

Effective Feedback Of Whole-Life Data to The Design Process

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- Key activities of the implementation of whole-life costing (WLC) as a management tool during the occupancy stage are outlined.
- Then, the logic of a novel whole-life management approach is designed around two recently developed generic WLC databases.
- The proposed approach allows the systematic data collection of the running costs of occupied buildings and provides the necessary link between occupied buildings and the design process.
- Besides, it employs a generic cost-significant relation that automatically identifies the cost-significance of the building components on the elements, activities and cost items levels over the analysis period.

Keywords: Cost significance, Whole-life costing, Whole-life management.

INTRODUCTION

In a recent paper (Kishk *et al.*, 2003), existing applications that provide whole-life costing (WLC) support have been reviewed. This review revealed that these applications vary from free simple spreadsheet models to sophisticated, commercial stand-alone applications. Besides, three main categories can be identified. In the first category, the application is used only as a financial tool to calculate the whole-life cost of a single alternative. Obviously, the usefulness of this category is limited. In the second category, including most of the applications, an application is mainly used as a decision-making tool to identify the ideal alternative from a number of competing alternatives. In the third category, the application is used as an asset management system. Typically, it is mainly a database manager that has the capability to record, modify, analyse and manage WLC data for an asset. Applications within this class are commercial, general-purpose systems that would require extensive training of users.

Another limitation of almost all existing applications is that the cost breakdown structure (CBS) is built manually by the user and is mostly non-elemental. Besides, various facets of uncertainty in WLC data are not effectively handled. Furthermore, none of the existing applications provides the necessary link between occupied buildings and similar subsequent buildings.

In another paper (Al-Hajj *et al.*, 2001), the authors have proposed a framework for implementing whole-life costing (WLC) in the design model within the OSCON integrated environment developed at Salford University (Aouad *et al.*, 1997). The main feature of this framework is that it employs two databases: a resource database and a project database. The resource database houses data for several options for every building element while the project database accommodates WLC data for the optimum set of options selected at the design stage to be used throughout the building life cycle. In a subsequent paper (Kishk *et al.*, 2002a), the resource database has been designed using an elemental cost breakdown structure (CBS). In another paper (Kishk *et al.*, 2002b), a compatible structure of the project database has been designed using the concept of the 'building object' that enables manipulating various building components in a practical and convenient manner within a CAD application.

The objective of the research work that underpins this paper is to extend the implementation of WLC to the occupancy stage. This will be achieved by extending the resource and project databases to allow collecting and recording actual performance and cost data of occupied buildings and the development of a whole-life costing management (WLCM) application. In the next section, the basic requirements for an effective WLC information management during the occupancy stage are outlined. Then, the project and resource databases are extended. This is followed by deriving a number of cost metrics to be used by the application. Next, the logic of the WLCM application is introduced. Finally, the research work is summarised and directions for further research are introduced.

KEY WLCM REQUIREMENTS

The main objective of whole-life costing management (WLCM) is to assess and control costs throughout the whole-life of the building to obtain the greatest value for the client (Flanagan *et al.*, 1983; Seeley 1996). A related activity called whole-life costing planning (WLCP) is to plan the timing of work and expenditure on the building, taking into account the effects of performance and quality. A third activity is whole-life costing analysis (WLCA) that aims to relate running costs and performance data and to provide feedback to the design team about the running costs of occupied buildings (Flanagan *et*

al., 1989). Thus, an effective whole-life management system should have four capabilities: (1) recording the actual performance and cost history of the building; (2) analysis of the recorded history feeding the accumulated experience back to the design stage; (3) assessment and control of costs throughout the whole-life of the building; and (4) planning the timing of work and expenditure. These processes are discussed in the following subsections.

Recording Performance and Cost Data

The main role of the project database during the occupancy stage is to record the actual performance and cost data of the building, i.e. to work as an asset register. Two categories of this data can be identified: elemental data and non-elemental data. The first category includes data that can be linked to specific elements of the building; i.e. data representing the history of various activities of the building elements, e.g. cleaning costs of external walls. According to Ashworth (1996, 1999), the value of any recorded elemental data is limited without its context information as defined by a number of data characteristics. He listed some useful characteristics such as the maintenance policy being applied, the cause of any component failure, timing distortions and the effect of delayed maintenance activities. Thus, the elements history should reflect not only the change in the predefined activities but the data of any new activities that might emerge during the occupancy stage as well due to change of the maintenance policy and/or the premature failure or unsatisfactory performance of some elements.

