EFFECTIVE MEASUREMENT AND VISUALIZATION OF WHOLE-LIFE COSTS OF BUILDING ELEMENTS

Mohammed Kishk[1], Assem Al-Hajj and Robert Pollock

The Scott Sutherland School, The Robert Gordon University, Garthdee Road, Aberdeen AB10 7QB, UK

Various metrics and procedures required to effective whole-life management of buildings are outlined. This is followed by introducing a novel generic whole-life cost significance relation to identify buildings' cost significant items on various levels. Then, the details of the implementation of this relation into a useful computer application are briefly presented. This application has been designed around a recently developed WLC project database. The unique feature of the application, amongst others, is that it has an interactive user-friendly interface to visualize various WLC metrics of the building object under consideration.

Keywords: cost significance, whole-life costing, whole-life management.

INTRODUCTION

The scope of a whole-life costing management (WLCM) application is the whole-life of the asset under consideration. Besides, each cost item is usually represented by a number of cash flows over time. Therefore, it is essential to employ cash flow techniques in modelling and visualization of whole-life costs during the occupancy stage. However, this could be a tedious task as several whole-life costing (WLC) profiles need to be created and updated and used in the effective management of the building.

Several applications purporting to provide whole-life costing support have been evaluated against a number of criteria by Kishk *et al.* (2003a). These applications vary from free simple spreadsheet models to sophisticated, commercial stand-alone applications. Most of these applications are for decision-making purposes and employ a generic non-standard cost breakdown structure. Few applications seemed to have whole-life management capabilities including the ability to record, modify, analyse and manage WLC data for an asset. All existing applications within this class are commercial, general-purpose systems that would require extensive training of users. Besides, the CBS is usually built manually by the user and is mostly non-elemental. Thus, it was concluded that there was and still is, a need to develop WLCM applications for construction assets.

The objective of the research work that underpins this paper was to develop an application to automatically develop and visualize whole-life costs of building elements. The rest of the paper is organized as follows. In the next section, various crucial WLC measures and processes are identified. This includes the introduction of a new WLC-based cost significance relation. Next, the development of the application is reported. Finally, the work is summarized and further future research is introduced.

[1] m.kishk@rgu.ac.uk

Kishk, M, Al-Hajj, A and Pollock, R (2003) Effective measurement and visualization of whole-life costs of building elements. *In:* Greenwood, D J (Ed.), *19th Annual ARCOM Conference*, 3-5 September 2003, University of Brighton. Association of Researchers in Construction Management, Vol. 1, 43-52.

CRUCIAL WLCM MEASURES

Effective whole-life costing management include, amongst others, four key processes (Kishk *et al.*, 2002b): (1) recording the actual performance and cost history of the building; (2) analysis of the recorded history and feeding the accumulated experience back to the design process and forward to future stages of the life cycle; (3) assessment and control of costs throughout the whole life of the building; and (4) planning the timing of work and expenditure. A number of WLC measures and procedures crucial to support these processes are outlined in this section.

WLC modelling

As mentioned above, it is crucial to employ the cash flow technique in deriving various procedures and measures of the application. The whole life cost contribution of any cost item C_i, represented by T cash flows C_t^i, can be calculated using the discounted cash low technique as

$$NPV_i = \sum_{t=0}^{T} PWS_t C_t^i \tag{1}$$

where PWS_t is the discount factor at time t given by

$$PWS_t = \frac{1}{(1+r)^t} \tag{2}$$

and r is the discount rate.

WLC profiles

Planning profiles of various activities will be represented in the form of cash flow diagrams (CFDs) or as discounted cash flow diagrams (DCFDs). A CFD of an activity shows the ‘real money’ required at every year of the analysis period to carry out that activity. A DCFD shows the present values of these real cash flows, i.e. the amounts of money that need to be invested today to meet future requirements of the activity.

