24 THE DEVELOPMENT OF WEB-ENABLED KNOWLEDGE BASED (WBK) SYSTEMS FOR THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

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Abstract

It is becoming evident that a significant proportion of international Architectural Engineering and Construction (AEC) industries are adopting Web-enabled Knowledge Based (WKB) approaches to the Life Cycle Development (LCD) of products to meet the needs of the global information economy. A WKB approach is fast becoming the new paradigm for designing client orientated product development systems. This paper examines the status quo on the Life Cycle Development (LCD) process in the building and construction industry, as well as new approaches, showing its principles, goals and benefits. It also introduces ORBIT, a WKB system, which provides a platform for the implementation of the new WKB approach and concludes with a presentation of a conceptual model of the ORBIT system.

Keywords: *Web-enabled Knowledge Based (WKB) approach, Life Cycle Development (LCD) process, knowledge delivery, knowledge manipulation.*

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INTRODUCTION

The emergent global information economy and customer's need for life cycle quality is increasing complexity in the LCD process. As a consequence, two issues are important: *Firstly,* the ability to deliver relevant life cycle project information and knowledge to distributed planners, designers, builders and managers and *secondly,* the ability to retrieve, view, evaluate and adapt life cycle project design fragments on the desktop with a chosen application, regardless of time and location.

Several initiatives are underway in international AEC industries to generate guidance in process improvements and stimulate real cost improvements towards global competitiveness[4]. Initiatives are usually a partnership between academic institutions and industrial sponsors. Standardisation activities on product development processes, suggest movements towards a generic global business process standard, based on system engineering principles, for life cycle product development in 2001 (Stephens *et al* 1999: 354). New developments in web technology and the development of information-handling toolsets are fast providing the new operational platform for such a standard and will support the vision of an integrated global AEC industry. In South Africa process improvement initiatives between the construction industry and research institutions are limited and the facilities LCD process to a large extent fragmented. South Africa is characterised by a well-developed infrastructure and building and construction industry. However, the need for construction delivery, services and infrastructure is still prevalent throughout South Africa, particularly in the previously disadvantaged communities. In addition to this, industry output has been falling steadily throughout the last 25 years with real output in the construction industry falling by an average 0,6% per year between 1970 and 1995 (Allen and Küsel, 1999:1). The problem of a large need but poor demand from potential industry clients, combined with increasing costs of construction, is exacerbated by a history of poor delivery and general failure of industry to embrace and invest in performance improvement initiatives and best practices that have been successful in international AEC industries (Allen and Küsel, 1999:1). However, the Construction Industry Development Board (CIDB) to be established in late April 2000 may become the vehicle to drive change in the construction industry and facilitate collaborative process improvement through research projects.

It is imperative for the South African building and construction industry to develop and adopt new LCD processes and knowledge systems tailored for the South African context. Such processes and systems should focus on empowering all the various functional disciplines in a project with the ability to evaluate and address life cycle issues early in the project life cycle, regardless of time and location. This paper examines the imperative within the context of a Web-enabled Knowledge Based (WKB) approach. Discussion in the paper will include the principles inherent in such an approach and a conceptual model of an implementation platform.

[4] For further reading please visit: http://www.bath.ac.uk/departments/management/research , http://www.construct-it.salford.ac.uk , http://pp2.dct.salford.ac.uk/overview.htm , http://www.abdeakin.edu.au/agile/aghome.htm , http://www.scpm.salford.ac.uk/cibw-65/SPICEproject.htm.

STATUS QUO ON LIFE CYCLE DEVELOPMENT PROCESSES

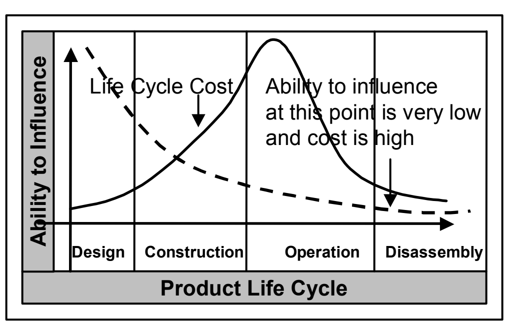
The development process in reality

The products of the building and construction industry (buildings, roads, bridges) are designed and custom-built to unique specifications and usually immovable. The facilities Life Cycle Development (LCD) process, also called the procurement process was defined by the International Council for Building Research Studies and Documentation, Working Group, CIBW92 as the *"framework within which construction is brought about, acquired or obtained"* or as the *"acquisition of project resources for the realisation of a constructed facility"* (Rowlinson and Mcdermott 1999: 34).

