The Lifecycle Costing Simulation for Building Construction and Maintenance in nD Modelling

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ABSTRACT

The simulation of building efficiency and cost is a crucial driver to contemporary building design today. This paper presents the development of a software tool to simulate the lifecycle costs of building construction and maintenance. It is a part of the nD modelling tool development and also based on the overall system architecture of the nD modelling tool. nD modelling aims to integrate a number of design dimensions into a holistic model, which would enable users to portray and visually project the building design over its complete lifecycle. The overall architecture of the nD modelling tool is based upon IFC models, which are visualized in an integrated and interactive user interface. Thus, this tool can inherit design information through IFC models, which may be converted from the design drawings generated in various CAD systems. This lifecycle costing tool provides users with the options of different building materials and constructing methods on individual building components. Designers can make their decisions based on the lifecycle cost performance of these materials and constructing methods. The detailed maintenance costs across the building lifecycle and the cost components are clearly illustrated in charts and tables. Some key parameters of lifecycle costing can also be modified, and the dynamic changes of the lifecycle costs can also be revealed in the charts and tables promptly. Finally, the evaluations and conclusions of this tool also are discussed and drawn.

KEYWORDS

Lifecycle cost, nD Modelling, IFC

INTRODUCTION

It is commonsense today that the initial construction cost as the most visible one, represent only a small proportion of the lifecycle cost of a building. It has been estimated that the lifecycle cost is about five times as much as the initial construction cost (Evans, *et al*, 1998). The lifecycle cost usually includes building operation cost, building maintenance cost and the subsequent support, of course the initial construction cost as well. One the other hand, in many practical projects, clients always stick with initial cost rather than lifecycle cost. They have difficulties in understanding the inter-dependant relations between the capital and life cycle costs of the buildings (Barrett and Stanley, 1999). Thus, it is very crucial for the cost or investment control to accurately predict, simulate and demonstrate the lifecycle cost in the early stage of a building project, such as the design stage. To prevent this confusion of client, any decision on buildings and their life cycle should be backed by appropriate life cycle costing data and procedures which involve complex trade-off options in the design process of a structure, where the major decisions are made (Akhlaghi, 1987).

Although the significance of lifecycle costing has been recognized as early as 1980s, the current implementation has not been very satisfied due to two major barriers: the historical data of building operation (Fischer and Kunz, 2004; Clift and Bourke, 1999; Chanter and Swallow, 1996; Flanagan and Norman, 1984), and maintenance and the complexity of the procedures and algorithms of calculating the lifecycle costs (Robinson, 1996; Bakis, *et al*,2003). Conventionally, the data regarding the costs of building construction, operation and maintenance has not been collected properly. This data would be a very large quantity of information across the long term of a building lifecycle, and some information regarding the operation and maintenance could be confidential to its owners. Thus, to manually collect this data has to be very costly and time consuming. Secondly, the LCC becomes an exhaustive process when practiced manually. It could concern thousands of building elements and a number of construction-type options and maintenance activities (Robinson, 1996; Bakis, *et al*,2003) for each building element at detailed design stages. And a simple change in the building material and its specification might take long hours of re-calculations. It is therefore difficult to assist users to manipulate the large design and LCC information.

This paper addresses these two problems by developing an LCC Simulation tool based on the application of Industry Foundation Classes (IFC) as an interoperable building information model. This LCC tool is developed as part of the British Engineering and Physical Sciences Research Council (EPSRC) funded research project called: *From 3D to nD Modelling* in the University of Salford's School of Construction and Property Management. The project aims to implement building information modelling (BIM) methods and technologies to assess entire building designs on multiple and integrated aspects of construction throughout the whole building project lifecycle with respect to time, cost, accessibility, sustainability, maintainability, acoustics, crime and thermal requirements. It is demonstrated in this paper that IFC-compliant LCC tool can support users to make decisions by carrying out nD-driven evaluations on proper construction types for each building element, and monitoring the total life cycle costs of a building project in respect to the design information.

nD MODELLING AND nD PLATFORM ARCHITECTURE

In recent years, the terms of ‘nD modelling’ are becoming escalating idioms associated with ICT applications in building design. This concept derived from increased interest and research, from both industry and academic, of building information integration and interoperability, and the expansion of 3D CAD modelling with various attributes in an attempt to improve the efficiency and effectiveness of design and construction processes (Lee et al, 2003).