Other crucial WLC profiles include the cumulative whole-life cost contributions (CWLC) and the remaining whole-life cost contributions (RWLC). The CWLC is the summation of all discounted cash flows within the period from the initial time, $t = 0$, to the present time, pt, i.e.

$$CWLC_i = \sum_{t=0}^{pt} PWS_t C_t^i \tag{3}$$

The RWLC is the summation of all discounted cash flows within the period from the present time, pt, to the end of the analysis period, T, i.e.

$$RWLC_i = \sum_{t=pt}^{T} PWS_t C_t^i \tag{4}$$

The cost significance relation

It has been long recognized that it is impractical to consider all whole-life cost components during the management of occupied buildings. Thus, many researchers (e.g. Al-Hajj, 1991; Al-Hajj and Horner, 1998) proposed to focus on the so-called ‘cost significant’ areas where cost effectiveness might easily be realized. Based on earlier work on cost significance (Horner and Zakieh, 1996; Al-Hajj and Horner, 1998), Kishk *et al.* (2003b) derived a generic relation to identify the set of cost-significant items from a given n items, I_i, as

$$S = I_i \,|\, SR_i \geq ST \tag{5}$$

where SR_i and ST are the items' cost ratios and the significance threshold, respectively, given by

$$SR_i = \frac{RWLC_i}{\sum_{j=1}^{n} RWLC_j} = \frac{\sum_{t=pt}^{T} PWS_t C_t^i}{\sum_{j=1}^{n} \sum_{t=pt}^{T} PWS_t C_t^j} \tag{6}$$

$$ST = \frac{1}{n} \tag{7}$$

The use of the RWLC measure to calculate the significance ratio of an item (Equation 6) is in line with the main objective of the planning process because it reflects the future significance of an item (Kishk *et al.*, 2003b).

DESIGN OF THE APPLICATION

The WLC database

The application utilizes a project-specific WLC database that as been designed and reported in Kishk *et al.* (2002a). This database is designed around the concept of the 'building object' that enables manipulating various building components in a practical and convenient manner within a CAD application. The original structure of the database includes four main tables: (1) the building information; (2) the building objects, (3) the object activities and (4) the object costs. The first table stores the building and economic data while the second table stores the building objects table. The other two main tables store the activities and cost items of the building objects.

The project database has been extended to allow recording the actual elemental and non-elemental data of occupied buildings. As shown in figure 1, the extended structure of the project database allows elemental data to be recorded in a straightforward way on the activities and cost items levels. This is facilitated by using two tables: the activities history table and the cost items. The first table stores the history of the elemental activities. Elemental activities data are stored in 7 fields to record information that uniquely identify the activity and map it to a specific building object and whether the activity has been done or rescheduled, the associated time and the reason behind that. Likewise, the cost items history table stores the actual cost of the elemental activities.

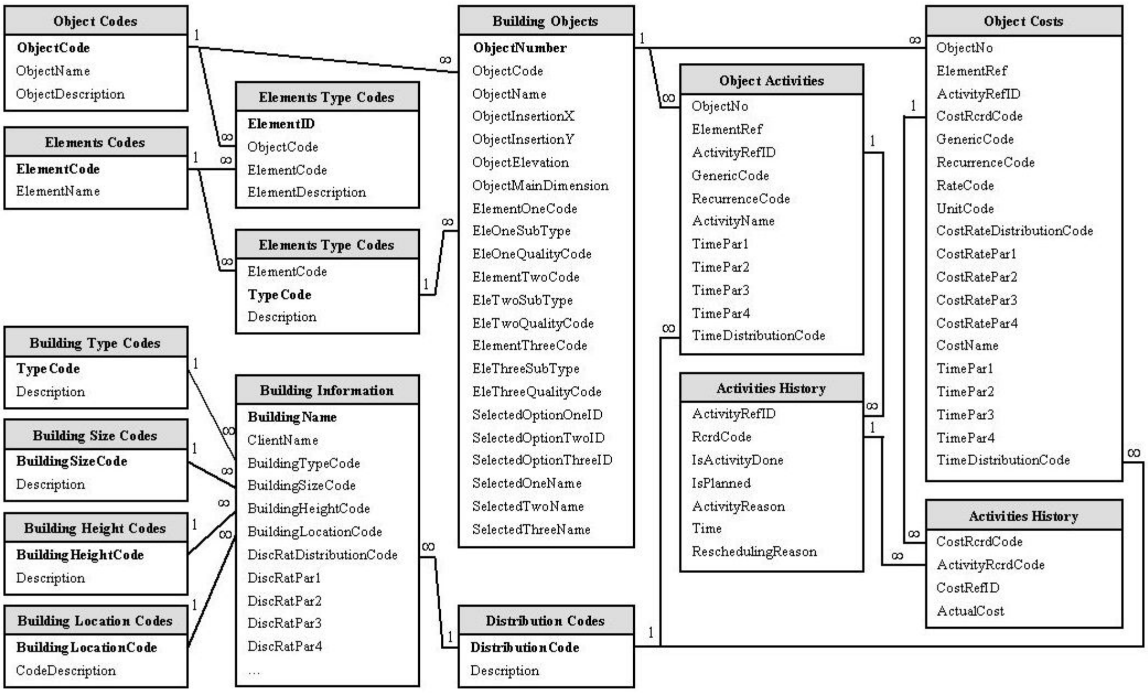

Figure 1: The structure of the extended project database.

