

Chapter 7: Summary, Conclusions, Recommendations and Assessment

Introduction

This chapter concludes the study with a summary of the research work, conclusions, recommendations for further work and a critical assessment of what has been achieved.

7.1 Summary

7.1.1 Out-of-industry methodologies

Product innovation methodologies are useful at various tacit and explicit levels. AI can play an important role in Knowledge Based Design. CBR is a promising sub-field of AI that can greatly contribute to the contextual storing of design knowledge. It is clear that AI should be used more in the background and especially in architecture automatic adaptation of designs should not be attempted. CBR, RBR and MBR should be not be seen in isolation but should rather be viewed as a continuum of techniques.

PREMIS provides useful insights into a deeper understanding of ontology in a Facilities Management environment. The development of PREMIS highlighted the inadequacies of Relational Databases with regards hierarchical structures. The problems with ontology will be perpetuated in the BPMs and life cycle information infrastructures investigated in this study.

Knowledge Management is becoming very prominent although there are still unsolved problems. However many researchers are working on the particular sub-problems due to the importance of this for the global economy. *Concept extraction* and *Natural Language Processing* remains problematic, however significant progress has already been made.

Fuzzy sets are useful for aiding the retrieval of design knowledge in general and cases specifically by means of dynamic linguistic variables. The semantic differential method of Snider and Osgood (Snider *et al.* 1957) and the semantic differential adjectives as used by Nagamachi bear a relationship to the approach advocated by the author.

The analysis of the characteristics of manufacturing such as process, flow and throughput indicate that these are not directly applicable to the problem under consideration, but should rather be applied at the process level. The theories of Goldratt indicate that the manufacturing environment is particularly applicable for Theory of Constraints and that the system optimum is not the sum of the local optima. Concurrent Engineering is an important technique to avoid the so-called time-trap. This is where the life cycle time of products are decreased while the time spent on product development is greatly increased.

Taguchi techniques indicate the importance of off-line and on-line quality control. These indicate that quality is related to the loss to society caused by a product during its life cycle. In terms of the current thesis these methods should rather be used to select appropriate materials to minimise life cycle costs in the context of sustainable development.

Kansei Engineering (KE) is a mature and useful technique to quantify cognition and product image in such a way as to influence the product development process. KE operates at a very high tacit level and could make a significant contribution to the storage of tacit architectural design information.

The QFD exercise undertaken indicates that the ability to generate what-if scenarios across the project life cycle as the most important user requirement. QFD as a technique to extract raw architectural user requirements was pioneered in the AEDES system. QFD is useful if the time and cost can be justified. QFD is an important technique in the manufacturing industry and was one of the techniques that saved the Detroit automotive industry from ruin in the face of severe competition from Japan. The contribution that QFD can make in architecture is dependent on the general acceptance of this slightly elaborate technique.

TRIZ is a powerful method to solve inventive problems. However the present available commercial TRIZ software emphasise engineering type of problems. A significant amount of work will have to be done to make its use tractable in architectural design.

7.1.2 Life cycle design knowledge

The use of objects is the preferred way to achieve abstraction, generalisation and interaction in systems supporting the life cycle development process. The unique way that objects are used in the precedent systems PREMIS and AEDES provides valuable insights. Microsoft ActiveX controls are a convenient means to implement ARGOS.

A life cycle information infrastructure based on XML is used as the basis for ARGOS. The use of XML as a design language facilitates design knowledge delivery to users. The use of Cascading Style Sheets, XSL and VML is explored. This proved the versatility of XML beyond doubt. The storage of a CAD drawing in XML is analysed in detail.

7.1.3 ARGOS intelligent component

Although AEDES can be viewed as a failure in commercial terms, it provided the first insights into the how user requirements might be extracted and structured to obtain a performance requirement. It was discovered that requirements and functions fall into two main groups i.e. active and passive. A set of functions to successfully enable the operational capability of the requirement could be identified. These functions could be individually characterised according to functional and physical characteristics and constraints. Finally a characterised function could be allocated to a physical element. This transformational method should however not be overemphasised.

An intelligent design component should be both object based and Internet enabled. Its knowledge must be structured and self-documenting. It should be able to operate in a wide variety of environments over a long period of time. It must be useful in small and large project teams using different design and construction processes. It cannot be predicted with certainty what the nature of these numerous processes will be in future.

ARGOS could improve activities such as:

- Concept selection
- Retrieval of design experience
- Test of relationships
- Scenario planning
- Collaboration on a global basis
- Modelling and simulation

Due to the generic nature of ARGOS the range of possible applications is large. The new innovative role in structured planning and design knowledge delivery is proposed. The relationships of ARGOS to other intelligent data sources were also explored.

A detailed parametric ARGOS object was written with the ability to switch between 2D and 3D modes. A compact miniature Internet browser was developed that could be combined with the basic ARGOS component. This will enable unlimited data access.

Internally the ARGOS design case should contain four main types of design information that consists of both alphanumeric and graphic information:

- Tacit design information
- Explicit design information
- Graphic information in the form of XML
- Functional design information and constraints

7.2 Conclusions

The focus of this study was to discover how useful techniques from the world of manufacturing and Artificial Intelligence are in the light of the unique characteristics of the early phases of design. To achieve these three sub-problems were identified.