CAD systems have been used in building design in the last two decades. The drawing files produced in the traditional CAD software packages were simply made up of basic geometric elements like dots, lines and polygons in 2D spaces. There was no automatic function that could generate elevations and sections from plans. Any changes in these CAD systems had to be made manually at least three times in the corresponding plan, elevation and section. The recent CAD systems based on Building Information Model (BIM) can enable users to directly deal with building elements in 3D world, such as walls, doors and windows, beams, columns, slabs and roofs. BIM is an integrated information model that is consisted of both attributes of building elements and relationships between these elements. These latest intelligent BIM-based CAD systems can not only generate elevations and sections according to plans automatically, but also correspond any changes in plans, elevations and sections automatically. For instance, if any windows or doors are moved or changed on plans, the new locations and dimensions of these windows or doors will be automatically reflected on elevations and sections.

nD Conceptual Model, widens the implementation of information technology in building design and construction. It differs from other 4D modelling tools as it develops infrastructure, methodologies and technologies that will facilitate the integration of time, cost, buildability, accessibility, sustainability, maintainability, acoustics, lighting and thermal requirements (University of Salford, 2004). An nD model is an extension of the building information model, which incorporates multi-aspects of design information required at each stage of the lifecycle of a building facility. nD modelling tools are a series of multi-disciplinary ICT-based building design and analysis applications that access an nD model through an interoperable data standard. (Lee, *et al*, 2003). Based on unified 3D building information models, nD Modelling aims to explore the possibility and potential of establishing an integrated information repository and a holistic mechanism to carry out the multi-criteria (multi-dimensions) checking for building design, such as costing, accessibility, maintainability, sustainability, crime, energy, acoustics etc. This will help to improve the decision-making process and building performance by enabling true ‘what-if’ analysis to be performed to demonstrate the real cost in terms of the variables of design issues (Lee et al, 2003).

The first key issue to conduct nD Modelling is to establish an integrated information repository that should contain the attributes of each building element and the relationship between these building elements. Although the drawing files produced in most contemporary CAD systems posses these features, the compliance between these drawing file formats will impact the usage of nD modelling tools cross multi aspects throughout the whole lifecycle of a building project. It is almost impossible to keep all parties in a building project using the CAD systems developed by a single vender. Therefore, it is essential to adopt a standard building information model specification to store and exchange the information of design.

IFC is developed by International Alliance for Interoperability. It is also represented in the EXPRESS language as well. However, IFC is a kind of modelling specification particularly focusing on the product and process modelling in AEC(Architecture/Engineering/Construction)/FM (Facility Management) industry. Therefore, it can present building information more effectively and efficiently. The IFC model defines an integrated schema to depict the main physical and logical building objects, their characteristics and their inter-relationship in the form of a class hierarchy of AEC objects. The IFC hierarchy covers the core project information such as building elements, the geometric and material properties of building product, project costs, schedules, and organizations. Moreover, IFCs enable interoperability among AEC/FM software applications and this means the end users in AEC/FM area can share the model data through IFC files. Today, most of the major CAD systems of architecture design can support the export of drawings into IFC model files. So far, IAI has public several versions of IFC files including version 1.5.1, 2.0, 2.X, and IAI is still updating IFC to include more and more building design and construction and facility management information (IAI, 2004).

In the nD Modelling project, the IFC's have been adopted as the specification of its data models. The flow chart in Figure-1 shows the holistic system architecture of nD modelling tool. The nD modelling tool is designed to enable users to conduct multi-criteria evaluation, analysis and decision support.