Construction projects involve several disciplines collaborating for relatively short periods in the various phases of the LCD process. Traditionally, facilities were developed using a sequential approach, where process steps are conceived as separate units with clear inputs and outputs, the process is compartmentalised and characterised by sub-optimal communication between team members. However, in real-life this approach falls short when confronted by the complexity of dispersed project teams, changing client expectations, e-commerce and emerging Information Technologies (IT), especially web-technologies. IT now facilitates concurrent development of facilities by a multi-disciplinary virtual team at a continuous 24 hour pace. As a result, many facilities development projects have for the last few years followed a Concurrent Engineering (CE) or fast track process, where the design and construction phases are undertaken simultaneously and briefing and design are viewed as a constituent part of the delivery process, although often not paid for.

CE is a common practice in the manufacturing industry, with its associated benefits of a reduction of fragmentation in a project, optimal product design, low production and delivery costs, as well as overall lower LCD process costs. Other terms referring to CE are "simultaneous engineering", lifecycle engineering, parallel engineering or the "multi-disciplinary team approach". CE aims to achieve more informed decisions upstream in the life cycle development process where costs are low and the ability to influence decisions is high (Sparrius 1998) (Figure 1). The CE process is further driven by the strategy of construction professionals to build long-term relationships with clients, which in turn leads to the integration of design, construction and facilities management activities into a seamless process.

Figure 1: Ability to influence system characteristics (Sparrius 1998)



Lack of realistic process guidelines

Despite worldwide -albeit uncoordinated - movements towards an integrated and concurrent LCD process, there is a lack of documented guidelines on best practice processes in both the South African construction industry and research institutions. Knowledge of the process is mainly experiential and resident in people. For example, *The Procedural Guide for Clients, Architects and Other Professionals* (PROCAP) is the formal South African guide that outlines the steps in the facilities LCD process. This guide does not reflect the concurrent, life cycle processes followed by leading organisations.

NEED FOR THE INTRODUCTION OF NEW APPROACHES

A recent study identified three key requirements for an integrated and concurrent project environment in the South African building and construction industry (Küsel 2000). The requirements are based on new LCD process approaches in international AEC industries. These requirements could serve as a guideline to a review of existing process guidelines.

Requirement 1: A collaboration strategy

The end product in the construction industry is the result of the contributions by a range of specialised organisations, which convene as a temporary multi-organisation to complete the project. Construction professionals are now presented with different organisational procedures and processes on one project, ambiguous objectives and constantly changing requirements. Rowlinson and Mcdermott (1999: 36) describes two key complications for this situation: *Firstly,* it makes the traditional *"control and command paradigm of project management"* inefficient, which is why methodologies such as value management, which is concerned with "*resolving ambiguity by constructing a shared consensus of the project objectives"* are brought onto building and construction projects more and more. *Secondly*, it makes implementation of the traditional fragmented procurement process very difficult, which is why methodologies such as CE and Systems Engineering (SE) have come into play to allow for simultaneous design, continuous inputs by the various project members and integration between enterprise objectives, project management and SE processes.

Team collaboration should be promoted between project members to ensure qualitative processing of client requirements, communication and co-operation between all stakeholders involved with the LCD process. The practice of partnering could facilitate this principle, which enables strategic relationships and knowledge supply chains beyond a project-to-project basis, towards a more long-term arrangement. Allen (1999) describes partnering as *"a management approach to construction that places the emphasis upon continuity and the development of long-term non-adversarial relationships between all project members".* Jason Mathhews in Rowlinson (1999: 273) emphasizes how the partnering approach[5] can facilitate "the development of an effectively integrated project team capable of improving procedures and processes through resource exchange and an adherence to agreed strategy" and describes strategic partnering as the "key to innovation". He summarises six benefits:

[5] Also see the EPSRC IMI Best Practice Partnering Guidelines for Partnering in Construction - (http://www.construct-it.salford.ac.uk)

- An improved contractual situation;
- Improved communication and information flow;
- Increased understanding;
- Improved efficiency of resources;
- Improved financial situation and
- Improved quality.

