Aouad, Ghassan, Bakis, Nick, Amaratunga, Dilanthi, Osbaldiston, S, Sun, M., Kishk, M, Al-Hajj, A and Pollock, R

An integrated life cycle costing database: a conceptual framework

Original Citation

Aouad, Ghassan, Bakis, Nick, Amaratunga, Dilanthi, Osbaldiston, S, Sun, M., Kishk, M, Al-Hajj, A and Pollock, R (2001) An integrated life cycle costing database: a conceptual framework. In: 17th Annual ARCOM Conference,, 5-7 September 2001, University of Salford.

AN INTEGRATED LIFE CYCLE COSTING DATABASE: A CONCEPTUAL FRAMEWORK

G. Aouad[1], N. Bakis[1], D. Amaratunga[1], S. Osbaldiston[1], M. Sun[1], M. Kishk[2], A. Al-Hajj[2] and R. Pollock[2]

[1]*School of Construction and Property Management, University of Salford, UK*
[2]*School of Construction, Property and Surveying, The Robert Gordon University, UK*

Life cycle costing (LCC) is a management technique that has been available to the industry for some time, but despite this it continues to languish in obscurity. Some clients, most apparently from the public sector, are fostering the technique by commissioning studies based on the LCC appraisal techniques. However, the majority of building designs are still currently produced unsullied by thoughts of maintenance implications, life expectancy or energy consumption.

Recent technological developments, particularly in Web, Virtual Reality (VR), and Object Oriented technologies and mathematical and computational modelling techniques will undoubtedly help in resolving some of the problems associated with life cycle costing techniques. This paper outlines a conceptual framework for an innovative system that facilitates the implementation of LCC in various design and occupancy stages. This system is being developed within an EPSRC-funded research project, undertaken through a joint collaboration between the Robert Gordon University and the University of Salford.

Keywords: integration, life cycle costing, object oriented, virtual reality, whole life costing.

INTRODUCTION

LCC is a decision making tool and it involves the examination of the initial capital costs and future running costs (Coullahan and Siefried, 1996). Introduction of new PFI (Private Finance Initiatives) schemes have raised the awareness of LCC applications within construction and the days where the construction was separated from its operation is over (Jones, 2000). Some clients, most apparently from the public sector, are fostering the technique by commissioning studies based on the LCC appraisal techniques and potential benefits of applying LCC lie at the very early stages of the facility's life cycle.

The research presented in this paper aims to add a generic LCC costing element to the design phase which will allow the user within a VR environment to navigate inside the facility and retrieve information about components that need replacement or refurbishment. This would allow the user to easily inspect the facility and retrieve information about maintenance and refurbishment programmes, running costs and cash flows associated with these alternatives.

Various state of the art technologies are being employed in the development of the system; namely: VR, object orientation (OO), fuzzy set theory (FST), and web technologies. The system is an extension to the Open Systems for Construction (OSCON) database developed at Salford to support integrated environments. Enhancements to the old system include the addition of a life cycle costing dimension that allows maintenance and other life cycle costing data to be visualized in VR.

Aouad, G F, Bakis, N, Amaratunga, D, Osbaldiston, S, Sun, M, Kishk, M, Al-Hajj, A and Pollock, R (2001) An integrated life cycle costing database: a conceptual framework. *In:* Akintoye, A (Ed.), *17th Annual ARCOM Conference*, 5-7 September 2001, University of Salford. Association of Researchers in Construction Management, Vol. 1, 421-31.

The proposed system will allow the user within a VR environment to navigate inside the building retrieving all information about the building components. Such information will include LCC cost estimates and profiles, maintenance plans, and planning views. Thus, it will allow a more practical way for incorporating LCC in the design process. Furthermore, the system will allow data to be updated continuously and thus can be used as an 'asset register'. In this way, it can be invaluable for management purposes as well.

IMPORTANCE OF LIFE CYCLE COSTING APPLICATIONS IN THE CURRENT CONTEXT

The life cycle cost (LCC) of an asset is defined as the present value of the total cost of that asset over its operating life including initial capital costs, occupation costs, operating costs and the cost or benefit of the eventual disposal of the asset at the end of its life (Hoar, 1996). The LCC approach is therefore concerned with the time stream of costs and benefits that flow throughout the life of a project.