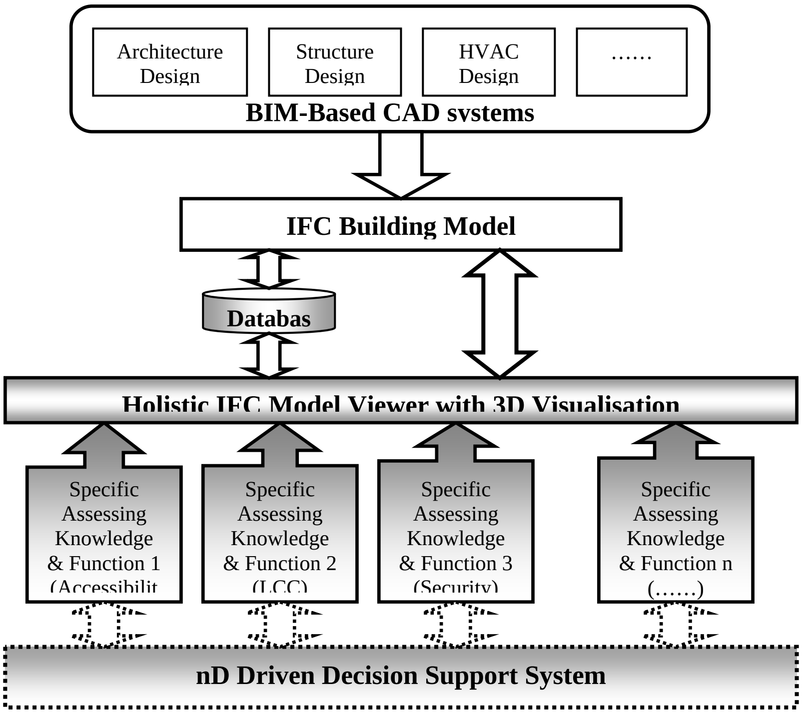

Fig. 1 The architecture of nD Modelling Tool

According to this diagram, the scenario of a nD modelling system can be portrayed as follows:

- Starting from the top of the diagram, multidisciplinary design information is generated by the various design teams using different BIM-based CAD systems. Thus, the CAD drawings should consist of building-component-oriented elements associated with 3D geometric information and relationships between these elements. As described earlier, these are the basic constituents of a BIM. An IFC model as a standard BIM actually inherits these kinds of information from the BIM-based CAD drawings. Therefore, in order to ensure IFC model files, the CAD drawings should be generated in BIM-based CAD.
- The next step is to convert the CAD drawings into IFC model files. Today, the major BIM-based architecture design CAD systems, such as Architecture Desktop produced by AutoDesk, Microstation produced by Bentley and ArchiCAD developed by Graphisoft, they all support the export of multiple versions of IFC files, especially the IFC 2.X version. Some CAD systems can even allow users to select different levels of detailed design information in CAD drawings to be exported to IFC files, such as the detail of doors and windows. Different levels of the detailed information will affect the file-sizes of IFC models.
- An IFC model viewer is developed as a holistic interface for the nD modelling prototype to provide users with an interactive environment to browse an IFC model file and conduct nD assessment on an IFC model file. Some of the processes or results of nD driven assessments will have to be visualised and simulated through this interface. Therefore, the development of the IFC model viewer is the most important part of the prototype development of the nD modelling tool. This viewer consists of three major functions. The first is that it allows users to view all of the building elements of an IFC file and some simplified and inherited links between these elements. 'Tree-view' is the best form to present these elements in an inherited structure. The second is to visually reveal an IFC model file. Virtual Reality Modelling Language (VRML) is used to represent an IFC model in 3D virtual reality world. The advantages of the VRML technique can be addressed that it can allow users to interactively navigate the 3D models and conduct some actions on any objects in a 3D VRML model. The third is to properly list out all the properties of a building element selected from either the tree-view or the 3D VRML window. In addition, the nD

model tool may also use the relational database to permanently or temporally save information or retrieve the information beyond an IFC model file, such as design criteria and relevant constraints.

