Model-Based Estimating for Concrete Bridges: A feasibility study

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INTRODUCTION

Designing and estimating civil concrete structures is a complex process which to many practitioners is tied to manual or semimanual processes and cannot be further improved by automated computer-based processes. This paper presents a feasibility study for the development of an automated estimator for concrete bridge design, and demonstrates that such estimators can add significant value to interactive design and estimating and, because of this, offer themselves a future.

An earlier CRC for *Construction Innovation* project on automated estimating has shown the key benefit of *model-based design methodologies* in building design and construction to be the provision of timely quantitative cost evaluations (Drogenuller 2003). A building model was input into the estimator which automatically produced the estimated prices of the concrete trade for the building's construction. The speediness of cost estimation has produced an important impact on building design – the easier cost estimation is obtained, the better it can be used to guide the design of buildings. From a theoretical perspective, Yum (2005) has shown that using a model-based approach during building design can improve the design options, result in shorter design turnaround times and better design quality as well as lower costs. The question is: Do the benefits of efficient estimation warrant further development of automated estimators outside the realm of buildings?

There are few, if any, automated estimating applications for civil engineering structures. The research partners in *Construction Innovation* expressed interest in evaluating whether it would be feasible to extend automated estimation for buildings to the realm of design for civil concrete structures. This paper presents the work done on these investigations, with the view that they can add value to the research and development of automated estimators for civil concrete structures.

The scope of the study is to investigate whether it is feasible to develop an automated estimator for civil concrete structures. Questions asked are:

- Do such estimators add value to the design and construction of concrete structures? And if the answer is 'yes'...
- Where does the benefit lie?
- What is the functional form of the estimator?

The following aspects are beyond the scope of this study:

- A fully developed business case for an automated estimator for civil concrete works
- Designing processes for the ideal model-based design approach
- Designing schemas for the planning/design/estimating of bridges
- Implementing the above designs in supporting software applications.

The contribution of this paper is threefold: (a) to identify points where values can be added to the processes of design, assessment and construction of concrete bridges, (b) to embed such values into the process of automated estimating, and (c) to specify the functional requirements of the automated estimator.

METHOD

Figure 16.1 shows the context and method used to investigate the feasibility of developing an automated estimator for civil concrete works. The study first established that there are two types of estimating in the current practice of bridge estimation. Of these two types only the type of *estimation for design* has potential to add significant value to the whole design–estimating process. The second part of the study, 'Opportunity for change' in Figure 16.1 identified the opportunities of improvement, that is model-based technology adds efficiency and functionality to software that supports the interaction of design and estimation. A value proposition is established: an efficient automated estimator can add value to the design–estimating process, i.e. reducing estimation errors, shortening the duration of success estimates, and increasing the benefit of doing cost estimation when compared with the current practice. The value proposition rests on the availability of an efficient automated estimator for design–estimating interaction – if such an estimator is available, the use of it will add significant value to bridge design and thus enable the tool to grow in the commercial market.

The last two parts of the study were in step with each other: designing typical use scenarios for use of the model-based estimator efficiently, and identifying the functional requirements for an efficient automated estimator for bridges.





CURRENT PRACTICE OF ESTIMATION

From this section onward estimating is considered within the context of planning and design, because estimating and planning/design are always intertwined to give the planner/designer some assurance of the quality and economy of the work. Also, in practice, the planning and design of bridges is always considered in the context of roads planning/design. As a result of these contextual dependencies, we have to consider the current practice of *bridge estimating* in the context of *roads planning/design*.

The Queensland Government Department of Main Roads (QDMR) has developed a full set of estimating standards (e.g. QDMR 1999; 2002; 2004; 2005), including standard work breakdown structures (WBS), to facilitate the infrastructure project tendering processes of the Queensland Government. We believed that investigating the current practice of estimation in Queensland would perhaps give us a good starting point in this feasibility study.

Estimating is executed in the context of project management in order to be an integral part of a system of interdependent core inputs of scope, resources, time, cost and quality.

A typical project budget results from the approval of a business case concept estimate at the end of the concept phase. This estimate is based on a sound definition of scope of the preferred option derived from completing a scope analysis. Once the project is justified, it is placed in the Roads Implementation Program (RIP) for further development. The total development time in RIP is about five years (indicative only). It is expected that project scope and details are progressively refined. As more information is added to the design over time, the estimation percentage errors relative to the final total cost of the project are expected to decrease.

