A TOOL FOR MODELLING THE BRIEFING AND DESIGN DECISION MAKING PROCESSES IN CONSTRUCTION

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Phase 1 of the Link IDAC project *The Development of Decision Making Tools for Controlled Innovation in Construction* focused on process mapping of the change order request system, using historical data from a number of case studies. The change order request system facilitates request and approval of contract issue design changes and can be thought of as analogous to the management of rework in manufacturing. This analysis demonstrated the potential for improving design decisions. The current phase includes an investigation of the criteria used to choose between options when making design decisions. This will provide insight into the causes of design deficiency so that the decision making process can be made more efficient. This paper describes the development of an electronic data gathering tool which is being used to model the briefing and decision making processes on several live projects. The tool is being used to record functional requirements, the designers visibility of design issues at the time the functional requirement was identified, and information regarding the mechanics of the briefing process. The tool is also recording the subsequent design decisions which are being made to meet those functional requirements, the options which are considered and the reasons why a particular option is selected or rejected. Details are given of the underlying philosophy and systematisation of the tool, together with how it is to be used and how the data is to be collated and analysed.

Keywords: Briefing, data-gathering tool, design decisions, modelling, variations.

INTRODUCTION

One of the major themes in current construction management research is the application of principles and practices from manufacturing to the construction industry. The theme of the EPSRC IMI (Innovative Manufacturing Initiative) programme “Construction as a Manufacturing Process” and the associated LINK-IDAC (Integration of Design and Construction) initiatives are evidence of this.

The reason for this focus on manufacturing is the evidence, both from the automobile and from the aerospace industry, that changes in working practices over the last 10-15 years have led to significant improvements in efficiency, productivity and customer focus. Improvements which are seen to be needed in the construction industry (Latham, 1994). Indeed Fisher (1993) states that a view is held by international clients that UK buildings cost too much for a particular specification. With the globalisation of business activities and the desire to attract foreign investment, this is becoming an increasingly important perspective.

The major change in working philosophy in manufacturing industry has been the adoption of ‘process-based’ management rather than ‘function-based’ management. In other words, manufacturing from initial establishment of customer requirements

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right through to final delivery of the product, is seen as a sequence of processes, including the whole supply chain, which need to be managed and controlled. This change in philosophy, as well as requiring cultural changes in management style, requires the application of tools for managing the processes. It is the application, sometimes with a need for modification, of these manufacturing derived process management tools to the management of construction projects which provides the need for, and focus of, much research at present.

This paper describes work from the second (and current) phase of the LINK-IDAC project "The Development of Decision Making Tools for Controlled Innovation in Construction" which is being carried out by a consortium of:

- Two architectural practices (Sir Norman Foster & Partners and The Stanley Bragg Partnership),
- one major contractor (Taylor Woodrow Construction),
- one consulting engineer (WSP Group),
- one cladding systems supplier (Pluswall),

led by Cranfield University. The overall aim of the project is to assess the applicability of Design For Manufacture (DFM) thinking to the construction Industry. The kernel of DFM thinking is to match the design of an artefact to the capabilities of the process that is used to deliver it (Boothroyd, 1994). In manufacturing, this is achieved through a quantitative evaluation of the effect of different designs on production cost and, to realise an appropriate return on investment, this needs to be done as early as possible in the product life-cycle.

THE IMPORTANCE OF CONTROLLING THE DESIGN PROCESS

In the construction industry, design is self-evidently the key process. It is during this phase of a project that the major decisions are taken which determine the shape, size, type of construction and services, as well as, obviously, cost and construction time.

Clearly, the "design" as well as conforming to the client's functional specification and being aesthetically satisfying, must be capable of being delivered in as economic and efficient way as possible. Hence the need to "control" design innovation without inhibiting architectural integrity or freedom to innovate. A design management tool, based on DFM thinking, could be a way of doing this by putting in realistic manufacturing and assembly constraints on the design process.

