RETHINKING WHOLE LIFE CYCLE COST BASED DESIGN DECISION-MAKING

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Procurement arrangements such as the Private Finance Initiative (PFI) and Public Private Partnership (PPP) have been instrumental in focusing stakeholders on the long-term cost implications of design decisions. As a result, Whole life cycle costing (WLCC) is now becoming standard practice in projects of this nature. The implementation of such metrics whilst desirable has been difficult to achieve in particularly complex design environments, hence the need for a methodology, which promotes the logical, and iterative application of the technique has emerged. Furthermore, it could be argued that existing WLCC models are used retrospectively and not as part of an iterative design decision-making process. In response, an innovative approach to WLCC modelling is presented. The originality of the research lies in the combination of a WLCC model with a novel decision support application, to assist in the optimisation of the design process. The integrated model enables the analyst to calculate WLCC results using the decision support element to facilitates the iterative application of the model throughout the entire design process, thus providing a repository of design decision-making information, which can be used on a micro level to inform and optimise the WLCC design, and also on a macro level to inform decisions on a global scale or for other similar projects.

Keywords: whole life cycle costing, decision-making, decision support, complexity, design, process mapping

PROGRESS IN WLCC BASED DECISION-MAKING

The past decade has witnessed a truly definitive shift in emphasis within the construction industry. The design and construction of buildings nearly always placed a strict focus on delivering at the lowest capital cost, but now a greater awareness and desire to consider costs over the whole life has prevailed. Clients now require buildings that reveal true value for money over the long-term, and are not interested simply in buildings that are the least expensive to build. These changes allied with key government initiatives such as Rethinking Construction, Best Value and the Private Finance Initiative have underpinned the importance that Whole Life Cycle

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Costing (WLCC) can bring to the industry. Existing approaches to WLCC are a response to the fallibility of Life Cycle Cost (LCC) models that originated from the late 1970s (the "terotechnology" era), these being, 1) A suspicion that life cycle cost estimates are in some sense inaccurate or based merely on guess-work and 2) The absence of sufficient and appropriate cost and performance data.

Recent work on WLCC methodologies and metrics has begun to deliver effective solutions to the problems of uncertainty quantification (Wirahadikusumah et all 1999, Kirkham 2002, Frangopol 1997, Choong 2002, Kirkham, Boussabaine and Kirkham 2002). The development of stochastic approaches to WLCC provides adequate response to the argument that without high quality data, WLCC is plagued with inaccuracy. Nevertheless, data collection is still important and recent work has demonstrated this (EPSRC GR/N34024/01) through a web-based risk simulation tool that can interact with whole life and risk data. One of the principle ideas behind this project is to develop a framework for effective data collection within a probabilistic environment. Whilst the research on WLCC metrics has been lively and informative, the methodological aspects of WLCC are still left open to wide interpretation and criticism. One such example is managing the complexity of the WLCC decision-making process. In many scenarios, where a building design may be multifaceted and of sufficient magnitude, data management within the WLCC model can be complicated. Therefore, this paper focuses on the need to handle, analyse and interpolate the data effectively - in effect recording the WLCC design decision-making process. This paper aims to identify the importance of these two concepts within WLCC, and to demonstrate the development of a software application that could begin to successfully address these issues.

EXISTING METHODOLOGICAL APPROACHES TO WLCC DECISION-MAKING

Classically, WLCC is used at the design stage to compare a series of options, this can range from a single building component such as an air conditioning unit right through to a complete building. Several possible design solutions are compared using a WLCC model, and in the most basic examples, comparing the Net Present Value (NPV) of each solution provides the bare minimum information needed to assess the cost implications over the life of the asset (Fig 1).