- On top of the IFC compliant viewer, a number of assessing functions (sub-tools), which focus on various aspects and phases of building design, construction and facility management, will be developed separately. In other words, each sub-tool can only concentrate on assessing and analysing the data and information from an IFC model file and revealing the result of assessment and analysis in different aspects. It can be seen that the LCC is a part of this nD model evaluating functions.
- The decision support system is a high-level intelligent, knowledge-based system, which is proposed as the second phase of the development of the nD modelling prototype. It should be able to synthesise the outcomes from the multi-aspects assessments, identify and structure the problems and conflicts among the assessed results, and finally produce a range of suggestions and options of the solutions to the decision-makers.

The Development of Lifecycle Costing Tool

This IFC-compliant LCC tool is initially based on a previous research and development of LCC on the platform of Architecture Desktop (ADT) version 2.0, which was undertaken by the joint collaboration between the Robert Gordon University and the University of Salford (Aouad, 2001). Therefore, some theories, algorithms and part of the data in the database of LLC used in this development are adopted from the previous research. These include a special database - Resource Database, which stores performance and cost data of difference types of building elements. The Cost Breakdown Structure used is based on the BCIS standard (Bakis, *et al.* 2003). In the Resource database, each type of building elements is linked to a number of cost options, which consist of the costs of material components, relevant constructing and maintaining activities and frequency, such as initial, maintenance, operating, replace, disposal and resale. Besides the Resource Database, another Microsoft Access© database called Project Database is also used to store the information of each individual building project. The Project Database contains the building information, building elements information and relevant constructing options selected from the Design Tool function module.

This tool is developed mainly with Microsoft Visual Basic 6.0 associated with IFCsvr 2.0, which is an ActiveX component for handling IFC model data and developed by the VTT in Finland. It has IFC model data input/output functions as STEP Part21 file or BLIS-XML file and provides additional operations, such as IFC object searching, changing, and creating (Adachi, 2002). Another auxiliary tool used in this development is the IFC-VRML converter developed by KLine Systems in Japan, which can convert an IFC file (.ifc) into a 3D VRML file (.wrl). Due to only the executive file provided but not API or SDK, this tool has to be run separately in the IFC viewer to generate a VRML file with a same file name. In the tool, users can set some visual attributes to each type of physical building elements, such as the level of the geometric detail, colours, transparent and lighting attributes. In addition, users can also select certain types of building elements to be converted into a VRML file. Every object in the VRML file converted by this tool contains the related IFC Global ID, which ensure the compliance between an IFC model file and its converted VRML file.

As described earlier, the nD Modelling prototype tool includes a holistic IFC viewer, which can enable users to visually browse the objects and their attributes of an IFC model file. The multi-dimensions (aspects) assessment functions, of course including LCC, will retrieve and reveal IFC data through this IFC viewer. This viewer shown in Figure-2 consists of four main parts – tree-view of building elements; the 3D VRML models, which can facilitate users an interactively visual environment to walk or fly through a building; the attribute list of a selected element from tree-view or VRML model, and the assessment result table on the bottom-right of the window, which will display the results of the nD evaluations. If any building element is selected in the tree-view window or the VRML window, it will be reflected (highlighted) in the other windows. For instance, once a door is selected in the VRML window, the door element will automatically be found and highlighted in the tree-view and its attributes will be listed in the attribute table as well. This inter-connected function can help users to easily retrieve and understand the information from an IFC model.