At a simple component level this has been done. Provided sufficiently large and detailed databases can be established for a whole range of items and components used in building construction then it is worthwhile, but probably minor, efficiency improvements can be made. The real opportunity is to apply the DFM philosophy (if possible) at a systems level rather than at component level. According to McGeorge and Palmer (1997) the greatest impact can be made at the system level in the early design stages. Kochan (1991) suggests that the design phase defines 70% of the cost of a manufactured product. Because it has the greatest potential to affect value and cost, this "systems level" approach to the use of DFM ideas is the focus of this particular research project.

A SYSTEMS APPROACH TO DESIGN CONTROL

In contrast to the generality of manufacturing, the output of the construction industry is a series of unique products, constructed in different locations and with different construction partners. Therefore the supply chain is less well established or stable compared to, say, the automotive industry and the “control” of the design process is therefore less easy to establish on a systematic basis. If we are to apply DFM type thinking at a systems level then we have to understand very clearly the process of how design decisions are made, what the consequences are of design decisions and how, ultimately, we can develop a robust feedback system so that the construction phase can inform the decisions taken at the design phase. This understanding, at a systems level, is missing so this sets the agenda for the research.

There is one design issue that is always well recorded and documented, however, and that is the request for, and approval of, contract issue design changes. This can be considered as analogous to “rework” in manufacturing (another well recorded and documented activity for obvious reasons). Engineering changes are the direct equivalent to change orders however both represent waste and can be thought of as analogous to rework at the production stage. Rework in manufacturing is waste generated by inconsistencies and imperfections in the *total* delivery process. Rework is a term usually associated with the production process as this is often where the imperfections in the total process are realised. In some cases rework maybe attributed to a specific manufacturing problem such as an inappropriate tool, but in others it is merely symptomatic of the fact that the product has been designed in such away that it is not well matched to its delivery processes or there is a failing in the way design information is transmitted and/or used to produce the article. This includes all activities from concept design through to manufacturing the product. Change orders are the *rework of the construction design process* and similarly to manufacturing are largely encountered/realised in the building phase. Change orders arise for numerous reasons such as the client changing his requirements, lack of co-ordination of design information, poor design decisions or to add value to the product by improving particular aspects of the building’s configuration. The extent to which the analogy of change orders to rework holds conceptually, hinges on two issues: (1) The proportion of the change orders which could have been avoided (i.e. those caused by co-ordination problems, mistakes, etc) and (2) The extent to which the design should be *frozen* at the time the contract award is made.

In the first part of this project an investigation into the change order request system was conducted (Cox, et al, 1997). The data showed for successful, well managed projects carried out by industry leaders, an average of 48% (with a high of 74%) of the costs generated by change orders and 51% (with a high of 76%) of the number of change orders were for the following reasons*: Forced on Upon Project by Shop Drawing Co-ordination, Designers’ Omission in Tender Documents, Co-ordination Defects in Tender Documents, Management Contractor Omission from Packaging, Other and Empty*. The remaining categories that the originator of a change order could select from are: *Improvement by Subcontract Design, Cost Saving Measures, New Information on Existing Site Conditions, Employer has Changed His Requirements, Programme Advantage or Assurance, Statutory Body Requirement Came to Light Since Placing the Trade Contract, Public Utility Requirement Came to Light Since Placing the Trade Contract.* If the view is taken that the briefing process (including feasibility studies, etc) should sufficiently address issues of Site Conditions and Statutory and Public Body requirements prior to the contract award then an average of 66% (with a high of 96%) of the cost of change orders, and an average of 61% (with a high of 84%) of the number of change orders analysed could have been avoided. Other design changes can be considered to be design development to add value/reduce cost, to improve the programme, or to respond changing client's needs. From the data examined an average of only 39% of contract issue design changes can be attributed to design development per se. That is not to say that on average 61% of the design changes studied were not necessary in the given circumstances, but they were avoidable. In the worst case only 4% of change order costs[2] could be attributed specifically to design development.