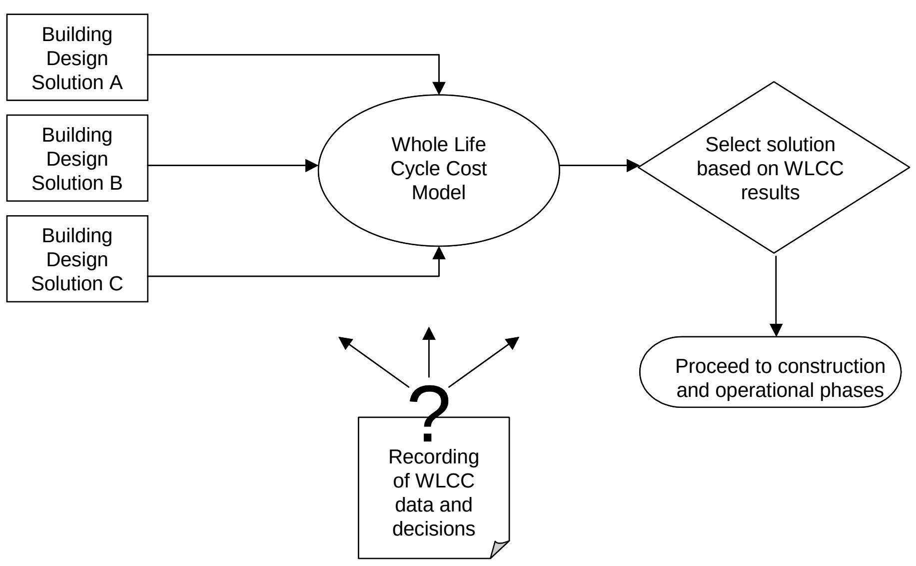


Fig 1: The standard WLCC modelling approach emphasising the lack of informative information recording

Although the process described in Fig 1 utilises WLCC metrics to inform a decision, it could be argued that the process is retrospective. The mere fact that the model has provided information on the WLCC of several different design solutions does not necessarily infer that the optimisation of the design WLCC. In other words, the design solutions were established without considering the WLCC, but simply compared for the lowest WLCC, post-design. This approach exists by virtue of the fact that most WLCC models fail to provide a way of systematically recording the design-decisions made. Ideally, a framework should exist which enables the design team and/or analysts to utilise a) WLCC methods as a dynamic tool throughout the entire design process, and b) record the data extrapolated from this process to inform future decision making.

RE-ENGINEERING THE BUILDING DESIGN DECISION MAKING PROCESS

If building design can be conceived as a systematic framework of activities comprising transformation, flow and value creation, (Koskela 2000), then it is appropriate to model the design process in a logical way. Such a model, it must be remembered, is a model of the design decision-making process (when decisions are made and by whom and how they are linked but not the actual technical decisions) and the information flows relating to the decision (input data, knowledge transfer, verification, recording, monitoring). Two issues arise as a consequence, the actual model of the process and the modelling medium (e.g. IDEF (o), Data Flow diagrams). When reviewing the research into these areas, particularly when related to construction design, these two issues became interrelated but with consensus view being that the established modelling methods are applicable. The debate centres on the complexity of the models and how a generic design model can be produced from these formal modelling methods.

A number of design process models have been developed for engineering manufacture (automotive, aerospace in particular) and these are often referred to as new product introduction process models as they attempt to involve activities in the supply chain outside the strict design activity and also may encompass more strategic issues. In addition, a number of models have been developed specifically for construction design. None of the models available extend, to any degree, beyond the start of manufacture or start of construction phase although a few make some reference to ‘operations’ without going into any detail. The approach in all cases is to assume that design is effectively a linear process (i.e. following the “transformation” concept) although with some integration into the manufacturing processes. The models are all very similar but differ in detail primarily because of the original aim in identifying and defining the model. The issue of design iteration whilst considered, is not usually a central feature of these models.

Macmillan et al (2001) produced a summary of an extensive review of design process models, which indicated, as expected, broad similarities between the different models but some significant differences at the conceptual design stage. These differences relate to whether they are engineering based (very prescriptive) or architect based (generalised descriptions of stages).