The preliminary design estimate is used to confirm the budget before the project moves into the last two years of firm RIP. At the end of the detailed design period, the design is completed; and tender documents are prepared for contractors to bid on.

Macro-level estimating

The planning and design of roads and bridges is a very complex process. To overcome the complexity, planning and design processes may be compartmentalised into lifecycle stages: concept stage, preliminary design stage, and detail design stage. The estimating process at the end of each lifecycle stage is needed for project budgeting and approval. Each project lifecycle stage has its own timeframe (with a duration ranging from months to five years) and a scope of work. It needs considerable work to get a project to progress from the concept stage to the next; and it needs even more work if a preliminary design plan is scrapped and work reverts to the conceptual design stage. Due to the long duration of the project lifecycle stage (months or years), the estimate for each stage cannot be used to fine tune the design options – too many design hours have gone into the plan and it would be inefficient to redo it all.

Estimating at the end of a project lifecycle stage is referred to as *macro-level estimating*. It is used for managing the *total* cost and/or estimating budget, but it is a blunt tool for planning and/or design.

Micro-level estimating

While the previous estimating process is related to project management, this subsection discusses estimating during the *design* process. The main difference is that the former process is performed to get approvals from one management lifecycle stage to another (total cost estimating), whereas the latter process is performed by a project team so that, at any time during the design of a structure, cost factors may be incorporated for partial and total cost estimation.

QDMR (2002) is a road/bridge planning and design manual that provides a comprehensive set of design parameters, including traffic parameters, human factors, speed parameters, safety barriers, sight distance, alignment design, intersections, transport systems, bridges, and so on. These parameters (formerly called *design domains*) and their values are selected for the justification of a design, based on empirical safety research, or theoretical physical models, or both.

Any design with respect to a design domain is a compromise between competing requirements, expectations and contextual information (i.e. in terms of location and geometry problems, cost, safety, driver expectations, economics, environmental and social impacts). Figure 16.2 shows a qualitative cost and benefit analysis of the selection of the width of a motorway shoulder (a

paved strip beside the motorway). Selection of a value within a design domain depends on a trade-off between the issue context and various benefits and costs.

The estimated cost is a part of the multi-criteria assessment (MCA) that helps select a solution from various design options. The key design parameters, such as traffic parameters, speed parameters, cross-sections, safety barriers, lighting, bridge deck, piles, a design domain (design parameter) is evaluated according to multiple values (such as mobility, maintenance cost, capital costs, environmental impact, accident rate) This loop defines the *micro-level estimating* which assesses the cost of *any part of the design at any planning/design time*.

In current practice, the decision points at various micro-levels of estimating are based on the judgment of bridge design experts, because there are no computerised tools to facilitate the decision process.

The most logical approach to automating the processes of micro-level estimating is to split the cost information and splice it with the components of various *design models* along the design life of the bridge. But before doing that, we need to answer these fundamental questions: What is the benefit of doing so? Is the benefit so significant that it will support the cost of developing the automated estimator?

VALUE PROPOSITION

This section develops the overall value proposition that an automated estimating system provides considerable advantages over the current process. It describes the areas where an automated estimating system adds value to civil works projects, discusses some of the issues impacting cost-benefit considerations, and suggests ways in which the characteristics of such an estimating system impact on an estimating strategy.



Figure 16.2 Micro-level Estimating and Multi-criteria Assessment (MCA)

Technological context: Model-based design

A model-based automated estimating system requires a semantically-rich project data model as input (e.g. a building information model, IFC model or similar). The project data model is an integrated model that can be used across a number of disciplines, such as geometry design of the road/bridge, structural loads, traffic requirements, stormwater systems, or electricity equipment, and is not simply limited to estimating.

It is only advantageous to develop an 'automated estimator' when this is based on model-based design so that estimators reuse the data from the design model to assess costs. There is little benefit in requiring the user to manually re-enter design data into the automated estimator to evaluate costs.

Model-based technologies add value in two broad categories:

- 1. they add efficiency and functionality to individual software tools by allowing automatic generation of 3D views and design versions for project management
- 2. they improve data sharing, integration, and interoperability between design and estimating (i.e. the geometry design data of bridges can be re-used for the purpose of structural engineering design and cost estimation).

By comparison, the general building construction industry appears to be in the early stages of adopting model-based technologies, and those companies that have made the transitions are experiencing positive overall outcomes. There is no reason to expect that the civil engineering industry would not similarly benefit from model-based technologies, although the required software systems, standards, etc. may be less well-developed at present.

