DSR research approach provides an opportunity to construct different kinds of theory during the various research steps. In (Kuechler & Vaishnavi 2012) theory construction opportunities are outlined alongside the DSR process steps as shown in Figure 9-1. The Awareness step presents an opportunity for abduction or induction in empirical data and similar cases across the organization. Suggestion step gives potential for deduction, triangulation of several perspectives from similar cases and or abduction from multiple similar cases. The Development step provides an opportunity for refinement of earlier conclusions and new explanatory knowledge. This development step also provides an opportunity for the start of codification of design theory. The evaluation stage presents an opportunity for theories based on artefact performance and also gives an opportunity to refine earlier hypotheses. The conclusion step presents an opportunity for final codification of design theory. Finally, the total DSR process provides an opportunity for creation of operational theory, theory based on reflection on earlier process steps based on data and revision of hypotheses accordingly.

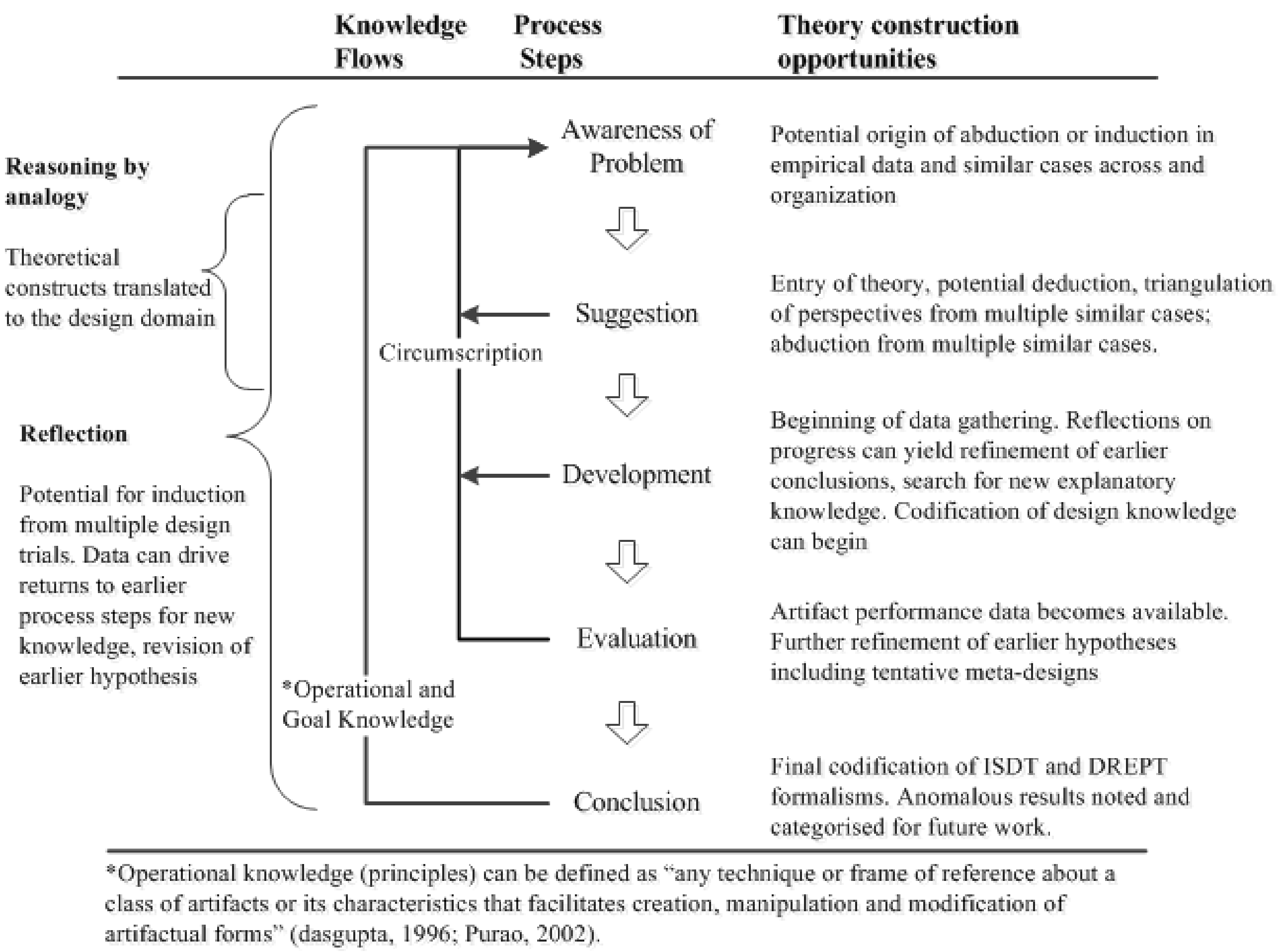

Figure 9-1: Theory Construction Opportunities in Design Research Cycle (Kuechler & Vaishnavi 2012)

The contributions made in this research are categorized into three groups based on the research cycle the contributions were made, namely main, secondary and other contributions as outlined in Figure 9-2. The main research cycle made two main contributions: 1) a biodiversity management knowledge transfer process model (BiMaKT model) and 2) a platform of fruit fly knowledge. The sub-cycles resulted in several secondary contributions. The first sub-cycle which entailed a review of knowledge transfer models for transfer of biodiversity management knowledge resulted in a literature review contribution on knowledge transfer process models. The second sub-cycle which investigated ontological modelling of biodiversity knowledge produced two contributions. The first contribution is a model for ontological representation of biodiversity knowledge and the second contribution is an ontology of fruit fly knowledge. The third sub-cycle investigated the use of crowd computing techniques in biodiversity knowledge transfer, and this resulted in a model that uses crowd computing techniques to support knowledge transfer.

Reflection in the overall research resulted in two other contributions. The first cintribution is the novelty of combining ontological modelling and crowd computing techniques to address biodiversity knowledge management challenges. The second contribution is a methodological contribution on development of biodiversity knowledge management applications. The contributions are presented in these three categories with the main contributions presented in Section 9.2, secondary contributions in Section 9.3 and other contributions in Section 9.4.

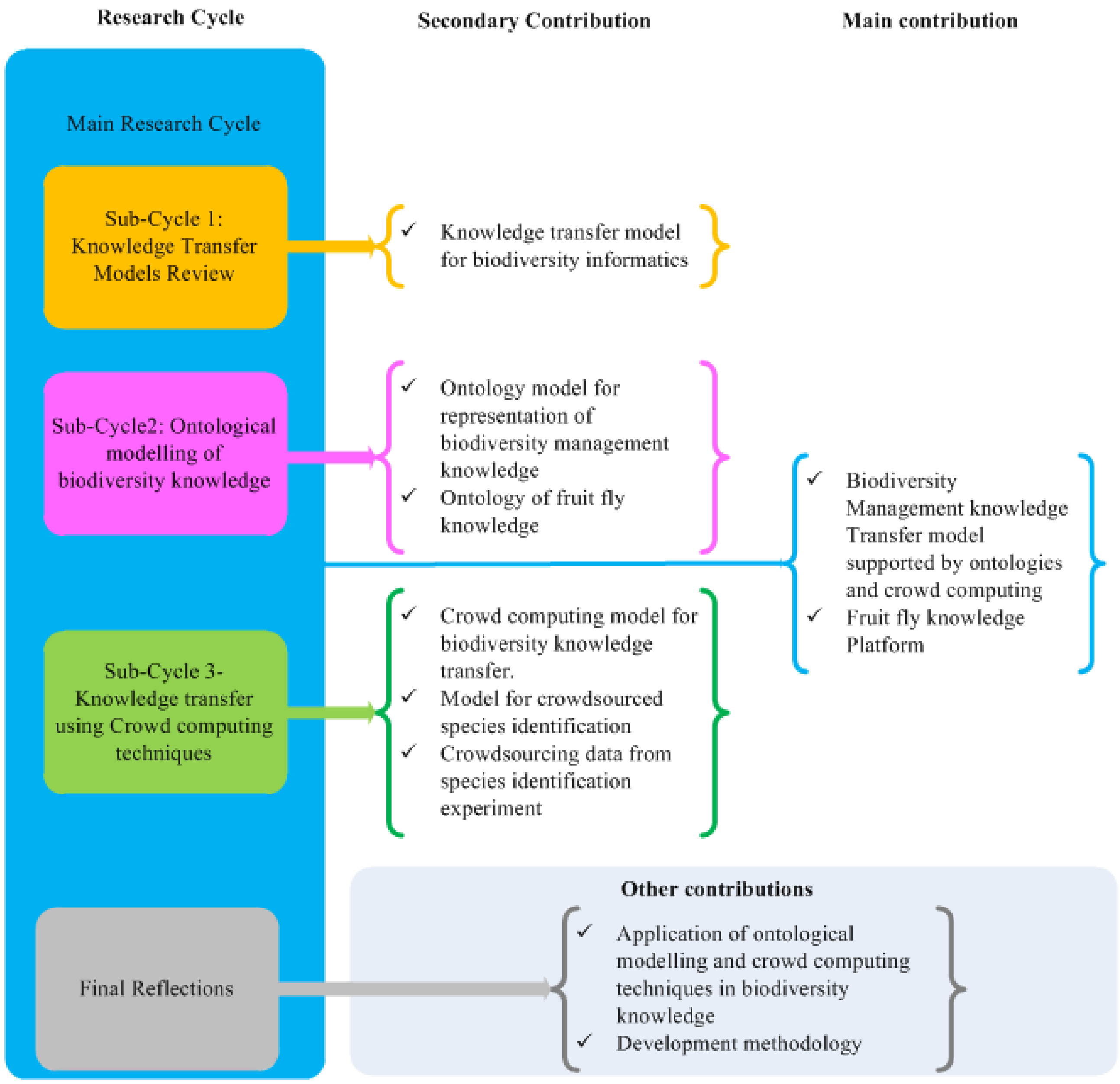

Figure 9-2: Outline of Research contributions

9.2 MAIN CONTRIBUTIONS

This research made two main contributions, a biodiversity management knowledge transfer model and a platform for fruit fly control and management knowledge transfer. The two contributions are discussed in Sections 9.2.1 and 9.2.2 below.

9.2.1 The Biodiversity Management Knowledge Transfer (BiMaKT) Model

The BiMaKT model addresses the main objective that sought to fill the main knowledge gap that was identified and motivated in Chapter 1, paraphrased as follows:.

“The lack of a biodiversity management knowledge transfer model for the transfer of explicit expert knowledge to citizens for practical use”.

This research contributes by filling this gap with a knowledge transfer process model that is supported by ontologies and crowd computing technologies. The model was developed through researching on the sub questions that were formulated to facilitate in answering the main question. The DSR approach was adopted and various activities undertaken during the different steps of this research approach. The objective of identifying a model that can be adopted was done during the awareness and suggestion step. Establishment of how knowledge can be modelled was done in the development step. Identification of techniques that can be used to involve non-experts in knowledge transfer was done during the development step and was a spinoff of that used the DSR approach within the main DSR approach. Combining the components identified into a model was done in the development step to create an improved model. In the evaluation stage, the model was evaluated and findings used to further improve the model. Throughout the research, circumscriptive steps were taken to improve results of previous steps until good results were attained.