The RIBA Plan of Work (Royal Institution of British Architects 2000) is a well know design model. It is designed to identify the main steps (from client instruction to commissioning) primarily as a contractual aid. Architects' fees can be paid against achievement of the various stages. It implies a particular procurement route (competitive tender) and, in reality, the gates between the stages are 'fuzzy'. However, it provides an easily understood, widely used and simple model of the process, which has been implicitly used in the development of more sophisticated design models. The British Airports Authority guide to the construction project process (BAA 1995) is a process map but with some features which relate to the specific needs of the authority. Inception is de-coupled from feasibility and there is no tendering stage. BAA operates via a partnership mechanism and has its own internal arrangements for project definition. The gates in this model are more pronounced and are used in an active way as part of the project management process. There is an attempt to cover operations and maintenance within this model but it seems to have been added almost as an afterthought.

Perhaps the most comprehensive and ambitious attempt to model the design process is the "process protocol"(Kagioglou et al 1998), which is a truly generic model although again, effectively restricted to the design of the building rather than including maintenance and operational activities. The process protocol model includes gates – both "hard" and "soft" to accommodate the fuzzy issues discovered by previous researchers. Current work is aimed at trying to bridge the gap between the high level abstraction and the detailed design tasks. Since briefing and the client/design team interaction are so critical in construction design, there have been a number of studies that have concentrated on this aspect. . (Latham 1994, Blyth and Worthington 2001) have modelled briefing as an iterative process including feedback from previous projects. Macmillan et al (2001) considers a fresh approach in the search for a generic framework for conceptual design. It is instructive to note that a "framework" rather than a "model" is proposed. What is described as a categorical framework with 5 levels is demonstrated, but extensive discussion with design professionals indicated that a 3 level approach was perhaps the most useful, and that a framework rather than a prescriptive model preferable.

A RE-ENGINEERED MAP FOR WLCC DECISION-MAKING

The process map proposed in Fig. 3 considers design (from identification of client requirement through to completed design) as a linear, sequential process along the time axis and indicates the issues/stages where decisions are made (and the relevant data and information needed) in relation to WLCC performance. It is not a map designed for the purposes of project monitoring and control. Note that it is of course recognised that the design is not easily described in detail by a formal model.

Furthermore, the detailed models of the design process, which have been suggested, do not necessarily reflect design practice. Consequently this is a map of the decision stages to enable the correct WLCC data and information to be available at the appropriate point in the design process. The map is designed to be at different levels (3 are proposed rather than the 5 or 6 proposed in some other design models) to preserve the generic nature of the map but to allow for varying levels of design detail.

