AN INTEGRATED ENVIRONMENT FOR LIFE CYCLE COSTING IN CONSTRUCTION

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SUMMARY

Life Cycle Costing (LCC) has become increasingly important in construction over the last few years. However, despite its importance, it has found limited application so far. Two of the main barriers in its application are the shortage of LCC data and the complexity of the technique itself. This paper presents a computer-integrated environment, which aims to overcome those barriers by providing a framework/mechanism for collecting and storing the LCC data and a number of tools for assisting and simplifying the application of the technique. The main characteristic of the environment is that it provides a holistic approach to Life Cycle Costing by integrating the collection of the data and the LCC-aware design and management of buildings within a single framework. A database, which is flexible enough to accommodate the needs of any user, is used to store the LCC data. An integrated and interactive design tool is used to assist and simplify the LCC-aware design of buildings. A three-dimensional visualisation tool is used to assist the facilities manager in the LCC-aware management of buildings. Information collected from each building is fed back into the system to update the existing LCC data.

INTRODUCTION

Life Cycle Costing (LCC) or Whole Life Costing has become increasingly important over the last few years. The introduction of PFI (Private Finance Initiatives) schemes and the recognition that the preoccupation with capital expenditure does not offer best value for money in the long term have dramatically increased the awareness of LCC. However, despite its importance Life Cycle Costing has found limited application so far. This paper presents an integrated Life Cycle Costing environment, which aims to address two of the practical reasons for the limited application of Life Cycle Costing: the shortage of LCC data and the complexity of the technique itself. The paper begins with the necessary background on Life Cycle Costing and then presents the integrated environment in more detail. It concludes with the directions for future work and conclusions.

The concept of Life Cycle Costing

Life Cycle Costing is an economic evaluation technique that concerns the assessment of the total cost of an asset over its operating life, including initial capital costs, maintenance costs, operating costs and the cost or benefit of the eventual disposal of the asset at the end of its life (Flanagan *et al*, 1989). Life Cycle Costing is a decision making tool, a management tool, and a maintenance guide. It is a decision making tool in the sense that it could be used to select among alternative projects, designs, or building components. It is a management tool in the sense that it could be used to estimate the costs that will incur during a building's life. It is a maintenance guide in the sense that it could be used to forecast the maintenance and operating tasks that will incur at each year of a building's life (Kirk & Dell'Isola, 1995).

Life Cycle Costing Techniques

Life Cycle Costing could be applied at any stage of procurement. It could be applied at the inception stage to select among alternative projects. It could be applied at the detailed design stage to select among different design options or building components. At the inception stage where only the client requirements are known the life cycle costs are estimated in broad terms based on costs that incurred in similar buildings in the past. As the design of the building becomes more detailed, the life cycle costs are estimated in more detail too. At the late design stages where the individual building components are known the life cycle costs are estimated based on performance and cost data of the building components. For example, by knowing the price and life expectancy of a building component as well as the cost and frequency of all the maintenance and operating activities associated with that component we can estimate its life cycle costs. The life cycle costs of all the components together with the building wide costs, such as energy consumption and insurance costs, constitute the life cycle costs for the building (Kirk & Dell'Isola, 1995).

The estimated costs at each year of the building's life must be *discounted* to make proper allowance for *time value of money* and enable the comparison of the alternatives on a common basis (Flanagan *et al*, 1989). What is meant by *time value of money* is that money has time value, as money set aside today would increase every year by the net inflation interest rate. This means that the present value of a future sum is less the further away in time the sum is due to be received or expended. To put it in another way, we have to set aside less today in order to meet a higher expenditure in the future. Calculating the life cycle cost of an option by merely adding up the constituent costs would be incorrect as to do so would be to ignore the timing of those costs. Rather, the costs should first be converted to present values and then added up to compare the different options on a common basis. The most common comparison measure used is the Net Present Value (NPV). However, other measures, such as the Equivalent Annual Cost, Payback Period, Return on Investment, and Saving to Investment Ratio could also be used (Ashworth, 1999). The risk associated with each option might also be taken into account. Various risk assessment techniques could be used to assess that risk. For example, sensitivity analysis could be used to assess the impact of a change in an input variable on the life cycle costs of an option. Or, Monte-Carlo simulation could be used to obtain a range of possible values for the life cycle costs of the option (Whyte et al, 1999).