Organisational context: Alliancing contract

In the traditional form of civil works project organisation, the owner engages design consultants who complete the project design before a contractor is appointed through the competitive tendering process. Increasingly, variations in projects' organisational forms introduce a range of new relationships, tasks, and sequencing among the project participants. These organisational forms include design-build contracts, alliancing agreements, public-private partnerships etc. Some of the outcomes of these organisational evolutions lead to a blurring of the boundaries between the design stage and the construction stage, increasing collaboration between design and construction parties, and increasing participation of contractors earlier in the project.

The greater the interaction between design and construction throughout the early project phases, the greater the opportunity for automated estimating systems to be used to produce frequent, reliable costs estimates throughout the design and tendering phases with minimal time, effort, and cost. This increased value arises because designers are able to provide early design information and take advantage of improved cost estimates to guide design decisions, contractors are able to provide construction

methods decisions and costing information to improve estimates' reliability, and the estimating system is able to convert this information to cost estimates with a high degree of automation (with a consequent reduction of time and cost).

Designer's value-adding proposition: Estimating utility theory

The most salient characteristic of model-based automated estimating is that, by automating quantity takeoff and other estimating tasks, a significant reduction of time and effort is required to produce estimate results. This increased speed and efficiency provides the following advantages:

- substantial savings in the cost of producing estimates
- quicker turn-around times for estimates, making estimating more convenient and timely
- relieves pressure on estimating resources; for example, it would increase the capacity of a single estimator and reduce the likelihood of bottlenecks in the design process
- ensures that estimates are of higher quality than might otherwise have been the case because measurements are prepared consistently and rigorously.

The less direct, but potentially greater value, proposition lies in the premise that, because it is much quicker, cheaper, and easier, estimates will be produced much more frequently throughout the design process and will thereby lead to better design outcomes. In its simplest form, this value proposition suggests that the outcome of any civil engineering project will be improved if an accurate cost estimate could be produced at any point throughout design and construction 'at the touch of a button'. This value arises because improved cost forecasts facilitate better planning, design, and construction decisions. This proposition is clearly hypothetical – complete and accurate cost estimates can never be provided with no time and cost. Yet, acceptance in principle of this hypothetical value proposition motivates an examination of how near to this ideal practical estimating solutions can approach, and how much value these solutions can provide.

A final value proposition is that cost-related risks could be reduced if better cost information were available throughout the planning and design phases.

Conceptually, the *value* of producing an estimate is taken to be the monetary *benefit* of producing the estimate divided by the *cost* of producing it.¹⁷ If the value (i.e. benefit/cost) is greater than 1.0, it should be worthwhile to produce an estimate, and given a range of possible estimating strategies, the alternative that yields the highest value should be chosen. To assess this value, the benefit and cost of producing an estimate need to be evaluated.

Planning and design practices involve a lengthy sequence of decisions intended to produce a final outcome that meets cost and other project objectives. Given perfect information and prediction capabilities, the outcome would be very nearly optimal. However, information and prediction capabilities are not perfect, so results follow a bounded rationality – they are the best choices available given the limited information available.

With respect to cost objectives, explicit cost estimating provides the best available prediction of project costs. However, this explicit cost estimating is carried out only infrequently during the design process, and it is only at these infrequent times that the designers have the best possible cost information upon which to base their design decisions. In between these estimate points, design decisions are not arbitrary with respect to costs, but are based on cost-related judgments that designers are able to predict *without* the benefit of full cost estimates.

The *benefit* of cost estimating arises from the difference in cost between the design that would be produced without the estimate information, and the cost of a more optimal design that could be produced with the estimate information. (The estimate information may also allow more optimal design decisions with respect to other project objectives such as lower risks, better decisions about additional features that could be included within budget targets, etc.) A number of factors impact the extent or magnitude of this benefit, including the accuracy of the estimate, and the time intervals between successive estimates.

The benefit of the cost estimate will be proportional to the accuracy of the estimate. Very accurate estimates provide nearperfect cost information and are clearly better than the assumptions that designers make without cost estimates. Very inaccurate estimates may be little better than a designer's judgment, thus providing negligible benefit. There are, of course, significant inherent uncertainties involved in predicting future construction costs, so there are very real practical limits to the accuracy attainable with cost estimates. Yet up to these accuracy limits, the following relationship exists: greater estimate accuracy can be achieved with greater estimating effort (i.e. the more accurate the estimate, the more costly it is to produce the estimate).