The traditional approach to costing building projects has been to focus primarily on capital costs. However, with occupancy costs representing up to 70% of the total cost of a building over its entire life cycle (Flanagan and Norman, 1987), this pre-occupation with capital expenditure has led to designs which do not offer the client best value for money in the long term. With the recent introduction of PFI procurement strategies, it is important to understand the benefits of LCC (Kirk and Dell'Isola, 1995). Many of the running costs items for buildings are labour-intensive and there has been a steady annual increase in labour costs. Energy prices have also risen and are subject to wide price fluctuations. As a result, clients are more aware that running costs should be examined very closely. In addition, mounting concerns over the long term environmental impact of a building have forced designers to adopt a more holistic attitude and to look more closely at the costs incurred over the whole life cycle, from conception to demolition (Al-Hajj and Horner, 1998).

PFI Schemes

PFI schemes involve creating partnerships between the private and public sectors (Loesch and Hammerman, 1998; Jones, 1995). For example, in the health sector, the NHS will continue to be responsible for providing high quality clinical care to patients, but, where capital investment is required, there will increasingly be a role for a private sector partner in the provision of facilities (NHS Executive, 2000). Major PFI schemes are typically "design, build, finance and operate" type of schemes. This means that the private sector partner is responsible for designing the facilities, building the facilities, financing the capital cost and operating the facilities. Risks in each of these areas will be assumed by the PFI partner, if best placed to bear them, in such a way that overall the risks associated with procuring new assets and services will be reduced (Jones, 2000). The role that LCC has to play in circumstances like this is clear and moreover, because the PFI partner's capital is at risk, they will have strong incentives to look into to running costs of the building accurately at the initial stage of the building design and continue to perform well throughout the life of the contract.

In essense of PFI is that the client defines its needs in terms of "outputs", that is, the nature and level of the service required, and invited private sector bidders to present their solutions to meet the service needs. This further allows the private sector to make the highest possible use if its experience and knowledge in LCC applications in order to bring innovating solutions to the needs of the client.

Uses of LCC

The main objective of LCC is to ensure cost control during the life of a project and to give optimum value for money invested. Apart from the issues identified above in relation to PFI procurement initiatives, in the process of LCC, a variety of other benefits are occurred. They can be summarized as follows:

- *Identifies total costs* – the LCC costing techniques enable to identify the total costs arising in a building during it's operational life without considering only the initial costs, in terms of present money value;
- *Acts as a decision making tool* – one of the most significance use of LCC is that it aids in decision making and leads to effective and economic investment policies;
- *Acts as a management tool* - the LCC technique enables better management of a building. Firstly, it enables to select the optimum solution and then it enables effective management of the building during its operation;
- *Acts as a maintenance guide* – an effective LCC management system provides with economic maintenance policies during the operation of the building. It aids to select different maintenance systems to be adopted, the maintenance cycles and their frequencies and to make repairs/replacement decisions, improvements, alterations or refurbishment decisions and also so decide on the maintenance budget.

LCC planning, analysis and management enables different options to be compared. Comparison between alternative sites and/or design proposals for new projects, comparison between existing buildings in use to meet client's needs and proposals meeting these needs by way of new projects, comparison between similar buildings of the client, and comparison between alternative building components or elements in new building projects are some of the uses of LCC, in addition to the benefits identified above (Flanagan and Norman, 1987).

PROPOSED RESEARCH

As opposed to the use of LCC applications identified above, the primary aim of the research introduced in this paper is to develop applications of whole LCC to facilitate flexible methods of predicting total LCC of construction assets and their components. In this context, the main objectives of this research are to:

- Develop a framework for data collection and recording appropriate for LCC analysis;
- Develop IT applications of LCC to facilitate flexible methods of predicting total LCC of construction components;
- Integrate whole LCC information into an integrated computer database environment;
- Extent the OSCON (Aouad *et al.*, 1997a) database developed at the University of Salford to the operation stage to provide a holistic asset management model;
- Develop a system which allows the user within a VR environment to navigate inside the asset elements retrieving information about components, which need replacements or repairs; and
- Develop the VRML interface for use in the LCC

RESEARCH METHODOLOGY

Requirement for the LCC information management system for facilities and their components, requirement for a LCC asset management component model, framework deign for integration into the OSCON (Aouad *et al*., 1997a) database environment and interface for the VR language are the different components of this research and the research methodology was identified based on these components.