The application logic

- The application retrieves the recorded data from the project database, analyses it and generates various WLC profiles. This is done in the following steps (figure 2):

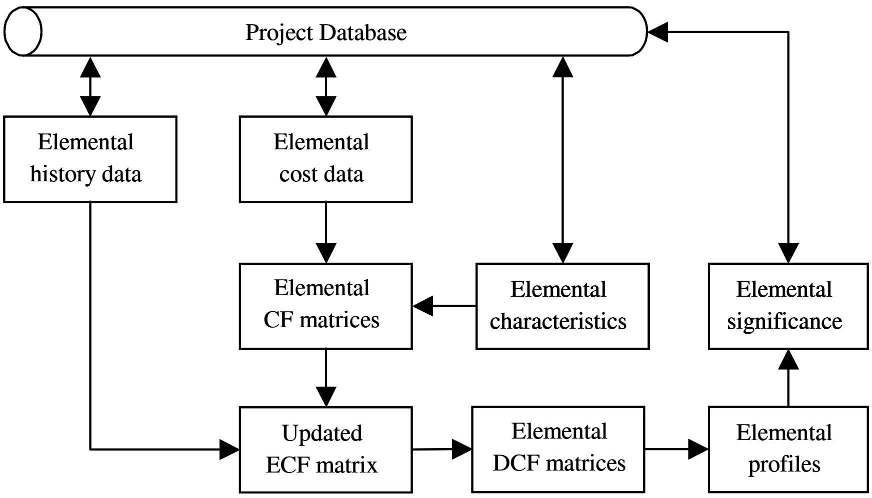

Figure 2: Simplified process flow diagram of the application.

- A connection to the project database is established.
- The object elements, activities and cost items data are retrieved.
- Each elemental and non-elemental cost item is expressed as number of cash flows based on its recurrence code and these cash flows are stored in a two dimensional matrix consisting of 3 rows and T columns as shown in figure (3). As shown, the first, second and third rows of a cash flow (CF) matrix are used to store the item's low, best and high estimates of the cost item, respectively.

Years

Estimates	1	2	3	4	5	6	7	8	9		T
Low	0	0	100	0	0	100	0	0	100	...	0
Best	0	0	110	0	0	110	0	0	110	...	0
High	0	0	120	0	0	120	0	0	120	...	0

Figure 3: The item's cash flow matrix.

- The characteristics of elemental cost items are stored in a matrix for later use. For each cost item, this data includes the cost item's name, recurrence, rate, unit and generic codes and its object, element and activity numbers.
- The elemental history data is retrieved and used to update the cost items' cash flow matrices through a time series model. Because the development of an advanced time series model is outside the scope of the current project, a simple model has been employed. In this model, the recurrence time of a cost item is the average of the recorded recurrence times of this activity. Besides, future low, best and high estimates are the minimum, average and maximum of the recorded costs of that item.
- The updated elemental matrices are combined into an elemental cash flow matrix, ECF
- Equation 2 is used to calculate the discount factors at various years of the analysis period. These factors are stored in a two dimensional matrix, DF, consisting of 3 rows and T columns similar to that shown in figure 3. The first, second and third rows of this matrix store the minimum, mean and maximum values of the discount factors.
- Using the elemental characteristics matrix, CF matrices of the current object are constructed on the generic, element and activity levels and their corresponding DCF matrices are calculated using the DF matrix. Then, equations 3 and 4 are employed to calculate the CWLC and RWLC matrices.
- Equation 6 is used to calculate the elemental significance ratios on the generic, element and activity and cost item levels from their corresponding RWLC matrices. Then, the cost significant items, activities and elements are identified using the significance relation 5.