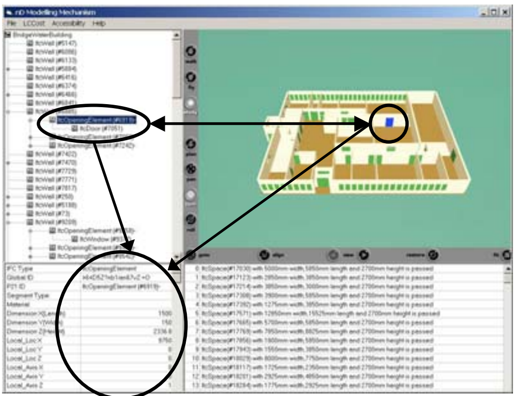

Fig. 2 Integrated IFC Viewer

The Figure-3 shows the main function modules of this LCC tool and the information flows among these modules and the databases. The LCC tool based on the IFC viewer consists of three LCC function modules. The first module is Project Setting, which allows users to input some initial data concerning a building project. The second is Design Tool, which provides users with an interactive environment to compare and assign different constructing options to each building element based on different costing issues. These options include a number of material components, relevant constructing or maintaining activities and the costs of these materials and activities, which are pre-set in the Resource Database. The third is LCC Calculation, which can summarize the final costs and breakdown details of the costs of a building project throughout the whole lifecycle defined by users in the Project Setting. The use of tool should start at the Project Setting, then go back to the IFC viewer to pick up an object (building element) from the tree-view or the VRML model. Next, the Design Tool of the LCC tool will list out all the constructing options for the type of the selected building element from the Resource Database. Users can use the functions of the Design Tool to compare the different constructing options and make their final decision based on the different cost performances. All information of the settings and the final option of the constructing type for each building element will be saved in the Project Database. After all of the elements of a building have been assigned with the better-chosen constructing types including the detail of material, the LCC Calculation module can work out the overall construction and maintenance costs of the building. In addition, the breakdown costs throughout the lifecycle expectancy of the building can also be calculated and revealed in tables and charts. The following sections will give the detailed functions and interfaces of each function module.

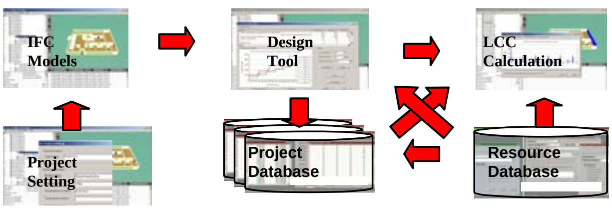

Fig. 3 The Function Modules and The Information

The initial inputs of Project Setting includes (Figure-4):

- The natural information about a building project such as Building Name, Building Type, Geographical Location, Specification Level. Although this sort of information will be not really taken into account for LCC calculation, it can help to choose the appropriate set of data from the resource databases
- Distribution Codes,
- Life Expectancy, which specify the duration of a building.
- Discount Rate, which is a crucial factor to the LCC calculation based on BCIS standard.

The Design Tool is a central part of the LCC tool. It will provide users with a number of options of materials and constructing types of each type of building elements, and their cost performance over the years of their lifecycle. This will help users to compare different constructing types based on their cost performances and achieve the better decisions in term of lifecycle costs. The Figure-5 is the first interface of the Design Tool module. Once a building element is selected from the IFC viewer, users have to choose a certain element of the building element. For instance, as shown in Figure-5 there are two elements included in the building element of an external wall – External Wall Element and Wall Finish Element. The “Statue” in the table signifies whether the detailed information related this element has been specified in the Resource Database. After a certain element being select, users have to go to the Select Type, which will give users a number of difference options of the constructing type.

