

DESIGN COST MODELLING – A WAY FORWARD

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1. Introduction

Accurate cost modelling is fundamental to the efficiency of the construction industry in general, and the stakeholders within the industry in particular. Clients, consultants and contractors all have much to lose from the consequences of inaccurate cost modelling, e.g. through the time and cost ramifications of tender results not matching clients' budgets. Such ramifications include:

- the costs of redesign and retendering / negotiating of projects (perhaps of reduced scope and quality) and the associated time delay, or;
- increased construction costs requiring additional funds to be sourced by clients.

Potentially this can impact upon the financial returns of a building project to a client and, at worst, lead to the abandonment of a project altogether.

Design cost modelling (i.e. during the design stage of the development process) has traditionally been undertaken by consultant quantity surveyors, at times with less than adequate results. Research undertaken at the Department of Building and Construction Economics at RMIT investigated potential means for improvement of the accuracy of design cost modeling, and has concluded that the way forward may lie in the manner of procurement for building projects. The objective of this paper is, firstly, to review the current status of design cost modelling in terms of the techniques used, their accuracy, levels of usage, and deficiencies. Secondly, the paper identifies a way forward for research in this field through the emergence of non-traditional methods of building procurement.

2. Cost Modelling

Cost models are technical aids which enable management decisions to be made in the context of building design (Skitmore and Marston, 1999). The primary function of cost models in this context is to provide reliable cost forecasts (Elhag and Boussabaine, 1998), either for the client or the contractor (Ashworth, 1999). More specifically, the management decisions supported by cost models include:

- forecasting the total cost of construction.
- comparing design alternatives.
- forecasting the economic effects upon society of changes to design codes and regulations (Skitmore and Marston, 1999).

Because clients undertaking construction projects will wish to have an understanding of their financial commitment, it is appropriate to apply cost modelling techniques as early as possible in the development process, prior to commissioning extensive design work (Ashworth and Skitmore, 1983). Further, because design precedes construction in the development process, cost modelling is generally commenced at the beginning of the design stage. At its earliest, this could be the initial feasibility study of a project. Various cost modelling techniques may then be utilised throughout the design process, generally in accordance with the level of design information (drawings, specifications etc.) available at any particular stage.

Importantly, such design information portrays the completed product or building, rather than the production processes of construction. That is, the design information represents **what** is to be built (in terms of the completed building), as opposed to the **production process** of (explicitly) **how** the building is to be constructed. As such, cost modelling

techniques used during the design process, which are based upon such design information, have also traditionally focused upon modelling the completed **product price**, rather than modelling the **production process cost**, of construction. Consequently, two distinct paradigms of cost modelling techniques exist:

- product based – where the completed building is modelled.
- process based – where the construction production process is modelled (Skitmore and Marston 1999).

These differences have been recognised for some time. Beeston (1982) suggests that cost modelling techniques are either “black box” (product based) or “realistic” (process based). Realistic methods are derived from attempts to represent costs in the ways in which they arise. ‘Black box’ methods do not attempt to represent the

ways in which costs arise. Brandon (1982) considers that the cost modelling techniques used during the design stage of the development process are distinctly “black box”, and suggests that “modelling the reality, i.e. the way costs are incurred on site, does not enter into the (development) process until operational costs are considered, usually at the post contract stage.”

The cost modelling techniques themselves are now considered separately in terms of product based and process, or resource based, cost modelling techniques.

3. Product Based Cost Modelling Techniques

Fortune and Lees (1996) and Fortune and Hinks (1998) identified the following “traditional” (product based) cost modelling techniques in widespread use, as summarised in Table 1.

Technique	Description
Judgement without quantification	The use of professional expertise and intuition to formulate strategic cost advice.
Functional Unit	A monetary rate or amount applied to a unit commensurate with the function of the building e.g. \$/ carparking space
Superficial	A single rate applied to the floor area of a building e.g. \$/m ² .
Principal item	A single \$ rate applied to the major item of a project.
Interpolation method	The application of costs from previous projects by way of interpolation.
Elemental analysis	A summation of the application of costs to the design elements within a project.
Significant items	The measurement and pricing of significant items of work.
Approximate Quantities	The measurement and pricing of a small number of grouped items.
Detailed Quantities	The measurement and pricing of many items, such as a Bill of Quantities.