An important concept in Life Cycle Costing is the *Cost Breakdown Structure (CBS)*. The Cost Breakdown structure represents the way life cycle costs are broken down and presented. As the aim of Life Cycle Costing is the comparison of alternatives, the life cycle costs – and consequently the LCC data – should be presented in a way that enables that comparison. A product based classification scheme would not help, as alternatives are identified on the basis of their functionality and not on their design specification, construction method, or materials used. For example, as wall paints and wallpapers play the same role – that of a wall finish –, both should belong to the same category. Or, as the internal walls would have different life cycle costs from the external ones they should belong to different categories. In Life Cycle Costing the building components are grouped into categories according to their functionality. The term *building elements* is traditionally used to refer to those categories. A classification scheme that is based on an elemental classification is simply called *elemental*. Examples of elemental CBS are the Building Cost Information Service (BCIS) Standard Form of Cost Analysis for Building Projects (Whyte et al, 1999), the cost classification scheme used by BMI in its Price Information Book (BMI, 1999) and UNIFORMAT (Charette & Marshall, 1999). An elemental CBS is usually hierarchical to enable costing at different levels of detail. The complexity and detail of the CBS depends on the scope and objectives of the LCC exercise.

Barriers in the application of Life Cycle Costing

Despite its importance Life Cycle Costing has found limited application so far. Recent surveys in the UK indicate that the application of Life Cycle Costing remains limited to PFI projects and is mostly undertaken at the early stages of procurement (Clift and Bourke, 1999; CBPP, 2000). Surveys in other countries also indicate a limited use of Life Cycle Costing in construction (Wilkinson, 1996; Sterner, 2000). There are a number of reasons for the limited application of Life Cycle Costing so far. Some of them are practical while others are political. Bull (1993) mentions that capital costs and operating expenditure are usually met by different parties and there is no incentive on behalf of those responsible for construction to reduce the subsequent costs-in-use. Ferry and Flanagan (1991) mention the difficulty in forecasting over a long period of time factors such as life cycles, future operating and maintenance costs, and discount rates. NSA (1991) mentions several reasons for the reluctance of the public sector to invest in Life Cycle Costing: (i) the fact that many facilities have long service lives compared to the lifetime of agency missions and legislated programs; (ii) the fear that the use of a facility could change in the future and the application of Life Cycle Costing could be seen as a waste of money; (iii) the practice of many decision makers to opt for minimum initial investment either to increase return on investment or meet budgetary restrictions; and (iv) the fact that the government agencies are reluctant to invest in the more expensive options when there are no solid technical data to guarantee any future savings.

Two other reasons, which the system presented here aims to address, are the shortage of LCC data and the complexity of the LCC exercise. The LCC data consist the basis for Life Cycle Costing. Without them the application of Life Cycle Costing is not possible. However, at the moment the availability of LCC data is rather limited. One of the main reasons for this is the lack of any frameworks or mechanisms for collecting and storing the data (Clift and Bourke, 1999). The accounting systems used by building managers and contractors seldom make it possible to identify accurately the costs of maintenance and repair of specific components (NSA, 1991). The estimation of the life cycle costs itself is a rather complex exercise to be applied manually, especially at the detailed design stage. The analyst has to estimate the life cycle costs of each alternative option for each building element. The life cycle costs of each option might consist of seveal cost items. For each cost item he has to retrieve the related performance and cost data. As the cost data are expressed in unit rates, he has to estimate each cost based on the option's physical characteristics. In addition to the costs related to the building's elements, he has to estimate the building wide costs, such as for example energy consumption and insurance costs. All costs must be discounted, added up and projected over the building's life cycle. The same process must be repeated for each alternative design. Complex interrelations between different types of costs and elements might make it difficult to select the best possible option, as improvements in one area might have negative effects in others. The selection of the best option might be further complicated by the fact that other factors besides life cycle costs, such as aesthetics and easy of use, might also be deemed important.