The second category includes other data items that cannot be linked to specific physical building objects or involve the interaction of more than one object like energy consumption. Obviously, almost all these cost items are related to operating the facility under consideration such as energy, general rates, insurance and security costs. Energy costs of buildings depend heavily on the use and hours of building systems operations, weather conditions, the performance level required by owners, the building's design and insulation provisions, location, size and position (Kirk and Dell'Isola, 1995; Boussabaine *et al.*, 1999; Bordass, 2000). Ashworth (1999) listed some factors affecting the rateable values of buildings including the location, size, and amenities available. He pointed out also that safety factors such as type of structure, materials used and class of trade affect the insurance premiums and security costs.

Analysis of Recorded Data

The recorded history of various elements of the building should be analysed to predict future activities and their associated costs within the occupancy stage of the building (i.e. feed-forward of information) and to inform the design stage of other projects (i.e. feedback of information). Obviously, the feed-forward and feedback information should be stored in the project and resource databases, respectively.

During each feed-forward process, future timings and costs of various activities are predicted. In doing so, either statistical or artificial neural networks (ANNs) time series analysis models can be used. In the first few years of the occupancy stage, the forecasting process will rely mainly on the original data set used in the design of the building. Eventually, the process will rely on the data that has been generated within the project itself.

The feedback process aims to provide the link between occupied buildings and similar subsequent buildings whereby performance and cost data collected during the occupancy stage can be fed back to the design stage. In this way, the design of new buildings will be based on real information leading to informed WLC-based decision making during the design process. Without this feedback loop, however, this process will remain entirely based on arbitrary assumptions or expectations.

Assessment and Control of Costs

To obtain the greatest value for the client, the costs and performance of various activities need to be assessed and controlled during the whole-life cycle of the building. In doing so, two main steps may be identified. In the first step, areas in which the costs of using the building as detailed by the WLCA are identified (Flanagan et al., 1989).

Noting that costs – like most things - are unevenly distributed, Al-Hajj (1991) and Al-Hajj and Horner (1998) proposed to focus on a small number of cost items known as the cost significant items (CSIs). They developed a method to identify CSIs using a statistical approach based on the Pareto's 80/20 rule. Although their point was to use the CSI idea to develop simple cost models to predict the running costs of buildings, the idea can be used to identify high cost activities as potential study areas. However, a new definition of these items is needed for elemental items. Rintala et al. (2001a, 2001b)

investigated analogy-based estimation (ABE) as a potential approach to identify CSIs. However, they concluded that ABE couldn't be used at that stage because its estimation performance was poor. They attributed this to the inadequacy and inconsistency of the data used in their study and emphasised the need for systematic data collection.

The second step is to monitor the identified areas (elemental and non-elemental) and re-assess their costs against benchmarks and/or targets. The monitoring and benchmarking processes help to keep costs on targets or to modify these targets if necessary in the light of the accumulated experience through the feed-forward and feedback processes.

Work and Expenditure Profiles

All WLC calculations and planning at the design stage are based on two assumptions. First, elemental maintenance activities will follow a planned maintenance program to meet the standards of maintenance and lives of various elements of the building as retrieved from the resource database. Secondly, all non-elemental costs are based on characteristic values from comparable buildings or set by appropriate experts.

The actual performance and cost data of the building should be recorded and analysed throughout the occupancy stage to predict and plan for future activities. Failure to do so may result in escalated replacement and maintenance costs as well as premature obsolescence (Kirk and Dell'Isola, 1995). Thus, it is crucial to update the initial maintenance and replacement profiles and the estimated project cash flows estimated at early stages of the project.

EXTENDING DATABASES

The Project Database

The project database has been extended to facilitate recording the actual data of the occupied building under consideration and to allow the feed-forward process discussed earlier. The original structure of the project database allows elemental data to be recorded in a straightforward way on the activities and cost items levels using two tables. The first table stores the history of the elemental activities. The first table stores information that uniquely identify each elemental activity and maps it to a specific building object. Besides, it records whether the activity has been done or rescheduled,

the associated actual or rescheduled time and the reason behind that. Likewise, the cost items history table stores the actual cost of the elemental activities.

To allow standardisation of non-elemental data collection and recording, a coding system for these costs was needed. Because non-elemental costs are not associated with specific building objects and are mainly occupancy costs, the codes used in the BMI property-occupancy-cost analysis form seems to be a logical choice. Besides, these costs depend on the hours of use and the occupancy profile of the building especially for public buildings such as hospitals and schools (Hobbs, 1977; Flanagan *et al.*, 1989). Thus, two tables have been included in the project database to store non-elemental data and the occupancy profile of the building. Figure 1 shows the structure of the extended project database.