In *sub-problem 1*, the hypothesis was that a building can be seen as a production product and hence established Systems Engineering techniques and quality measures can be applied to the briefing and design process. Although there are many similarities between the two industries in the sense that efficiency and globalisation are forcing improvement there are also significant and problematic differences. The numerous examples studied from the various out-of-industry perspectives indicated that structured methodologies can only assist at the various tacit and explicit levels, never equal the phenomenal creative capabilities of the human brain. It is clear that the techniques should not be seen in isolation, but rather forms a continuum that should be used when appropriate. Rule-Based Reasoning is useful with for example acoustical design, Model-Based Reasoning assists with the testing of structural behaviour of a design, wind loads and circulation. Case-Based Reasoning is useful to remember previous designs and as such extend the designer's vocabulary. Due to the importance of context in architectural design CBR proved to be useful as a means of recording past experience for possible future use and in the process expedite the design process.

In *sub-problem 2*, the hypothesis was that the architectural briefing and design process could be structured in such a way that it can be implemented on a software system to ensure total life cycle design. The surprising discovery was made that the structuring and storage of in-context design information will become more important than the software application that originally created it. This study has shown that the use of XML as a design language is a viable alternative for the highly complex Building Product Models currently proposed. The flexible structure and extendibility of XML forms a useful basis for a design language and further processing can be achieved by means of style languages such as CSS and XSL. It is already viable to display XML data in vector format by means of VML and the SVG standard announced very recently. The other forthcoming W3C standards such as the XML Fragment Interchange Working Draft and XML Query Data Model will leverage XML even further. Although XML was not primarily intended to be used as a means of storing BPM type of knowledge the inherent characteristics makes it very powerful. According to Cohen (2000:257) XML will, if it widely adopted, result in data sharing and electronic commerce in the building industry on a scale not previously imagined. This is confirmed by the recent (September 1999) first meeting of the aecXML Working Group that was held in Dallas, Texas, attended by over 130 companies and organisations (Cohen 2000:259).

The intelligent component ARGOS, together with the miniature Internet browser developed, makes it feasible to source any design information (graphic and alphanumeric) from anywhere in the world inside any number of autonomous instances of ARGOS in any Microsoft

compliant container. ARGOS is a non-prescriptive autonomous component that makes it possible to use any external process to manipulate or interrogate it. ARGOS can be used at any level of specificity, but practical considerations are likely to limit it to larger architectural units such as spaces, buildings and facilities. ARGOS succeeded in integrating the two important technologies of object-oriented design and XML.

It is clear that the approaches previously followed in software products placed the software application more centrally. This is seen in movements such as Knowledge-Intensive CAD. Microsoft started a new approach that placed the intelligent electronic document in a more central position. The possibilities of this approach were explored throughout the dissertation. Although this is very different from the more traditional approach followed in PREMIS and the prototype AEDES, it is more likely to succeed. The reasons for this can be summarised as:

- A Low-level minimum entry-level platform can be used
- Low cost starting point
- The convenience of portable object technology possibly structured in the form of cases
- Avoids the use of expensive CAD during the early briefing and design stages
- The same technology can be used in small and very complex applications
- The starter kit (intelligent design broker) can be used throughout the life cycle of the building
- Independent third parties can produce starter kits (packaged cases)
- The user can use his own case templates to facilitate what if questions
- Ubiquitous availability of structured design knowledge through the Internet for international teams

In *sub-problem 3*, the hypothesis was that architectural designs and design parameters can be quantified and electronically packaged in such a way as to expedite future designs that require similar designs or parts of designs. The Microsoft object technologies (ActiveX) as well as the modern interpretation of Object Oriented Computer Aided Design prove that it is the preferred way to store architectural designs. If the power of the Internet is taken account of then the design language that is likely to be preferred would be XML.

7.3 Recommendations for further work

The ARGOS methodology would still require more research to refine the initial prototype. It is envisaged that different generic types of ARGOS objects should be created to support the various aspects of the design activities better. The problem of adaptation was not adequately addressed in this thesis. The implementation of constraints will also need more research.

From the work done in AEDES it is clear that an important requirement is the further development of technologies such as Construction Project Simulators. This could be based on ARGOS type technology to provide professionals with the ability to manipulate project information across the life cycle of a facility and to create what-if scenarios by means of affordable desktop tools.

A major challenge is to change to a paradigm where the life cycle information infrastructure becomes primary and the applications that use it secondary. The current international emphasis of XML indicates that it is important that researchers first establish a sound BPM (the means of expressing design information) basis before placing too much emphasis on formalising processes.

7.4 Assessment

Although exciting breakthroughs were made in this study with the discovery of an intelligent component that could be used to bridge structured methodologies and the creative aspects of design there are unfortunately also a number of shortcomings such as:

- XML was never designed as a means to structure design knowledge. It will take a while to formalise and prove the idea to other academics and the commercial world.
- The graphic XML examples shown still have mistakes in the processing of text and the correct translation of the bulge factors for arcs and circles. At this stage the XSL style sheet translation into VML is still primitive and slow. This will improve significantly as SVG begins to gain wider acceptance. However the success of XML is fortunately not dependent on these technologies that use it as basis for processing. With the information overload experienced in the global community the ability to deliver information profiled to the needs of the individual knowledge worker is important. Here XML is again a useful means of achieving this.
- ARGOS in its present form is very orthogonal and makes the design of organic free flowing forms difficult. It is impossible to say whether designers will accept this new type of blackboard autonomous component approach in design. At the moment CAD still dominates the production of drawings although experience has shown that the contribution of CAD to the creative aspects of design has been disappointing over many years.
- The Internet bandwidth in South Africa is at the moment too slow for the collaborative projects envisaged.
- The unsatisfactory contribution up to date of Knowledge-Based Computer-Aided Architectural Design in the conceptual stages of design will make critics highly sceptic as to the possibilities of ARGOS. In the light of the exciting new information supporting technologies available today, the author is of the opinion that a sensible solution is imminent.