A comprehensive literature review has been undertaken on all the related work in the areas of LCC, Integrated Construction Environments and VR visualization. This has led to the identification of the most appropriate methodologies and technologies for use during the project.

Data collection framework

The LCC approach is concerned with the assessment of the time stream of costs and revenues that will flow throughout the life of a construction project option (Bull, 1993). As money today has a different value from money tomorrow or money in ten years time, a technique has to be adopted that will express future costs or revenues in present values. Accordingly, in order to use LCC techniques, assumptions will need to be made in relation to such factors as inflation, interest and risk, and in the light of these assumptions discount rate will need to be determined.

The review of the literature included an in-depth examination of the material relating to current LCC applications in general and in its IT related applications in particular. The literature review reveals the established and generally accepted facts of the situation being studied, and enables to identify and understand the theories or models, which have been used by previous researchers in the field, and assists the research team.

The main purpose and outcome of this was to identify important components to be addressed in the database development. Although the area of LCC is not new, the constructs are neither well established nor standardized across and even within the construction profession. There are, therefore, an abundance of areas that require further investigation:

- *Accuracy of data* - the accuracy of LCC planning largely depends on the accuracy of historic databases available for analysis purposes. But the nature of the components of LCC are such that no proper record keeping system is available in a readily extractable form;
- *Market conditions* – the prevailing market conditions bear significant impact on LCC. The future is unpredictable, but LCC involves a great deal of predictions and assumptions of the future, such as constant rate of interests, inflation, material and component prices, maintenance and running costs. But in reality, these factors do change in different rates and different scales;
- *Life of building, components of materials* – the predicted life bears an impact on the LCC and the life could largely be influenced by the maintenance standard and the user of the building. Due to careless use and improper maintenance the LCCs may vary;
- *Type of investor/user* – the propose of the investment and the type of investor or user too would influence the LCC of a building. A developer or vendor may only be concerned with the initial costs. Where the investment and maintenance are

done by different bodies, namely in public and non-government sector, decisions may be influenced only by the investors where the concern would be only on capital costs;

- *Constraints on investment* – the shortage of capital and high financial costs and interest rates can restrict the investor on higher investment expending to reduce the running costs though however, much the LCC in this case is low; and
- *Maintenance policy and management* – one of the most common forms of problems associated with LCC is the economic obsolescence of the building occurring due to improper maintenance policy and maintenance management; etc.

LCC for construction recognizes that the technique of LCC involves the manipulation of a large amount of data (Osbaldiston and Aouad, 2000). Thus, the examination of a range of options using LCC techniques can generate a large amount of detailed working. It is important to ensure that clients are given correct level of detail upon which they will make a management decision. Further, data for LCC is uncertain because much of it relates to future costs that will be affected by inflation and other factors. Therefore, much for the current level of research is concerned in relation to the reliability of data and other associated issues identified above.

THE CONCEPTUAL FRAMEWORK DEVELOPMENT

It is well known that the benefits to be gained from a LCC analysis are maximized by applying the concepts as early as possible during the design phase of a construction project (Kirk and Dell'Isola, 1995). It is therefore critical that designers are fully aware of the impact of their design decisions on the subsequent costs-in-use of a facility. This can be difficult since the information required to make these judgements such as maintenance and operating costs may be inaccurate or may not exist in a form, which the designer can easily interpret.