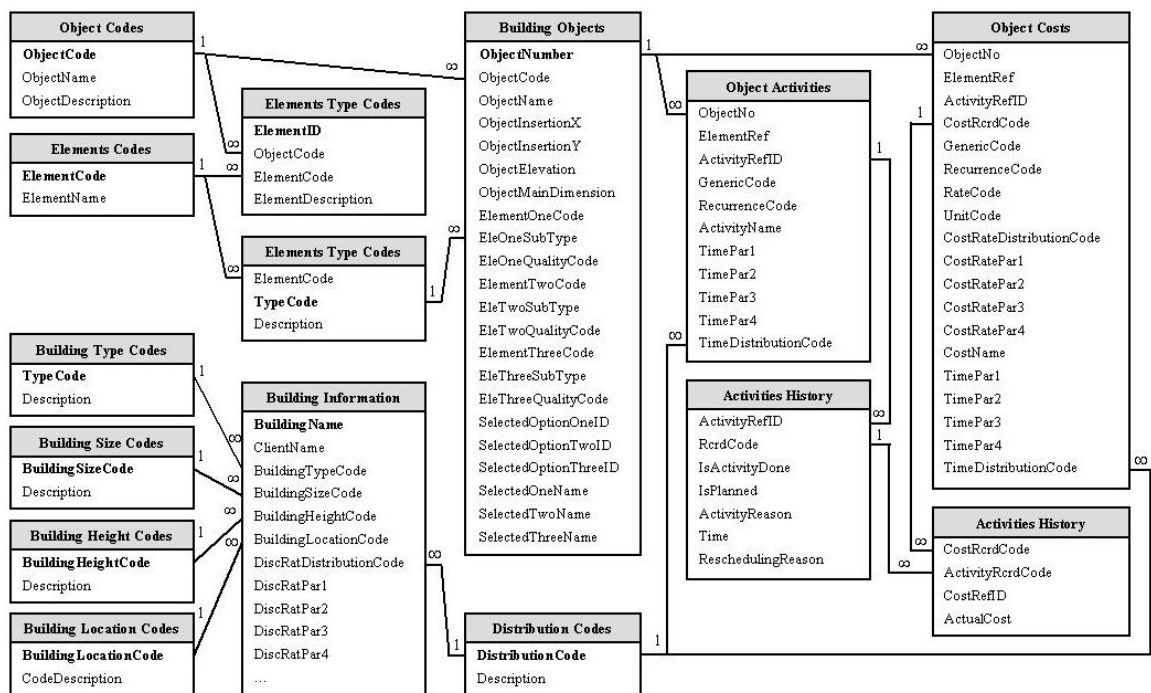


Figure 1: The structure of the extended project database.

The Resource Database

The resource database has been also extended to allow the feedback process. This has been facilitated by the inclusion of three tables. The first table stores the main characteristics of buildings whose cost and performance information are fed-back to the resource database. For each building, a record is used to store the building size, height, location, age, and type. The other two tables store the fed-back non-elemental and

elemental data, respectively, as well as information that uniquely identify each record and the building that generated it. Figure 2 shows the structure of the extended resource database. More details of the extended resource and project databases will be reported in two separate papers.