IMPLEMENTATION

The above procedure has been implemented into a computer application using the MATLAB® programming environment (The MathWorks, 2000). Figure (4) shows the application interactive interface where the user can select to view various WLC profiles of a specific building object. The interface includes 2 combo box controls and 5 push buttons. The first combo box control sets the visualization level of the data. As shown, this can be on the object, the element, the activity or the cost item levels. The other combo box control sets the visualization detail. As shown in figure (4), one or all of the generic cost categories of the object can be viewed if the visualization level is set to the object level. Similarly, one or all of various elements, activities or cost items can be viewed if viewed if the visualization level is set to the element, activity or cost item levels, respectively. The five push button controls are used to display the cash flows, discounted cash flows, cumulative whole life costs (CWLC), remaining whole life costs (RWLC) and significance factors for the selected visualization level and detail.

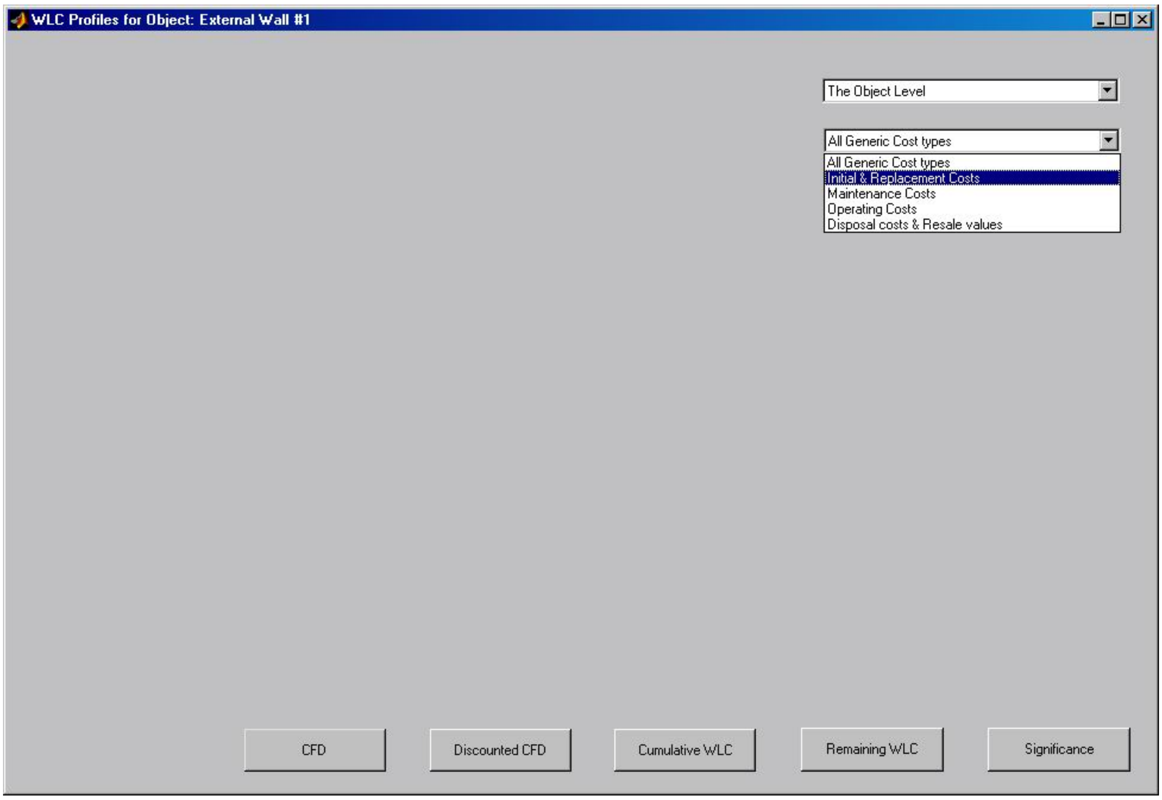

Figure 4: The interactive interface of the application.

To illustrate some aspects of the application, data of an external wall object that has been inserted into the project database using another WLC design application (Kishk *et al.*, 2002a) has been processed by the application and are shown in figures (6 to 9). As shown, bar charts, stacked bar charts or line graphs are used, where appropriate, to visualize various WLC profiles of the wall object.

Bar charts are used to visualize cash flow diagrams. For cash flows of a single generic cost, element, activity or cost item, a novel bar chart is employed whereby low, best and high estimates are shown simultaneously (figure 5). On the other hand, stacked bar charts are used when the cash flows of multiple generic costs, elements, activities or cost items are being compared as shown in figure 6.