Other studies into change orders have established that there are adverse affects on the total construction process. Thomas and Napolitan (1995) found changes reduced labour productivity by an average of 30%, although some changes could be made with out loss of efficiency. Krone (1993) found that the Environmental Protection Agency (EPA) in the US, had to request additional information on 40 to 50% of change submissions due to inadequate documentation. Machowski and Dale (1995) established that there are large administration costs associated with engineering changes.

An analysis of construction design change order requests provides a clear and credible measure of the consequences of inadequate design decisions. The first phase of the project was an historical study using data from a number of case histories, the data being the outputs from the change order request system in each case (Cox, et al, 1997). Figure 1 illustrates the roles of those involved and the activities undertaken in the change order request system. A request is made by a project team member (in this particular case this refers to the wider project team - includes subcontractors etc), this is passed to the Quantity Surveyor and Management Contractor who comment on cost and programme implications respectively. The design team then ratify (or reject) the request and make the appropriate amendments to the contract issue drawings. An Architect's instruction is issued by the Architect followed by a corresponding site instruction by the Management Contractor, leading ultimately to the modification of the work package(s) by the Works Contractor.

The data was analysed with a method that provided visibility of the cumulative effects of contract issue design changes over time, for each of the work packages for each case study (subject to the availability of data).

[2] That is 4% of the net cost, i.e. the data set included change orders with negative costs or cost savings to the project which were attributed to reason categories associated with design development. For this case study, total change order cost savings/total change order costs ≈ 11%

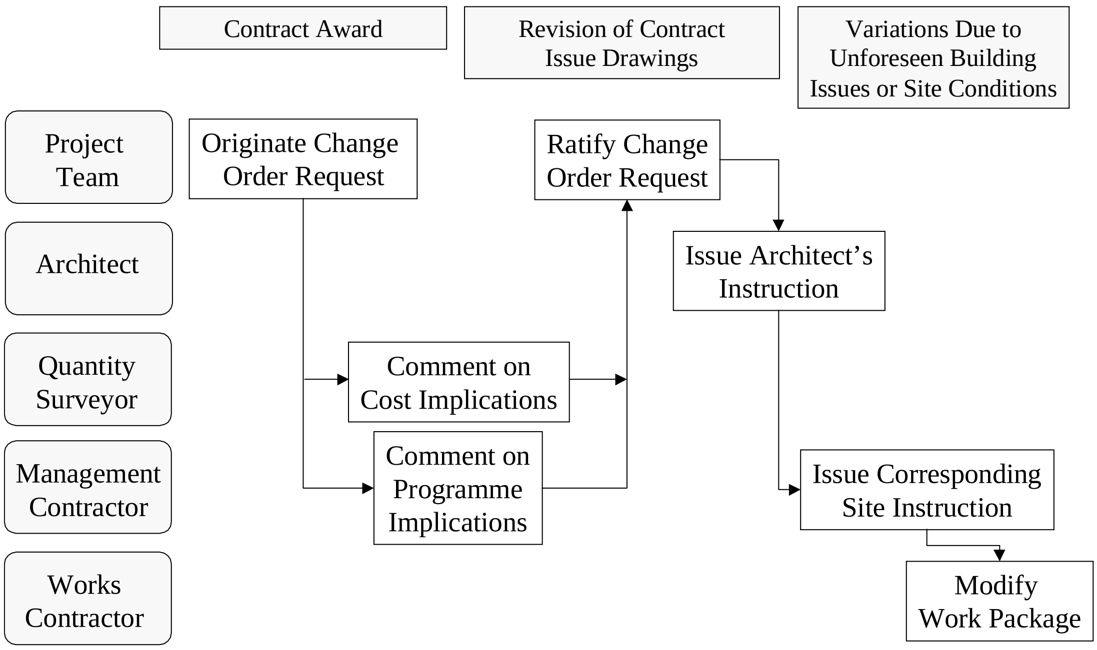

Figure 1: Project team procedures manual (section 13): monitoring and issuing of works contractor instructions

The investigation also revealed the most common reasons for requiring design changes. It was found that even in well managed projects, contract issue design changes cost between 5 and 8% of total construction costs. These are the direct costs of design changes and do not take into account consequential costs or delays and as such are under estimates of the *real* cost to construction projects. However the research provides an insight into the size of the opportunity that exists to make savings by reducing the amount of rework. Another important finding was the difficulty of conducting historical studies in the construction sector because of the quality and completeness of records. Also, the aim of record keeping is an important issue. It was found that few systems were in place capturing information with the main objective of process improvement.