THE LCC INTEGRATED ENVIRONMENT

To assist the application of Life Cycle Costing, we have developed a computer-integrated environment, which provides a framework/mechanism for collecting and storing the LCC data and a number of tools for assisting and simplifying the application of the technique. The main characteristic of the environment is that it provides a holistic approach to Life Cycle Costing by integrating the collection of the data and the LCC-aware design and management of buildings within a single framework. At the moment, the environment supports only the life cycle costs of building elements, however, it could be extended to support other building wide costs such as energy consumption, insurance costs and security costs.

As illustrated in figure 1 below, the integrated environment consists of four main components, with each one feeding forward the other. The *Resource Database* stores the performance and cost data

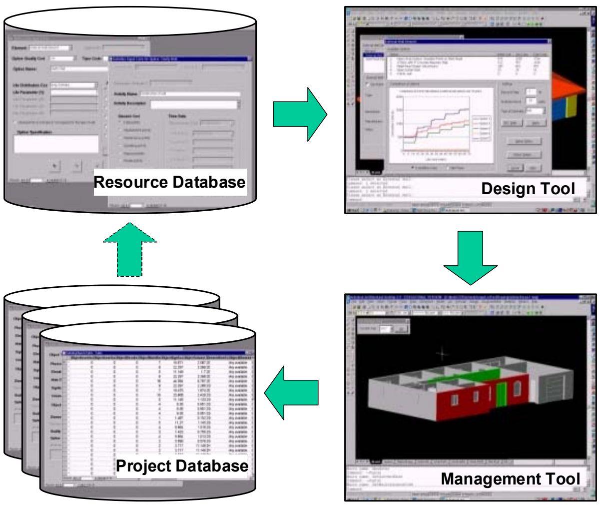

Figure 1 The LCC Integrated Environment

used for the Life Cycle Costing estimations. The *Design Tool* is an integrated and interactive design environment that assists the LCC-aware design of buildings. It uses the data stored in the Resource Database to assist the designer in selecting the most appropriate, from a Life Cycle Costing point of view, option for each building element. It also estimates the life cycle costs of the building's elements and provides a number of tools for analysing those costs. The *Management Tool* is a visual, three-dimensional environment, which is used during the occupancy stage to assist the facilities manager in the LCC-aware management of buildings. It indicates the maintenance and operating tasks that should be undertaken at each time, and records information about the tasks that have been performed. The information collected from each building is stored in a dedicated *Project Database.* The data stored in each Project Database could then be analysed to update the overall LCC data stored in the Resource Database, completing thus the feed forward cycle in the system. The following sections present each of those components in more detail.

The Resource Database

The Resource Database stores performance and cost data of building elements. The Cost Breakdown Structure used is based on the BCIS standard. For each building element the user could specify any number of different options. For each option he specifies the life expectancy and initial cost as well as the costs and frequencies of all the maintenance and operating activities associated with it. An important characteristic of the Resource database in relation to other efforts (El-Haram, 2002) is that it does not predefine any maintenance and operating activities with each building element. Instead it lets the user to specify those activities according to his needs.

For each building element stored in the database the user can specify any number of activities. For each activity he specifies the name, the frequency and whether the activity is initial, maintenance, operating, replacement, disposal or resale. For each activity he can then specify any number of cost items. The use of cost items enables to break down the costs at a higher level of detail. For example, the costs of the 'Wall Construction' activity could be broken down to the 'Wall Construction' and 'Initial Costs of Sealant at Joints' cost items. For each cost item, the user specifies the name, the rate, and one of the predefined rate codes (e.g., per unit, per significant element area, per element value), which indicate how to calculate the cost. One might argue that some costs could not be expressed using single rates but require more complex functions. However, what we have seen is that, on the one hand, this is rarely the case and, on the other, we could always use a simpler function to express a fair approximation of the cost.