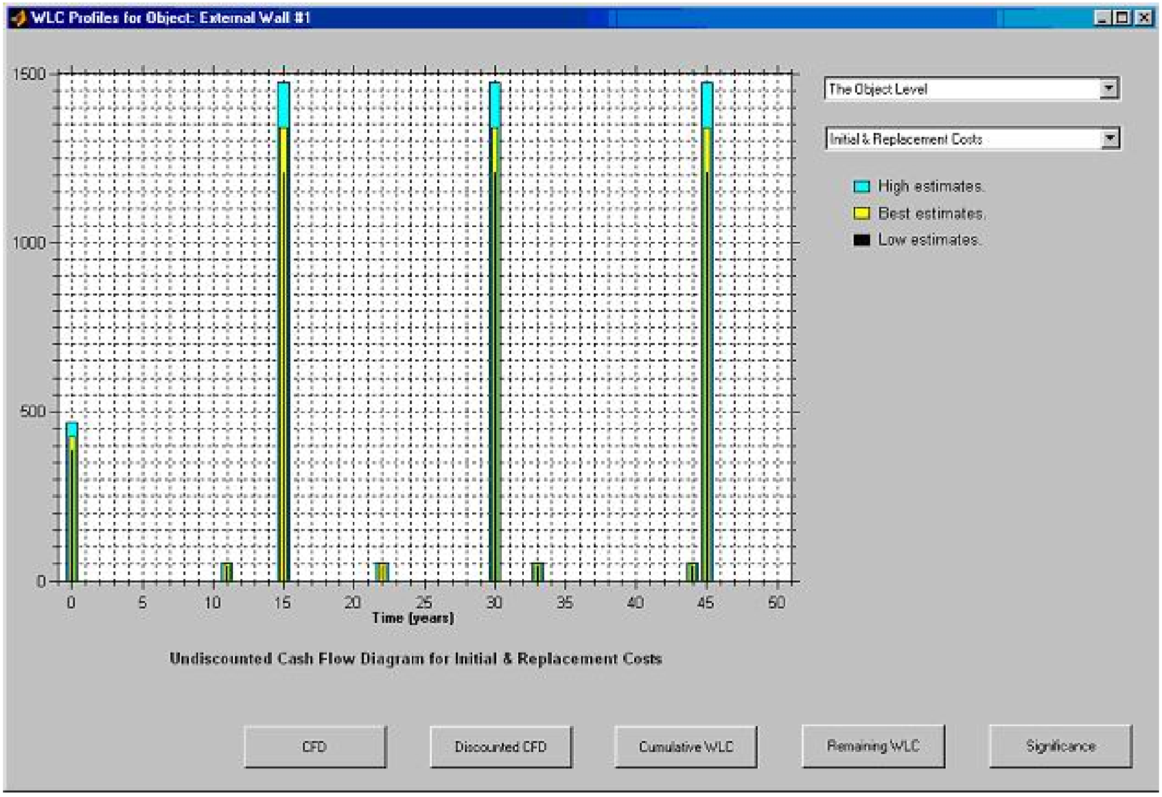

Figure 5: Visualization of various estimates of generic costs.