The combined effect of benefit/cost, as shown in Figure 16.3, relates the value of the estimate to the accuracy achieved. This relationship suggests an estimating strategy: that for a given situation, there will be an optimal level of accuracy to try to achieve (more accuracy will lower value by disproportionately increasing costs, less accuracy will lower value by disproportionately decreasing benefit). Using a similar argument, the relationship between the value of estimating and the time interval between estimates is shown in Figure 16.4.

¹⁷ In this section, the term 'cost' is referring to the *cost* of producing estimation. It is different from the terms like 'project cost' and 'cost estimating', which refers to the cost of the project.



Note: Value is defined as the benefit/cost

Figure 16.4 Value of Estimates Versus the Time Interval between Successive Estimates





Figures 16.5 and 16.6 show the effect of automated estimating. The greater estimating efficiency will increase the relative value of the estimates and will shift the points of maximum value to the left in both figures. This will lead to a change in estimating strategy that constitutes the motivation for designers to use automated estimating: the total cost of producing estimates will be less, estimates of greater accuracy will be produced more frequently, the overall value of the estimates will be higher, and the design outcome will be more cost-optimal.

Figure 16.5 Value of Producing an Estimate Versus the Accuracy Achieved with Current Practice and with Automated Estimating



Figure 16.6 Value of Estimates Versus the Time Interval between Successive Estimates with Current Practice and with Automated Estimating



Time Interval between Estimates

The exact degree of these changes is difficult to predict until model-based estimating systems are more fully developed. At the extreme, the estimating process will be highly front-end loaded, with the bulk of the work required to produce estimates coming near the beginning of the design process. In this scenario, each successive incremental estimate could be derived from the design model at essentially no cost, thus providing essential continuous and 'real-time' cost estimates during design.

Contractor's value-adding proposition: Contractor's early input to design

If contractors use a model-based automated estimating system solely to produce total project estimates *at the time of bidding*, then the value proposition lies in the fact that they will be able to produce these estimates more quickly and at less cost. This value proposition is very narrow in focus, because it produces little or no impact on design quality.

A more far-reaching value proposition arises in situations where contractors have an opportunity to provide input throughout the design process, as in alliancing agreements, design-building contracts, etc. In such cases, one of the primary roles of early construction input is to provide cost-related advice on the whole and/or parts of the bridge design to improve the design constructability and overall value. This requires cost estimating activities at multiple times throughout the design process. Here, the value proposition parallels that of the designer's value proposition shown previously, except that the contractors have the potential to produce even more accurate and therefore significant cost information throughout the design. Doing so is closely associated with an increase in their scope of work over their traditional role, and can result in substantial value improvements to the overall project outcome.

PROPOSED PROCESSES

This section provides a series of scenarios that describe typical processes (use cases) of using an automated model-based estimating system.

Generate WBS From project model

The estimating system takes a semantic project information model of a bridge as input (e.g. output from a model-based CAD tool, IFC file, or similar). By evaluating the contents of the bridge model, the system must be able to derive a work breakdown structure (WBS) for the proposed project. This WBS is a 'quantity takeoff' type of WBS (called 'assemblies' in some estimating systems): it lists the units of work to be completed at a level of detail that corresponds to the quantity measurements derived from the design information. In addition to the input project model, the system will receive input from some standard or master WBS (a list of all possible work items), and a component that maps, or reasons about, the linkages from the project model to the WBS. Users may be required to enter information about projects that are not contained in the project model (any such information should be retained for use in subsequent estimates).

Generate quantity takeoff

Given the project model and the derived WBS, the system must apply geometric and semantic reasoning to calculate the quantities associated with each WBS item. Most input will come directly from the project model but, again, some additional user input may be required and should be retained for successive estimates.

Derive detailed WBS

From the 'quantity takeoff' or assemblies WBS and the calculated quantities, the system will apply mapping rules to develop the WBS at the level of individual estimate line items. This step is identical to the 'assemblies-to-estimate items' that is performed by traditional estimating systems.

Determine unit prices

The system determines the appropriate unit prices to apply against each estimate item. The process of selecting unit prices from a database containing prices for each type of estimate item is quite straightforward. However, the system should also be able to apply adjustments to these unit prices to reflect the specific context of a project that will lead to price variations from historical averages (e.g. remote and difficult locations, novel technologies, work force shortages). These adjustments may be either automated or entered manually. Some such adjustments may be reasonably simple to apply, but other adjustments will require increasingly complex levels of reasoning if they are to be automated.

