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Life-cycle costing analysis to assist design decisions: beyond 3D building information modelling

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Abstract

Design decisions are increasingly required to take full account of life-cycle-cost to facilitate specification choice for different building and engineering components. To this end an integrated framework for life-cycle analysis through identification of contributory elements and sub-elements allows analysis via an appropriate tool. The framework presented discusses the opportunity for the utilisation of statistics and probability, fuzzy set logic, artificial neural networks and objected orientated analysis to go towards a life-cycle-cost system able to form part of an overarching model supporting decision making within the building design process.

Keywords: Life-cycle costs, decision modelling

1 Introduction

New technologies able to model life-cycle analysis and predict life-cycle cost at the feasibility and early design stages of a project are increasingly important. Whole-life analysis and life-cycle-cost assessment of proposals is a key factor for decision-making models in an environment of scarce natural resources, given that maintenance and operation items contribute up to 5 times the initial capital expenditure of an investment (Ishizuka et al 1992).

Building information (built-environment digital) modelling, or BIM, requires life-cycle data to facilitate appropriate virtual prototyping of development proposals to assist specification choices prior to committing to construction. Whilst a raft of digital technologies are available in Australia, the Built Environment Digital Modelling Working Group (Green, 2009) call for further research in this area; they argue that there is much work to be done in the development, promotion and utilisation of digital models that address appropriate life-cycles, if productivity and environmental gains are to be realised in the Australian construction industry.

Although the concept of BIM as a 3D model is well known in Australia, the Cooperative Research Centre for Construction Innovation (CRC, 2009) find that there is: (i)lack of awareness of BIM as a fully integrated data management tool; (ii)lack of modelling expertise in the Australian construction industry particularly from contractors; (iii)major issues in communication between the consultant disciplines charged to realise the client's design brief of a project; (iv)reluctance by the design team to share BIM information with contractors as a risk management strategy; (v)lack of agreed standards and guidelines able to instil confidence (amongst architects and engineers) regarding the trustworthiness and reliability of data entered by many (sub)contractors; (vi)concerns over risk sharing and liability; (vii)lack of knowledge and training across the supply chain that prevents greater adoption in the Australian construction industry; and, (viii)low uptake as a result of a lack of understanding of life-cycle analysis.

Watson (2005) also recognises that building development in Australia can benefit from life-cycle assessment tools, couched within appropriate information and communications technology (ICT) platforms, to aid the decision-making process; however she finds that, as yet, no tools cover the entire building life-cycle and that there are many gaps in current tool attributes covering whole-life (economic) assessments. Hu (2008) and Arayici (2005) argue similarly that computer integrated construction (CIC), whilst beneficial, must address requirement-gaps in information sharing.

Life-cycle cost analysis is a major consideration if modelling is to assist decision-making successfully; Green (2009) asserts that in Australia, markets will increasingly demand buildings with a low operating costs, driving demand for digital tools that simulate a building's operational performance and incorporate and budget for building life-cycle costs. It can be argued, as shown in figure 1 below, that life-cycle economics have yet to be fully integrated into BIM applications, and that this remains an essential part of the roadmap towards future development of Building Information Modelling for Australian construction.