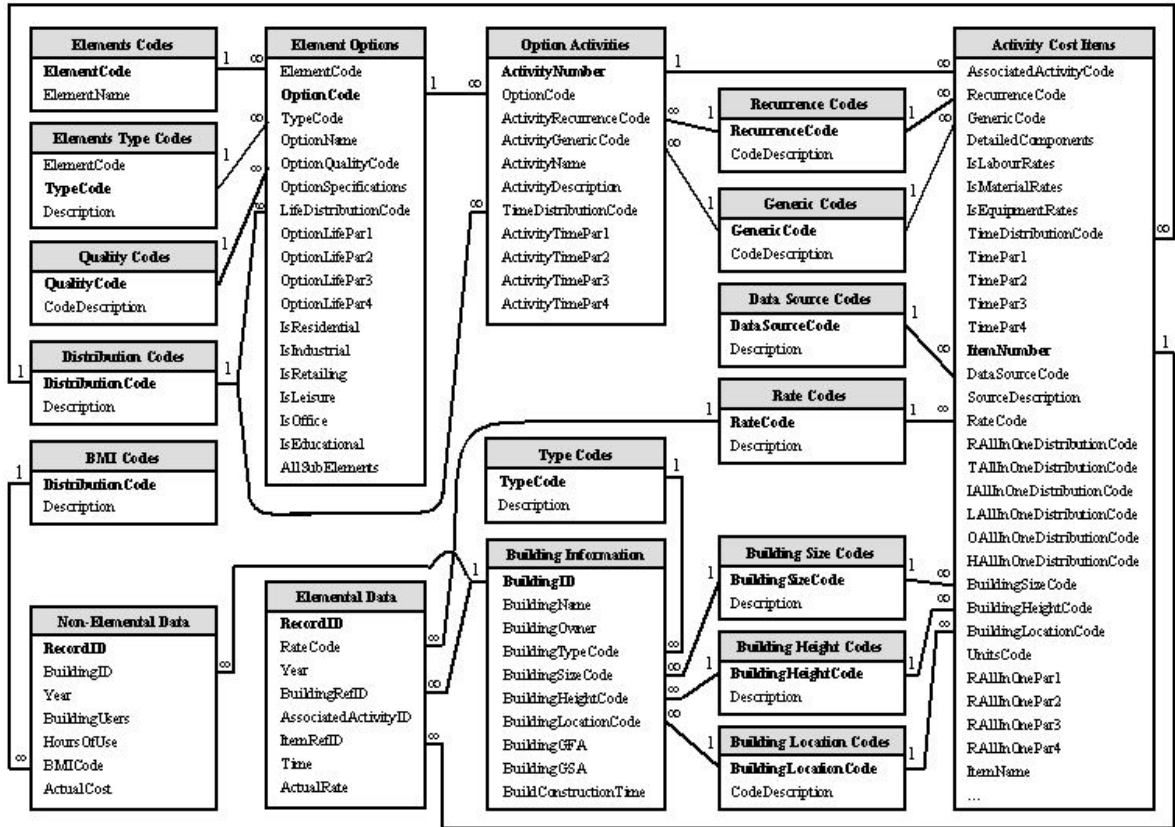


Figure 2: The structure of the extended resource database.

COST SIGNIFICANT ITEMS

The Cost Significance Relation

Based on earlier work on cost significance (Poh and Horner, 1995; Horner and Zakieh, 1996), Al-Hajj and Horner (1998) defined a cost significant item as that whose cost is greater than the mean item value. For n cost items, I_i , this significance condition can be expressed as

$$S = \left\{ I_i \mid C_i > \frac{\sum_{j=1}^n C_j}{n} \right\} \quad (1)$$

where S is the set of significant items and C_i are costs of the items. In their work, the identified sets of significant items from 5 sets of data constituted between 75% and 89% of the total costs in these sets.

Because this definition provides a simple procedure to identify the significant items in any batch of cost data, it will be adopted herein with the following slight modification.

$$S = \left\{ I_i \left| C_i \geq \frac{\sum_{j=1}^n C_j}{n} \right. \right\} \quad (2)$$

This modified relation indicates that a cost significant item is that whose cost is greater than or equal the mean item value. It is important to note that this is not to describe an average cost as a significant cost. Rather, this modification is necessary because if all the items have the same cost, no item would be identified as significant using relation 1. The modified relation, however, needs to be generalised such that significant activities, elements and objects can be identified as well.

Dividing both sides in the above inequality by $\sum_{j=1}^n C_j$, relation can be expressed as

$$S = I_i | SR_i \geq ST \quad (3)$$

where SR_i are the items' cost ratios given by

$$SR_i = \frac{C_i}{\sum_{j=1}^n C_j} \quad (4)$$

and ST is a significance threshold given by

$$ST = \frac{1}{n} \quad (5)$$

The significance relation 3 indicates that an item in a given data set is significant if its cost ratio exceeds a threshold given by the reciprocal of the number of items of that set, i.e. the cost ratio given by equation 4 may be regarded as a significance measure. Thus, relation 5 can be used to identify the significant activities of given element, the

significant elements of a given object and the significant objects of the building by comparing their cost ratios with the significance thresholds of the element activities, the object elements and the building objects, respectively.

The Cost Measure

Another issue has to be addressed: what is the cost measure to be employed in the calculation of cost ratios? In their methodology, Al-Hajj and Horner (1998) used a deflated cost measure whereby all cost data were deflated to a common year using the inflation indices published by the BMI. In this way, the effect of inflation was accounted for. They did not, however, discount costs to account for the time value of money. This seems reasonable because the main purpose of their work was to develop models to predict the annual running costs of buildings and the discounting process might have no effect on their methodology because all costs incurred at the same year will be discounted with the same factor.