We have obtained a picture of the pattern and significance of incorrect or incomplete design decisions via historical data of change order requests in construction, albeit on a limited sample. We must now look at the issue of how design decisions are made in this industry to establish the root causes of change order requests and the extent to which they are contingent upon both the decision maker and the macro design process. To this end it is necessary to model the design decision making process to establish the criteria that are being used to choose between options, how the decisions attempt to meet the Client's requirements and what interactions take place and resources are used to facilitate this process. This model, together with change order request data, will allow a link to be made between the need for a particular contract issue design change and specific design decisions. If this information is fed back to the designer in an appropriate manner it will lead to a more efficient decision making process and lead to cost savings by reducing the amount of rework required. This approach compliments Lindemann's et al (1997) assertion that there is a need to counter the *cause* of design changes rather than just the symptoms.

Due to the findings from phase 1 of this project about the availability of historical records regarding process information, it was decided that data tailored to modelling requirements should be collected on a number of *live* projects as decisions are being made. To facilitate this data capture an electronic data-gathering tool has been produced.

TEMPLATE STRUCTURE

The design of the data-gathering tool was based on a series of interviews with our industrial collaborators. Questions targeted both the mechanics of the process, i.e. identifying the participants, their roles and the level of interaction between them, and also questions regarding the nature of design from the designer's perspective. These interviews, together with our understanding of design in the manufacturing context, provided sufficient insight into the nature of the macro design process in construction, and the decisions made, to identify the information required to model how client's requirements are identified and realised through the design decision making process.

The information requirements were logically arranged into information fields and split into two *templates*: one focusing on clients' needs and the identification process - *Briefing Template*, the other addressing the issues relating to how the designer fulfils those requirements - *Decision Making Template*. The language used to probe the designer's insight was taken from Suh (1990). The language is familiar to design practitioners in construction, albeit with slightly less specific definition for each of the terms. Design teams use Suh's and similar terminology to communicate effectively the complex issues involved in design practice.

Briefing template

The Briefing Template records information about the briefing process or the elicitation of what the client wants the product to do and how it should perform. Suh describes these needs as functional requirements. Suh's view of functional requirements is that they should be defined in solution neutral terms, so for example a functional requirement would be the need to provide a suitable working environment for milling machines and their operators, not for a factory workshop which is a possible solution. There is a functional requirement to transport people from one country to another, quickly and economically. One option is to build an aeroplane. It is possible that practitioners will not be purist in their approach to using the tool and that functional requirements will be defined in terms of solutions rather than function. This would prove to be informative in itself and would lead to the question 'to what extent does thinking in terms of solutions rather than functional requirements affect the level of innovation within the construction industry?'

The information captured is structured around the identification and documentation of functional requirements. The template asks for a description of a particular functional requirement and the visibility that the designer has of the design parameters and constraints which affect it at the time the functional requirement was identified. Following Suh, we define design parameters as "the key variables that characterise the physical entity created by the design process to fulfil the functional requirements" and constraints as "those factors which create boundaries on the design space and hence potential solutions." To assist the analysis procedure the functional requirement is assigned a category. The template also provides the opportunity to trace the refinement of functional requirements, or those which have been superseded. This facility allows the evolution of the brief to be captured. Other information fields include: who is completing the template, the date the functional requirement was identified, the RIBA (Royal Institute of British Architects) stage and why the functional requirement was recorded. To provide insights into the mechanics of the process we record who identified the functional requirement, along with who else was involved in the identification process, the type of meeting where the functional requirement was identified and what information sources and IT were used to support elicitation.

Decision making template

The Decision Making Template captures the decisions which are made to realise the Client's requirements, as indicated by the briefing process, and information pertaining to the activities and reasoning involved in the decision making process.