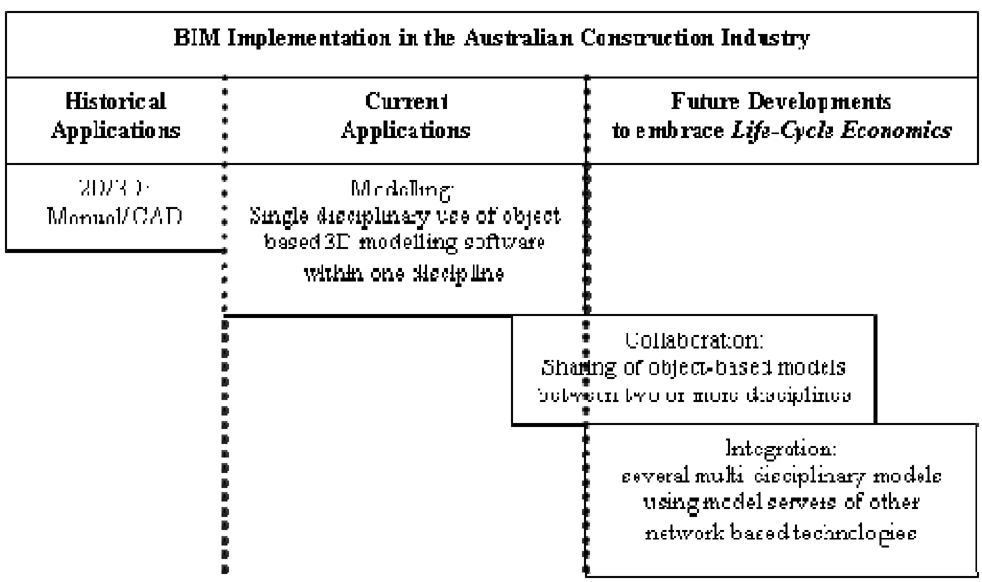

Figure 1, Building Information Modelling in the Australian Construction Industry, *adapted from AIA/ CRC-CI conceptual framework for BIM implementation*

2 Modelling Costs, Uncertainty and Risk

An asset's whole-cost requires an initial cost of construction as well as the operational and maintenance cost throughout its life-cycle, off-set by the residual cost accrued from decommissioning. Decision-trees to aid specification selection, in conjunction with analyses of alternatives using mathematical life-cost models, seek generally to aid design-team decision making at the initial stages (Al-Hajj et al 2000).

The decision making process in construction involves a degree of risk, which can be addressed by either traditional sensitivity analysis or by probability approaches. Flanagan (1993) highlights the use of the Monte-Carlo Simulation technique as a way to generate probability distribution for total costs from elemental cost distributions, although it is recognised that these whole-cost statistical applications are not infallible. Whilst some of the limitations of probability as a method to assess life-cycle cost, may be removed by considering subjective probability, other concerns remain, firstly that a probability that is subjectively measured today may be different tomorrow, and secondly that additional costs in time and expertise are necessary to extract and input knowledge. Kishk (1999) argues that the modelling of uncertainty (and predicting future cost) requires a framework able to go beyond probability theory, and argues that the incorporation of fuzzy logic and artificial neural networks goes towards such a framework.

Cost predication processes where human reasoning or human decision making are involved appear to suggest a fuzzy logic approach as one way to address the limitations of probability theory. Whilst debate regarding fuzziness and probability continues, it is claimed by some that probability may be seen as a subset of fuzzy-set-theory and that fuzzy-set-theory may be an effective tool for modelling uncertainty associated with vagueness, imprecision and/or a lack of information (Kishk et al 1999; Zadeh 1995).

3 Fuzzy Logic and Artificial Neural Networks

The fuzzy approach has the ability to match any set of input-output data (input-output data forming the basis for life-cycle prediction) and has been used favourably, on the one hand, to estimate the initial cost of construction and on the other hand as a tool for decision making in the specification of engineering components (Kishk et al 1999; Mason & Kahb 1997; Choa & Skibneiwski 1998). Indeed the fuzzy approach can be blended with traditional techniques and bodes well for an integrated framework for life-cycle costing in building when considered in conjunction with other systems that deal with the interconnection of elements, namely artificial neural networks (ANNs), where an input layer, with one or more hidden layers, allows progression towards an output layer in which a neuron receives information for the other neurons, processes it through activation functions and produces output to other neurons.

Stated somewhat glibly, whole-cost analysis requires a similar input-output pattern, such that a simplistic parallel may be drawn from input-information for the initial capital, affected by neurons of operations, maintenance, elemental interrelationship, the time value of money, discount rates, life-span and ultimately decommissioning.

A neural network has an ability to learn and generalise, allowing reasonable outputs not encountered during training, and offering computer-integrated-construction and life-cycle computing-technology a means to share theories and learning algorithms with other domains; the application of ANNs in construction in an integrated consistent approach is described by Adeli (1998), whilst Boussabaine (1997) describes models that use both fuzzy logic and neural networks, neurofuzzy systems, for financial assessments of construction projects.

These neurofuzzy systems are categorised by two forms, on the one hand, where an ANN is used to extract the required rules and membership functions for a fuzzy systems and used consequently to deduce rules and functions within a given set of complex data, and on the other hand, where fuzzy logic is used in the pre-processing &/or post-processing of data for an ANN, especially for less tangible judgmental data (Rao & Roa 1993; Bossely et al 1995).