Because the main purpose of the WLC management of buildings is to obtain the greatest value for the client, the choice of a whole-life cost measure, e.g. the net present value, is logical. Besides, it should reflect any change of the significance of an item over the analysis period. Two measures that satisfy both requirements can be identified: the cumulative WLC contributions and the remaining WLC contributions.

The cumulative WLC measure, $CWLC_i$, of a cost item C_i , represented by a number of cash flows C_t^i , is the summation of all discounted cash flows within the period from the initial time, $t = 0$, to the present time, pt , i.e.

$$CWLC_i = \sum_{t=0}^{pt} PWS_t C_t^i \quad (6)$$

where PWS_t is the discount factor at time t given by

$$PWS_t = \frac{1}{(1+r)^t} \quad (7)$$

The use of the CWLC measure to calculate the significance ratio of an item (Eq. 5) would reflect the past significance of an item.

The remaining WLC measure, $RWLC_i$, of an item 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.

$$RWLC_i = \sum_{t=pt}^T PWS_t C_t^i \quad (8)$$

The use of this measure to calculate the significance ratio of an item (relation 5) would reflect the future significance of an item. This is in line with the main objective of the planning process. Thus, the RWLC will be employed to calculate the significance ratio as

$$SR_i = \frac{RWLC_i}{\sum_{j=1}^n RWLC_j} = \frac{\sum_{t=pt}^T PWS_t C_t^i}{\sum_{j=1}^n \sum_{t=pt}^T PWS_t C_t^j} \quad (9)$$

DESIGN OF THE APPLICATION

The WLCM application has been developed in three modules: WLCPre, WLCPro and Feedback as shown in figure 3.

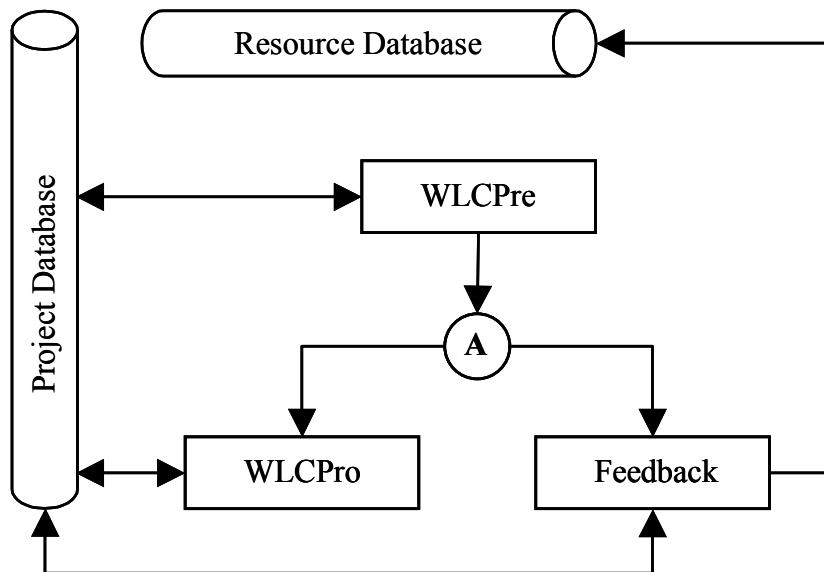


Figure 3: Simplified process flow diagram of the WLCM application.

The WLCPre Module

The WLCPre module retrieves the recorded data from the project database and generates the information required for the WLCPro and Feedback modules as follows:

- A connection to the project database is established.
- The object elements, activities and cost items data are retrieved.
- Each cost item is expressed as a number of cash flows (CFs) stored in a two dimensional CF matrix.
- The characteristics of each cost item are stored in a matrix for later use. For an elemental item, this data includes the item's description, recurrence, rate, unit and generic codes and its object, element and activity numbers. For a non-elemental cost item, this data includes the item's recurrence, generic and BMI codes.
- The elemental and non-elemental history data are retrieved to update the cost items' CF matrices through a time series model.
- The updated elemental and non-elemental matrices are combined into two elemental and non-elemental cash flow matrices, ECF and NECF, respectively, which are then carried forwards to the WLCPro and Feedback modules.

A simplified process flow diagram of the WLCPre module is shown in figure 4.