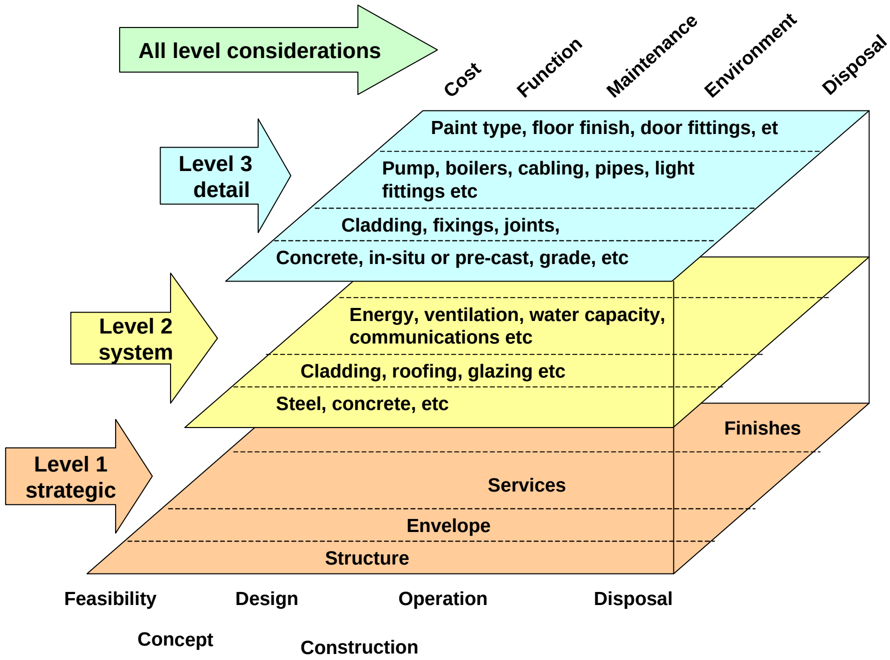


Fig 2: Proposed design process map

By having different levels in this way it should be possible for performance and cost data to interact with the design map at different levels depending upon the precision and detail of the data and the level of detail decision. It is envisaged that, as design proceeds, the cost, performance and environmental data can become progressively more precise and can then be entered into the lower levels of the design map. Another advantage of this multi-level approach is that it may be able to handle the inevitable design interactions. In practice, the interaction between the 3 levels is likely to be at the later stages of design (after the feasibility and concept stages) so the 3 dimensional map will be of this general nature. To relate the design process to WLCC specifically, Fig 3 demonstrates a methodology aimed at re-engineering the WLCC process. The WLCC model progression is characterised again by the 3 phases of detail, representing WLCC decision stages

1. Strategic level (i.e. structure, envelope, services etc.)
2. System level (i.e. steel, concrete, timer frame etc.)
3. Detailed level (i.e. concrete pre-cast or in-situ, RC grade etc.)

The strategic level stage involves WLCC modelling in the broadest sense, looking at the building design in it's entirety, and not detail specific focus. This appraisal should be used initially to assess the substantially differing design solutions that are presented to the client at the briefing stage. It is at this juncture that the design team can begin to focus the client on WLCC, helping to deliver a cost effective solution.

The results from this analysis and any subsequent data extrapolation forms the basis to Stage 2, where a more detailed system level analysis can be performed on the solution(s) identified in Stage 1. Here, WLCC methods can again be used to assess the economic viability of various systems within the design such as the WLCC comparison of steel, concrete and timber frames, for example.