Requirement 2: Integrated process management

"Systems engineering is about creating effective solutions to problems and managing the technical complexity of the resulting developments. At the outset it is a creative activity, defining the requirements and the product to be built" (Stephens *et al*, 1999: 5) Companies are pressured to compete globally and are driven by an increasing need for an ability to handle complexity. SE (http://www.incose.org) is a key technology to manage this complexity. The SE process (Figure 2) aims to achieve 'time to market with the right product', where right means what users really want, affordable and produced ahead of competitors.

The emphasis of the SE methodology to deliver the right product to the customer makes it crucial for business success. A large-scale study of several thousand engineers (http://www.standishgroup.com/visitor/chaos) listed the two most common reasons for project failure as incomplete requirements and a lack of user involvement. Five of the eight main problems were about requirements; three managerial and none were about technology. The study again emphasized the need for a good front-end SE process. Several case studies illustrate the benefits of clearly defined criteria upstream in the development process and the value of SE to reduce cost over-runs (Stephens *et al* 1999: 4). The benefits of SE for the construction industry lies within its ability to provide the integration framework for the work of all other disciplines, remaining independent of discipline and product type. It defines user requirements and creates the development architecture for those requirements. It could play a critical role as an integrator of the various stakeholders involved in the product LCD process. This is in contrast to the role of the project manager, whose task it is to ensure that everything is done, but not necessarily to do it.

The systems engineer needs to understand technical issues, translate them into user needs and negotiate with the project manager about the schedule and cost impacts. Steven *et al* (1999: 7) call project management without system engineering meaningless: "*Successful management requires trade-offs between variables such as cost, schedule, quality and performance. These tasks cannot be meaningful without the information produced by systems engineering. Because time and resources are easy to measure, management sometimes attempt to control projects without the key element of requirements. What use is meeting cost and budget targets without producing a useful product?"* Stephen *et al* (1999) propose a multi-level approach to ensure consistency of requirements, design, costs, schedule and risks. They describe a generic system development process (Figure 2), which, when applied recursively and concurrently describes the whole development. They further describe the results of this realistic system development approach as:

- Feedback from design before commitment to requirements;

- Concurrent exploration of design options at many levels;
- A multi-level recursive structuring of the system into separated developments;
- Additional engineering processes to cope with the inevitable changes at all times.