**Table 1 – Cost modelling techniques in widespread use
(Source: Fortune and Lees 1996, and Fortune and Hinks, 1998)**

Technique	Description
Cube (Smith, 1998).	A single cost rate applied to the internal volume of a building.
Functional Area (Smith, 1998).	Similar to the superficial model, although different cost rates are applied to different functional areas within a building on the assumption that those different areas will cost different amounts to construct.
Superficial Perimeter (Ashworth, 1995)	A variation on the superficial method. As well as taking the floor area of a building into account, the length of building perimeter is also included in an endeavour to increase accuracy.
Storey Enclosure (James, 1954)	The measurement and costing of the area of the external walls, the floor and ceiling which enclose each storey within a building.
Regression Analysis (Flanagan and Norman, 1978)	A statistical technique whereby historical data is analysed in a structured format. The major components of construction are identified and a mathematical relationship between them, in the form of an algebraic equation, is determined using historical data.
Probabilistic Treatments (Mathur, 1987)	The use of probability theory and random number generation to produce cost models with risk profiles which recognise the inherent variability and uncertainty of design cost modelling, due to its predictive nature.
Expert Systems (British Computer Society, as cited in Ogunlana, 1989)	The capture, bottling and dissemination of expert knowledge for use by less qualified / experienced personnel, generally by computer program.

Table 2 – Lesser used product based cost modelling techniques

Additional traditional or product based cost modelling techniques identified from the literature are summarised in Table 2 (above).

As stated, traditional or product based cost modelling techniques model the completed building as opposed to the production process of construction. However, such models contain an implicit assumption about construction processes. This assumption is that similar designs will always be constructed in the same way. Whilst this assumption may be valid at a general level, it is likely to be less so at more detailed levels. Therefore, if some variation in construction process is inevitable, and product based cost modelling techniques do not explicitly deal

with it, how acceptable is the accuracy of these models?

4. Accuracy of Product Cost Modelling Techniques

Studies have been undertaken to determine the accuracy of cost modelling techniques. Ashworth and Skitmore's (1983) literature review of the accuracy of "estimating" in the design stage of the development process indicates a perceived level of accuracy of design stage cost modelling ranging from +/- 20 – 40% in the early stages, and improving to +/- 10 – 15% in the latter stages of the design process.

Studies by Flanagan and Norman (1983) compared the "last price prediction prior to

tender” with the lowest tender price received in two English County Council Authorities. The results indicated that approximately 50% of projects were estimated within +/- 10% and all projects were estimated within +/- 25%; a considerably higher level of inaccuracy than Ashworth and Skitmore’s perceived accuracy levels.

Beeston (1974) outlined the variability of design cost modelling in terms of the co-efficient of variation (standard deviation expressed as a percentage of the mean), based upon investigation of submitted tender bids. With respect to estimating the lowest tender, Beeston concluded that the variability of consultant quantity surveyors’ estimates, when combined with the inherent variability of the tendering process itself, resulted in a best possible co-efficient of variation of 7%. According to Beeston, such a co-efficient of variation would result in 52% of quantity surveyors’ estimates being within 5% of the lowest tender, 68% of estimates within 10% of the lowest tender, and all estimates within 30% of the lowest tender. It is not clear which cost modelling techniques, or stages of the design process, are being referred to in Beeston’s work, other than “using present methods in the best way under average circumstances”. Beeston considers that improvements to the quantity surveyor’s estimating variability (and hence accuracy) could be made through a model which makes a “direct evaluation of contractors’ costs”, considering that “if this assesses costs by a method related to the way in which they arise it will be especially suitable for giving cost advice to designers.”

Morrison (1984) outlines the difficulty of comparing design stage cost forecasts with tender bids, due to the constant state of flux of the design of many construction projects. Morrison’s work compared the quantity surveyor’s pre-tender estimate with the lowest tender received on 557 projects in which it was possible to exclude prime cost and provisional sum items common to both figures. The results found a mean deviation between the pretender estimate and the lowest tender

of 11.97% (co-efficient of variation of 15.45%). Morrison contrasts these results against studies done into the accuracy of contractor’s estimating (Barnes and Thompson 1971; Barnes 1972; and Flanagan, 1980) which indicate a mean deviation in the order of 6% (co-efficient of variation of 8.22%), reducing to a mean deviation of 3.75% (co-efficient of variation of 6.59%), when projects valued under 100,000 United Kingdom pounds are excluded from the sample. Morrison considers this estimating performance of quantity surveyors to be “very poor”, yet likely to represent the best performance achievable, concluding that “this level of performance is unlikely to fulfil clients’ requirements for controlling the cost of construction within pre-determined limits”.