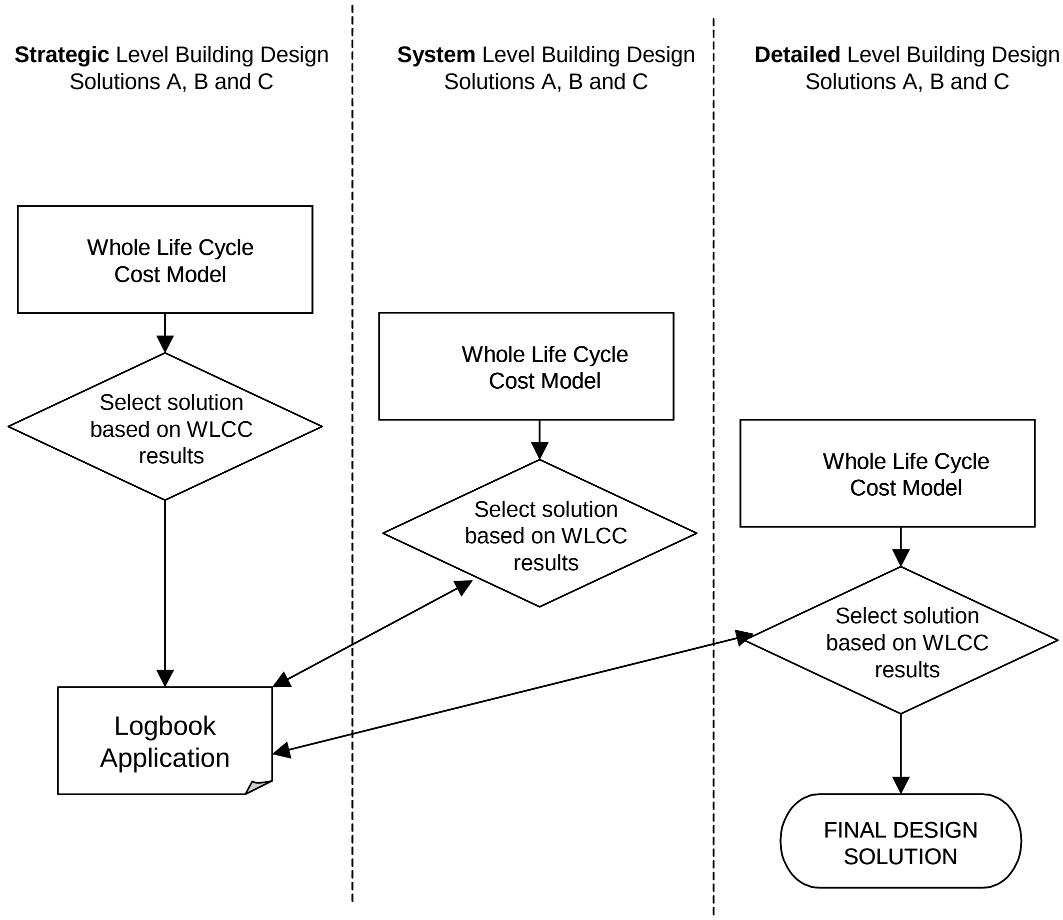


Fig 3 The 3 stage iterative WLCC modelling process

The data elicited from this stage should again provide the design team with the key information necessary to develop the design to stage 3 where component specific WLCC analyses can be performed. At this stage, it is rare that WLCC methods are used on all design selections. Usually, a sensitivity analyses will be performed in stage 2 to identify the most uncertain costs. This then allows the design team/analyst to focus detailed level WLCC analyses on the cost sensitive items. The complexity of the WLCC modelling required at stage 3 depends to a significant extent upon the availability of cost and performance data, as well as the uncertainty attached to any assumptions. A review of the key analytical tools available at this stage is presented in Boussabaine and Kirkham (2003).

Rethinking WLCC in this way should ensure that the process is used logically and systematically, as opposed to the ad-hoc, "bolt-on-at-the-end" procedure, which WLCC is currently perceived as. In order to realise this methodology within a design scenario, there is a need for some form kind of underlying database structure with which to record the decisions and data at each stage (this is identified in Fig 2). The remainder of this paper therefore describes the development a decision support application to facilitate the implementation of the proposed methodology.

THE LOGBOOK DECISION-SUPPORT APPLICATION

The design decision support application proposed in this paper, "The Logbook", is a highly innovative attempt to capture the key information and data elicited from a WLCC analysis. This data is rarely extrapolated in a coherent fashion; it could be argued that without a clear methodological approach, WLCC results are open to severe scrutiny. Software implementation is often the key to bridging the research-practice divides, and in this paper, the Logbook is the "physical" attempt to translate the methodology into a workable solution. The application will not be confined solely to the design process and construction phase of the project however. In line with recent initiatives such as the CIBSE Building Logbooks (CIBSE 2003), the application will also facilitate a Post Occupancy Analysis (POA). The initiative being that the building owner will utilise the logbook to record the most up-to-date cost-in-use data on an annual basis, enabling the WLCC model forecasts to be matched against actual costs as these accrue. In essence, the logbook facilitates a dynamic WLCC model rather than one that is static in nature. This will also have the added advantage of increasing the availability of accurate cost and performance data. Accordingly, accurate forecasting of operating costs is essential to minimise the total WLCC of the building. Recent research has suggested that for every £1 spent on capital costs, £50 is spent on maintenance costs and £200 is spent on operational costs (Royal Academy of Engineering). It is therefore clear that the accuracy of WLCC is strongly correlated to the accuracy of the operational cost forecasts. Furthermore, the vast majority of costs are committed to during the design process, but incurred during the operational phase, so a question to consider is: do we increase the planned maintenance regimes or look for improvements in the design process itself?