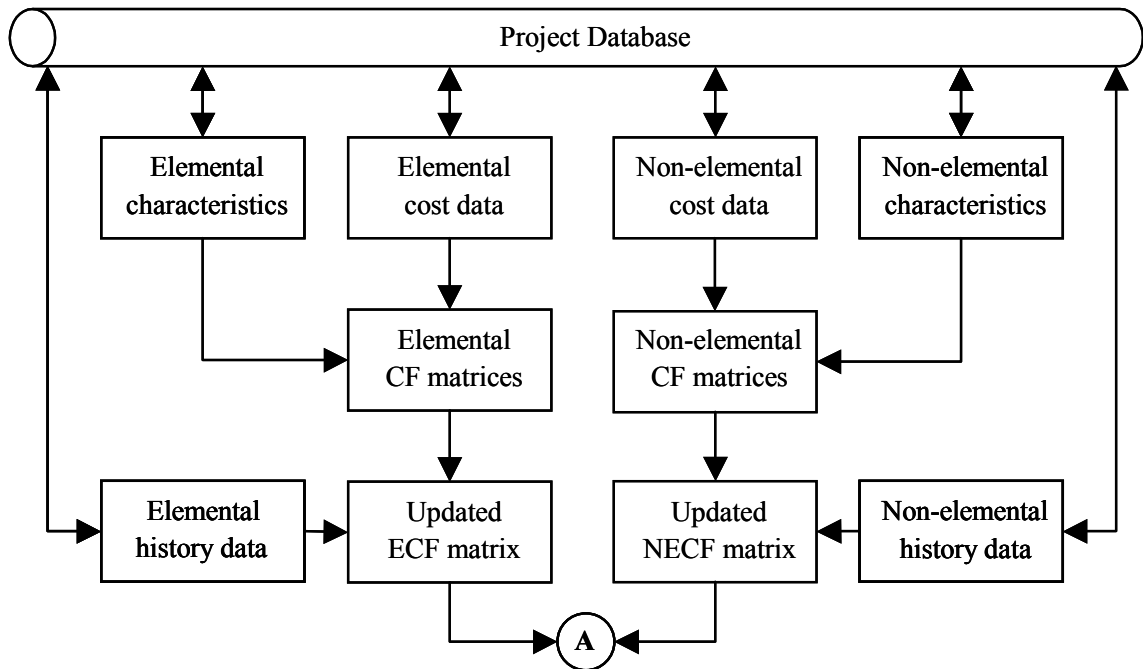


Figure 4: A simplified process flow diagram of the WLCPre module.

The WLCPro Module

The WLCPre module generates various planning profiles and identifies significant items of the building. This is done in the following steps (figure 5):

- Equation 7 is used to calculate the discount factors at various years of the analysis period. These factors are stored in a two dimensional matrix DF.

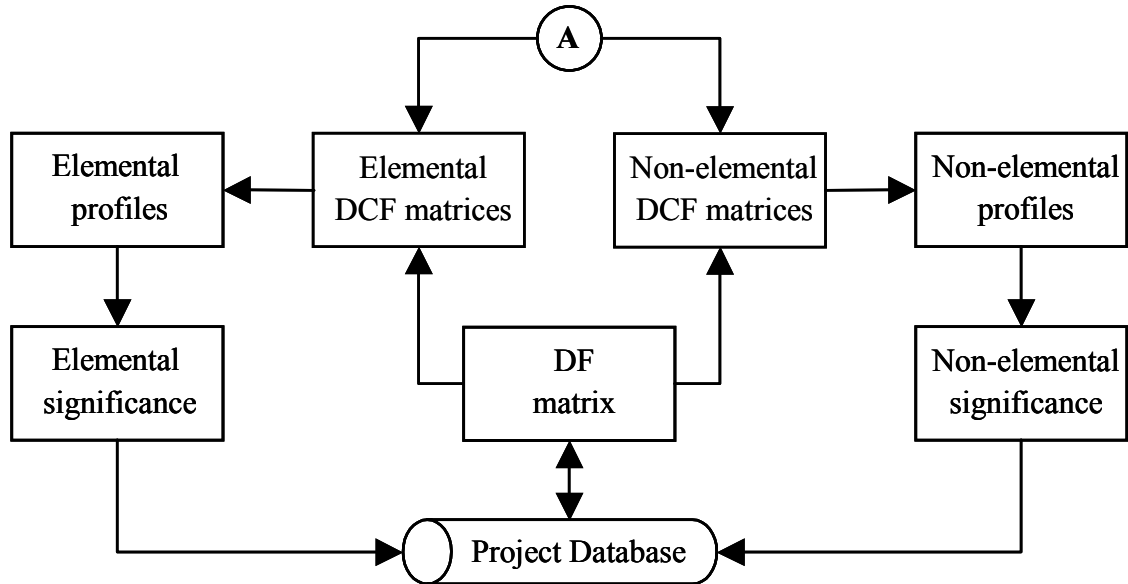


Figure 5: A simplified process flow diagram of the WLCPro module.