The nature of knowledge transfer this model should be applied to include those that involve transfer of explicit expert knowledge to non-experts for practical use. The model is represented graphically in Figure 9-3 consisting of five processes that connect knowledge sources to receiver and two feedback process from receiver to source. The processes include: - *Awareness, Acquisition, Codification, Annotation, Extraction, Application and Structured feedback and Unstructured feedback.* The model also recommends different crowd computing technologies that can be used to support each process and the use of ontologies to model knowledge and support some processes. A description of each process is presented next.

Process 1: Awareness - The Awareness process is recognition by both source and receiver that, knowledge needs to be transferred. The awareness process leads to identification of the *Required Knowledge*. Web 2.0 and social computing were found appropriate for supporting this process.

Process 2: Acquisition - *Acquisition* involves gathering the knowledge that needs to be transferred. The output from this process is the *acquired knowledge*. Web 2.0 was found ideal for supporting this process.

Process 3: Codification - The *codification* process involves systematically arranging the acquired knowledge in a form that can be interpreted by computer applications. This makes the knowledge accessible through the use of computer programs and re-usable for other related purposes. Codification requires domain experts and knowledge representation experts to work closely to ensure the codified knowledge is accurate and consistent. Ontological modelling is a key technology in this process and web 2.0 technologies could also be used to support the process.

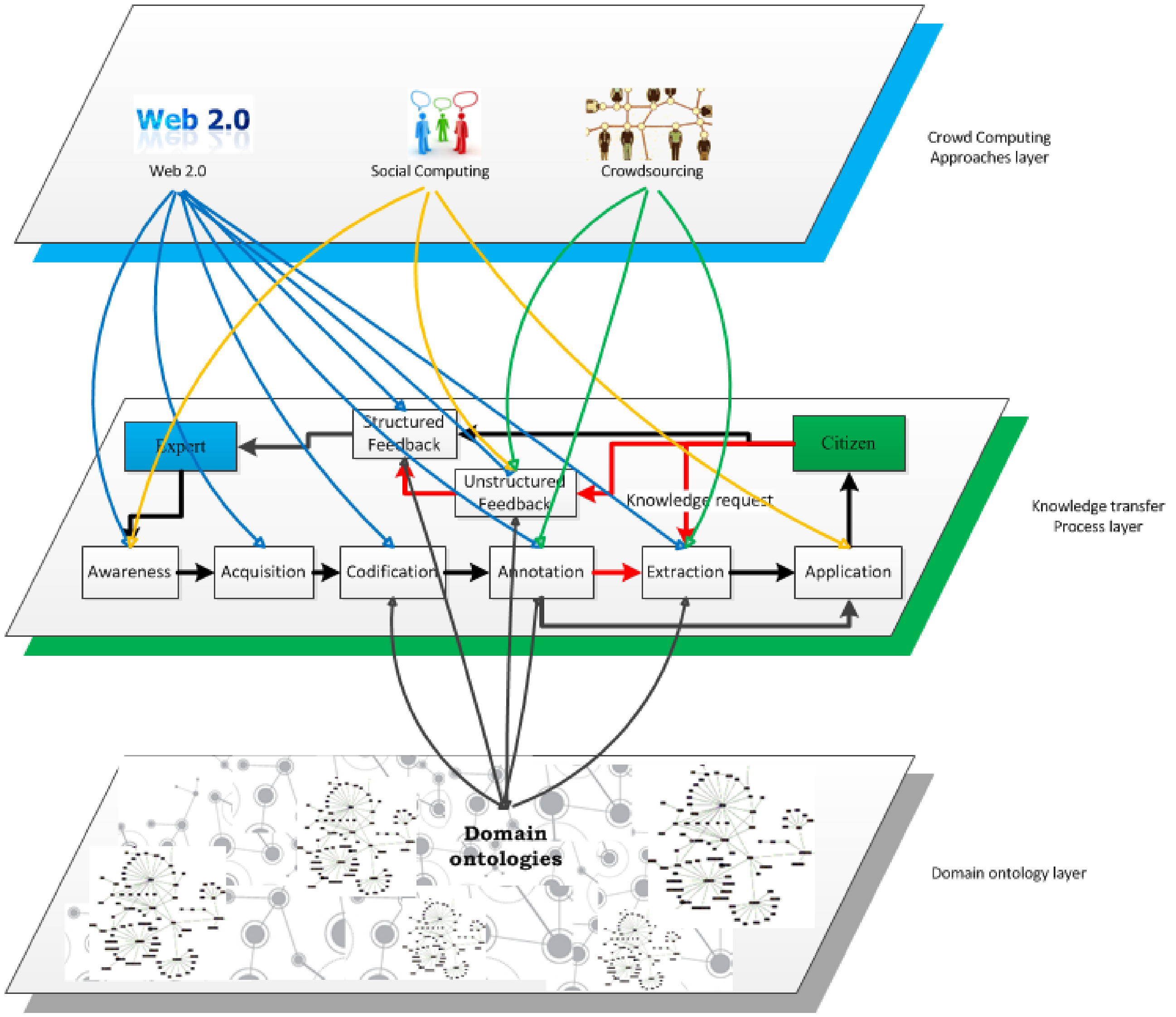

Figure 9-3: Biodiversity management knowledge transfer (BiMaKT) model

Process 3: Annotation - The expert knowledge that is codified remains complex and not accessible to non-expert citizens. The *annotation* process is aimed at mitigating against this challenge by making the knowledge understandable to non-experts. This process involves adding a layer of translated knowledge that can be understood by non-experts. The output of this process is knowledge that is in a form understandable by receiver and we call it *useful knowledge*. This knowledge can then be used by non-experts for practical purposes. Besides ontology development tools, web 2.0 and crowdsourcing techniques were found appropriate for supporting the process.

Process 4: Extraction - In some cases availing expert knowledge in a form that can be understood by non-experts does not guarantee usefulness. This is because the procedures for applying the knowledge can be too technical for non-experts. In such cases, the knowledge receiver can make specific knowledge requests, which go to the *extraction* process. This extraction process is aimed at providing a receiver with specific nuggets of knowledge that is extracted based on their requests. The process generates useful requested knowledge that can then be applied by the receiver.

Process 5: Application – the application phase is the process of application of the new knowledge by the citizens. Social computing could be used to share experiences.

Process 5: Structured feedback - Feedback to experts from citizens can be facilitated through structured interfaces. This process ensures that feedback can be readily analysed since all citizens provide feedback in a similar format. Biodiversity management is already characterized by numerous data sources that cannot be jointly analysed, so structuring feedback using standards that meet biodiversity data standards can alleviate this problem and ensure the data collected is usable. This process could be supported by web 2.0 technologies for designing feedback interfaces. Ontologies could be used as input to the structured feedback process.

Process 6: Unstructured feedback – it was noted that structuring feedback process could introduce substantial complexity to feedback process for citizens consequently leading to lack of feedback. This process is an alternative to structured feedback where citizens can give feedback in an unstructured form which can then be structured making it valid scientific data. The crowd computing technologies that can be used to collect this feedback include web 2.0 and social computing. Crowdsourcing techniques was recommended for structuring the feedback together with ontologies.

In general, all processes that interact with an ontology are expected to result in enhancement or extension of the ontologies as indicated in the bidirectional arrows joining the processes and the ontologies.

9.2.1.1 Theoretical Implications

This contribution fills a gap in theory by providing a model for online knowledge transfer. The model is intended for cases where documented expert knowledge needs to be transferred using technological means to novices for purposes of practical application.

In this research, the view that knowledge is successfully transferred if it can influence action was adopted. Other models put emphasis on the absorptive capacity of the receiver (Liyanage et al. 2009; Cohen & Levinthal 1990). In this model, absorptive capacity is not emphasised since the model allows knowledge receivers to tap into absorptive capacities of others and still be able to use the knowledge to influence their actions. Use of technology provides an opportunity to implement solutions that enables one to tap into a network of many users with different skills. This improves the overall knowledge transfer since the absorptive capacity barrier is reduced.

Estabrooks et al (Estabrooks et al. 2006) opined that multiple theoretical perspectives in the area of knowledge translation are better than one overarching theory for all domains. This is because there are contextual differences that characterize different domains. In this study, the model has been developed and tested for the biodiversity domain. This contextualization is paramount in the area of knowledge transfer since different factors come to play in different domains.

Current research in knowledge transfer has been done in the context of organizational knowledge (Cohen & Levinthal 1990; Dyer & Nobeoka 2002; Hansen 2002; Tsai 2001). Kumar and Genesh (Kumar2009) presented a simple model where individuals are identified as possible actors but no detail on the process is provided. In Liyanage et al. (2009), the model recognizes individuals but in an organizational context. This study looks at transfer of scientific knowledge to communities for purposes of influencing action. This contribution, therefore, provides an elaborate foundational knowledge in the context of experts transferring knowledge to the larger society for action.

Annotating expert knowledge with terms understandable to non-expert presents opportunity to store both knowledge together. This means that both experts and citizens can interact with the same knowledge from their perspectives. Unlike traditional methods where the translated knowledge is stored independently from the source, annotating allows deeper levels of analysing and interpretation of knowledge from both perspectives. Structuring knowledge in this way provides an opportunity to structure feedback along the same lines and therefore, present framework to develop stronger communication models between communities of experts and non-experts.

Finally, the model will generate debate in the area of knowledge transfer. The model has been tested using a case in the biodiversity control and management domain. There is a need to test it with other cases in this domain. There is also need to test it in other domains where knowledge generated by experts needs to be applied for practical uses by citizens. All these are opportunity to contribute to theory through further testing and interrogation of the model.

9.2.1.2 Practical Implications

The BiMaKT model is a new addition to application development resources now available to information system developers. The model is intended to guide development of applications that have the objective of knowledge transfer using online technologies. The model provides the necessary components of such a system, the process that each component addresses and how the components are linked from source to receiver to achieve knowledge transfer. Use of online technologies currently cuts across all sectors, and this model provides a much-needed starting point for transfer of expert knowledge to non-experts.

The ontology developed during this study is available for interested researchers. Development of ontologies is a tedious task and re-use of existing ontologies is advised. The ontology is available for use in other applications that may require the knowledge represented in it.

The platform developed as part of this research can be adopted and enhanced by other applications with similar and or related requirements.

Development of the fruit fly case used in this study provides methodological guidance for developing applications of a similar nature. The technologies recommended for use in implementing different processes is as a result of research on available options and selecting appropriate ones. Development of systems of this nature can utilize those technologies without the need to re-evaluate available technologies thus saving on costs and time.