Each template records a single decision, the reasons for making it at a particular point in time and the issues which constrain the decision making process. Of particular interest are the options that are considered and the reasons why the particular options were thought to be suitable alternatives. The template captures which of the options is selected as the most appropriate solution, the reasoning behind the choice and hence the reasons for rejecting the alternatives. Each decision, where appropriate, can be linked to a specific functional requirement and the template also records whether the decision has superseded a previous decision. Similarly to the Briefing Template, information regarding the date the decision was made, the RIBA Stage at the time the decision was made and the identification of the person inputting the information is recorded. Process details are also captured: who made the decision, who else was involved, the level of agreement (imposed by the decision maker or consensus), type of meeting where decision was made and support in terms of IT and information sources.

An issue of considerable importance regarding the value of this work is the type of design decisions which are recorded. The key factors in resolving this matter are the ability to add maximum value and affect the greatest cost reduction. It is on this basis that it was decided that the decisions which should be recorded should be those pertaining to the selection of systems for building attributes for each concept design.

Figure 2 shows the level of decisions of interest. Every building can be considered to consist of high level building *attributes* such as structure, foundations, cladding. Some of the attributes are generic to most, if not all, buildings whilst others will be project specific, depending upon the level of innovation or how unusual the nature of the design. When designing a particular concept a number of options are considered for any given attribute. The example in the diagram is structure with the options considered - concrete frame, steel frame and wooden frame. Also for each of those options, variations on a theme maybe considered - steel frame arrangement 1, steel frame arrangement 2…steel frame arrangement X[3]. The decisions of interest are those which choose between arrangements for a given option, and decisions which select options for a given attribute pertaining to a particular concept. This is for every attribute identified for every concept design produced. Also of interest are the decisions made to choose between concept designs to develop to scheme designs, and decisions made to choose between schemes leading to a final product.

[3] Depending upon how options/arrangements are considered, the two lowest tiers in Figure 2 could be combined (conceptually). For example, steel frame arrangement 1, steel frame arrangement 2, concrete frame 1, concrete frame arrangement 2, etc, could be considered as option 1, option 2, option 3, option 4, etc.

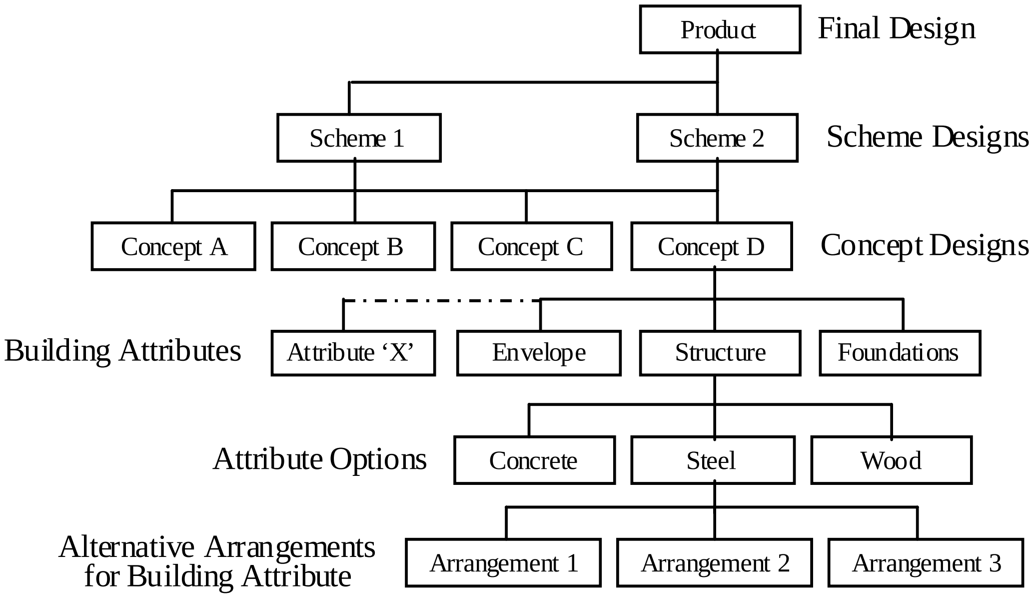

Figure 2: Design decisions to be recorded by the data-gathering tool

TEMPLATE SYSTEMATISATION

The templates have been systematised using Microsoft Access 97, which is a relational database. Each template consists of a number of forms with information fields which the user will input data about functional requirements (Briefing Template) and design decisions (Decision Making Template). The programme was selected because of its fitness for purpose and because it is software common to all the project participants who will be using it to collect data.