4 Physical Modelling

Physical modelling shows how the components, flagged-up by mathematical modelling, relate to each other, and allows an environment for interdisciplinary professional interaction; notwithstanding the need to acknowledge the attitudes, values and distinct professional cultures of the specialist disciplines expected to use such models (Whyte & Al-Hajj 2000). Carrubba (1992) is not alone in promoting the use of physical models as a means to close the gap between clients and consultants to improve understanding of the inter-relationships of factors involved in projects, where a major problem has long been that clients are ill-advised about the benefits of whole-life-costing and lack an over-arching financial picture.

Integrated modelling approaches establish interaction between products, design, specification and facility management activities (Aouad et al 1997). In essence, information modelling is described within three steps: firstly a definition of the information requirements for detailed design, estimating and planning, secondly an assessment of the extent to which (some) information is required to be shared, and thirdly input of the shared information into a core model that goes beyond initial costs and incorporates life-cycle analyses.

An integrated holistic system, placing whole-life cost analysis within the remit of design decision makers, is supported by the concepts of Computer-Integrated-Construction (Brandon & Betts 1995). Object-orientated-analysis (of scope-definition, object-identification and relationship-description) models design, and hides or displays information where appropriate (Ford et al 1994). Life-cycle costing, for example, may be continually updated as a result of design changes, whilst being on-hand to aid future decision-making and proposed changes in specification.

A framework for life-cycle costing that utilises fuzzy system theory, artificial neural networks, probability and statistics to address whole-cost within an overall integrated design system allows data to be evaluated in terms of availability, tangibility and certainty (Kishk & Al-Hajj 1999). Applications allow users to manipulate construction components and operate within an AutoCAD environments and Virtual Reality Modelling Language standards to generate web-based open-systems (Al-Hajj et al 2000).

The inclusion and integration of life-cycle cost analysis to address the issues of sustainability in building is a major, essential step (see figure 1 above) to extend historical applications of 2D and 3D (representing the traditional three dimensions of width, length and height) towards 4D (recognition of time phasing/sequencing in a project), alongside what might be termed 5D & 6D (life-cycle cost-estimating and facilities-management respectively).

Modelling a specialist database about life-cycle costing requires (i)a description of the inter-relationship of the factors that make-up life-cycle costing; (ii)the conceptual LCC model itself, and; (iii)the implementation of the LCC model into an overarching central encyclopaedia of information held within a design data-base.

5 Towards a framework for life-cycle cost analysis

Any framework for a life-cycle costing approach must build upon a foundation of knowledge concerning discounted cash flow and LCC analysis procedure, as well as a classification of asset components, significant cost and quantity items and the cumulative affect of linking components. Clear understanding of the rationale for ‘input’ variables may then be used as a decision support tool to aid the design team and becomes a vehicle for designers to validate the choice and value of particular specifications and concept designs.

The outline for the life-cycle cost analysis tool presented here draws upon previous work to go towards a model able to integrate easily within the multi-faceted process of design (Whyte 2007). Key variables include: significant cost items (of operation and maintenance) within an appropriate level or elemental division of the project; specification of material in terms of the design brief and service-life required; factors affecting component deterioration and failure, maintenance, preservation and operational cost variables, and; net present value indicators for the whole-cost of the life-cycle of the asset.

An initial user-friendly format that allows designers to acknowledge the concepts of life-cycle analysis quickly yet concisely, was developed allowing the design team to progress through a series of drop-down menus allowing inclusion and sharing of as little or as much detail as is required. This simple spreadsheet format, incorporating visual-basic, is the first step towards an overarching computerised model.

A summary-sheet created for alternative assets (based on a given number of alternative component specifications) describe whole-costs in terms of the building elements of substructure, finishes, fittings, services and builders work. Alternative specification whole-cost differences are presented explicitly to describe the capital, maintenance, operation and residual costs to assist decision-making.

5.1 Application

Alternative specifications are identified (via updated design changes shared by an overarching holistic system where possible). Designers specify materials from any number of alternative systems that make-up sub-elements, elements and group-elements (as figure 2 below). Design alternatives are then examined in terms of life-span and deterioration (ideally utilising fuzzy-system/artificial-neural-networks, probability and statistics to better assess cost data for availability, tangibility and certainty), allowing comparison of alternatives (figure 3 below).