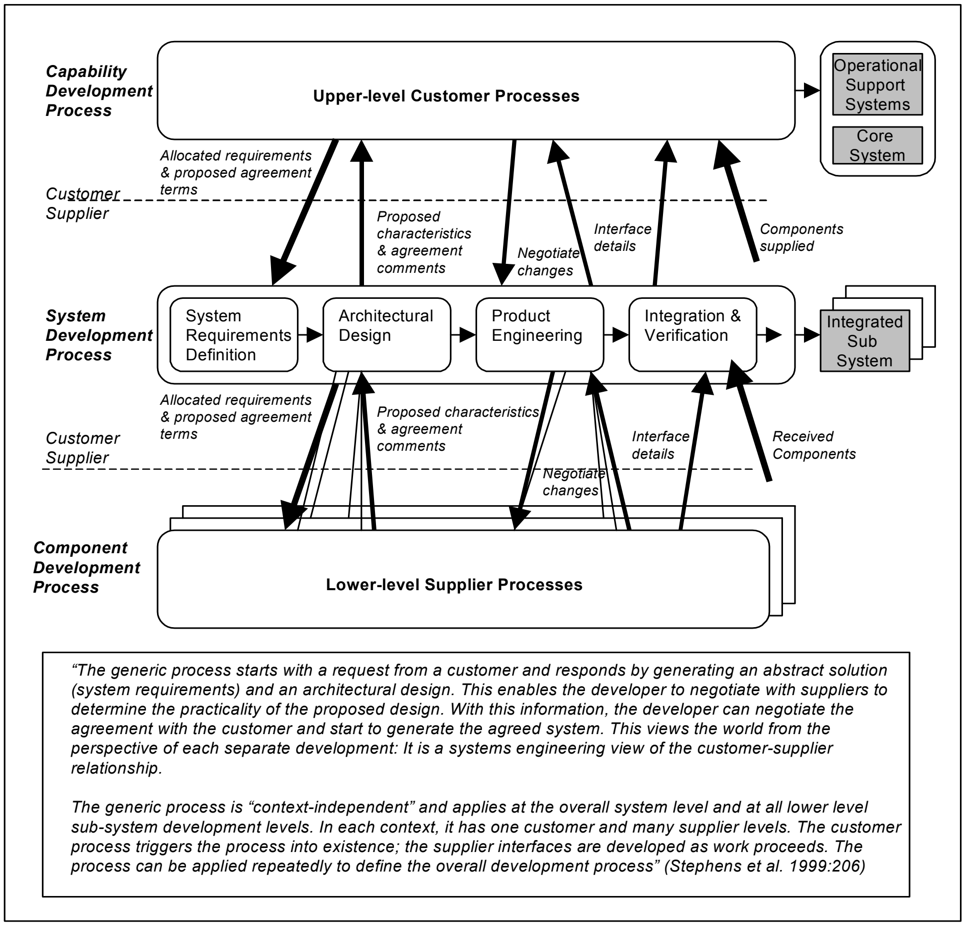


Figure 2: Generic system development process (Stephens et al 2000: 207)

The structured methodology of SE enables translation of a client's requirement into a physical solution (trace-able to the requirement) by means of a logical sequence of activities and decisions. The construction industry is under pressure to co-ordinate organisational processes involved with the facility LCD process to manage the increasing complexity and fast-track nature of construction projects. SE should be applied at the enterprise level and all organisational processes should be interlinked and co-ordinated. Web technology provides the new operational platform for integrated process management, regardless of time and location.

Requirement 3: Concurrent Modelling and Simulation

"When we mean to build,
we first survey the plot, then draw the model,
and when we see the figure of the house,
then must we rate the cost of erection;
Which if we do find outweighs ability
What do we then but draw anew a model
In fewer office, or at least desist to build at all?"

- Bardolph Shakespeare, Henry IV, Part II, Act I

A recent study into the requirements of a dispersed multi-disciplinary project team within a R1 billion South African project, revealed a key need in the South African construction industry for a capability in what-if scenario modelling and simulation across the LCD process (Küsel 2000). Due to increasing building costs, distributed project teams and difficulty grasping the holistic picture it is becoming increasingly important for construction professionals to study and evaluate the effectiveness and emergent life cycle behavior of a facility, before actually constructing it and during the construction process if changes occur. This ability is specifically important for emerging economies with limited resources.

Modelling can be described as a representation of the behaviour of a system (Roodt and Basson 2000: 1). Axelrod (1997) describes simulation as the act of driving a model of a system with suitable inputs and observing the corresponding outputs. Concurrent Modelling and Simulation (CMS) can be described as the principle of multiple parties working simultaneously on projects through a standardised and structured LCD process allowing open information exchange, modelling and simulation of design solutions and prototypes. Modelling and Simulation (M&S) add value by improving the final operational capability through primarily changing the design information and clarifying the risk.

The application of CMS in the South African construction industry is a challenge, largely due to a lack of a standardised facility LCD process, structured LCD information and a culture of fragmentation within the project environment. However, several prototype software systems have been developed in an attempt to integrate and structure LCD information. Examples are Conradie (2000), Bjoerk (1999), Anumba and Evbuomwan (1999) and Conradie and Küsel (1999). Most of these attempts concentrated on the development of an environment that will facilitate the flow of project information between the various IT support applications, during a concurrent LCD process. Such an environment is described as a *modularised project model*, which is defined by Bjoerk (1999) as *"a software representation of construction data, which supports the project throughout its life cycle"*.

The modularised model is capable of serving existing and future construction applications. In the modularised model design review and control are supported by full electronic trace-ability. Structured and hierarchical design information are linked to a relational database, where all actions, changes and decisions are stored for rapid retrieval in multi-media reports. The benefits of such an approach is that it ensures electronic trace-ability and integrity of all customer requirements and technical solutions throughout the facilities LCD process. It also facilitates the creation of an information model of the project, which supports successful decision-making. The modularised model further captures relationships and interactions that exist between the different architectural building classes. Two emerging technologies, OOCAD and XML, are key to enable the modularised model and a more integrated design and construction process within networked organisations. With OOCAD and XML entire sets of construction documents can be prepared in the form of live Web sites rather than a collection of static documents, where various levels of specificity is not supported.