Complete estimating calculations and present results

When the WBS, quantities and unit costs have been developed, the final estimate costs and mark-ups can be computed. The resulting estimate can then be presented in a suitable output format. This includes mapping the detailed estimate WBS to any standard WBSs required by tendering or reporting requirements. Optionally, the resulting cost information may be transferred into a combined project data model to be available for appropriate uses by others.

FUNCTIONAL SPECIFICATIONS

The following is a summary of functional requirements of the model-based automated estimator for concrete bridges.

Support direct and indirect cost

The estimate must be able to include both direct and indirect costs associated with a project (including all temporary works, all construction equipment and project overhead costs, etc.). Since there will typically be no direct element in the project model that corresponds to indirect costs (e.g. the costs associated with providing general cranage on-site), the system must be capable of reasoning from the direct product components to the required indirect costs. Where possible, indirect costs should appear as explicit line items in the detailed estimate, but some indirect costs may appear as mark-up values to be applied to the total direct project costs.

Support project lifecycle conceptualisation

The value propositions require that the estimating system be able to provide cost advice throughout the design process. Thus, it must be able to produce cost estimates based on preliminary, conceptual and incomplete design information. As a result, changes in the middle of project lifecycle stages can re-use what has been established up to that point.

There are at least three principal approaches for achieving this requirement:

• **Conceptual estimating through separate estimating modules:** One possibility for providing estimates throughout the design process is that the system has multiple modules for a variety of different stages of the design. For example, the system may have distinctly different modules for estimating at conceptual stage, preliminary design stage, detailed design stage, etc. Each module may have distinct work breakdown structures, mapping and quantity takeoff rules, unit prices, etc. This approach may offer the best potential for taking early design information, as it currently exists, and yielding reasonable cost estimates. However, it has several significant drawbacks, such as the very onerous task of developing and maintaining several different versions of the system, or the fact that estimates can still only be produced at certain 'milestone' points during the design.

- **Conceptual estimating through template project models:** An alternative approach for providing estimates throughout the entire design process is to use template project models. With this approach, template (typical) project models would be developed for each different type of project. There would be some degree of modification of the standard template models to adjust them for the current project (e.g. adjustments for inflation, size scaling, and numerous other parameters). The template model, then, would be a complete and detailed model from which a detailed cost estimate could be produced. The resulting estimate would provide a crude estimate of the actual project costs, since the template model will only loosely reflect the actual project. Then, as the design of the actual project progresses, the actual design information will begin to replace the template model information, until at the end of the design, the entire model reflects the actual project design with no remaining traces of the template model. In this way, a complete model information and the cost estimates increases throughout the design process. This approach provides an elegant solution to the model-based estimating requirements, but it requires the use of template models in a way that does not exist in current practice, and further development is required to determine the practicality of the approach.
- **Conceptual estimating through parametric approaches:** Another option for achieving estimates throughout the entire design process is to rely on parametric approaches such that, by selecting a number or parameters that define a proposed bridge structure, allow the system to automatically generate appropriate design solutions (as design models, from which the estimates can be produced). This approach is not limited to an estimating technique; rather it introduces a full design paradigm. This is a potentially extremely powerful technique, and certain elements of road and bridge design appear to have been parameterised in current practice. Nevertheless, it represents a significant systems development effort to adopt this approach.

Support incremental estimating

In addition to supporting estimates throughout the design process, the system should be able to support a process whereby estimates are developed incrementally. For example, estimators or designers should be able to use the system to compare the relative costs of two design alternatives based on relatively minimal information about the two options. The system should be able to support multiple versions of an estimate developed throughout the project lifecycle, including roll-back capabilities, etc.

Accommodate non-model-based information

While the central characteristics of the estimating system are that it can automate estimating from a project model, it should restrict itself only to pricing the contents of the model. Even in a fully model-based design process, there will be many items that contribute to the overall project cost that simply do not appear in a project data model. In other cases, the project will follow only partial model-based processes. The estimating system should be able to accommodate non-model-based estimating in much the same way as traditional estimating systems. This should extend all the way to serving effectively as a traditional estimating system if no model-based information is available.

Interface with legacy systems

The estimating system must be able to interface with all relevant legacy systems, such as unit price database systems.

Support for estimators and designers

The system should support use by both estimating specialists and by designers who may have relatively little estimating expertise (possibly two different modes or even versions of the system).

Support for visualisation

Like model-based design processes, the automated estimating system will be equipped with visualisation capability. Both line items and their corresponding 3D view of bridge elements are automatically generated from the model.