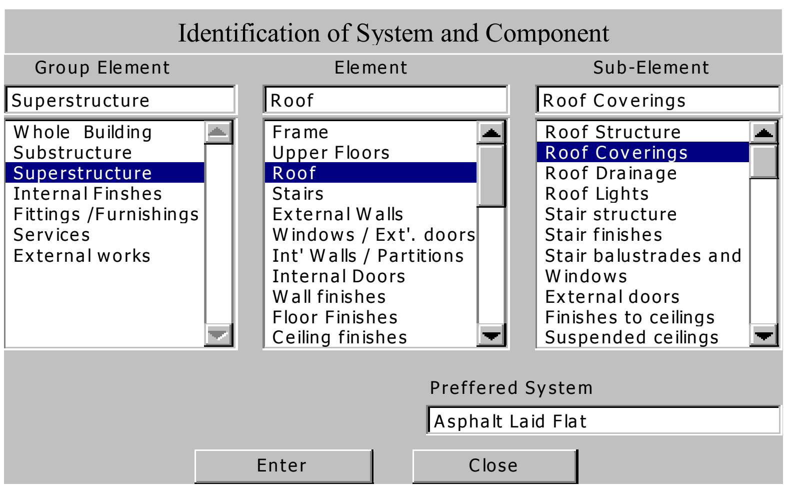

Figure 2, System and Component Identification and Inter-relationship Menu

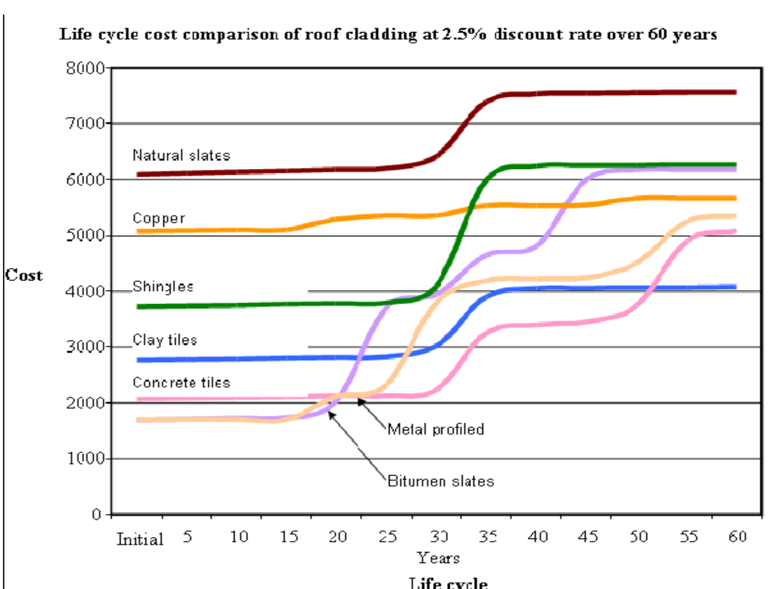

Figure 3, Specification Comparison Output

The example described here used data that was input directly into the life-cycle costing tool to allow comparison of alternatives; it is hoped that future applications shall share design choice data more remotely. Once all group, element, sub-element and preferred-system alternative specifications are considered, concept designs are compared in totality. Whole-life cost results are summarised graphically and design decisions regarding the economic viability of alternative design options become clear, assisting client understanding of life-cycle greatly.

6 Conclusion

Building Information Modelling must increasingly address life-cycle economics if productivity gains are to be realised by virtual-prototyping prior to development. Overarching systems that incorporate life-cycle-costing may be enhanced by fuzzy-set-theory/artificial-neural-networks to address information gaps in predicting whole-cost. The basic-modelling technique presented addresses the need for a life-cycle-cost system able to form part of an overarching construction model, supporting decision making in building design process. It is shown above that the first two steps of the process are underway; work describes firstly that a description of the inter-relationship of the factors that make-up life-cycle costing has already been established and secondly that standard conceptual life-cycle model development is being addressed. The next step must be recognition that input information stems from different levels of data and information availability. These different levels of uncertainty must be addressed before beginning the process of integrating the optimum life-cycle cost system, into a holistic design data-base and central encyclopaedia of design and specification information.

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