- The non-elemental discounted cash flow matrix (NEDCF) is obtained by discounting the NECF matrix using the DF matrix. Then, equations 6 and 8 are employed to calculate the non-elemental CWLC and RWLC matrices.
- Equation 11 is used to calculate the non-elemental significance factors from the non-elemental RWLC matrix. Then, the non-elemental significant items are identified using the significance relation 5.
- Using the elemental characteristics matrix, CF matrices of the current object are constructed on the generic; element and activity levels and their corresponding DCF are calculated using the DF matrix. Then, equations (8 and 10) are employed to calculate the CWLC and RWLC matrices on the generic, element and activity and cost item levels.
- Equation 9 is used to calculate the elemental significance factors 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.

The Feedback Module

The Feedback module automatically feeds back the building performance and cost data to be used in other projects. This is done in the following steps (figure 6).

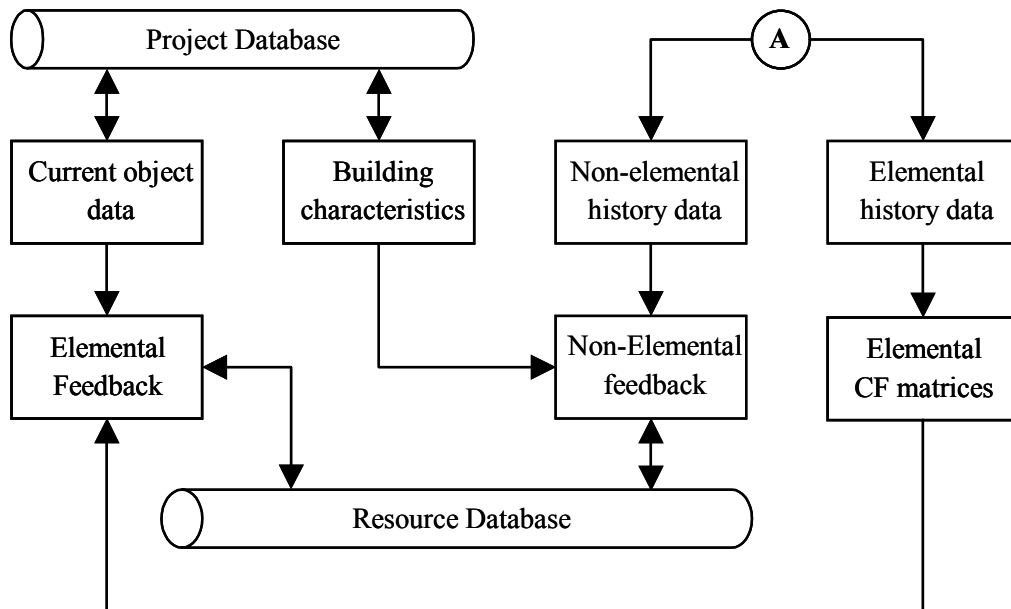


Figure 6: A simplified process flow diagram of the Feedback module.

- The building physical and general data are retrieved from the project database.
- A connection to the resource database is established.
- The resource database is checked for an existing record for the building. Otherwise, a new record is inserted.
- The records of elemental costs for the current year are retrieved from the project database. Each cost item is transformed to a cost rate through interpretation with the corresponding object/building physical data. Then, a record is inserted in the corresponding table in the resource database.
- The records of the building non-elemental data for the current year are retrieved from the project database. Then, a record is inserted in the corresponding table in the resource database.
- The connection to the project database is closed.
- The connection to the resource database is closed.

A complete process flow diagram of the application is shown in figure 7.