Object-orientated CAD (OOCAD) enables the modelling of rich information about building components accessible to a wide variety of software applications that can be used throughout a building's life cycle without translation into other formats. The internal relationships that exist between these classes are identified through the use of object-oriented CAD (OOCAD). Knowledge is embedded in objects in the CAD system (knowledge-based OOCAD), which enables analysis of the whole product modelling process. This means that unique performance attributes (for example shape) and embedded links (for example building regulations) can be included in an electronic "object". For example, a door object will describe the physical attributes needed for design by CAD and the cost, maintenance, supply and installation properties of the door for project costing and scheduling, which will be required for facilities management (Cohen, 2000: 255). These relationships were not captured by traditional CAD systems, which complicated the management of issues in downstream applications, for example facilities management.

Extensible Markup Language (XML) is a new web language for describing information. An *aec*XML Working Group met in Dallas, Texas in September 1999 and five sub-committees were formed charged with laying the groundwork for XML implementation in the construction industry. The group also works in tandem with the integration efforts of the International Standards Organization for the Exchange of Product Model Data (STEP) and the International Alliance for Interoperability (IAI). The STEP aims to create an international standard for computer based description and exchange of the physical and functional characteristics of products throughout their life cycle and the IAI aims to develop a mechanism for sharing information during design and construction throughout the life cycle of buildings. *Extensible* means authors can add their own self-defining tags to web documents that identify information semantically and thus go beyond the relative primitive formatting, linking and display options offered by HTML. Where HTML describes how data should be presented, XML describes the data itself. For example <INSULVAL> might tell the browser that the next section of bracketed text describes the insulating properties of a material (Cohen 2000: 256). XML is seen as a key technology to enable open information exchange between systems that uses different forms of data representation – a problem to date. A number of industries, for example the medical and newspaper publishing industries are already using the technology to exchange information across platforms and applications (Cohen (2000: 256). However, as Cohen mentions (2000: 256) the key to successful application of XML in the AEC industry is to find a standardised AEC terminology. If XML is widely adopted, it will enable data sharing and e-Commerce in the building and construction industry on a new scale. Internet-delivered product data will be classified and delivered with life-cycle performance data.

KNOWLEDGE BASED DEVELOPMENT APPROACHES

Role of Web-enabled Knowledge Based Approach

Web technology is the new paradigm for designing a client orientated LCD Process and project delivery IT system. It provides the mechanism to implement a collaboration strategy within an integrated, concurrent project environment. The role of a WKB approach is to enable construction professionals to retrieve, view, evaluate, model, simulate and adapt life cycle project design fragments on their desktops, using a chosen application, regardless of time and location. WKB is of importance to the South African construction industry as a tool to achieve global competitiveness, customer satisfaction and life cycle quality in product development. It could play a significant role in improving information delivery, decision-making and knowledge management within a distributed project environment.

ORBIT - A design knowledge delivery system

The ORBIT system (Figure 3) is a prototype WKB system. Analogous to the way books are delivered to potential users from Amazon.com, the system aims to deliver relevant design knowledge to project team members and facilitate the secondary manipulation of relevant parts of the knowledge on the desktop. The research that led to the systems' evolution involved an extensive review of design philosophies, models, methods and systems in both the architectural and manufacturing field (Table 1). It further involved the development of a prototype system called AEDES (Architectural Evaluation and Design System) (Conradie and Küsel, 2000) and innovative work on the design of web-enabled intelligent components for briefing and design (Conradie 2000).