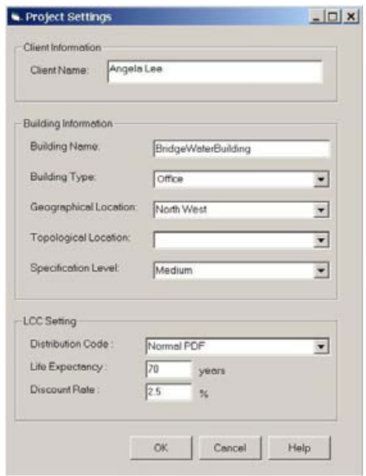

Fig. 4 LCC-Project Setting

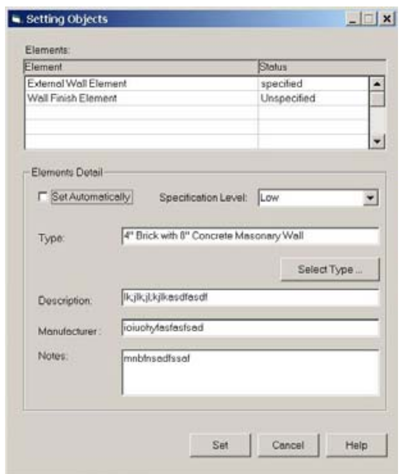

Fig. 5 LCC-Setting Objects

The Figure-6 shows the options of various constructing types and the linear chart of their costing performances. In this dialogue, users can change some variables, such as discount rate, and analysis period. Once any variables changed, the cost performance linear chart changes instantly. So that users can compare the cost performances of these constructing types to each other under the difference circumstances. Moreover, users can also select one of these constructing types and click "View Detail" to see the breakdown details of the costs in each year (Figure -7) and components of the costs. All these functions target to provide users with more and detailed information of the different constructing types, and ensure users finally make the better decision on the constructing type for each building element.

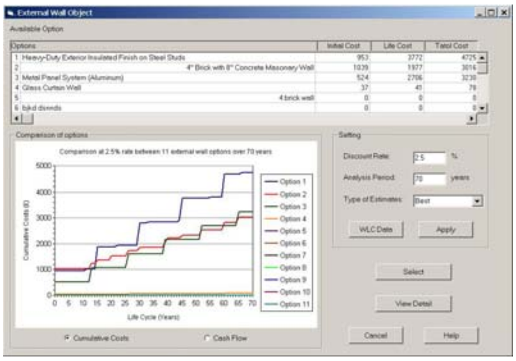

Fig. 6 LCC-choosing a construction type for a selected object

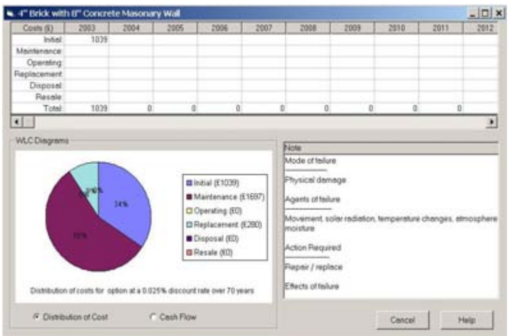

Fig. 7 LCC-Breakdown detail

Once all of the elements of a building have been assigned with the proper constructing types in the same way above, the overall costs of a building project throughout the whole lifecycle will be worked out by this tool automatically and displayed in the breakdown table or the chart of cash flows (Figure 8). And the relevant maintenance activities, which will be conducted in each year through the building lifecycle, will also be retrieved from this tool.

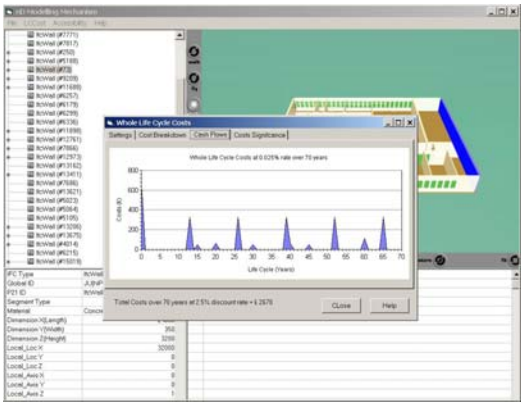

Fig. 8 The cash flow chart of the LCC tool

As a pilot study of the nD modelling research project, this prototype has been demonstrated to expert panels in a number of workshops to receive their feedback. Their feedback can mainly be categorised into two points: Firstly, this IFC-based LCC tool demonstrates the interoperable delivery of building design information across different CAD systems. In other words, this LCC tool can take the design information generated in different CAD systems, such as Autodesk Architecture Desktop, Microstation, ArchiCAD, and so on. And secondly, in comparison to other IFC-based developments, which rely on some expensive commercial tools, such as IFC viewers, EDM database, this tool is more practical and cost effective due to the exclusive application of easily accessible auxiliary tools, such as IFC ActiveX Component, and IFC-VRML converter. This can not only reduce the cost of the IFC –based developments, but also promote the flexibility of the IFC-based development.