9.2.2 Fruit fly knowledge transfer platform

A knowledge transfer platform based on the BiMaKT model was developed in this research. The platform was aimed at facilitating transfer of expert knowledge in the control and management of fruit flies to citizens and other stake holders in the horticulture industry. The platform combines ontological modelling and crowd computing techniques to provide tools for accessing key knowledge in the control and management of fruit flies. Development of the platform adopted the agile approach which allows for flexibility in the development process rather than fixed requirements and development plans that characterize old methodologies. The Feature Driven Development (FDD) methodology was adopted in the development of the platform. The development of the platform is presented in Chapter 8.

The knowledge accessible in the platform includes, first, the identification knowledge which is basically taxonomic knowledge that can be used to identify the taxonomic groupings of the flies to species level. The second category of knowledge is that on the host plants to different species of the fruit flies. Research has shown that different species of flies attack different host plants, and this knowledge is necessary in taking necessary prevention measures and in predicting spread patterns. The third category of knowledge accessible from the platform is on lures that can be used on different species of flies. Different species of flies are attracted to different lures, and this knowledge aids in identifying the lures to use on fly traps. A screen shot of the platform is shown in Figure 9-4

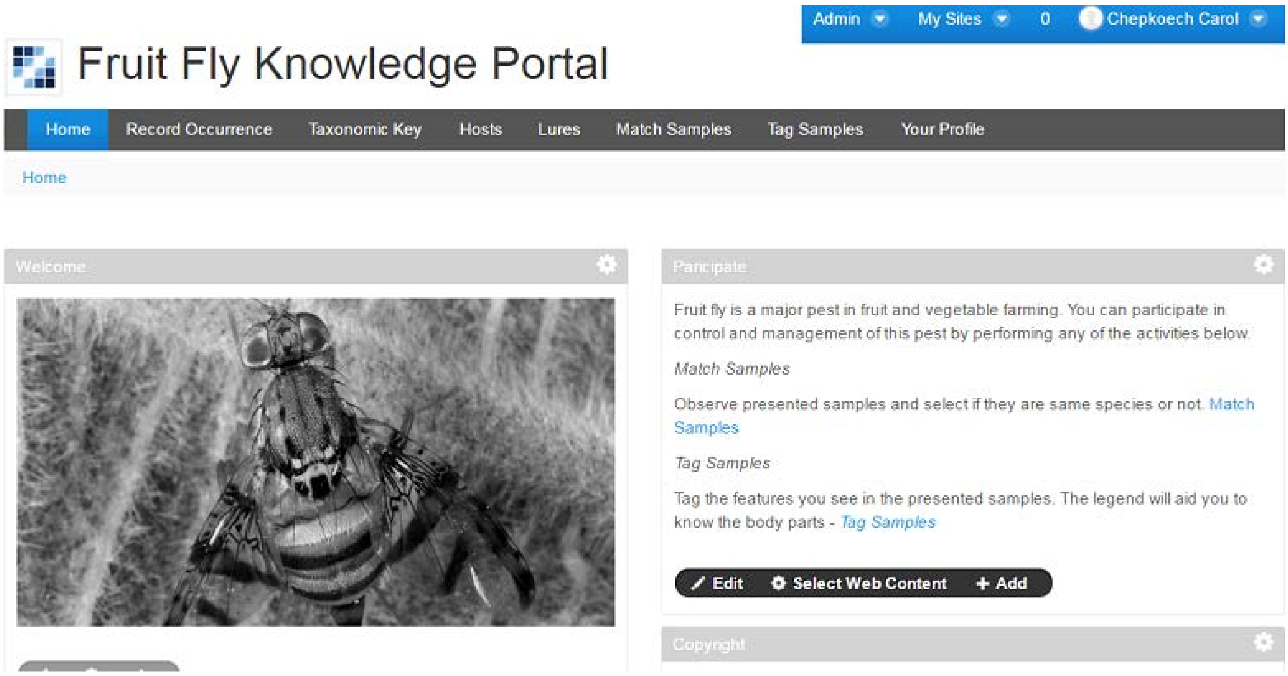

Figure 9-4: Fruit fly knowledge platform

The platform provides functionalities for citizens to access knowledge on their own or to get support from online crowds through crowdsourcing tasks. For instance, if one is not able to identify fly species using taxonomic key, they can submit occurrence to online crowds who can aid in identification by performing the full identification or recording observed features. These crowd activities are then aggregated using aggregation algorithms to arrive at identification results.

9.3 SECONDARY CONTRIBUTIONS

During the intermediate phases of the DSR approach used in this study, secondary contributions were made during the sub-cycles of the research process. These contributions are presented in this section.

9.3.1 Biodiversity management knowledge transfer: A review

The research conducted a systematic literature review on the knowledge transfer models with the objective of identifying a model suitable for transfer of biodiversity management knowledge. The review found that literature on knowledge transfer is scattered across knowledge management literature and different disciplines. A total of 317 sources were identified in the search processes that were further reduced to 48 upon refinement through preliminary reading of sources' abstracts. The details of the review process is presented in Chapter 4.

The systematic review process brought together all the appropriate sources and accessed their suitability for use in online transfer of biodiversity management knowledge. The review created a novel reference point for knowledge transfer models and their suitability for the transfer of biodiversity management knowledge. The process model proposed by Liyanage et al. (2009) was found suitable for use in the transfer of biodiversity management knowledge.

9.3.2 Ontology model for biodiversity management knowledge representation

Development of domain ontologies benefit greatly from ontology models for representing knowledge in that domain. This research contributed such a model for representing biodiversity knowledge. This model supports representation of biodiversity knowledge by providing a model to guide in modelling of biodiversity knowledge. Biodiversity knowledge is characterised by different kinds of relationships within and between organisms and their environments commonly known as organism traits. The model provides a structure for modelling this traits knowledge and guidelines on extracting facts from the modelled knowledge.

The model is of the form: given an organism grouping O with a property has feature hF and with features F1, F2…….Fn, then this knowledge should be modelled as:

$$O = O \text{ and } hF\ F_1 \cap hF\ F_2 \ldots\ldots \cap hF\ Fn$$

Where hF is the property of relationship between the two, for instance "has morphological feature", "has reproduction feature", "has offspring feature", "has product feature" and other features that constitutes organisms traits.

To extract facts from the ontology, an intersection or a union of the features may be used depending on the problem being addressed. For example, if one wants to extract all the organisms with a given set of taxonomic features as the case with multi-entry taxonomic keys, then an intersection of the features must be used. Another example is cases that require getting items that match a union of features. Getting fruit flies that are attracted to a mixture of attractants is an example use of the union in the fruit fly case. A detailed discussion of the model is available in Chapter 5 Section 5.7.3.

9.3.3 Fruit fly ontology

This study developed an ontology containing knowledge on fruit flies considered to be of economic importance in Africa documented in (Billah & Ekesi 2007). The objective of the ontology was to represent knowledge necessary in the control and management of these flies. Tree dimensions of knowledge on these organisms were found necessary; taxonomic identification knowledge, lures for different species and host plants to the different species. The modelling of this ontology was done in the development phase of this research and documented in Chapter 5.

The ontology was developed using OWL, guided by the methodology proposed by Horridge et al. (2011) and Noy et al. (2001) . The taxonomic knowledge was represented using the model presented in Gerber et al. (2014) where taxonomic groupings are associated with defined features using *hasDiagnosticFeature* property. Three sub-properties of *hasDiagnosticFeature* were defined; *hasMorphDiagnosticFeature,* *hasAttractantDiagnosticFeature* and *hasHostPlantDiagnosticFeature.* The three sub-properties were used to associate taxonomic groupings with morphological features, lures and host plants respectively.

A set of morphological diagnostic features were defined and associated with different taxonomic groups using a property called *hasMorphDiagnosticFeatur*. This means that every taxonomic group has a set of diagnostic features as documented in the taxonomic key. The same modelling approach was used in modelling the knowledge on lures and host plants. A different class of all the lures and another for host plants was defined, and the lures and host plants defined under them. The lures and host plants were then associated with the taxonomic groupings through *hasAttractantDiagnosticFeature* and *hasHostPlantDiagnosticFeature* respectively. The association of a taxonomic group with features using the sub-properties is shown in Figure 9-5.

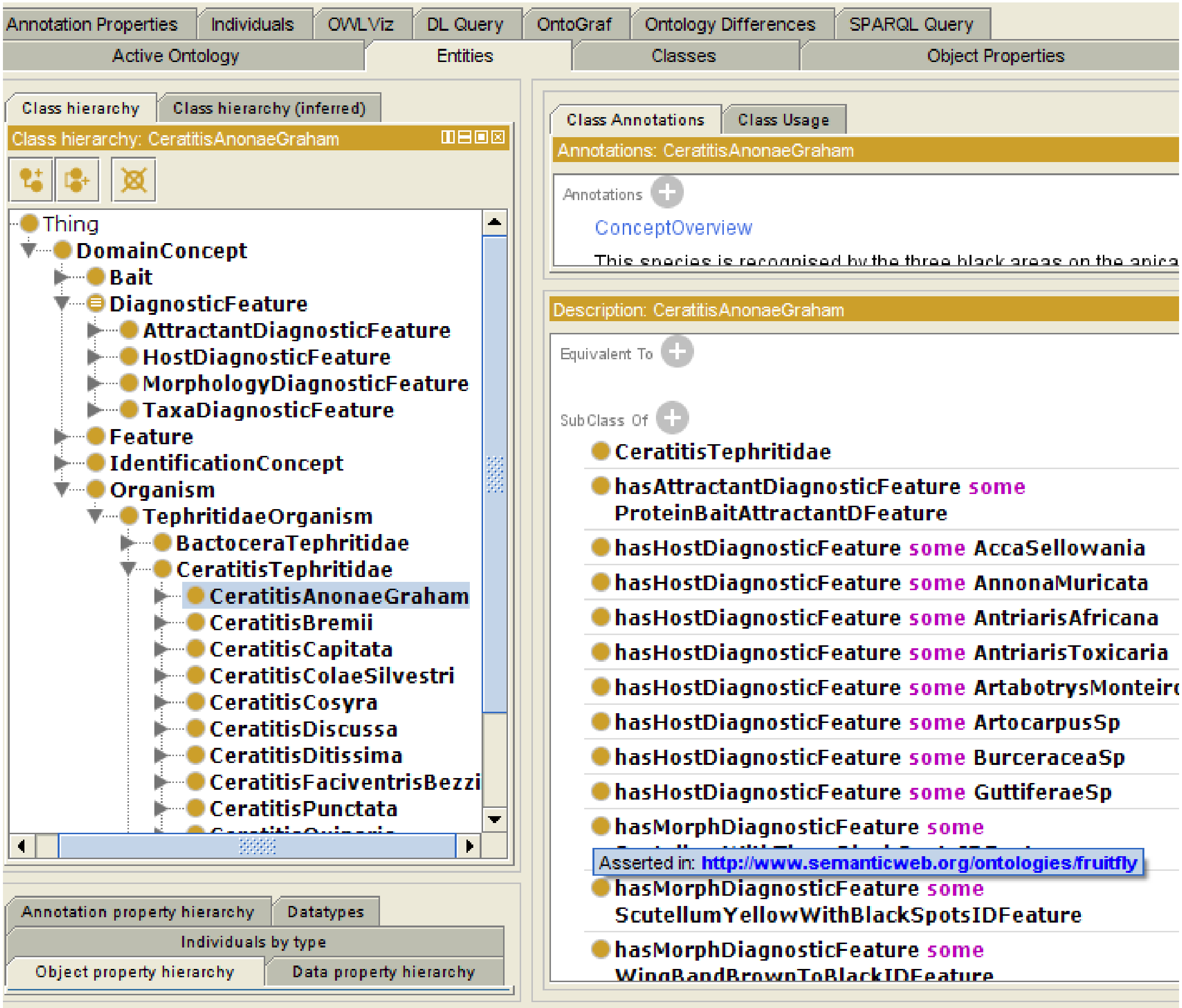

Figure 9-5: Ontology extract

The knowledge on all host plants for the different species was not captured due to constraints of resources. The structure, however, does exist and can be extended when need be. Using Protégé metrics, the current ontology has a total of 9574 axioms, 1177 classes and 30 object properties.