Table 1: ORBIT research base

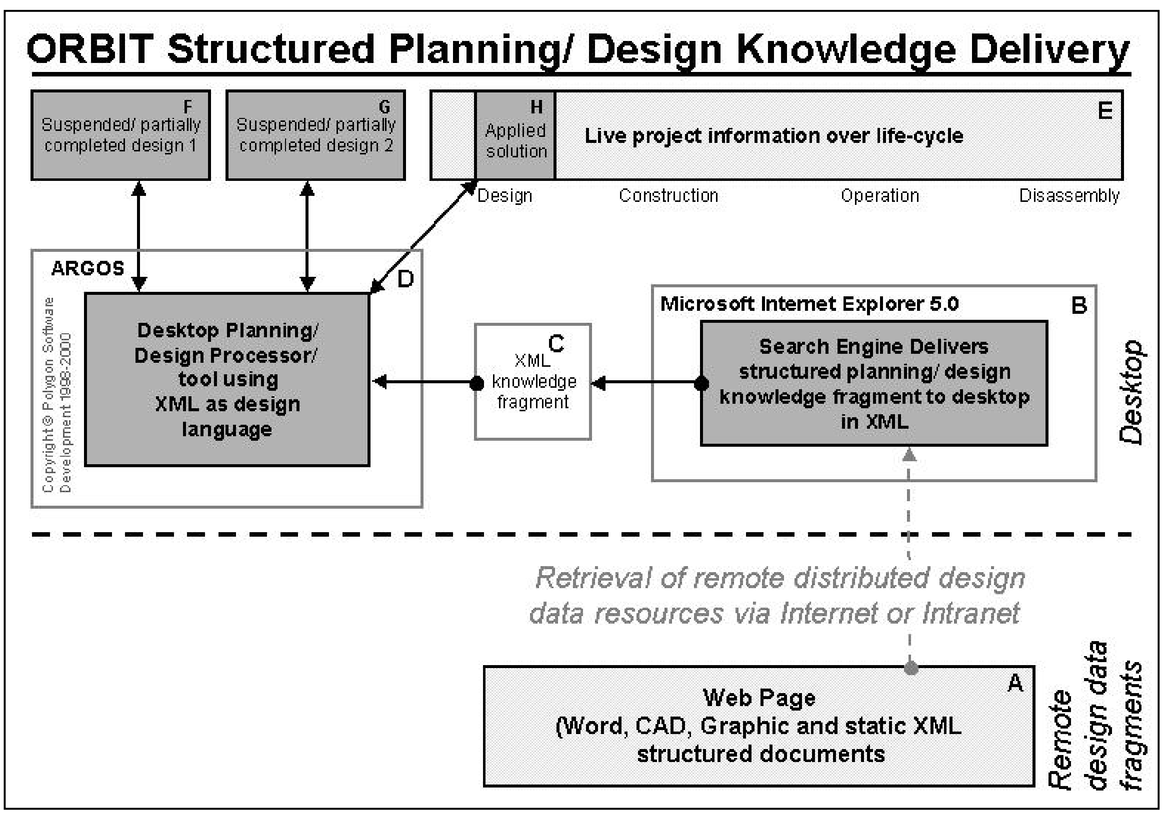
METHOD	LESSONS LEARNT
Concurrent Engineering	Integration of LCD process phases
Systems Engineering	Multi-level, hierarchical approach, recognises complexity of projects
Quality Function Deployment	Technique to translate customer requirements into design specifications
Object Orientation	Packaging of architectural elements for manipulation in a process
Case-Based Reasoning	Methodology for hierarchical structuring of objects
Extensible Mark-up Language	Enables open information exchange and hierarchical structuring of objects.

A few precedent websites exist in the world that gave an insight into the possibilities of the proposed web system. Of note is the site http://zoomon.com. The site facilitates collaborative operation and basic manipulation of drawings in a web environment. To achieve the goal of knowledge empowerment at the desktop requires structured and homogeneous design knowledge and a ubiquitous carrier such as the Internet. Such knowledge standard has been identified in the

World Wide Web consortium XML referred to previously. It must be stressed that although the conceptual model in Figure 3 is an oversimplified purist example, the following important principles are used:

- The designer remains in full control of the ultimate solution at all times.
- Design experience is stored in a structured format.
- Most information required in the planning and design environments are basically hierarchical and occur at various levels of specificity.
- XML supports the inclusion of non-XML data and can act as an integrator of diverse data sources.
- XML supports distribution of data and hyper linking.
- XML supports multi-media data sources.
- The system attempts to support design as a pragmatic and cognitive activity.
- The solution assumes that planning and design requires a continuum of design methods that use model based, rule based and case-based reasoning. It is ultimately up to the designer to decide what method he prefers.
- Current relational databases such as Oracle already support the generation of XML data from a relational query.

Figure 3: Structured planning and design knowledge as suggested with ORBIT (Conradie and Küsel 2000)



The ORBIT system will conceptually work as detailed in Figure 3. A designer that wants to design a facility or solve a specific operational problem will activate the search engine [B] in Microsoft Internet Explorer. The search engine [B] will enable the user to set basic constraints and search criteria in order to expedite information retrieval. If the relevant information is found it will be packaged in the form of an XML knowledge fragment. The user can first view the result in Internet Explorer and if he is satisfied ask the system to download it to the desktop. The ARGOS desktop planning/design processor (Conradie 2000) [D] will retrieve the downloaded XML knowledge fragment [C]. Due to the fact that design takes place in an open world it is expected that many different planning concepts might exist that need to be explored. These partially completed scenarios are stored in [F] and [G] again in XML format. Once the planner is satisfied the solution can be plugged into the live project environment [H]. It is also possible to publish good designs back into the designers personal website.