CONCLUSION

This paper firstly reviews the importance of lifecycle costing simulation and the two problematic areas in the utilisation of LCC. The nD modelling theory and technology have been introduced as the foundations supporting this development. The holistic architecture of nD modelling prototype shows the integrated system structure to seamlessly inherit design information from various CAD systems through IFC models, and conduct comprehensive assessment on multiple aspects of building design. It also shows that the IFC viewer of nD modelling plays an intermediate interface to provide user with an interactive environment to browser the details of an IFC model. Later, the details of functions, interfaces and technical details about the LCC prototype are introduced to show its solutions to the problems identified in the conventional lifecycle costing processes. It demonstrates the capability to handle the data collection and store of lifecycle costing, and the automatic calculation of lifecycle costs, which can also immediately simulate a scenario of lifecycle costs and maintenance. The applications of this tool will liberate users from heavily manual works and improve the effective and efficiency of lifecycle costing. Moreover, the techniques and auxiliary tools, which are adopted in this development to deal with the IFC models, are proven to be a practical and economic way of IFC-based developments. In conclusion, this paper suggests that the LCC tool can assist users to achieve better decisions in terms of lifecycle costing by choosing an appropriate construction type with better cost-performance for each building element from various options.

In the future research, the development of the LLC tool will also take into account of the lifecycle costing of building service and energy consumption, rather than building construction and maintenance only. This will improve the tool to become more practical to the industry applications. The energy consumption cost issue will incorporate with the analysis of energy efficiency in nD modelling prototype tool.

REFERENCES

Adachi, Y. (2002) Overview of IFC Model Server Framework, The international conference of ECPPM 2002 – eWork and eBusiness in Architecture, Engineering and Construction, Sept. 9-11, Portoroz, Slovenia.

Akhlaghi, F. (1987) Life cycle costing – A tool for decision making, Facilities (8) 6, pp 4-10.

Bakis, N., Kagioglou, M., Aouad, G., Amaratunga, D. (2003), An Integrated Environment for Life Cycle Costing in Costruction, the 20th CIB W78 Conference on Information Technology in Construction, Auckland, New Zealand, 23-25 April 2003

Barrett, P. and Stanley C. (1999) Better Construction Briefing, UK: Blackwell Science.

Chanter, B and Swallow, P. (1996) Building Maintenance Management, London: Blackwell Science.

Clift, M., and Bourke, K. (1999), Study on whole life costing, BRE Report, CRC.

Evans, R, Haryott, R, Haste, N and Jones, A (1998) The long term costs of owning and using buildings, London: Royal Academy of Engineering.

Fischer M. and Kunz, J. (2004) The Scope and Role of Information Technology in Construction, CIFE, Stanford University.

Flanagan, R & Norman, G. (1984) Life Cycle Costing for Construction, London: Surveyors Publication.

IAI (2004) International Alliance for Interoperability Web Site, http://www.iai-international.org/, review in 2004.

Lee, A., Marshall-Ponting, A., Aouad G., Wu, S., Koh, I., Fu, C., Cooper, R., Betts, M., Kagioglou, M., Fischer, M. (2003) Developing a Vision of nD-Enabled Construction, UK: Construction IT Centre for Excellence.

Robinson, J. (1996) Plant and equipment acquisition: a life cycle costing case study, Facilities, 14(5/6), 21–5.

University of Salford (2004) nD Modelling, Available at: <URL: http://ndmodelling.scpm.salford.ac.uk>, [Accessed August 11, 2004].