Such criticism of quantity surveyors’ estimating performance implies deficiencies with the cost modelling techniques upon which this performance is based. Such deficiencies are now considered.

5. Deficiencies of Product Based Cost Modelling Techniques

The product based cost modelling techniques outlined are considered useful on the basis of their ease of application, familiarity and speed, and a tolerable level of accuracy as noted above (Ashworth and Skitmore, 1983; Ashworth, 1995).

However, the same models have also been criticised on the basis that:

- they are not (explicitly) founded upon construction production criteria as the generator of cost (Brandon, 1982; Morton and Jaggard, 1995)
- they do not fully represent the relationship between design decisions and the resulting construction processes (Bowen, 1993).
- they fail to consider the uncertainties of the construction process (Bowen *et al*, 1987; Bowen, 1993).
- the cost data used to support such models is often taken from previous projects, previous bills of quantities, price books etc.

and does not represent cost as a function of resource usage, but rather as a function of the completed building product (Raftery, 1984; Morton and Jagger, 1995). Additionally, such cost data is often “massaged”, or subject to “noise” (Newton, 1989), by having the actual resource costs spread over the unit rates, and also when unit rates are allocated into elemental costs.

Thus the criticisms of traditional product based cost modelling techniques are focused upon two main concerns:

- Firstly, the lack of an explicit relationship between the cost modelling techniques and the construction process.
- Secondly, the use of distorted cost data to support such cost modelling techniques.

It is contended that “process” or “resource based” cost models more accurately reflect the way in which construction costs are incurred. In simple terms, this would comprise the necessary labour, material, plant and equipment required to construct a building. McCaffer and Baldwin (1986) and Beeston (1974, 1987) consider that the greatest opportunity for improved accuracy in design cost modelling lies in aligning the modelling techniques as closely as possible with the generators of such costs, i.e. the methods by which they arise. Bowen *et al* (1987) contend that truly realistic cost models must simulate the construction process. Such models are hence termed “process based” or “resource based” (hereinafter referred to as “resource based”) cost modelling techniques, and are deemed to be inherently more reliable than their product based counterparts (Skitmore and Marston, 1999).

6. Resource Based Cost Modelling Techniques

In response to the deficiencies of traditional product based cost modelling techniques, a number of “resource based” cost modelling techniques have been

developed. These are summarised in Table 3.

All of the resource based cost modelling techniques outlined in Table 3 share a common theme of utilising the contractor's resource based data during the design process. However despite their potential, the literature contains no reported cases of the use of such resource based cost modelling techniques. Their effectiveness, therefore, remains a matter of academic conjecture, and the question arises as to the extent of use of cost modelling techniques in the design stage of the development process.

7. Use of Cost Modelling Techniques in the Design Stage of the Development Process

Fortune and Lees (1996) surveyed cost modelling technique usage during “early cost advice”¹ by “organisations” in Northern England and Wales. Consulting quantity surveying firms made up 62.6% of the sample frame in this study, the remainder comprising project management, contracting and multi-disciplinary organisations, and local and regional authorities. Later studies were conducted by Fortune and Hinks (1998) into the use of cost modelling techniques by consultant quantity surveyors in the provision of “early cost advice”² throughout the whole of England. The results of these studies are shown in Table 4.

¹ “Early cost advice” was defined as being “any cost advice given to the client prior to a formal offer of contract being made”

² “Early cost advice” was defined as being “any cost advice given to the client prior to a formal offer of contract being made”