CONCLUSION

Summary

The status quo on facilities LCD processes in an information age context has been shown. The requirements of an integrated and concurrent project environment were discussed and new approaches to the LCD process introduced. The key principles and benefits of a WKB approach and a prototype WKB system, called ORBIT were also discussed.

Key benefits to South African building and construction professionals include:

- Improved ability to evaluate and adapt LCD information throughout the LCD process, regardless of time and location.
- Improved ability to provide customer value, by empowering professionals to model emerging life cycle behaviour before actual construction.
- Potential barriers/disadvantages include:
- Any innovation encounters resistance, even if it is only the inertia of set procedures.
- The change entails a considerable investment in training cost, which the industry may be hesitant to invest in a scenario of stop-go demand and the impact of AIDS.
- Government departments in the building sector seem to have other priorities than efficiency and international competitiveness.
- Commercial developers even work in the speculative market with tenuous linkages to end-users. In this case the Voice of the Customer is very faint.

Recommendations for future work

The South African building and construction industry, which includes all stakeholders at all levels, has an opportunity to become part of the global e-Commerce AEC industries. Although there are South African building and construction businesses and clients who are already a part of e-Commerce, several remain outside the circle of involvement. Empowerment of all stakeholders into global e-Commerce, will require investment and support into the research and development of collaborative, knowledge based systems, such as ORBIT, web-based learning environments and supporting information-handling toolsets, tailor made for South African usage. Participation in a global construction economy can only strengthen the local construction economy and lead to the creation of more job opportunities.

REFERENCES

ALLEN, S. 1999. *Partnering: A guideline for Managing Complex Projects*. Pretoria : Council for Scientific and Industrial Research.

ALLEN, S. and Küsel, K. *Effective Delivery of Construction Projects: Integrating Supply Chains for Delivery of Customer Benefit and Value for Money*. Proposal prepared for DACST Innovation Fund, Council for Scientific and Industrial Research, Boutek, November 1999.

AXELROD, R. 1997 Advancing the Art of Simulation in the Social Sciences: Obtaining, Analysing and Sharing Results of Computer models. *Complexity*. Vol. 3 (2): 16-22.

BJOERK, B.C. 1999. A Modularised Integrated Computer Environment for the Construction Industry: SPACE. *Internet*: http://itcon.org/1999/31.

COHEN, L. 1995. *Quality Function Deployment: How to make QFD work for you*. Reading, MA : Addison-Wesley.

COHEN, J. 2000. *Communication and Design with the Internet: A Guide for Architects, Planners and Building Professionals*. W.W. Norton & Company : New York.

CONRADIE , D.C.U. & Küsel, K. The Use of QFD for Architectural Briefing and Design. In *Transactions from the 11th Symposium on Quality Function Deployment,* Novi, Michigan, June 1999.

CONRADIE, D.C.U. 2000. *The Use of Software Systems to Implement Case-Based Reasoning Enabled Intelligent Components for Architectural Briefing and Design.* Dissertation presented for the Degree of PhD (Applied Science), University of Pretoria: Unpublished.

CONRADIE, D.C.U. & Küsel, K. 2000. *Development of ORBIT:* A *New Generation Building Industry Website.* Proposal prepared for BOUTEK, Council for Scientific and Industrial Research, Pretoria, 2000.

EVBUOMWAN, N.F.O. and Anumba, C.J. Towards a Concurrent Engineering Model for Design-and-Build projects, *The Structural Engineer,* Vol. 74, no.5, March 1996,pp. 73-78.

KüSEL, K. 2000. *The Requirements of an Integrated Project Environment in the South African Construction Industry.* Dissertation presented for the degree of MSc. University of Pretoria : Unpublished.

ROWLINSON, S & Mcdermott, P. 1999. *Procurement systems: A Guide to Best Practice in Construction*. London : E & FN Spon.

ROODT, J. and Bason, M. *Modelling and Simulation with specific reference to Hardware-in-the-Loop Testing*. Version 1: *Internet*: http://www.aoc.org.za.

SPARRIUS, A. 1998. Specification Practices. Course documentation, Ad Sparrius Systems Engineering and Management (Pty) Ltd, South Africa, June 1998.

STEPHENS, R., Brook, P., Jackson, K. & Arnold, S. 1999. *Systems Engineering: Coping with complexity.* Internet: http://www.complexsystems.com.