9.3.4 A reference Architecture for citizen-expert knowledge sharing in biodiversity management

This research developed a reference architecture that use ontology and crowdsourcing techniques for online knowledge sharing of biodiversity knowledge between experts and citizens. This architecture was developed to guide development of applications where online crowds of non-experts can independently record observations of different organisms in online platforms, others to observe the recorded samples and participate in identification tasks through recording the features they can observe in the samples. These features are then processed using algorithms that analyse the crowdsourced data to make identification decisions.

Development of the architecture was done after the evaluation stage and was based on reflection and abstraction from the fruit fly identification case. The model consists of eight components; amateur observation recorders, amateur recordings, online crowd, ontology of identification features, crowdsourced features, algorithms, data standards and identification results.

Developers interested in applications that use crowdsourcing techniques for recording and preliminary identification of the amateur observations can use this model to guide their development. Existing platforms that engage amateurs to record organism information can also use the model to introduce a feature level crowdsourced identification in the platforms. The model is documented in Kiptoo et al. (2016b).

9.3.5 Crowd sourcing data from fruit fly identification experiment

The evaluation step of this study was done through an experiment that used crowdsourcing techniques to identify samples. The experiment was conducted using the fruit fly platform described above where the fruit fly ontology was used as the expert knowledge source and images from different researchers used as samples for identification. Over 70 online participants were recruited to participate in the experiment, and their role was to tag samples with axioms of features from the ontology. In the experiment, thirty nine images of various species of fruit flies were used, and the experiment ran for three months. A total of 8,728 tags with the user with highest no of tags making 547 tags and the lowest 11. The sample that was tagged the most had 531 tags and the least 27 tags. This data is available for interested researchers for analysis and new interpretations.

9.4 OTHER CONTRIBUTIONS

9.4.1 Ontological modelling and crowd computing for biodiversity knowledge transfer

This research combined two technologies (ontologies and crowd computing) to solve a biodiversity knowledge transfer problem. Use of ontologies in representing scientific knowledge and specifically biological knowledge is not new. Ontologies have been used to represent different kinds of biological knowledge with examples being ontologies have been used in representation of genomic knowledge (Ashburner et al. 2000), taxonomic knowledge (Gerber et al. 2014), environmental knowledge (Buttigieg et al. 2013), organism ontologies (Maglia et al. 2007; Jaiswal et al. 2005; Yoder et al. 2010) among others. Crowd computing technologies has also been used around biodiversity knowledge. First Web 2.0 technologies have been used to create different citizen science portals for citizen participation in collection and processing of biodiversity data, e.g. inaturalist.com. Second, social computing has been utilised to ask and share different kinds of biodiversity knowledge, e.g. different interest groups have been created in social media to share photos of organisms from taxonomic groups of interest, e.g. the Bat conservation trust face book page for sharing information on bats. Finally, crowdsourcing has also been used in addressing scientific problems through games or volunteer activities, e.g.

the medical image analysis crowdsourcing uses a simple game to solve a biomedical problem of identifying potentially infected blood samples (Mavandadi et al. 2012).

From the examples highlighted above, it is clear that the two kinds of technologies have been used in addressing scientific problems. Combination of the technologies was, however, not found, and this research has demonstrated that combining the two technologies brings desired enhancements. Incorporating ontologies into crowd computing increases opportunities for crowd participation. In Chapter 8, it is demonstrated that crowds can participate in organism identification, without knowledge on taxonomic identification, through the feature level crowdsourcing. Increasing the crowd base is important since biodiversity data processing is labour intensive and making problems solvable without demanding deep knowledge in the discipline is necessary.

In this research, the combination of ontological modelling and crowd computing to address a knowledge transfer problem has been studied. This combination and application to biodiversity knowledge is novel and presents a foundation for research into using the model and the two technologies to address problems in other scientific disciplines.

9.4.2 Methodological contribution

The development of the fruit fly knowledge platform adopted the agile approach for software development, specifically the Feature Driven Development (FDD). The feature driven methodology entails creating an overall model, identifying a list of features, feature planning, feature design and feature development. Reviews are made after completion of feature and re-prioritizing of features done and another cycle of feature planning to development is done again (Rychlý & Tichá 2008). This research proposed use of a model and preliminary requirements to the creation of the overall model. Some domains, biodiversity informatics included, have domain level requirements that must guide development of applications. These requirements are necessary and if new applications are to comply with the domain requirements, then they must adhere to domain models and standards. In this research, the FDD methodology was adopted with introduction of the BiMaKT model as an input to the creation of overall design. This made the development process easier since the model already identifies the necessary process steps for knowledge transfer and the technologies to adopt for different processes. This research, therefore, demonstrated the value of incorporating a model to the FDD software development methodology.

9.5 SUMMARY

This chapter presented the new knowledge generated during this study. Three categories of contributions were made and presented, the main contributions which answer the main research question and were made during the main research cycle, secondary contributions, which were made when answering the sub-questions, during the sub-cycles of the research and other contributions which are not tied to specific research objectives and were made from reflections on the research process. The main theoretical contribution is the BiMaKT model generated during the main cycle of the Design Science Research (DSR) research approach used in the study. Several secondary contributions were made including; ontology of fruit fly control and management knowledge, crowdsourced data of sample organism features and reference model for crowdsourced species identification. Other contributions include the novelty of combining ontologies and crowd computing technologies to solve a knowledge transfer problem across non homogeneous groups; and a methodological contribution for application development.

The BiMaKT model has four process steps that expert knowledge go through before it is useful for novices to put to practical use; awareness, acquisition, codification and annotation. The model also provides an extra component for extracting knowledge for specific needs based on requests by receivers. Expert knowledge sometimes require additional technical skills in that domain to be able to extract the relevant knowledge, this step is aimed at assisted extraction. The model relies on willingness of both source and receiver with minimal requirement for absorptive capacity on the side of the receiver. Theoretical and practical implications of the BiMaKT model transfer model are also presented. The other main contribution in this research is a platform for fruit fly knowledge transfer. The platform was developed based on the model as demonstrated in chapter 8. The secondary and other contributions are discussed in Sections 9.3 and 9.4 respectively.

Part V - Conclusion

In this part, the conclusion of the study is presented. The part has one chapter, the conclusion and future work and is contextualised within the rest of the study as shown in Figure V-I below.

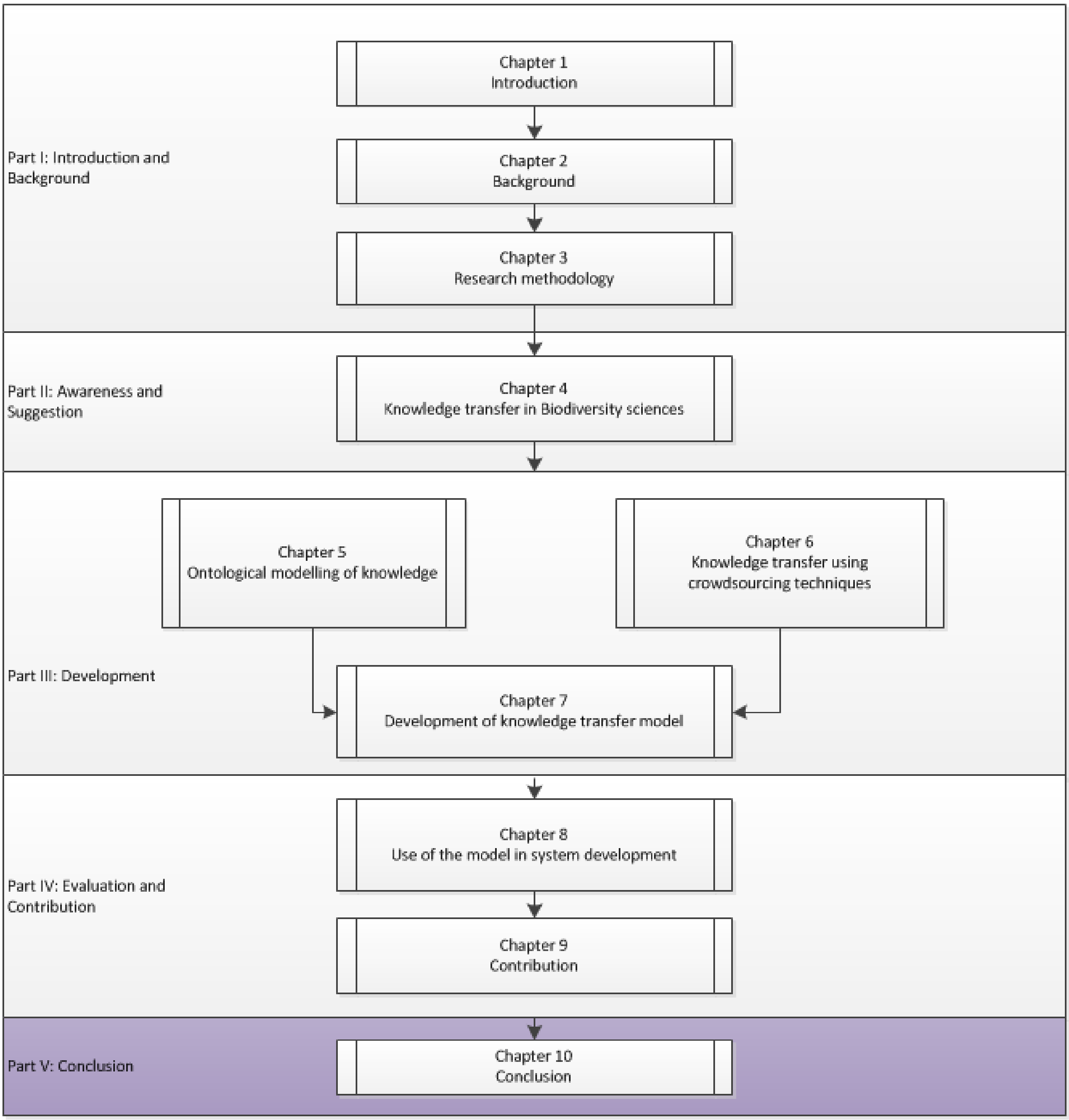

Figure V-1: Part V Outline

Chapter 10 - Conclusion and Future work

10.1 INTRODUCTION

This chapter presents the overall conclusion of the research study reported on in this thesis. The aim of the research was to create a model for knowledge transfer between experts and citizens in the biodiversity domain using ontological modelling as knowledge representation technology for expert knowledge, as well as crowd computing technologies to harness citizen participation. To achieve this objective, three sub-objectives were formulated. The first sub-objective was to identify a knowledge transfer model from the existing body of literature that could be adopted for biodiversity knowledge transfer between experts and citizens; the second sub-objective was to create a model for the representation of expert biodiversity knowledge using ontological modelling techniques and the third sub- objective was to establish how crowd computing technologies could be used to engage citizens and support the knowledge transfer process.