Development phases - Enabling Visualization of Life Cycle Costing using OSCON

Technology, particularly integrated databases and Virtual Reality, can provide the mechanism to facilitate the integration of the whole life cost information (Greening and Edards, 1995; Sun, 1998; Aouad *et al.*, 1994; Rezgui *et al.*, 1996). This can be achieved using the OSCON (Open systems for Construction) database. OSCON application, and will extend the Virtual Reality Interface to allow the visualization of life cycle costs. This system was developed with the aim to ease and actively share construction information via a central project oriented project database. The OSCON application currently supports the functions of design, estimating and planning by allowing these phases to effectively share information dynamically and intelligently. The systems revolves around a central object oriented information model which consists of domain models which support integration of information within a specific domain, such as for example, estimating. The LCC analysis tool will increase the functionality of the system, particularly the design element and will effectively extend the scope of the OSCON suite to the occupancy stage (Osbaldiston and Aouad, 2000). Figure 1 shows the architecture of the existing suite and the proposed extensions.

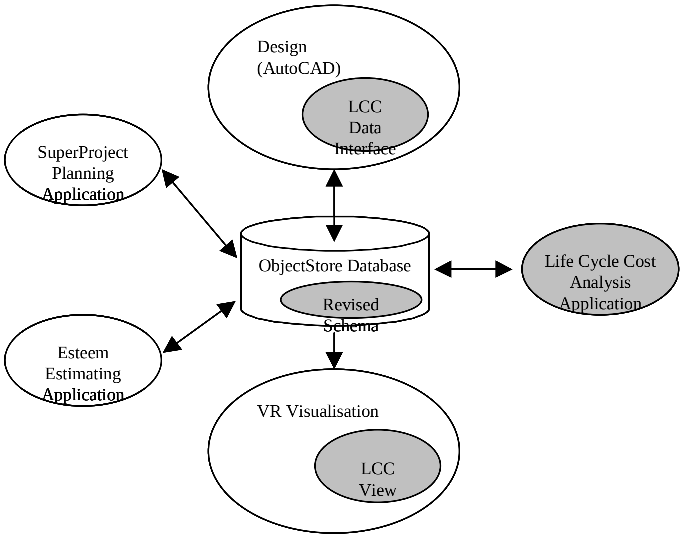

Figure 1: OSCON Architecture and proposed extensions to accommodate LCC

The virtual reality interface to the OSCON database will also be enhanced to enable visualization and interrogation of the LCC data. Virtual Reality is considered a more natural means for interfacing with complex information (Aouad *et al.*, 1998) and this has the capacity to present all relevant information within a single, visually appealing environment. This will enable designers and any other interested party to navigate the facility in real time and where necessary to interact with individual assets. The information requirements of such an operation may be determined by studying the information necessary to undertake a comprehensive LCC analysis and by examining the many worked examples, which abound in research literature (Ferry and Flanagan 1991; Kirk and Dell'Isola, 1995).

A data collection system suitable for use in conjunction with the analysis tool will also be included. This must be flexible enough to allow data collection from existing sources where available or to be entered within the design environment via a user-friendly interface. This interface will, where appropriate, guide the user through a rigorous process of component selection and specification to ensure they are made fully aware of all the cost implications of a particular design decision.

The LCC analysis will be conducted on two levels as proposed by Whyte (1999). Firstly, individual elements will be considered, taking into account all planned costs over the life cycle of that particular component. These costs will include acquisition, maintenance, operating, disposal and any others considered to be significant for that element. The second level of analysis is at the building, or overall asset level, and will give an indication of building performance, including such issues as energy consumption, management, cleaning, rates and insurance.

The VR interface is based around VRML, an open standard for the specification of Virtual Worlds on the Internet (Aouad *et al.*, 1997b). By using this open technology, no proprietary software is required to view the model and users are not restricted by geographical location. This interface will provide an entirely new "Life Cycle Cost" view in addition to the capital cost and planning views already offered by the OSCON system.

Systems Architecture

Studies on LCC involve an extensive data gathering exercise. Computer aided systems will play a substantial role towards the efficient application of the LCC technique considering the amount of information that needs to be taken into consideration when dealing with LCC analysis and planning (Osbaldiston and Aouad, 2000). Hence, the role of IT is becoming increasingly recognized for LCC as access to information is becoming universally viable through the Internet. This research aims to provide LCC data to designers and other interested parties through a familiar visual interface, which should significantly reduce the effort necessary to perform simple LCC analyses on a number of design alternatives.