It is clear however that some method or procedure should be established to facilitate the effective collection of operational phase WLCC data. Moreover, this information should be stored exclusively with the design information so that information on the impact of certain design solutions on WLCC can be elicited. The framework referred to in the previous section could encompass a dual role by also providing a useful application for the collection of occupancy phase WLCC of the building.

LOGBOOK APPLICATION ARCHITECTURE

The logbook application forms the preliminary WLCC modelling process, and so by definition, can be envisaged as the user interface. The application will be the point of entry for the input of data by the user and also the source of information for records of historical whole life cost data throughout the project. Fig. 4 shows this process in general terms. It should be noted that the design of the application architecture is generic and applicable to any type of construction/engineering project. The process shown in Fig 4 could be considered as a "query", design solutions are selected within the building model, using the logbook to record the selection of various components. The data is then assessed in the LCCP model, resulting in outputs that can then be used to make decisions. The decisions made are then recorded in the logbook (the outcome of the query). In essence, the model is used to query if a set of selections are acceptable. The stages of the process are thus:

- Stage 1: Specific project information is recorded in the logbook (i.e. name, function, GFA, site location etc). Selection of components is also recorded with the rational behind the decision
- Stage 2: Using a variety of data sources, cost and performance data is obtained; this is fed directly into the WLCC model
- Stage 3: The WLCC model computes the whole life cost and probabilistic analysis that may wish to be performed.

- Stage 4: The results are presented in a variety of methods, Probability Density Functions, Sensitivity Charts, Cost Profiles and Performance Analysis. These results can then be used to make decisions
- Stage 5: The decisions made are recorded in the logbook

This process continues through the 3-stage design process identified earlier in the paper. By using this approach, the design team can create and audit trail of all decisions that have been taken and on what evidence. This approach helps focus all the stakeholders on WLCC and can additionally help with other matters such as CDM regulations compliance, Local Authority Best Value directives etc. Fig 4 details the composition of the logbook – four key parts each representative of the life of the building. It should also be noted that a fifth section is also available – Environmental Impact Analysis, this is not dealt with in this paper however.

Part 0 is the client brief registry logbook. Information is stored here regarding the client brief, and any other information relating to the briefing stage. It is now widely held that in the construction industry, professionals have to now, more than ever before pay adequate attention to understanding as far as possible the needs and wants of the client. These professionals need to look for opportunities to add value both to clients and to themselves. This is can be achieved through many ways and in particular, by building on the unanticipated consequences of the decisions that are made that are positive and fortuitous and can lead to benefits to all involved. By recording these decisions in the client brief registry, a greater understanding can be achieved of how and why certain decisions have been made on a project.

Part 1 is the design team logbook. The ability to influence whole life cycle costs is greatest during the design phase as the types of material specified, the quality of the design and the contracting method chosen impact directly upon long-term operation and maintenance costs. For example, projects that are procured using partnering, PPP, PFI, design and build or traditional methods influence to certain extended the quality of design, construction, maintenance and operational policies. This information is therefore essential and should be recorded. Part 1 also records the final materials and components selected by the design team, and is a registry of the elemental details of the final design. More specifically, Part 1 consists of two distinct sections; the first section provides the designer with the ability to review any previous decisions that have been made on the project. This section will also include the ability for the user to define a new scenario analysis (or any other type of analysis).