This chapter presents a conclusion on the entire research study, and the items discussed include a summary of the research findings, implications of the findings, limitations of the research and recommendations for future research. The chapter is structured as follows: - Section 10.1 is an introduction to the chapter; Section 10.2 is a summary of the research questions and objectives; Section 10.3 is a summary of the research methodology used in the study; Section 10.4 is a summary of key findings consisting of the outcomes of the sub-objectives; Section 10.5 contains a summary of contributions; Section 10.6 is an evaluation of the main contribution; Section 10.7 contains limitations of the research study; Section 10.8 presents recommendations for future research and Section 10.9 is a summary of the chapter. Figure 10-1 is an outline of the chapter.

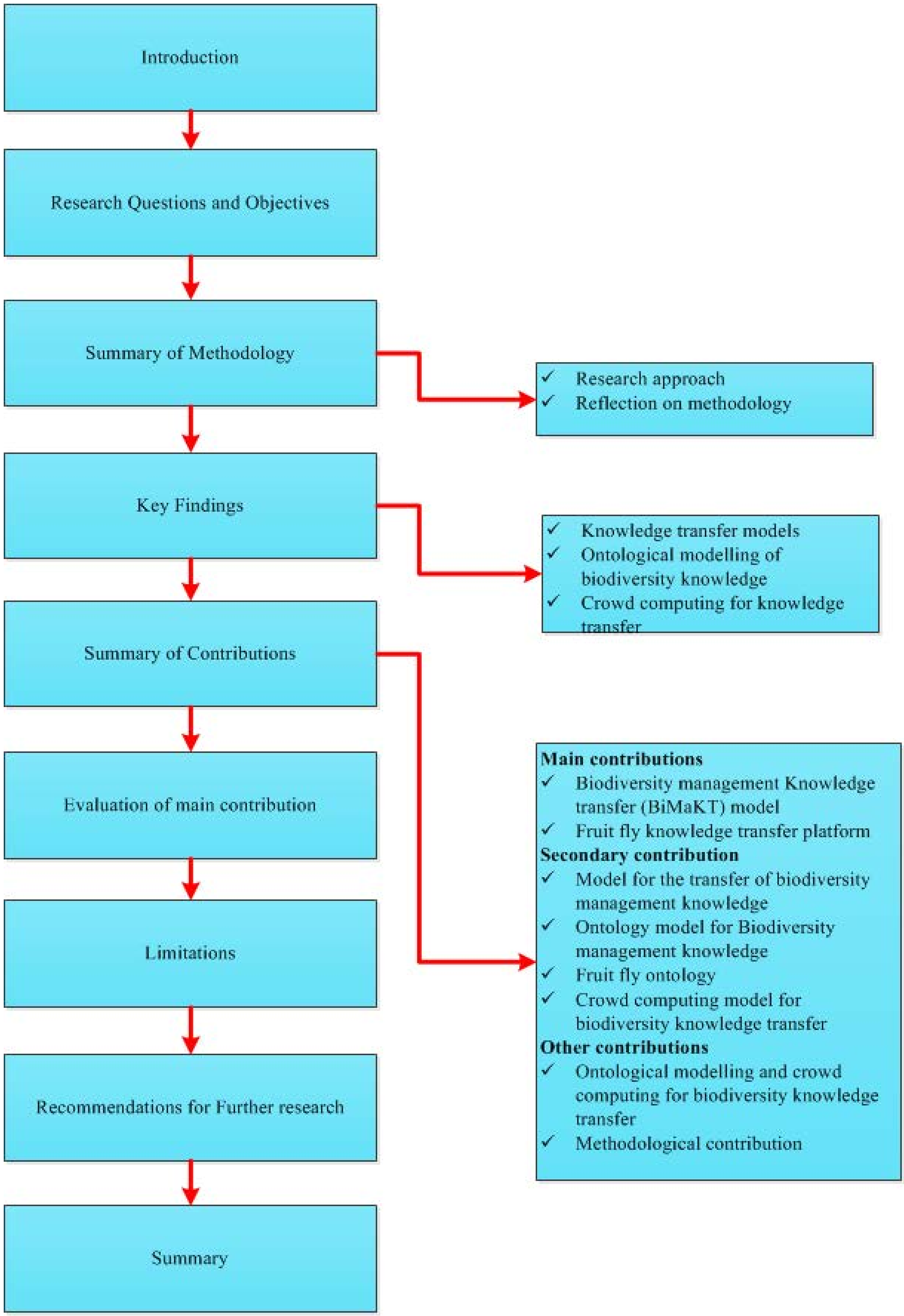

Figure 10-1: Outline of Chapter 10

10.2 RESEARCH QUESTIONS AND OBJECTIVES

The main research question and sub-questions that guided this study were:

Main Question

What are the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management?

Sub-questions

1. Which knowledge transfer model is applicable for expert-citizen knowledge transfer in biodiversity management?
2. How can ontologies be used to capture biodiversity management expert knowledge?
3. How can crowd computing technologies be used to support biodiversity management knowledge transfer?

The objectives, therefore, were:

Main objective

To identify the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management.

Sub Objectives

1. To identify a knowledge transfer model applicable for expert-citizen knowledge transfer in biodiversity management.
2. To establish how ontologies can be used to capture biodiversity management expert knowledge.
3. To establish how crowd computing technologies can be used to support biodiversity management knowledge transfer.

10.3 SUMMARY OF RESEARCH METHODOLOGY

In this section, a summary of the research methodology used is presented consisting of an overview of the approach and a reflection on the applicability of the approach for the study.

10.3.1 Research approach

At the philosophical level, the study assumed the pragmatic worldview which is a real-world problem solving centred paradigm (Creswell & Clark 2011; Seyppel 1953). Within the pragmatic worldview, the Design Science Research (DSR) paradigm was taken. The DSR view beliefs that knowledge can be generated through construction of artefacts that solve practical problems. The research process by Kuechler and Vaishnavi (2008) consisting of a research cycle with five circumscriptive phases of awareness, suggestion, development, evaluation and conclusion was adopted.

The research was designed into a main cycle which answered the main research question and sub-cycles within the main cycle which answered the sub-questions of the research. The main cycle was designed to answer the main research question - "What are the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management?"- had the five circumscriptive phases of awareness, suggestion, development, evaluation and conclusion. The awareness phase research was conducted through literature review. The suggestion phase was designed into a sub-cycle that sought to answer the first sub-question of the research which was "*Which knowledge transfer model is applicable for expert-citizen knowledge transfer in biodiversity management?*" The first sub-cycle research was conducted using systematic literature review.

The development phase of the main cycle was designed into two sub-cycles to answer the second and third sub-questions of the research, "*How can ontologies be used to capture biodiversity management expert knowledge?*" and "*How can crowd computing technologies be used to support biodiversity management knowledge transfer?*" The researches for both sub-cycles were conducted using DSR approach. The evaluation phase of the main cycle was done using a case that evaluated the model developed during the development phase. The research design is discussed in great detail in chapter 3.

10.3.2 Reflection on the research methodology

The overall objective of this research was to solve a biodiversity management knowledge transfer problem between experts and citizens using selected technologies. The pragmatic worldview was found appropriate for this research because the objective of the research was to solve a real-world problem which is in line with this view. DSR paradigm was found applicable because the paradigm is a problem solving paradigm that solves problems through introduction of new artefacts. The DSR paradigm was confirmed appropriate for this research since the objective was to create a new model for knowledge transfer.

In order to fully reflect on the appropriateness of the methodology to the study, the DSR guidelines presented in Hevner et al. (2004) were used. Use of the guidelines for methodological reflection was adopted from Smuts (2011). Reflection on the appropriateness of the methodology for answering the main research question is presented in Table 10-1

Table 10-1: Study assessment using design research guidelines (Hevner et al. 2004)

Guideline	Main research question: What are the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management?	Reference in the thesis
#1: Design as an artefact – DSR produce artefact in the form of a construct, a model, a method or an instantiation	Study produced three artefacts; the Biodiversity Management Knowledge Transfer (BiMaKT) model, trait knowledge representation model and Fruitfly knowledge transfer platform.	Chapter 5, Chapter 7, Chapter 8

Guideline	Main research question: What are the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management?	Reference in the thesis
#2: Problem relevance – objective of DSR in IS is to introduce technological solutions relevant to non-routine problems in the real world	The study was aimed at addressing a knowledge transfer problem between experts and citizens in biodiversity management. This is a non-routine problem, and same model can be used to solve similar problems and extended to other domains where knowledge needs to be transferred between experts and novices.	Chapter 1 Chapter 4 Chapter 9
#3: Design evaluation – Well executed evaluation methods must be used to measure utility, quality and efficacy of developed artefact	Evaluation was done using a case of Fruitfly knowledge transfer. The evaluation was done at two levels, evaluation of the ontology model using competency questions and evaluation through platform development using the BiMaKT model.	Chapter 5 Chapter 8
#4: Research contributions – DSR must make contributions in the areas of the design artefact, design foundations and/or design methodologies	The study contributed two main contributions, a design artefact, the BiMaKT model and an instantiation of the model; the Fruitfly knowledge transfer platform.	Chapter 9
#5: Research rigour - The construction and evaluation of the design artefact must be done using rigorous methods	Rigor was ensured through reference to relevant literature during the research process. Appropriate research approaches of systematic literature review, DSR, IS development and evaluation were used.	Chapter 1 to chapter 9, Appendices
#6: Design as a search process – Search for effective artefact means exploring different options to reach desired goals while satisfying existing laws.	The study was done through exploring different ideas and identifying what works best.	Chapter 3 to Chapter 8
#7: Communication of research – DSR research outcomes must be presented clearly to both technical and problem domain audiences.	The research has published output both in technical journal (Kiptoo et al. 2016b) and in a user domain publication(Kiptoo et al. 2016a)	Chapter 1 to Chapter 9, Publications

10.4 SUMMARY OF FINDINGS

In this section, the findings from the research are discussed within the structure of the sub-questions. The key findings were as discussed in the subsections below.