COMPARISON BETWEEN THE CURRENT PRACTICE AND THE NEXT GENERATION ESTIMATING

Currently, design engineers analyse designs using computer-based simulators of theoretical models such as Spacegass, Aces, Coldes and many in-house designed spreadsheets and DOS-based programs. Input and output data from all these tools are likely to have minimal compatibility with each other. As design experience accumulates over time, design parameters are collected in project databases. This simplifies design processes. With the help of these design databases, they can zero-in on a mature estimation of the design prior to computer-based modelling and analysis.

Once the design has been verified to meet alignment, geometric, aesthetic and any hydraulic requirements (e.g. flood forces, speed environments, flood immunity), it is handed over for drafting finalisation. Designers can then draw on their database of previous drawings to efficiently produce drawings to suit new projects. This often saves significant time during the drafting process. Customisations of computer-aided design software packages are sometimes used to draw at least part of each drawing and, in the case of deck units, all of the drawing.

Cooperation and interaction between drafters and engineers occurs during the preliminary fixing (e.g. fixing span lengths, skew, coordinates, type of deck) and design stages and is more pronounced during a complex or one-off design. This may include some 3D drafting to provide models for Spacegass analysis. All drawings are produced in a 2D environment (plan/elevation/section) unless there is a case-specific need to do otherwise.

The above can be compared with the processes of model-based estimating as follows:

- Unlike the current uncoordinated practice of design and estimating, model-based estimating is derived from a project data model of a bridge (e.g. the equivalent to a building information model or IFC model). Such a model must either be produced as a result of a preceding model-based design process, or must be produced as the first step in the estimating system.
- Estimated items in automated estimating are generated from a bridge project data model, whereas the current practice requires full manual intervention to list them.
- The estimate items in automated estimating will include temporary works (e.g. falsework), costs associated with specific construction methods (e.g. cranage), etc. whereas the current practice requires full manual intervention to list them.
- The automated estimating system can produce a quantity take-off by evaluating the geometric and non-geometric parameters of the project data model to derive the quantities required for the estimate items, whereas the current practice requires full manual intervention to list them.
- The automated system will be able to apply appropriate unit prices to the estimate items, which combine with the quantities to produce the overall cost estimate. This is similar to what is done in the current practice through a semi-automatic system using price databases linking to WBS tables.
- The automated estimating system is likely to work with multiple sets of estimate items at varying levels of detail, e.g. a higher level of assemblies or standard estimate items, which map to a lower level of detailed estimate items.
- The automated system offers partial as well as whole estimates. It supports partial and complete planning/design. In contrast, the current manual estimation process focuses on the estimation of the complete bridge/road system.
- The automated system may use 'template estimates' to provide default values for information that is missing during early design phases. This is similar to what is done in the current practice through a manual process.
- The automated estimating system supports various stages of project lifecycle conceptualisation. It allows users to jump into various points of change while allowing them to re-use what has been established up to those points of change. This is by far the most efficient way of re-using established data in contrast, the current manual way has to re-draw the design on a 2D diagram from scratch.
- The automated estimating system generates automatically 3D view (drawing) from the (modified) model, whereas the current practice must redraw the 2D drawing every time when changes are made.
- All of the steps described above will be largely automated, but are likely to require certain manual inputs and decisions (e.g. selection of certain construction methods).
- The automated system enables users to make changes at any point in any lifecycle stages without the need to repeat what has been correctly established. On the other hand, for every change made, the design drawings must be re-drawn.

CONCLUSIONS

This paper has represented a feasibility study of model-based automated estimating for the civil works/bridge industry. The research has defined and assessed relevant contextual issues, such as the state of model-based design and estimating in the building construction industry. It has examined current practices and systems used in the design and estimating of roads and bridges. It has then developed value propositions for moving to model-based automated estimating and has developed a series of use cases to outline the functional requirement of such an approach. Finally it compared the new model-based automated estimating processes with the current practice to highlight similarities, differences and points where efficiency is derived.

ACKNOWLEDGMENTS

This research was funded by the Cooperative Centre for *Construction Innovation* under the project 2005-008-C. The advice and assistance from the following people are greatly appreciated: Robin Drogemuller (QUT), Bala Balakumar (BCC), John Evans (BCC), David Golightly (JHG), Paul Moloney (JHG), Robert Rackemann (QDMR), John Spathonis (QDMR), Greg Foliente, Allen Kearns and Matthew Inman (CSIRO).

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