Therefore, the data for each building element will be stored as additional attributes in the object oriented (OO) database along with the existing detailed specification. This additional information then automatically becomes available to all applications sharing the integrated database. New modules will be developed which when integrated into the AutoCAD drawing package allow a designer to view the additional LCC data and consequently to make more informed decisions as to the choice of design. A designer or cost engineer may also change the financial and other parameters on which the lifecycle cost calculations are based enabling a sensitivity analysis to be undertaken. This will give some indication as to the reliability of the calculations.

Design considerations of the development of the LCC Database

An integrated LCC environment not only simplifies the LCC analysis process but also provides the flexibility for a better consideration of the factors that influence the life cycle costs of a building. Therefore, it is worthwhile to address some of the design considerations in developing LCC database in the context of integrated environments:

- The level of granularity of the LCC data. LCC data come at various levels of granularity with each one of them reflecting a different level in the building decomposition hierarchy;
- Decisions on the type of database management system that is going to be used. Some of the options available are; a relational database management system (RDBMS), an object-oriented database management system (OODBMS), or an object-relational database management. The choice of the system depends on the complexity of the data and the complexity of the queries (Celko and Celko, 1997; Kember and Moerkotte, 1994);
- The way in which the LCC data are organized. The main purpose of an LCC database is to facilitate the what-if analysis of the different design options in order to identify the best possible design solutions(Charette and Marshall, 1999). In an integrated environment where this what-if analysis could be automated to some extend this issue becomes even more important. To perform that what-if analysis the integrated design tool must be able to query the LCC database for the life cycle costs of alternative components. But how can alternative components be identified? Answers needs to be found to these questions at the design and development phases of the framework;
- The way in which factors that influence the LCC data are stored in the database and used in the LCC analysis. One of the main problems of using LCC data is that it depends on many different factors that in many cases are complex and difficult to quantify;

- The ways of handling the complexity of LCC database. The development of a LCC database can be significantly simplified without any significant loss in the accuracy of predictions by identifying and using only the most significant cost components and the most important factors that influence those components. Kirk and Dell'Isolla (1995) state that 20% of the cost components account for 80% of the total life cycle costs; and
- The ways of dealing with the fact that LCC data are very sparse. If different databases for each different type of buildings are being used, then a requirement arises to devise a scheme where data common to all the types of buildings are shared between the different databases. This is particularly important if LCC data are particularly considered to be sparse.

On the basis of the above discussion and the relevant design considerations and tools identified above, a framework to incorporate the LCC element will be developed. A conceptual framework is presented in Figure 2 and a screen snap shot of how the system will look like in Figure 3.

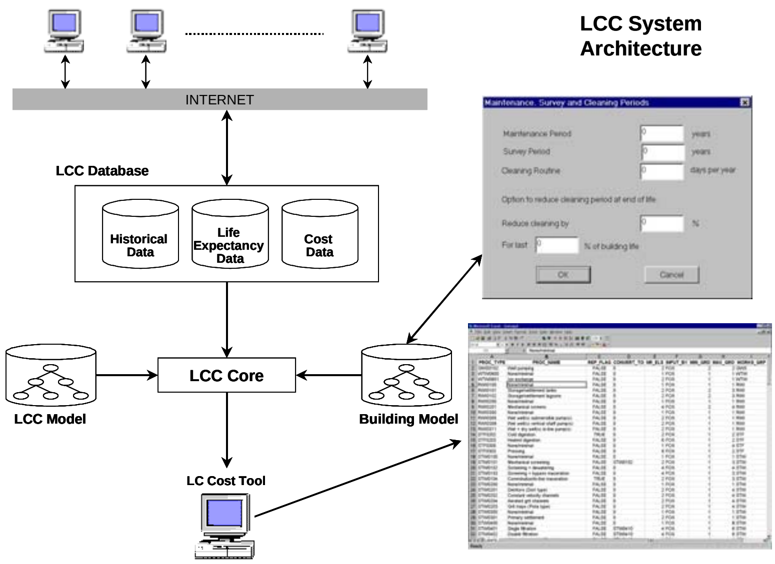

Figure 2: The conceptual framework

Intended contributions

By focusing on particular desired LCC outcomes, and working back to discover the relative importance of LCC variables in construction projects, it is expected that an insight into the subject can be provided. Another academic contribution will be to include LCC database variables into existing frameworks of building construction related data bases (e.g. OSCON), which will ultimately provide an adapted model which academics and construction industry personnel can make use of in their attempt to build data models of LCC. Furthermore, providing an all-encompassing definition for LCC and operational components of LCC in terms of certain critical factors will primarily help to expand the theoretical and empirical literature base in this currently less developed area.