10.4.1 Knowledge transfer model for biodiversity knowledge transfer

The identification of a knowledge transfer model for biodiversity knowledge transfer between experts and citizens resulted in several findings. First, it was found that the models and frameworks for knowledge transfer have different levels of abstractions. Second it was found that those that address the knowledge transfer process have similarities, and some processes are common across models. Third, it was also found that most models focus on transfer of knowledge from an identified source to an identified receiver. Fourth, the models emphasize the importance of absorptive capacity on the side of the receiver in order for knowledge transfer to take place. Fifth, knowledge transfer models have been developed in different contexts / domains and the importance of adapting a model to a new domain is recognised as an important aspect of knowledge transfer.

Finally, the knowledge transfer process model by Liyanage et al. (2009) was found adequate for extension for expert-citizen knowledge transfer in biodiversity management. The model is based on knowledge communication and translation models and is characterized by six processes. Five processes facilitate knowledge transfer from source to receiver and include: - awareness, acquisition, transformation, association and application. The sixth process step is externalization and deals with feedback from the receiver back to the source. The model was the main finding of the first sub-objective which was "*To identify a knowledge transfer model applicable for expert-citizen knowledge transfer in biodiversity management*". The findings and the identification of the model was through systematic literature review and is discussed in Chapter 4.

10.4.2 Ontological modelling of Biodiversity expert knowledge

The investigation into how ontologies could be used to represent biodiversity management knowledge resulted in several findings. The first finding was that the use of ontologies to model biological knowledge is on the rise. Secondly, in terms of species knowledge, it was found that ontologies of organism anatomy were the most common kinds of knowledge represented using ontologies. The anatomy ontologies were mainly aimed at reconciling terminological inconsistencies, a common problem in the anatomy knowledge of different organisms.

Finally, the investigation found the morphology ontology model by Gerber et al. (2014) suitable for extension for the representation of different kinds of trait knowledge for biodiversity management. These findings were made in the second research objective whose aim was "*To establish how ontologies can be used to capture biodiversity management expert knowledge*". The research towards this objective was conducted using design science research, and the findings are documented in detailed in Chapter 5 of this thesis.

10.4.3 Crowd computing for support of the knowledge transfer process

The investigation into the use of crowd computing to support the knowledge transfer process resulted in several findings. First, it was found that different types of crowd computing technologies have been used in addressing biodiversity management challenges. The most common use of crowd computing is in transfer of ground knowledge from citizen to experts through species monitoring projects. The projects are implemented using web 2.0 and allow citizens to submit species occurrence data. Secondly, it was also found that crowdsourcing techniques have been explored in sorting of data collected through citizen science projects. In terms of the knowledge transfer process, it was found that although not in the biodiversity domain; crowd computing techniques have been used in some knowledge transfer processes such as translation. These findings were made in the third sub-objective which was "*To establish how crowd computing technologies can be used to support biodiversity management knowledge transfer*". The research for this sub-objective was conducted using the design science research approach and is documented in detail in Chapter 6 of this thesis.

10.5 SUMMARY OF CONTRIBUTIONS

The contributions of this research were:

Main contributions

- Biodiversity Management Knowledge Transfer (BiMaKT) model
- Fruit fly knowledge transfer platform

Secondary contributions

- Model for the transfer of biodiversity management knowledge
- Ontology model for Biodiversity management knowledge
- Fruit fly ontology
- Crowd computing model for biodiversity knowledge transfer

Other contributions

- Ontological modelling and crowd computing for biodiversity knowledge transfer
- Methodological contribution

10.5.1 Main contributions

The research generated two main contributions namely:

- Biodiversity Management Knowledge Transfer (BiMaKT) model
- Fruit fly knowledge transfer platform

The two are described in the sub-sections below.

10.5.1.1 Biodiversity Management Knowledge Transfer (BiMaKT) model

The Biodiversity Management Knowledge Transfer (BiMaKT) model is the answer to the main research question investigated in this study. The model combined ontological modelling and crowd computing technologies for knowledge transfer in the biodiversity management domain. The model allows bidirectional knowledge transfer between citizens and experts. The BiMaKT model has six process steps for transferring knowledge from experts to citizens, namely awareness, acquisition, codification, annotation, extraction and application; and two processes of transferring knowledge from citizens to experts, namely structured feedback and unstructured feedback. The BiMaKT model was developed using the design science research approach and is described in detail in Chapter 7. In Chapter 8, an evaluation of the model is done using a case of fruit fly control and management knowledge transfer between experts and citizens.

Although technology has been used to support knowledge transfer in different biodiversity projects, models that explicitly address the knowledge transfer process using technology as a mode of transfer were not found in literature. The BiMaKT model adds to knowledge transfer theories by introducing an ontology and crowd computing technologies based model for knowledge transfer. The model extends an existing theory (Liyanage et al. 2009) by proposing how the two technologies - ontology and crowd computing - can be used to support the knowledge transfer process. Existing knowledge transfer theories, models do not specify the mode of transfer but in the BiMaKT model, the mode is specified and is focused on the two specific technologies.

10.5.1.2 Fruit fly knowledge transfer platform

The fruit fly knowledge transfer platform is a knowledge transfer portal that was developed based on the BiMaKT model, and its objective was to facilitate the transfer of Fruitfly knowledge between experts and fruit and vegetable farmers. The platform was developed in the evaluate cycle of the design science research approach used in this study. Development of the platform adopted an agile approach, specifically the Feature Driven Development (FDD) and is described detail in Chapter 8. Through the platform it was demonstrated that the BiMaKT can be adopted in the development of applications using ontology and crowd computing technologies for biodiversity knowledge transfer between experts and citizens. The significance of the platform includes the opportunity to create theory through evaluation of usage. The platform can also be used to create new theories through creation of enhancements and extension of functionality.

10.5.2 Secondary contributions

The secondary contributions that resulted from the research are:

- Model for the transfer of biodiversity management knowledge
- Ontology model for Biodiversity management knowledge
- Fruit fly ontology
- Crowd computing model for biodiversity knowledge transfer

10.5.2.1 Model for the transfer of biodiversity management knowledge

The research found the knowledge transfer process model in Liyanage et al. (2009) suitable for adoption in biodiversity knowledge transfer between experts and citizens. The Liyanage et al.'s (2009) model consists of six processes of awareness, acquisition, transformation, association, application and feedback.

The identification of the model was done through systematic literature review process. The review identified seven sources that discuss the knowledge transfer process in detail and in a form that could be adopted for practical knowledge transfer. Detailed analysis of the seven sources showed a close similarity in the knowledge transfer steps of the different models. Analysis of the steps led to selection of the Liyanage et al.'s (2009) model for adoption in citizen-expert knowledge transfer in the biodiversity domain. The identification of the model is described in details in Chapter 4.

10.5.2.2 Ontology model for Biodiversity management knowledge

A model for representing biodiversity management knowledge was created. The model provides a structure for modelling different kinds of species traits knowledge making it possible to jointly analyse and answer questions cutting across the different kinds of traits knowledge. The model extends the model by Gerber et al. (2014) which represents morphological features of Afrotropical bees. The Afrotropical bee ontology model represents morphological features as body parts with features and associates those morphological features with taxonomic groupings. In this research, the Afrotropical bee ontology model is extended to include other traits, which are associated with the taxonomic groupings in a similar manner. The practical significance of the model is that developers of other ontologies representing organism traits knowledge can adopt the model.

Creation of the model was done using the design science research approach consisting of awareness, suggestion, development, evaluation and conclusion phases. The awareness phase was done through literature review; the suggestion phase was done using conceptual modelling; the development phase was done through ontological modelling of a case and abstraction from the case; the evaluation phase was done using ontology evaluation methods, including evaluation for correctness and appropriateness for use in target applications. The details of the ontology model is presented in Chapter 5.

10.5.2.3 Fruit fly ontology

The research contributed an ontology of fruit fly control and management knowledge. The ontology contains knowledge on morphology of fruit flies, host plants to different species and lures that can be used to attract different species of the flies. The ontology used the model presented in section above and is documented in Kiptoo et al. (2016) . The ontology evaluates the model and confirms it can be used to represent traits knowledge. The practical significance of the ontology is that it can be used by those interested in development of fruit fly knowledge systems.

10.5.2.4 Crowd computing model for biodiversity knowledge transfer

The research contributed a crowd computing model for biodiversity knowledge transfer. The model consists of the different steps of the knowledge transfer process in the Liyanage et al.'s (2009) model with suitable types of crowd computing approaches that could be used to support the different process steps. The model has three overlapping classes of actors who participate in the knowledge transfer process. The classes of the actors are: - experts, online crowds and citizens.

The creation of the model was done using design science research approach, adopting the circumscriptive research process of awareness, suggestion, development, evaluation and conclusion phases (Vaishnavi & Kuechler 2007). The awareness and suggestion phase was done through literature review and recommendation of approaches for the knowledge transfer steps based on evidence in literature. Development was done through conceptualization based on crowd computing knowledge, and the requirements of different knowledge transfer steps. Evaluation was done in Chapter 8 through development of the fruit fly knowledge transfer platform that adopted the model. The significance of this model is that it provides a practical reference foundation for development of crowd computing-based systems for knowledge transfer processes. The development of the model is presented in detail in Chapter 6.

10.5.3 Other contributions

The other contributions that resulted from the research study are:

- Ontological modelling and crowd computing for biodiversity knowledge transfer
- Methodological contribution

10.5.3.1 Ontological modelling and crowd computing for biodiversity knowledge transfer

The synergy of combining ontology and crowd computing technologies is a novel one in the management of biodiversity knowledge. Reflections on this research identified this novelty as a contribution made by this research. The significance of this contribution includes the need to investigate this synergy for other biodiversity management problems other than knowledge transfer. As stated in the introduction, biodiversity management is characterized by huge data sets that is not curated and ontologies and crowd computing technologies present opportunity to curate and make it valid data.

10.5.3.2 Methodological contribution

This research introduced use of a model in the Feature Driven Development (FDD) methodology (Rychlý & Tichá 2008). The FDD methodology has five steps, namely: - creating an overall model, identifying a list of features, feature planning, feature design and feature development. This research proposed incorporation of an existing model to creation of an overall model of the system. This methodology is particularly relevant in domains that develop systems whose data needs to be jointly analysed with data from similar systems in the domain. Biodiversity domain is one such domain, and the methodology was found adequate in development of the Fruitfly knowledge transfer platform described in Chapter 8.

10.6 EVALUATION OF MAIN CONTRIBUTION

To evaluate the main contribution of the study presented in this thesis, the evaluation criterion developed by Introna (1992) were used. The criterion consists of a list of questions that help a researcher to evaluate scientific progress research contribution. The evaluation using this criterion is summarized in Table 10-2 below.