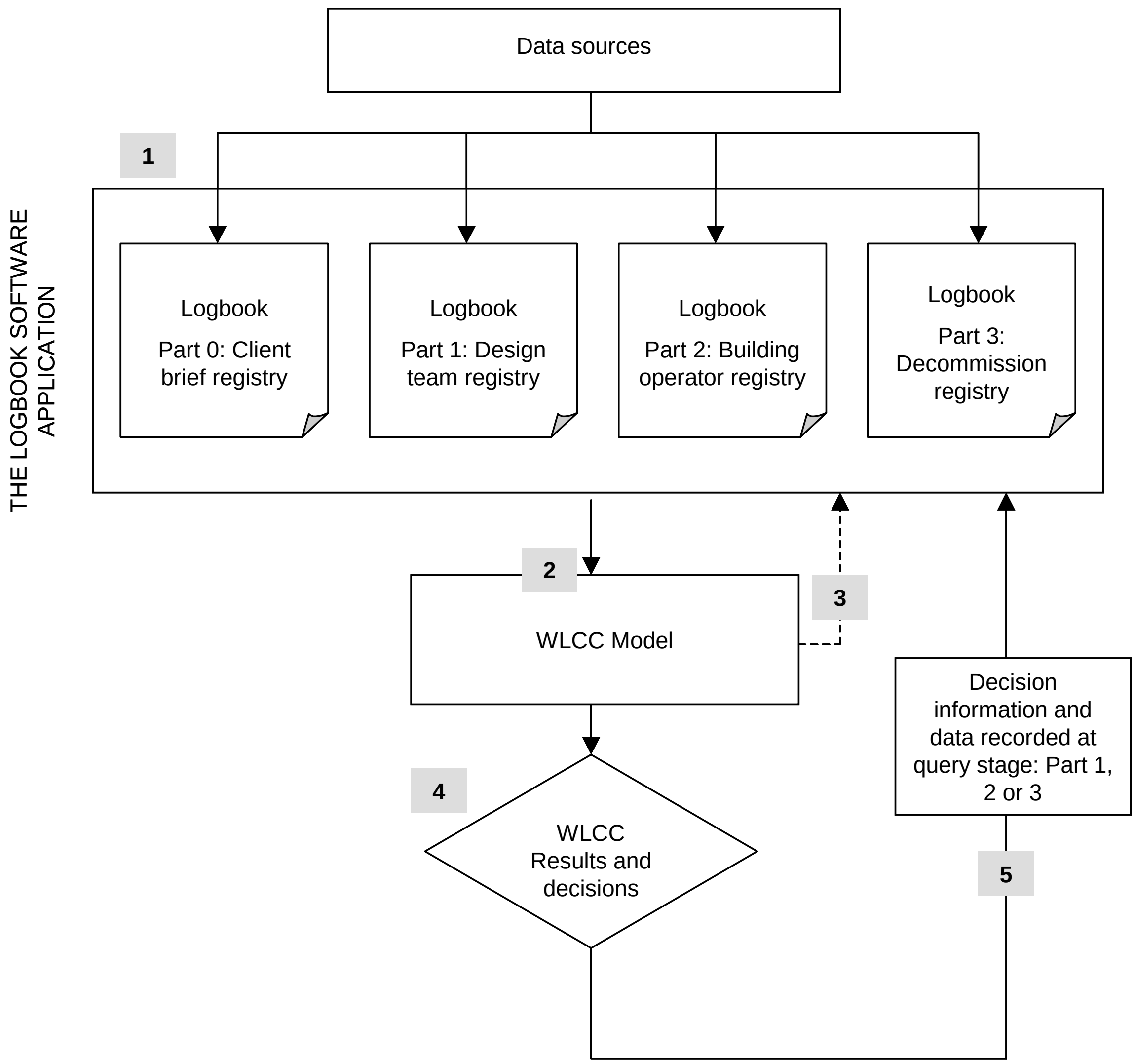
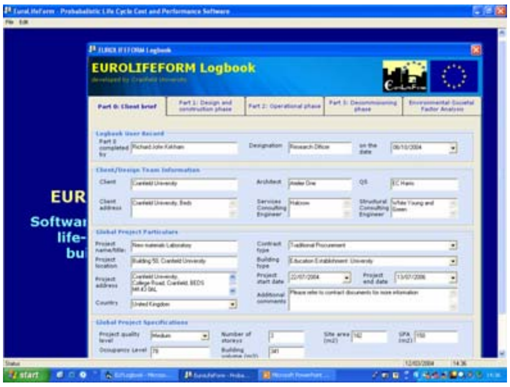


Fig 4: Logbook process

Once the user has reviewed previous decisions and specified a new scenario analysis, the second part of the tab (Section 2) is then activated. Section 2 considers each design scenario analysis that is produced within the WLCC model. Once all simulations have been completed, the designer is then able to select the simulation that represents the optimal WLCC. When making the decision, the analyst is presented with a form to enter a textual description of why the decision was made, which is then recorded with the file in the database.