Resource Based Cost Modelling Technique	Description
Operational Bill of Quantities (Skoyles, 1968).	An attempt to restructure the traditional bill of quantities to correlate with the way construction work is carried out.
Construction Unit Planning Approach (Bowen, 1993).	Similar to the operational bill of quantities.
British Property Federation System (Morton and Jaggard, 1995).	Use of a construction program for the tender bid, in lieu of the bill of quantities.
Cost of Contractors Operations (Beeston, 1974).	A cost modelling technique that enables designers to consider the construction implications of design decisions and design alternatives by simulating the thought processes used by construction planners in terms of selecting plant and allocating labour to a project.
Pre-established Critical Path Method Networks (Bowen, 1993).	a cost model for use in early stage cost forecasting, which is sensitive to both construction method and construction duration. The model is based upon the use of default critical path method networks, with the injection of algorithms to determine the duration of construction activities.
Simulation (Bennet and Ormerod, 1984).	a cost modelling technique which mimics the construction process to provide a “simplified representation” of likely duration and cost, through the use of a computer program.
A Process Based Modelling System (Bowen <i>et al</i> , 1987; Bowen 1993).	Similar to simulation, with critical path and sub-networks used as the underlying cost modelling structure.
Data Integration Systems (Morton and Jaggard 1995; Kim <i>et al</i> , 1999).	Models developed to accommodate the differing data requirements of the design and construction stages of the development process.

Table 3 – Resource Based Cost Modelling Techniques

The results of these surveys indicate that traditional product based cost modelling techniques (with the exception of the principal items model) have the highest relative incidence of model usage, and resource and process based cost modelling techniques the lowest incidence in usage.

Studies by Bowen and Edwards (1998), investigating cost modelling techniques employed amongst South African quantity surveying practices, revealed that traditional cost modelling techniques such as elemental analysis and approximate quantities are the most popular methods employed. Additionally, the superficial

method and bills of quantities are also employed at particular stages of the design process; i.e. the brief and documentation stages respectively.

This study revealed that a large proportion (83%) of respondents “seldom, if ever, utilise (resource based cost models such as) critical path methods or activity bills of quantities in the preparation of price forecasts”. Bowen and Edwards concluded that “South African quantity surveyors show little inclination to adopt models which attempt to more closely represent the construction process itself, i.e. resource based cost models”.

Model	Incidence in use (% of Respondents) Fortune and Lees (1996)	Incidence in use (% of Respondents) Fortune and Hinks (1998)
Judgement	85.80	82.96
Functional Unit	75.50	69.74
Cost per m ² (Superficial)	97.30	96.96
Principal Items	47.30	39.57
Interpolation	87.00	84.13
Elemental Analysis	88.70	88.05
Significant Items	73.00	69.83
Approximate Quantities	96.20	93.34
Detailed Quantities	68.70	63.66
Resource Based* ³	50.40	46.23
Process Based*	31.80	26.35

**Table 4 - Use of various cost modelling techniques by Northern England “Organisations” (1996) and all England Quantity Surveyors (1998)
(Source: Fortune and Lees, 1996. Fortune and Hinks, 1998)**

No comparable study could be found of the use of cost modelling techniques by consulting quantity surveyors in the Australian context. However, the similarities of structure of the Australian, English and South African development process in general, and cost modelling techniques in particular, make it reasonable to suggest that similar findings would prevail.

These studies indicate that whilst consultant quantity surveyors do at times make use of resource based cost modelling techniques in some semblance, they clearly prefer to use traditional product based cost modelling techniques. However, if resource based such cost modelling techniques do in fact more realistically represent the cost of construction, and hence provide for greater levels of modelling accuracy, why are they not used to a greater extent?

8. Inhibitors to use of Resource Based Cost Modelling Techniques

Skitmore and Marston (1999) adumbrate the difficulty of using resource based cost modelling techniques during the design stage of the development process due to the additional assumptions required to convert design information into process information.

Formoso (cited in Bowen, 1993) contends that the primary reason for the low level of usage of resource based cost modelling techniques in the design stage of the development process is due to a fundamental lack of understanding by the design team of construction processes. Ogunlana (1989) considers “design cost estimators” to be “ill-equipped” to estimate construction costs as contractors do. Skitmore and Patchell (1990) and Bowen (1993) have cited lack of understanding of the construction process on the part of “design cost estimators” as the reason for

³ For the purpose of Fortune and Lees' study, resource based cost modelling techniques were defined as those which use schedules of materials, plant and labour. Process cost modelling techniques were defined as those which use bar charts and networks.

the lack of usage of the simulation and Cost of Contractors Operations resource based cost modelling techniques respectively.