Table 10-2: Evaluation of academic contributions using the criteria presented in Introna (1992)

1. Does the theory raise problems previously not perceived, such as problems of an increasing depth, and does it display an ever-increasing fertility in suggesting new problems?	The answer to this question is affirmative. The theory is a result of exploration of the synergy between ontology and crowd computing for knowledge transfer in biodiversity management. The research demonstrates that the two technologies could be combined to address the citizen-expert knowledge gaps in biodiversity management and especially to provide services to disadvantaged communities. The same synergy can be explored to solve other problems within the biodiversity management domain. Combination of the two technologies could also be explored to address similar challenges in other domains.
2. Does the theory anticipate novel facts and auxiliary theories?	The answer to this question is affirmative. The study contributes BiMaKT model, which could be used to generate more theories through application to other cases in biodiversity management and through application similar domains. The theory also provided an ontology and crowd computing technology-based model for comparison with new models using other computing technologies.
3. Is the theory more precise in the assertions and in the facts it explains than previous theories?	The answer to this question is affirmative. The BiMaKT model is more precise than previous theories since it presents a practical process that can guide application development. The model is based on two specific technologies; ontology and crowd computing. The process steps of knowledge transfer are clearly described making it possible to clearly understand what is involved at each step and how each technology is useful for the steps.
4. Has the research unified or connected various hitherto unrelated problems or concepts?	The answer to this question is affirmative. The research has connected ontology and crowd computing technologies for biodiversity management knowledge transfer. Although ontology use in representation of biological knowledge is not new, it is often used to assist experts in answering complex problems. Crowd computing too has been used in different citizen science projects in biodiversity management. Combining the two for knowledge transfer as done in this research is novel.

5. Does the theory have positive and negative heuristic power?	"Positive heuristic power indicates which research paths should be pursued, and negative heuristic power indicates which research paths should be avoided. Without heuristic power, a research program would collapse into ad hoc-ness" (Introna 1992). The research in Chapter 4 and Chapter 5 performed literature reviews in order to decide on the models to adopt for this research. This is positive heuristic power as the research provided justified guidance on the direction to explore. The research also provides reasons why ontological modelling is chosen over other forms of codification. This is a positive heuristic on ontology use and negative on the other forms of codification.
6. Has the theory produced new perspective on existing problems and thus created new understanding of these existing problems?	The BiMaKT model has created a new perspective to knowledge transfer between experts and citizens. The model has demonstrated that expert knowledge can be represented and transformed for citizen use. This allows for citizens to get services using terminologies from their world, but the services are based on expert knowledge. The theory has also introduced a layer of mode of transfer to knowledge transfer process.
7. Has the research produced unconventional ideas, ideas that radically change current preconceptions?	The answer to this question is affirmative. Knowledge transfer models have not been related to modes of transfer in previous models. Although codification of the knowledge is discussed in literature as shown in Chapter 4, the specifics of codification technologies used are not discussed in the knowledge transfer. Combination of ontologies and crowd computing technologies for knowledge transfer between experts and citizens in the BiMaKT model is unconventional and introduces a new dimension in expert-citizen collaborations in the domain.

10.7 LIMITATIONS OF THE STUDY

It is acknowledged in literature that theory has different forms of limitations, which could be as a result of many factors affecting the study. Kuhn (1970) stated that "To be accepted as a paradigm, a theory must seem better than its competitors, but it need not, and in fact never does, explain all the facts with which it can be confronted". This observation is supported by (Walsham 2002) who argue that theory illuminates certain aspects of a specific case environment but is inevitably incapable of identifying all aspects that might be relevant. This study had two key limitations.

The first limitation is the use of one case in the evaluation cycle of the development of the model. As discussed in the methodology in Chapter 2, this research adopted the design science research which is characterized by a design cycle of build and evaluation of the artefact within a practical and theoretical environment. The evaluation cycle was done using a case of knowledge transfer between fruit fly experts and farmers in the horticulture industry. Using other cases could enrich the theory generated. It is, however, worth noting that the structure of knowledge in biodiversity management is generally the same irrespective of the organism and therefore, use of an additional case may enhance but not alter the model.

The second limitation is the crowd computing platform used was created by this research and did not adopt the existing crowd computing environments. This means that this research did not benefit from existing crowd environments. The research created its own crowd computing environment since existing environments do not provide technical support for combining ontologies and crowd computing in the manner desired in this research. To avoid the limitations in those platforms and be able to explore the objectives of this research, the viable approach was therefore to create a crowd computing environment that could be used in this research. This means that the potential of large crowds already existing in those platforms was not tapped. Use of these large crowds may not affect the model but could present an opportunity for optimization.

10.8 RECOMMENDATIONS FOR FUTURE RESEARCH

This research created a biodiversity management knowledge transfer model using ontology and crowd computing technologies. The research used a case of knowledge transfer between experts and farmers in control and management of an agricultural pests, Tephritidae fruit flies. The research took an organism perspective to biodiversity knowledge. Further research is needed in order to generalize the model phases and knowledge representation model for other dimensions of biodiversity management. It is also recommended that other cases involving knowledge transfer between experts and citizens be used in order to test the model and improve where necessary.

The transfer knowledge between experts and citizens in the biodiversity domain does not differ significantly with transfer in other domains dealing with transfer of scientific knowledge to practice. Future research should look into adopting the model for other domains such as the biomedical domain. Most scientific domains are characterised by expert knowledge that needs to be passed to citizens for practical use, but complexity and lack of enough expertise continue to stifle the flow of such knowledge. Exploring the models in these domains could allow citizens in poor communities to benefit from such knowledge at reduced costs.

10.9 CONCLUDING SUMMARY

This thesis has presented the answer to the main research question namely *"What are the components of an ontology and crowd computing based expert-citizen knowledge transfer model for biodiversity management?"* as the Biodiversity Management Knowledge Transfer (BiMaKT) model. The answer was arrived at through a main research approach of Design Science Research (DSR) consisting of a process of awareness, suggestion, development, evaluation and conclusion. The model is aimed at guiding development of application systems for the transfer of knowledge between experts and citizens.

It is conceptually possibly to conclude that the BiMaKT model has the necessary components to guide development of applications that tap into the synergy of combining ontology and crowd computing technologies for the transfer of biodiversity management knowledge between experts and citizens. The BiMaKT model includes an ontology model for representing biodiversity expert knowledge and process steps supported by crowd computing for transferring expert knowledge to citizens for practical application. It also has feedback steps for transmitting feedback and ground knowledge from citizens to experts supported by crowd computing and structured using the expert knowledge represented in the ontology.

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APPENDICES

Appendix I: Knowledge transfer sources

INTRODUCTION

This appendix contains a complete listing of all the resources reviewed in identification of the knowledge transfer model adopted for this study. The identification was done through systematic literature review and was done as part of the awareness and suggestion phase of this research documented in Chapter 4.

Detail* is the level of detail for practical implementation of knowledge transfer based on the model. The scale starts from 1 to 4, with 1 being highly implementable and 4 means highly abstract and only aids conceptualization.

The following sources were reviewed:

	Source	**Description**	**Detail***	**Cited by**	**Discipline**
1	(Nonaka & Takeuchi 1997) The knowledge creating company	Knowledge creation process and conversion of knowledge from one form to another	3	35531	Management science
2	(Rich 1997) Measuring knowledge utilization process and outcomes. Knowledge and Policy	Utilization process model	4	235	Health
3	(Rogers 1995) Diffusion of Innovations	Theoretical model	4	123	Multi-disciplinary
4	(Ward et al. 2009) Developing a framework for transferring knowledge into action: a thematic analysis of the literature	Conceptual framework for the knowledge transfer process	3	207	Health

	Source	Description	Detail*	Cited by	Discipline
5	**(Swinburn, Gill, & Kumanyika, 2005)** Obesity prevention: a proposed framework for translating evidence into action	Health practical framework	4	359	Health
6	(Böcher & Krott 2014) The RIU model as an analytical framework for scientific knowledge transfer: the case of the ''decision support system forest and climate change''	Framework for analysis of knowledge transfer	4	10	Biodiversity management
7	(Perera et al. 2006) Knowledge Transfer in Forest Landscape Ecology: A Primer	General hypothetical model presenting role of and relationships between actors	4	9	Biodiversity management
8	(King & Perera 2006) Transfer and Extension of Forest Landscape Ecology: A Matter of Models and Scale		4	11	Biodiversity management
9	(Cohen & Levinthal 1990) Absorptive Capacity: A New Perspective on Learning and Innovation Wesley	Three process model	1	30042	Management science
10	(Krogstie et al. 2006) Process models representing knowledge for action: a revised quality framework	Framework for evaluating knowledge for action models	4	276	Management science

	Source	Description	Detail*	Cited by	Discipline
11	(Carrillo et al. 2006) A Knowledge Transfer Framework : the PFI context	Framework discussing general components	4	73	construction
12	(Horton 1999) A simple guide to successful foresight	Describes foresight as a form of knowledge transfer	1	171	Strategic thinking and policy
13	(Major & Cordey-Hayes 2000) Knowledge translation: a new perspective on knowledge transfer and foresight	Conceptual model for knowledge translation Focused on translation	1	61	Strategic thinking and policy
14	(Trott et al. 1995) Inward technology transfer as an interactive process	Knowledge transfer process model	1	116	Technology
15	(Nieva et al. 2008) From Science to Service: A Framework for the Transfer of Patient Safety Research into Practice. Advances in Patient Safety: From research to implementation	Conceptual model to accelerate transfer of results	4	45	Health
16	(Goh 2002) Managing effective knowledge transfer: an integrative framework and some practice implications	Integrative factors that influence knowledge transfer	4	831	Knowledge management

	Source	Description	Detail*	Cited by	Discipline
17	(Carlile & Rebentisch 2003) Into the Black Box: The Knowledge Transformation Cycle	Describes knowledge transformation	2	455	Management science
18	Research utilization: the state of the art. Knowledge and policy (Huberman 1994)	Based on relationship between source and receiver (Diffuser and receiver)	4	241	Policy
19	(Lin et al. 2005) A Sender-Receiver Framework for Knowledge Transfer	Framework for studying knowledge transfer	4	223	Knowledge Management
20	(Roux et al. 2006) Bridging the Science–Management Divide: Moving from Unidirectional Knowledge Transfer to Knowledge Interfacing and Sharing	Generic model for bidirectional knowledge flow	3	345	Management science
21	(Lavis et al. 2003) How Can Research Organizations More Effectively Transfer Research Knowledge to Decision Makers?	Framework for knowledge transfer	4	833	Management science
22	(Whelan 2006) KNOWLEDGE EXCHANGE IN ELECTRONIC NETWORKS OF PRACTICE: Toward a Conceptual Framework	Focus on transfer of tacit knowledge through conversations, interractions etc..	4	3	Management science