A concern with this type of methodology is finding people who are able to find time to record data on a regular basis during a project to reap the medium to long-term benefits of research. The data-gathering tool in its present configuration has gone someway to alleviate this problem by incorporating features which are useful to the practitioner in real time project management. For instance the tool offers traceability of the decision making process, the reporting mechanism in Microsoft Access 97 allows the user to produce relevant reports from the data which is being collected. These can be used in design team meetings to stimulate dialogue. For example a list of functional requirements can be produced which can be presented to the client as the designer's articulated interpretation of the client's needs. The client can then respond to this in the appropriate manner. There is the possibility that articulation of design issues, for example, which will affect a particular functional requirement may help to clarify the designer's thoughts and prove to be proactive from the user's point of view.

The tool provides a method of tracking information transactions made between the user company and all other parties involved in the construction project. A report of outstanding information can be viewed to indicate which pieces of information need to be given further attention in terms of sending out, or have not yet been received. This can be used to direct the user to information issues which require attention. Incorporated into the information transaction records are questions which will provide insights into the data sharing process. For each transaction the user is asked to specify how the information was requested, the medium in which the information was requested, and the medium in which the information was *actually* supplied. This data, together with data regarding IT support captured in the Briefing and Decision Making

Templates, can be compared with the IT audit of each of our industrial partners, conducted as part of this research project, to facilitate a matching exercise of IT tools available within the participating companies vs. those which are actively used to facilitate business processes. Another driver for companies to record information about the decision making process to enable traceability is for contractual reasons. The construction industry has a reputation for its adversarial nature (Rooke & Seymour, 1995) and companies want to protect themselves by keeping accurate information about the evolution of a building and events transpiring within a construction project.

COLLATION AND ANALYSIS OF DATA

The tool is currently being used on five live construction projects to capture information about briefing and the design decision making process. The design process is highly complex and requires the fusion of individuals' creativity through a number of interactions and exchanges, and as such any prescriptive model has its limitations. However, these models are still useful to provide some insight into the mechanics of the process, not least of which is the RIBA document (1992), which provides a contractual view of the design process by splitting it into a number of design stages as follows: A-B - Inception and Feasibility, C - Outline Proposals, D - Scheme Design, E - Detail Design, F-G - Production Information and Bills of Quantities

The tool will be used to record information from stage A through to stage D/E as indicated by this model. The data is being recorded by partner companies which are providing insights into a number of projects and allowing comparisons to be made vertically along the design process and horizontally at specific stages. This is with a view to identifying patterns within the data to model the processes and key decision points which ultimately lead to contract issue design changes (rework). The change order request data for each project will then be analysed so that the need for a particular design change can be related to a specific design decision, or number of decisions, where possible. This information can then be used to inform the designer of the effects of incorrect or incomplete design decisions, and in the long-term lead to a more efficient and efficacious design process.

CONCLUSIONS

A methodology has been developed for modelling briefing and the design decision making process in construction. The approach captures the Client's functional requirements, the subsequent decisions that are made to meet those requirements and information pertaining to the activities that facilitate the processes. A systematised version has been produced in Microsoft Access 97 which is being used on a number of live construction projects. The tool has been developed with a view to modelling briefing and the design decision making process so that links between specific design decisions and the need for particular contract issue design changes can be made. This cause/effect model will be used to improve the efficiency of the decision making process in construction projects by feeding back knowledge of the consequences of design decisions to the designer, to reduce the amount of rework generated.

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