Part 2 consists of the building owner registry logbook. This is the most important part of the logbook and is essential to providing the building owner with the information necessary to make decisions over the operational life of the building. It will allow the user to record, monthly and annualised cost data and also to record capital investment decisions and maintenance overhaul. This part of the logbook is dynamic in that it should be updated on a yearly basis so that WLC forecasts can be recalculated and updated based on the latest cost in use information.

Part 3 is the decommissioning registry. This part of the logbook will only be completed when a query is made as to whether the building is still economically viable to run. Other factors may also be included in this assessment such as environmental factors. The results of the analysis are again locked into the project archive. Fig 4 shows examples of the application layout and composition for Part 0 and Part 1 specifically.



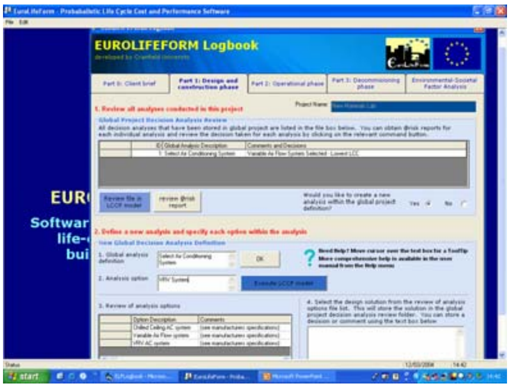


Fig 5 Screen shots of the logbook application

BENEFITS OF THE LOGBOOK APPLICATION

It is anticipated that the final outcomes will present a user-friendly application that will facilitate the logical recording of whole life costs throughout the life of the building. It will enable the user to quickly identify the assumptions and impact that these assumptions had on the decision. Furthermore, the application is ideally suited to PFI projects, where a seamless handover of the logbook from the design team to building operator should occur. The logbook also provides an audit trail of decisions, to enable designers to see when decisions based on WLCC have been made and the reasons why

FUTURE RESEARCH ISSUES

One issue that requires further investigation is the applicability of the application for most procurement routes – this is potential problem since the contractual relationships are more complex in traditional procurement as opposed to PFI (in PFI the organisations are harmonised, therefore it is easier to appoint an individual to be responsible for the application) in that there are many separate organisations working on a project. Potential solutions include Internet based WLCC models, which allow real-time update of the models and logbook. Consideration must also be given into whether the logbook will be attractive to organisations such as developers. Presently, many developers are not interest in WLCC since they building are generally sold quickly to other investors. However, the logbook could be promoted to developers as a way of providing added value to clients however, thus increasing possible sales revenue. Other factors current being considered include: Technological risk, will future IT systems support the logbook application? Is the logbook easily transferable between building owners/operators?

SUMMARY

This paper has discussed in some detail the issues related to data handling and the WLCC model. The arguments presented by Bird (1987) and Smith (1999) set the agenda for the logbook. The logbook serves as the vehicle by which to encourage the building owner to remain focused on whole life costs, and establish procedures to accurately record cost-is-use data. The logbook should however, not be envisaged as a standalone product. There is no added value is to be gained from the logbook on its own, it should be used complimentary to the WLCC model. Moreover, the logbook is intended to be dynamic by its very nature, to be used not only during the design stage, but throughout the life of the building as well. Consideration should be given as to the purpose of the logbook in post occupancy evaluation. The logbook is the common denominator in both design stage and post occupancy WLCC analysis.

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