The advantage of predefining the tasks is that we could develop a standard database that could be shared by the whole industry. However, as with all standards, it is rather difficult to satisfy the needs of all the users. Different users might wish to express the LCC data at different levels of detail. In addition, as our experience has shown, it is rather difficult to find large volumes of data, which we'll need to analyse before devising any standard. But even if a standard is devised, the success of an industry-wide database is questionable as LCC data represent a valuable resource that many organisations, especially cost consultants, might not wish to share. By adopting a more flexible approach we could at least provide a tool that could be used immediately by the industry. And as we'll in the next section, the fact that there is not any predefined structure does not mean that an automated life cycle costing tool, like the Design Tool presented in the next section, could not use the data stored in the database to estimate the life cycle costs of a building. Based on the rate codes and the physical characteristics of each building element it could calculate all the cost items associated with that element. Based on the CBS and the type of each activity it could report the costs in a meaningful way.

To improve the accuracy of the data, the database enables the user to specify various meta-data, such as the specification level, type, height, size, and location of the building that each set of data refers to. The user is free to use any level of granularity for the meta-data. The greater this level is, the more accurate, but also sparser, the data will become. The user could specify a single value for each parameter or a min, max and mean value depending on the statistical distribution that he wishes to use. For each cost item, he can specify a single all-in one rate or each of the labour, material and equipment rates separately. The Resource Database has been implemented in Microsoft Access and provides a number of user-friendly forms to input and access the data. For more information on the database and its development the reader could refer to Kishk *et al* (2002).

The Design Tool

The Design Tool is an integrated and interactive design environment that assists the LCC-aware design of buildings. The Design Tool has been implemented on top of AutoDesk Architectural Desktop 3.3, but it could be ported to any other object-oriented design package. The Design Tool is interactive in the sense that assists the user in selecting the type of each building element as he designs the building. In Architectural Desktop each building object, i.e., a window, has a specific style but not a specific type. The Design Tool assists the user in specifying that type by accessing the Resource Database and calculating the life cycle costs of the various types available. Before describing how this is done in more detail, we should mention that there is no direct, 1-1 mapping between the architectural objects in Architectural Desktop and the building elements in Life Cycle Costing. For example, a wall object consists of three building elements, i.e., the wall itself and the two wall finishes. Or, while there is no distinction between internal and external walls in Architectural Desktop, there is one in Life Cycle Costing.

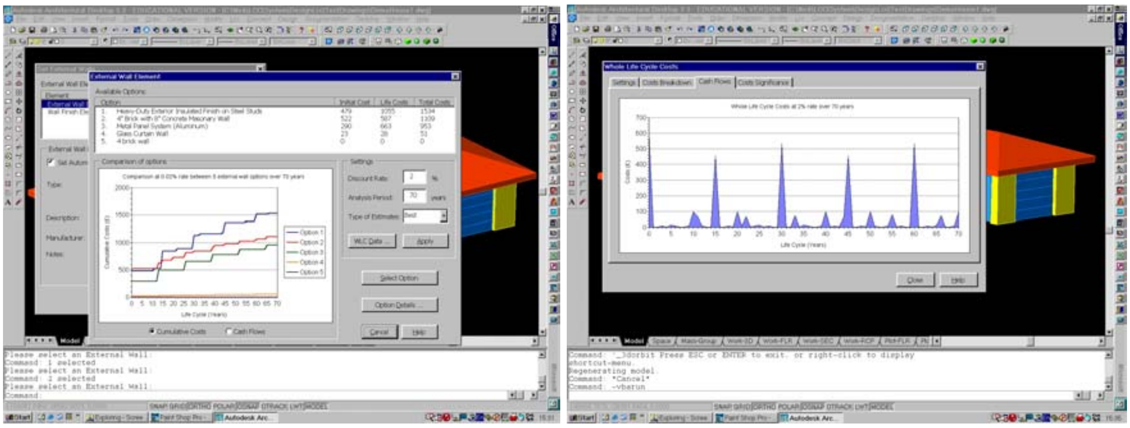

Figure 2 A snapshot of the Design Tool.
(a) Comparison of alternative options. (b) Cash flow analysis.