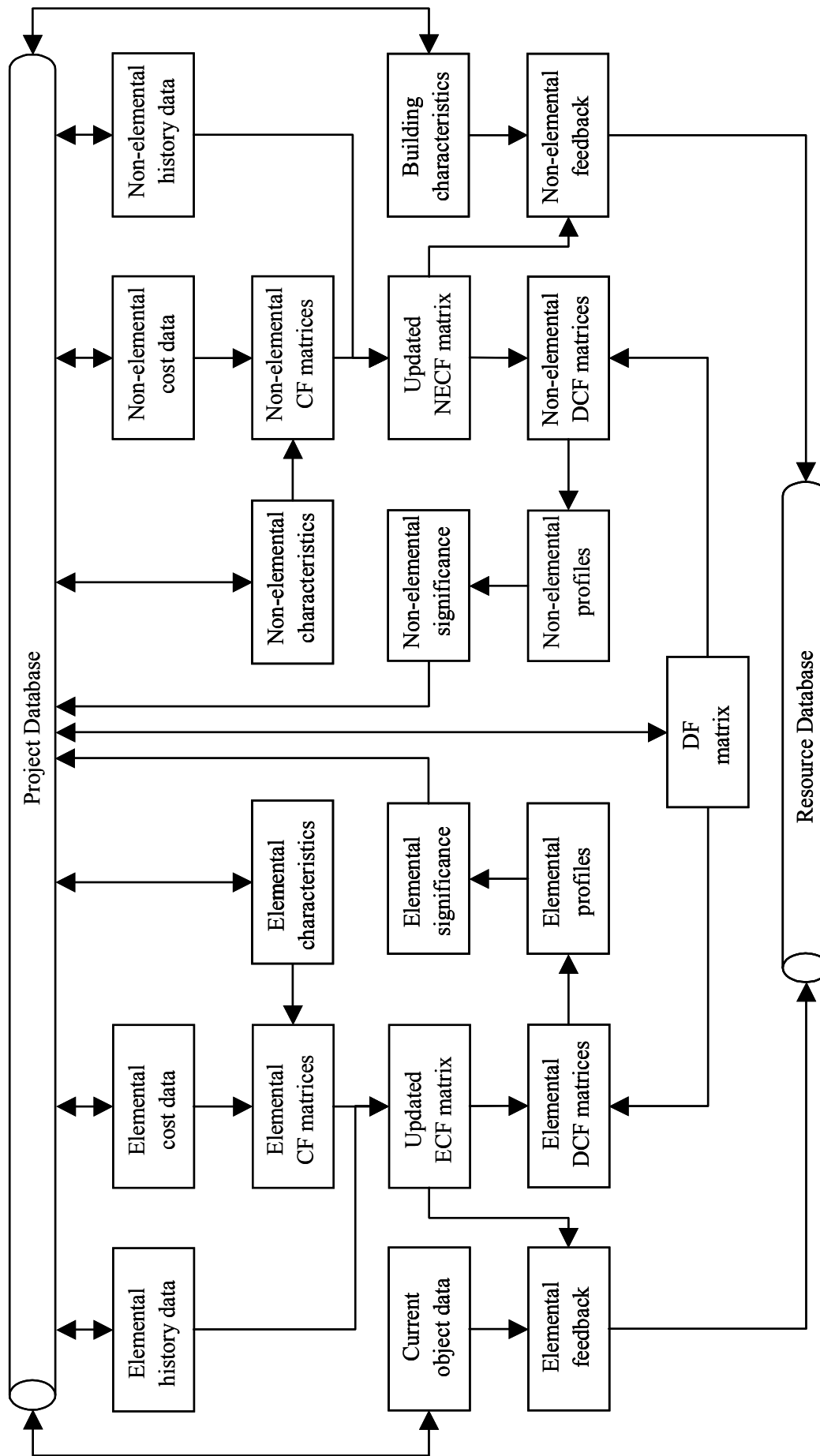


Figure 7: The complete process flow diagram of the application.

SUMMARY AND THE WAY FORWARD

Following a brief review of existing applications that provide whole-life costing support, the basic processes of effective whole-life management of buildings have been explored. The first process is to record the actual performance and cost history of the building. The second process is to analyse this recorded data to predict future activities and their associated costs within the occupancy stage of the building (i.e. feed-forward of information) and to inform the design stage of other projects (i.e. feedback of information). The feed-forward and feedback information are stored in the project and resource databases, respectively. The third process is to assess and control costs whereby the main activity is to identify cost significant items. The fourth process is to produce various work and expenditure planning profiles.

Two recently developed WLC databases have been extended to facilitate the first two processes. Then, the logic of a WLCM application has been developed to automate the other two processes. The proposed approach has two unique merits. First, it puts forward a systematic framework for data collection and recording using a well-defined cost breakdown structure and keeping its context information. Secondly, it offers a starting point for a practical feedback mechanism that links occupied buildings to the design process.

The proposed approach, however, handles elemental and non-elemental costs independently. It should be developed further to cover the interaction of various building elements and operating costs of the building. Besides, the transformation of actual costs to cost rates is done through a predefined code that identifies which object/building physical quantity to use. In the future, a procedure should be included to identify which physical quantities have the greatest correlation with actual costs.

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