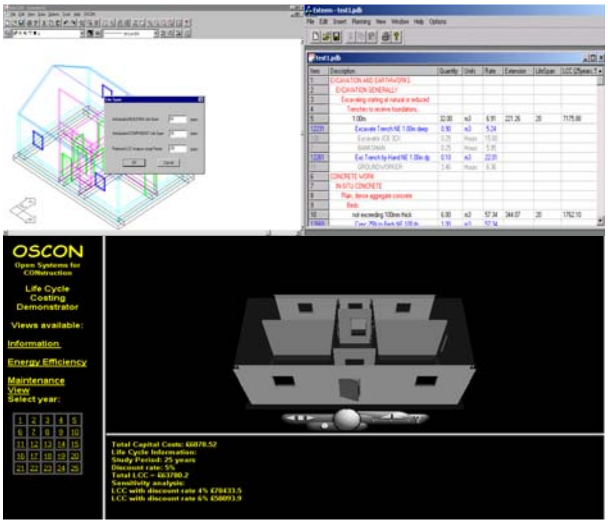

Figure 3: The LCC system presented in VRML

Practical use

The practical implications occurring from the results of this study are quite clear. It will enable the development of a database system to visualize LCC applications within the current construction context. By finding the correlation between the LCC variables, project managers can be equipped with an effective tool to determine the value and the level of acceptance of each factor contributing to the total life cycle of the building and to the overall project performance. Also this type of model will be particularly useful as it indicates the relationships between each constituent part and its associated cot element, and will be helpful to determine which types of solution will be more conducive to success. The proposed model in turn will offer a reference to assess the benefits of LCC. By clarifying the nature of the relationship among variables of LCC, it will also be helpful to derive future decisions on investment activities.

Perspectives offered would include a maintenance perspective, whereby a 4D view of the maintenance requirements of particular assets may be visualized by using a pre-defined colour scheme to highlight those elements in need of maintenance or repair at any time during the lifecycle of the building. Perspectives of operating such as cleaning costs over time may be similarly visualized, allowing a designer or client to build up a picture of the entire range of costs-in-use over the anticipated life span of the facility.

Environmental concerns may also be addressed in part by considering the energy or thermal efficiency of individual components. By rating each component with an efficiency factor relative to other similar components, it is possible to get an outline view of the efficiency of the building as a whole. Components with similar efficiency factors can be displayed in the virtual environment with similar shades, immediately highlighting any component or building element, which does not fit the desired efficiency profile of the building.

CONCLUSIONS

The value of LCC is its ability to present more comprehensive cost indications in order to permit the most appropriate selection from the available alternatives. There is an increasing realization of the importance of operation and maintenance as opposed to capital costs throughout the life of an asset. In addition, new initiatives such as PFI schemes are becoming more popular. This will result in addressing the construction project within its holistic picture including the design, construction and maintenance and running. It is therefore vital to embed the LCC element of a building within its design and construction. In this context, whole life costing is a technique used to facilitate effective choice between alternatives in the search of value for money. However, a lack of accurate data and a difficulty amongst design teams to visualize the impact of their decisions on occupancy costs have reduced the effectiveness of this technique.

This paper has given an overview of a project currently in progress to embed a LCC analysis tool within the design phase of an Integrated Construction Environment. This will effectively allow a designer, working in a familiar environment, to attach the required data to various design alternatives and immediately visualize the effects on the life cycle cost of the asset. As introduced above, the main contribution of this research will be a LCC model implemented in an integrated database and a virtual reality environment, which will help construction professionals to visually identify elements that need repair, maintenance or replacement. It is hoped that as a consequence, the industry will appreciate more the benefits of applying a LCC analysis during the early design stage as a mechanism for considering the cradle to grave implications of their work.