To use the Design Tool, the designer initially specifies some general information about the building, such as its specification level (low, medium, high), its type (industrial, educational, residential, etc), and its geographical location. This information is used to select the appropriate set of data from the Resource database. As he designs the building, or even after finishing the design, he can query the database for a list of all the alternative options for any of the building's elements. He first selects the objects that he is interested in, for example any of the internal walls, using the standard Architectural Desktop's commands. If the object has more than one element, he selects the element that he's interested in. The system then accesses the Resource Database and retrieves all the existing options for that element. For each option it calculates the life cycle costs by retrieving all the activities associated with it and all the cost items associated with each activity. For each cost item it calculates the cost based on the unit rate and the dimensions of the selected objects. The costs are estimated for each year of the building's life and discounted using the discount rate set by the user. Based on the type of each activity (initial, operating, maintenance, etc), the costs are grouped and presented in a meaningful way.

To assist the comparison of the different options, the Design Tool orders them based on their life cycle costs and draws several charts. It draws a chart that compares the options' cumulative costs over the building's life cycle (figure 2(a)), a chart that compares the options' distribution costs over the building's life cycle, and a chart that indicates the significance of each option in relation to the total costs of the building. The system also enables the designer to check each option in more detail. In addition to the LCC data, the Resource Database stores textual information, such as for example the sensitivity of the option in several environmental conditions or the danger to health that this option represents in the case of failure. This information might be proved more important than the life cycle costs in the selection of the preferred option.

One interesting point that we should make at this point is that there could be interrelations between the different elements of a building (Horner & Zakieh, 1996; Woodward *et al*, 1994). For example, a particular type of wall might not require a finish or it might require a particular type of finish. At the moment, the system supports only the interrelations between elements of the same building object and not between elements of different objects. The user could specify in the Resource Database whether there is an interrelationship between the elements of an object and the Design Tool will indicate that interrelationship while comparing the options. However, such a simple scheme might not be adequate for more complex cases. In more complex cases, we might have to compare combinations of options rather than single options.

Once the designer have specified the type of all the building's elements, the Design Tool can estimate the life cycle costs of the building and present them in various formats, including a breakdown of the costs per year, type and element, a comparison of the most significant costs, and a chart of the costs' distribution over the building's life cycle (figure 2(b)). At the moment the Design Tool does not provide any risk assessment tools, however, the user could try different discount rates and analysis periods to get an indication of how the costs could be affected.

The Management Tool

The estimation of the life cycle costs of a building and the selection of the best components during the design stage is based on the assumption that a particular operations and maintenance regime will be followed during the occupancy stage. Most of the LCC data, such as for example the anticipated life expectancy of the building's components, presuppose a specific level of maintenance. If this level is not reached the life cycle costs may increase dramatically and the selected components might not be proven to be the best options. To assist the facilities manager in following the anticipated operation and maintenance regime, the Management Tool indicates the tasks that must be performed at any point in time using a three dimensional visual interface as shown in figure 3 below. The Management Tool also records information about the tasks that have been completed, operating thus as a front end to the building's Project Database.