Ashworth (1999) notes that the data required to use resource based cost modelling techniques is not available to the design cost estimator, whilst Ogunlana (1989) contends that even if such data were available, unfamiliarity would act as a barrier to their usage. Such arguments are supported by the earlier study of Fortune and Lees (1996). In analysing the relationship between organisational type and incidence of cost modelling technique, they note that project management and contracting organisations are more frequent users of resource based cost modelling techniques than quantity surveying practices. A possible explanation offered by the authors for this discrepancy concerns the limited access of quantity surveyors to appropriate construction resource and process data, as opposed to information (bills of quantities etc.), which support traditional product based cost modelling techniques. Additionally, lack of understanding of resource based cost modelling techniques was considered to “significantly” contribute to their comparatively lower level of usage by quantity surveying practices.

Ogunlana (1989) notes the time constraints of resource based cost modelling techniques; considering them to be “relatively painstaking and time consuming compared with other techniques.” Bowen and Edwards (1998) agree, considering that time constraints “appear to preclude more detailed attention to the construction resource implications of building design.”

Such inhibitors to the use of resource based design cost modelling infer a “gulf” existing between the users of such techniques (consultant quantity surveyors) and the construction process they are attempting to model. It is contended that such a gulf emanates from the traditional method of building procurement.

9. Design Cost Modelling and the Traditional Method of Building Procurement

Notwithstanding the time constraints of resource based cost modelling techniques, it is postulated that any lack of resource based data, or understanding of construction processes, on the part of consultant quantity surveyors is predominantly a function of the traditional method of building procurement itself. Such a method distinctly separates the design and construction stages of building development and creates cost specialists in each; consultant quantity surveyors in the design stage and contractors in the construction stage. Any time constraints which preclude the use of resource based cost modelling techniques merely serve to reinforce this division caused by the traditional method of building procurement.

Love *et al* (1998) consider that this traditional fragmentation of the design and construction functions has created “walls” around the project participants, resulting in ineffective communication processes. Such “walls” create an environment in which processes such as cost modelling, and the information upon which they are based, are often conducted in a climate of self-perpetuating isolationism. In such an environment, consultant quantity surveyors “suffer” from modelling a design which does not explicitly represent all the cost generators which are fundamental to the accuracy of the cost model. Kim *et al* (1999) consider such a problem to result from the “functional gap” created from differing data requirements and “traditional barriers” existing between professionals.

In addition, the separation of the design and construction processes under the traditional method of building procurement has effectively excluded contractors from the design stage of the development process. As contractors are the specialists of construction, and by extension construction processes and methodology, the implementation of construction process expertise into design cost modelling techniques is also excluded.

10 Alternative Methods of Building Procurement

The traditional method of building procurement has generally not accommodated the implementation of resource based design cost modelling. Indeed, the obstacles created by the traditional method of procurement have possibly stalled research into this area.

However, if the construction expertise of contractors were available in the design stage of the development process, it is reasoned that a resultant increase in the accuracy of design cost modelling can be expected. In this regard, recent shifts in the procurement methods of projects may provide a way forward. The growth in popularity of non-traditional procurement systems which incorporate the contractor into the design stage of the development process, such as design and construct, construction management and management contracting (Turner, 1997; Franks, 1998) provide a “window” by which the design cost modelling techniques of contractors may be examined. If the design cost modelling techniques used by contractors can be identified, they can then be compared to those used by consultant quantity surveyors. Such a comparison will give an indication as to the importance of resource based cost modelling in overall forecasting accuracy. In turn, areas of potential improvement to traditional design cost modelling techniques used by consultant quantity surveyors may be identified.

11 Conclusions

Consultant quantity surveyors generally utilise product based design cost modelling techniques; such techniques reflecting the design information upon which they are based. These techniques do achieve a tolerable level of accuracy. However, they are deficient in terms of lacking an explicit relationship with the construction process they are purporting to model, and by using distorted cost data to support them.

Whilst resource based cost modelling techniques have been developed, the traditional product based cost models retain greater favour with consultant quantity surveyors. Reasons proffered for lack of use of resource based cost modelling techniques by consultant quantity surveyors include lack of data, lack of understanding of construction processes, and time constraints. These restrictions emanate from the traditional method of building procurement which distinctly separates the design and construction processes and thus militates against the easy transfer of data between the actors engaged in them.

However, the emergence of non-traditional methods of building procurement provides fresh opportunities for the advancement of design cost modelling research. Such procurement methods position the contractor directly in the design stage of the development process, making it possible to examine their design cost modelling techniques and utilise their process expertise. It is postulated that such an investigation would provide indicators of potential improvement to the accuracy of design cost modelling techniques used by consultant quantity surveyors.

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