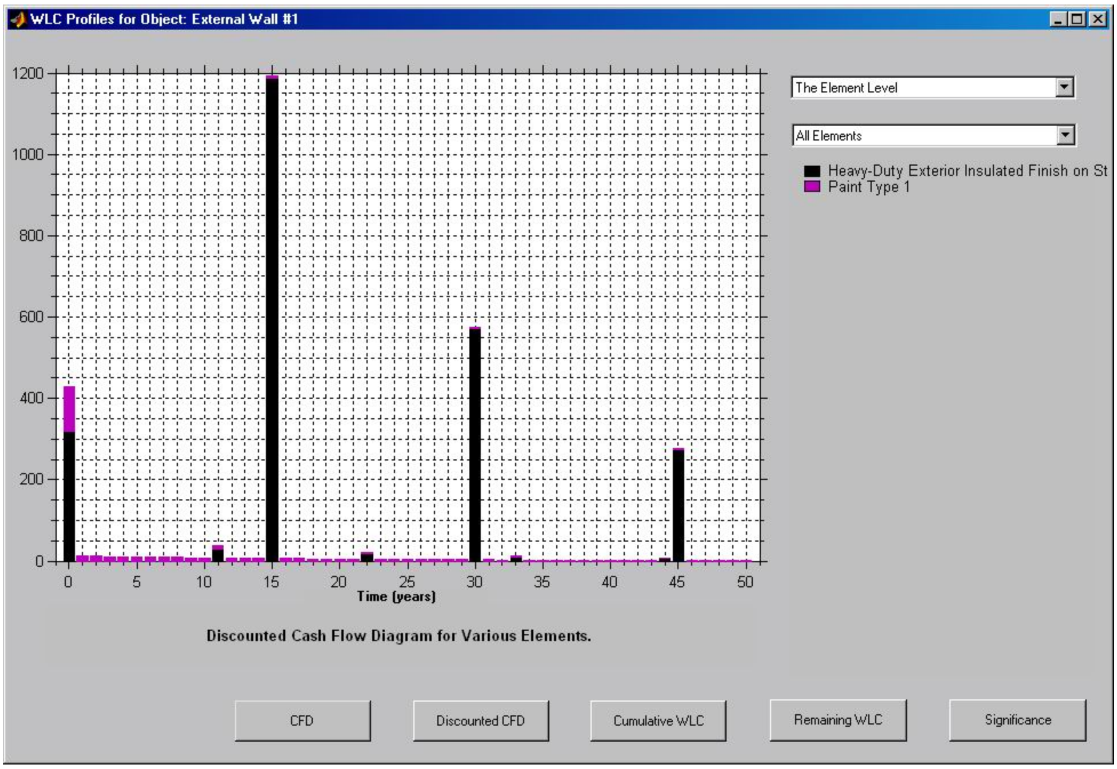

Figure 6: Stacked DCFD of various elements.

Line graphs are employed to depict cumulative and remaining whole-life costs whereby the past and future significance of various costs can be identified. Besides, the prevailing recurring type of contributing costs can be easily spotted. For example, the smooth RWLC curve of the wall finish element in figure 7 clearly shows that almost all costs of this element are due to annual activities; while the stepped curve of the exterior wall element indicates that these costs are due to a 5-year, non-annual recurring activity.

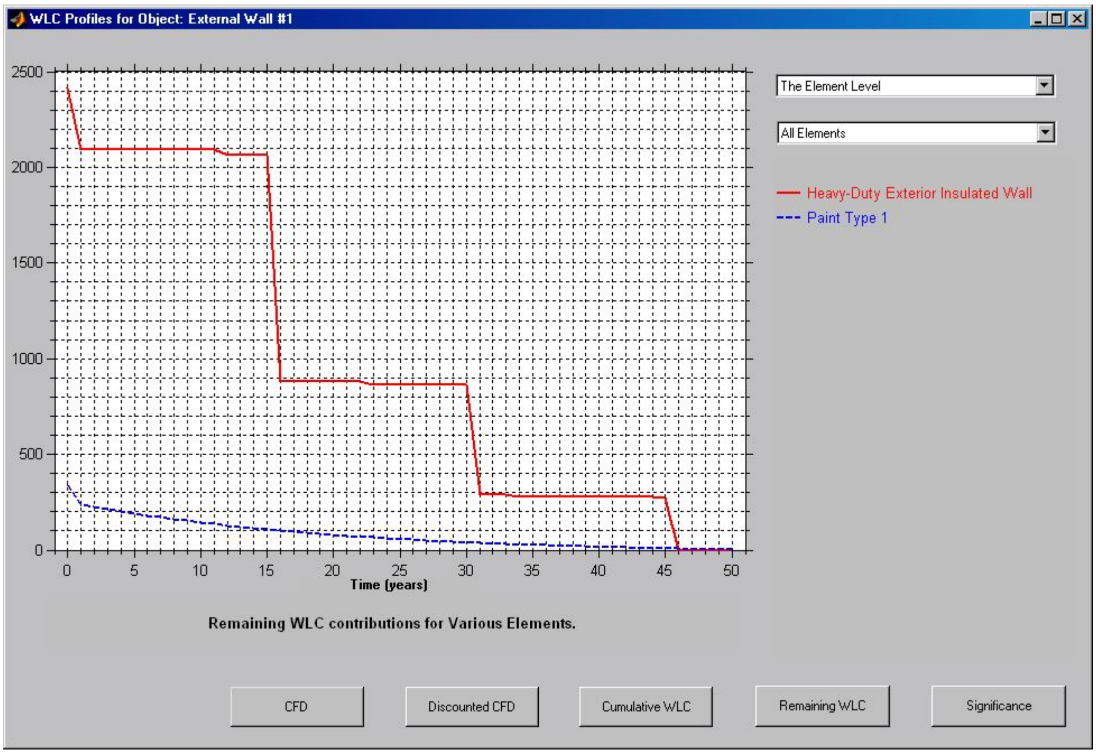

Figure 7: RWLCs of various elements.