The Management Tool has been built on top of AutoDesk Architectural Desktop 3.3, and as the Design Tool, it could be ported to any other object-oriented design package. Based on the LCC data

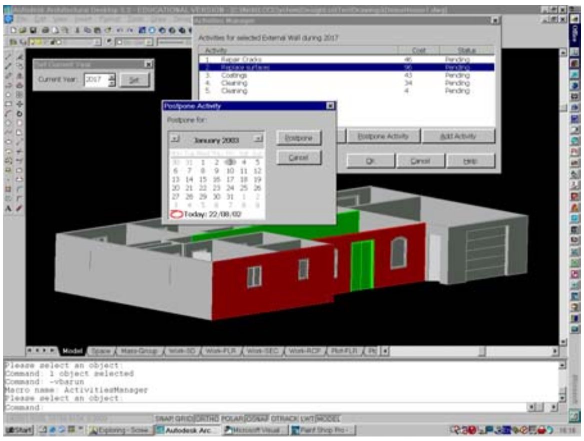

Figure 3 The Management Tool

stored in the Resource Database, the Management Tool could indicate the operating, maintenance and replacement tasks that must be performed at any point in time. By using the building's 3D design and a simple colour-based scheme it highlights the building components that are associated with any operating, maintenance or replacement activities. Although for small buildings this visualisation aid might not be important, for large buildings it could be proved very useful as it assists the facilities manager in focusing his attention to the most important areas of the building. The user can select any of the highlighted objects and the tool could display all the tasks associated with that object. He can then schedule the tasks for a specific date or postpone them for some later data in the future. He also can mark the tasks that have been performed and specify their actual costs. The actual cost of each task as well as its frequency is saved in the building's Project Database. An interesting question that arises is how the actual LCC data from each building could be used to improve any future predictions for that building (Ashworth & Au-Yeung, 1987). For example, a difference in the actual frequency of an activity might indicate a special condition for the building. The question of how to take into account those data remains open and the integrated environment does not address that question at the moment.

The Project Database

As it was already mentioned above, there is a dedicated Project Database for each building. The Project Database stores all the products that have been used for each building element over the building's operating life. For each product, it stores all the operating and maintenance activities that have taken place over the product's life. For each activity, it stores the actual frequency and costs. In essence, the Project Database stores the history of the activities associated with each building element. The data stored in the various Project Databases could be used to update the historical data stored in the Resource Database. This could be done automatically, however, the integrated environment does not provide such functionality at the moment.

FUTURE WORK

From a practical point of view, the integrated environment could be extended to support all types of life cycle costs and provide some additional functionality. At the moment, the environment estimates only the life cycle costs of building elements and it could be extended to estimate and the building-wide costs, such as energy consumption, insurance and security costs. Risk assessment tools could be provided. From a theoretical point of view, the development of the environment gave rise to three important issues, which are worth investigating. The first issue concerns the interrelations between costs and building components and the way those interrelations could be handled, especially at the user interface level. The second issue concerns the importance of the actual LCC data that each building generates in improving the future predictions for that building. The third issue concerns the way the actual data from the various buildings could be automatically analysed to update the overall, historical data stored in the system. Some of those issues might be addressed in the context of the *nD Modelling* project[1], undertaken at the University of Salford. One of the aims of the project is to integrate the system with a number of other design tools to provide a more complete design environment to construction. A research bid has also been put forward to evaluate the software in the development of Terminal 5 at Heathrow airport.

CONCLUSIONS

Despite its importance, Life Cycle Costing has found limited application in construction so far. This paper presented an integrated environment, which aims to assist the application of Life Cycle Costing by providing a framework and a mechanism for recording the LCC data and a number of tools for assisting and simplifying the application of the technique. The main characteristic of the environment is that it provides a holistic approach to Life Cycle Costing by integrating the collection of the data and the LCC-aware design and management of buildings within a single framework. An additional characteristic is that it does not impose any particular structure to the LCC data but it rather lets the user to specify that structure according to his needs. The development of the system gave rise to two important issues. The first concerns the interrelations between the different building elements and the way those interrelations could be handled. The second concerns the importance of the actual LCC data of a building in predicting the future costs of that building. The system presented here addresses some of the practical problems in the application of Life Cycle Costing in construction. Hopefully the over increasing popularity of PFI and partnering schemes will help to overcome and the political ones, making Life Cycle Costing an established technique.

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[1] http:// ndmodelling.scpm.salford.ac.uk

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