	Source	Description	Detail*	Cited by	Discipline
23	(Graham et al. 2006) Lost in knowledge translation? Time for a map	Knowledge to action process	2	1755	Health
24	(Landry et al. 2006) The knowledge-value chain: a conceptual framework for knowledge translation in health	Describes knowledge transfer within a value chain of knowledge	4	166	Health
25	(Narteh 2002) Knowledge transfer in developed-developing country interfirm collaborations: a conceptual framework	Knowledge transfer model presented with process as one of four components	2	71	Knowledge management
26	(Kramer & Cole 2003) Sustained, Intensive Engagement to Promote Health and Safety Knowledge Transfer to and Utilization by Workplaces. Science Communication	A conceptual framework for research	4	55	Science
27	(Liyanage et al. 2009) Knowledge communication and translation – a knowledge transfer model	Detailed knowledge transfer process model	1	183	Knowledge management

	Source	Description	Detail*	Cited by	Discipline
28	(Dobbins et al. 2002) A framework for the dissemination and utilization of research for health-care policy and practice. Online Journal of Knowledge Synthesis for Nursing	Framework for research dissemination and utilization	4	242	Health
29	(Wilkesmann & Wilkesmann 2011) Knowledge transfer as interaction between experts and novices supported by technology	Knowledge transfer related to complimentary elements and technologies	3	42	Knowledge management
30	(Gera 2012) Bridging the gap in knowledge transfer between academia and practitioners	Knowledge transfer cycle – high level processes	3	27	Education
31	(Panahi et al. 2012) Social Media and Tacit Knowledge Sharing: Developing a Conceptual Model	High level model focused on tacit knowledge sharing using social media	3	68	Technology
32	(Kitson et al. 2008) Evaluating the successful implementation of evidence into practice using the PARIHS framework: theoretical and practical challenges	Framework for promoting action on research	4	561	Science

	Source	Description	Detail[*]	Cited by	Discipline
33	(McBeath 2012) Towards a framework for transferring technology knowledge between facilities	Framework for transfer of technical intellect	4	12	Management science
34	(Lavis 2006) Research, public policymaking, and knowledge- translation processes: Canadian efforts to build bridges	Link of knowledge translation to policy making process	4	230	Health
35	(Nguyen 2013) Knowledge transfer conceptual framework for small businesses	Based on communication model	3	1	Knowledge management
36	(Kutvonen et al. 2013) University-Industry Collaboration and Knowledge Transfer in the Open Innovation Framework	Generic model	4	2	Education
37	(Davis et al. 2003) The case for knowledge translation: shortening the journey from evidence to effect. British Medical Journal	Knowledge translation	4	609	Health

	Source	Description	Detail*	Cited by	Discipline
38	(Louise Hamilton et al. 2014) Development of an information management knowledge transfer framework for evidence-based occupational therapy	Combines knowledge transfer and information management into a framework	3	4	Knowledge management
39	(Anderson et al. 1999) The use of research in local health service agencies	Model for research transfer development	4	65	Health
40	(Lester 1993) The utilization of policy analysis by state agency officials	Knowledge utilization conceptual model	4	88	Science
41	(Walter et al. 2005) What works to promote evidence-based practice? A crosssector review	Mechanisms for promoting research to practice	4	112	Policy
42	(Fernandes & Raja 2002) A practical knowledge transfer system: a case study	Described approach tied to software development process	3	11	Technology
43	(Chen & McQueen 2010) Knowledge transfer processes for different experience levels of knowledge recipients at an offshore technical support center	Describes absorptive capacity as a function of transfer model	3	60	Technology

	Source	Description	Detail*	Cited by	Discipline
44	(Cooper & Lichtenstein 2010) Supporting knowledge transfer in web-based managed IT support	Support system process described	4	4	Technology
45	(Lam et al. 2010) Optimal knowledge transfer methods: a Generation X perspective	Knowledge transfer model focussing on strategies and mechanisms	4	48	Technology
46	(Goh et al. 2008) Knowledge access, creation and transfer in e-government portals	Describes dimensions of online knowledge sharing	4	40	Technology
47	(Duangchant & Kiattikomol 2016) Knowledge transfer in B-O-R-N Model to enhance computer learners' learning outcomes in knowledge and cognitive skills	Measures outcome of BORN model in knowledge transfer	4		Management science
48	(Curran et al. 2011) Knowledge Translation Research: The Science of Moving Research Into Policy and Practice	Knowledge to action framework	3	56	Health

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Appendix II – Biological ontologies

INTRODUCTION

In this appendix, a summary of the literature found relevant is presented. The sources were identified through search using Google scholar, scientific databases including Springer link, Science direct and Nature. Some sources were also identified through search for anatomy and traits ontologies in the OBO foundry website (Smith et al. 2007).

RESULTS

The sources that were found relevant in the review are summarised, providing the source and description of relevant content found in the source. The review process examined how the different sources represented anatomical and traits knowledge. The representation of class hierarchy was examined with attention to top concepts. The relationship between anatomical components were also examined and the object properties used to represent relationships. Also the representation of traits starting with top concepts and object properties used to define relations were examined. The findings are as summarised below: -

	Source	**Description**
1.	The plant ontology and plant ontologies (Plant Ontology Consortium 2002)	Describes the goals of the Plant Ontology Consortium, Department of Agronomy, University of Missouri Columbia, Missouri, 65211-7020, USA. The goal of the consortium is to produce ontologies of controlled vocabularies for accessing plant databases. The knowledge types considered include: - development, anatomy, morphology, genomics, proteomics, etc. The plant vocabularies are expected to make it possible to enable joint processing of data in disparate databases.
2.	The plant structure ontology, a unified vocabulary of anatomy and morphology of a flowering plant (Ilic et al. 2007)	Ontology representing knowledge on anatomical and morphological structures of flowering plants focussing on different plant species including maize, rice, and other species. Defined class hierarchies and different types of properties to represent the relationships between classes. Ontology is intended for expert use.

	Source	Description
3.	An anatomical ontology for amphibians (Maglia et al. 2007)	Ontology aimed at harmonization of terminological standadization for the anatomy of amphibians, focussing on three amphibian orders namely: - Salientia (frogs and toads), Caudata (salamanders and newts), and Gymnophiona (caecilians) Use OWL DL for development of ontology
4.	An anatomy ontology to represent biological knowledge in Dictyostelium discoideum (Gaudet et al. 2008)	Ontology of anatomy covering lifecycle of Dictyostelium discoideum. The lifecycle consists of two mutually exclusive states of vegetative growth cycle and development cycle. The top level of the ontology is based upon the Common Anatomy Reference Ontology (CARO) structure (Haendel et al. 2008) and uses three object properties to define relationships between classes : “is_a”, “Part_of” and “Develops_From”.
5.	CARO — The Common Anatomy Reference Ontology (Haendel et al. 2008)	Is an ontology of common anatomy characterised by single structure classification scheme. The CARO ontology is intended to promote promote interoperability among anatomical ontologies. Provides definitions and relations for high level anatomical concepts for canonical anatomies. Includes generic definitions of many generic anatomical concepts for cells, organs, tissues, and other anatomy components. The ontology uses “is_a”, “develop_from” and “part_of” object properties to define hierarchical relationships between these concepts.
6.	An ontology for Xenopus anatomy and development	Anatomy ontology of frogs Xenopus representing knowledge on the lineage of tissues and the timing of their development. Ontology was aimed at enabling robust database (e.g Xenbase model organism database) searches and analysis of data. Adopts the CARO to arrange top concepts and uses “is_a”, “Part_of” and “Develops_From” properties.

	Source	Description
7.	The Teleost Anatomy Ontology: Anatomical Representation for the Genomics Age (Dahdul et al. 2010)	Anatomy ontology representing knowledge on anatomical structures of teleost fishes consisting of over 25,000 species. Uses “is_a”, “develop_from” and “part_of” object properties to represent relationships between concepts
8.	Uberon, an integrative multi-species anatomy ontology (Mungall et al. 2012)	The ontology is aimed at providing a dedicated cross species anatomy ontology knowledge analysis. Ontology makes it possible to establish equivalent anatomical components across species making it possible to query for datasets in other dimensions such as genotypes in similar anatomical components from different species without the need to use multiple queries. Ontology has also been used as a reference for generic anatomical types when creating anatomy ontologies. The ontology uses different object properties to unify different anatomical components. The object properties include: - “is_a”, “part_of”, “Develops_from”, “ capable_of”, “is_a (taxon equivalent)” and “only_in_taxon”. Spatial and topological relationships are represented using “is_adjacent_to”, “continuous_with”, “anterior_to”, “in_left_side_of” and “in_right_side_of”. More properties are used to represent life cycle stages, Inter-ontology relationships, Managing taxonomic variation among others.

	Source	Description
9.	Animal trait ontology: The importance and usefulness of a unified trait vocabulary for animal species (Hughes et al. 2008)	Ontology containing traits and phenotype knowledge of livestock including cattle, pig, and chicken species. The ontology was aimed at standardizing terms and linking together semantically similar descriptions. Trait is defined as that which can be specifically measured and phenotype is a scalar trait. Trait information is organised in trait categories namely: - development traits (describes growth), exterior traits (anatomical features and behavioral), immune function traits (health of species), product quality traits (describes quality properties of the products of species), production traits (describes products) and reproduction traits (related to production of offspring). Uses "is_a" and "part_of" object properties to define relationships between terms.
10.	The Vertebrate Trait Ontology: a controlled vocabulary for the annotation of trait data across Species (Park et al. 2013)	Ontology of vertabrate traits. The traits is defined as a class with three sub-classes, namely: - organ system trait, organism subdivision trait, organism trait. Organ system traits include traits related to organism body systems such as reproduction system, respiratory system, endocrine system, etc. Organism subdivision trait includes traits of body segments such as head traits, leg traits, etc. Organism trait includes behavioral traits, lifespan traits, body size traits, etc.
11.	An ontology-based taxonomic key for afrotropical bees (Gerber et al. 2014)	Ontology-based multi-entry key is presented. The ontology represents taxonomic diagnosis knowledge of the different genera and species of the afro tropical bees. The ontology has two categories of knowledge; the anatomical components and diagnostic features. The anatomy components are described as classes and relationships between them described using "is_a" and "part_of" properties. The diagnostic features are described as anatomical components having some described features i. e "Diagnostic feature= anatomic part + feature". The diagnostic features are associated with taxonomic grouping using "hasDiagnosticFeature" object property.

	Source	Description
12.	Towards a Reference Plant Trait Ontology For Modeling Knowledge of Plant Traits and Phenotypes (Arnaud et al. 2012)	Presents model for representing traits and phenotypes. The trait and phenotype are modelled as: - " Entity + Attribute = Trait " and "Entity + (Attribute + Value) = Phenotype (observed)". Proposes a graphical reference plant trait ontology consisting of different ontologies that the plant ontology relates to.

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