Line graphs are also used to identify the significance of the building object under consideration on the generic cost, element, activity, and cost item levels. As shown in figures 8 and 9, the significance threshold is calculated using equation 7 and is represented by a thick dotted line and all the components having cost ratios exceeding or equal to this threshold at any given year are marked as significant.

SUMMARY AND FUTURE RESEARCH

Various WLC measures and processes crucial to effective whole life management of occupied buildings have been outlined. To automatically generate these measures, a computer application has been designed around a recently developed WLC project database. This application provides a visual framework for planning and management of occupied buildings whereby our understanding of how whole-life costs arise can be greatly improved. Besides, it can identify which building elements contribute most to the costs of construction, maintaining and management of buildings. This research work, however, has focused on individual elemental whole life costs. In the future, this will be developed further to cover elemental interaction and operation costs.

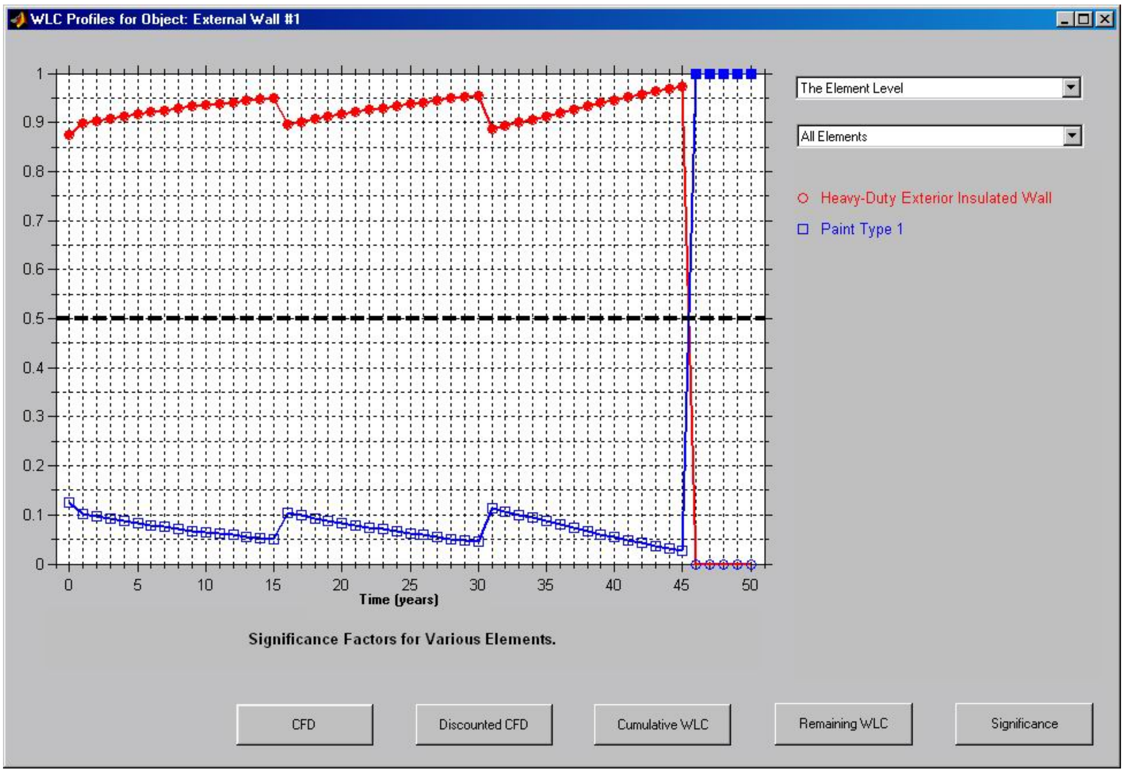

Figure 8: Significance of various elements.