ACKNOWLEDGEMENTS

Authors would like to acknowledge the support of the industrial partners. This project is funded by EPSRC.

REFERENCES

Al-Hajj, A., and Horner, M. (1998) Modelling the running costs of buildings. *Construction Management and Economics.* 16: 459-470.

Aouad, G., Betts, M., Brandon, P., Brown, F., Child, T., Cooper, G., Ford, S., Kirkham, J., Oxman, R., Sarshar, M., and Young, B. (1994) *ICON (Integration of Construction Information): Integrated databases for the design, procurement and management of construction*. Final Report, Dept of Surveying and Information Technology Institute, University of Salford.

Aouad, G., Child, T., Marir, F. and Brandon, P., (1997a) *OSCON final report*. UK: University of Salford.

Aouad, G., Child, T., Marir, F. and Brandon, P. (1997b) Developing a virtual reality interface for an integrated project database environment. *Proceedings of visualization in construction* London, (Aug.): 192–197.

Aouad, G., Child, T., Brandon, P., and Sarshar, M. (1998) Linking construction information through VR using an object oriented environment. *Proc. ARCOM 14th annual conference*. University of Reading, (Sept).

Bull, J.W. (1993) *Life cycle costing for construction* London: Chapman and Hall.

Celko, J., and Celko, J. (1997) *Sceptical about ODBMSes? That's fine, but arm yourself with the facts first.* BYTE Magazine, (Oct).

Charette R.P., and Marshall, H.E. (1999) *UNIFORMAT II – Elemental Classification for Building Specifications, Cost Estimating and Cost Analysis*. NISTIR 6389, USA: (NIST) National Institute of Standards and Technology.

Coullahan, R. and Siegfried, C. (1996) Facilities maintenance using life cycle asset management. *AFE Facilities engineering journal*. (March/April).

Faraj, I., and Alshawi, M. (1999) A modularized integrated computer environment for the construction industry: SPACE. Electronic *Journal of Information Technology in Construction*. **4**, http://www.itcon.org/1999/3

Ferry, D. and Flanagan, R. (1991) *Life cycle costing* **-** *a radical approach*, CIRIA report no. 122. London: CIRIA.

Flanagan, R. and Norman, G. (1987) *Life cycle costing: theory and practice*. London: RICS, Surveyors Publications Ltd.

Greening, R., and Edwards, M. (1995) ATLAS Implementation scenario. *Proc. ECPPM '94: Product and process modelling in the building industry (ed. Scherer).* Balkema, 467-472.

Hoar, D. (1996) Life cycle Cost Management. *Quantity Surveying Techniques (ed. Brandon, P.).* London.

Jones, O. (1995) Corporate partnering in facilities management. *Facilities.* **13**(13): 21-26.

Jones, O. (2000) Future opportunities, scope and impact. *Facilities*. **18**(3/4): 133-137.

Kember, A., and Moerkotte, G. (1994) *Object-Oriented Database Management: Applications in Engineering and Computer Science* Prentice-Hall International Editions.

Kirk, S.J. and Dell'Isola, A.J. (1995) *Life cycle costing for design professionals.* New York: McGraw-Hill Inc.

Loesch, J. and Hammerman, D. (1998) Private/public partnerships to ensure building code compliance. *Facilities.* **16**(7/8): 180-191.

NHS Executive (2000) *Private Public Partnerships in the NHS : The Private Finance Initiative*. Department of Health.

Osbaldiston, S.J. and Aouad, G. (2000) Modelling and Visualizing Life Cycle Cost Data in an integrated environment, *Proceedings of the first international postgraduate conference*. UK: The University of Salford.

Rezgui, Y., Brown, A., Cooper, G., Aouad, G., Kirkham, J. and Brandon, P.(1996) An Integrated Framework for Evolving Construction Models. *The International Journal of Construction Information Technology*. **4**(1): 47-60.

Whyte, A. (1999) *The state of life-cycle costing in construction* Draft Internal Research Paper. Aberdeen: The Robert Gordon University, (Sept).