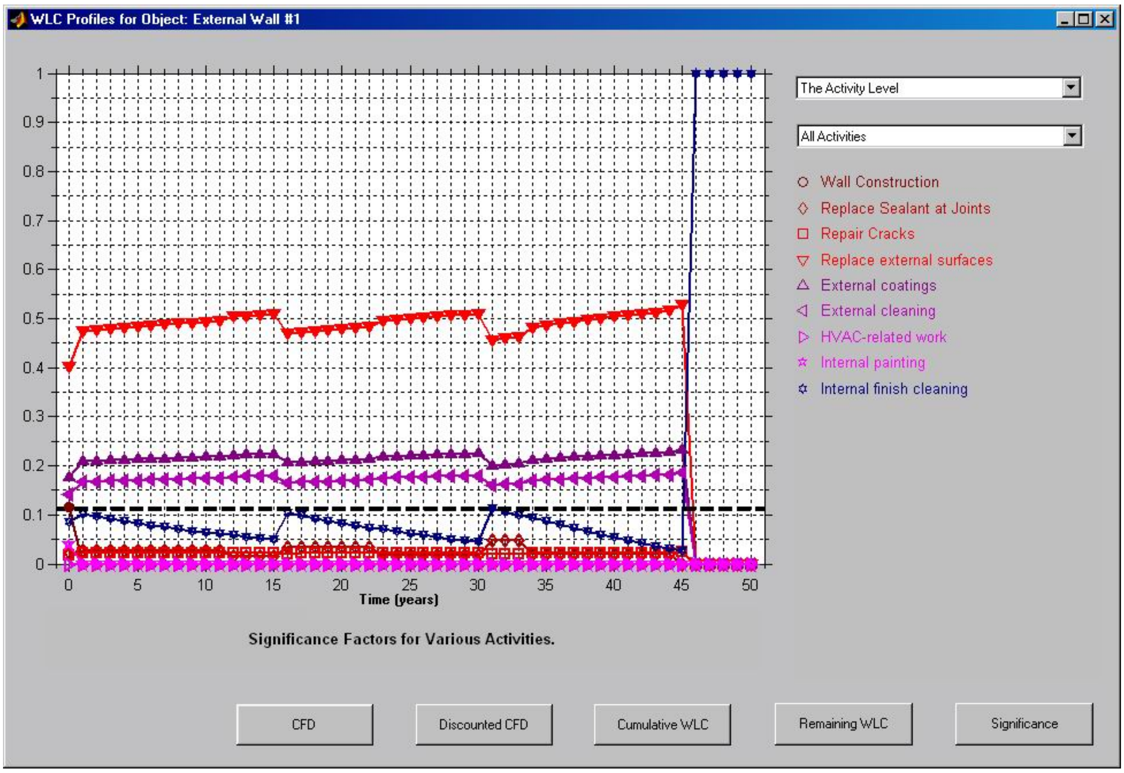

Figure 9: Significance of various activities.

ACKNOWLEDGEMENT

The research work that underpins this paper has been mainly funded by the EPSRC grant number GR/M83476/01 undertaken jointly with a team from the University of Salford led by Professor Ghassan Aouad.

REFERENCES

Al-Hajj, A (1991) *Simple cost-significant models for total life-cycle costing in buildings*. Unpublished PhD thesis, Department of Civil Engineering, University Of Dundee.

Al-Hajj, A. and Horner, M.W. (1998) Modelling the running costs of buildings. *Construction Management and Economics*, **16**(4), 459-470.

Horner, M. and Zakieh, R. (1996) Characteristic items - a new approach to pricing and controlling construction projects. *Construction Management and Economics*, **14**(3), 241- 252

Kishk M., Al-Hajj A., Pollock, R., Aouad A. and Bakis, N. (2002a) A whole life costing application for the optimum design of construction assets. *In:* Morledge, R (Ed.), *Proceedings of the Annual Conference of the RICS Research Foundation*, 5-6 September, The Nottingham Trent University. RICS Foundation, 108-119.

Kishk M., Al-Hajj A., Pollock, R., Aouad A. and Bakis, N. (2002b) Towards Effective Whole-Life Management of Occupied Buildings. *In:* Khosrowshahi, F (Ed.), *Proceedings of The third International Conference on Decision Making in Urban and Civil Engineering*, 6-8 November, London.

Kishk M., Al-Hajj A., Pollock R., Aouad A., Bakis, N. and Sun, M. (2003a) Whole life costing in construction - a state of the art review. *The RICS Research Paper Series*, **4**(18).

Kishk M., Al-Hajj A., Pollock R., and Aouad A. (2003b) On the effective feedback of whole-life data to the design process. Accepted for publication, *Journal of Financial Management of Property and Construction*.