DEVELOPMENT OF A PROTOTYPE BUILDING DESIGN MANAGEMENT TOOL

Simon Austin, Andrew Baldwin & Paul Waskett

Department of Civil & Building Engineering, Loughborough University, Leicestershire. LE11 3TU,UK

This paper describes techniques that are being developed to model the process of detailed building design and from this, to determine design sequences and produce design programmes. The basis of the methodology is that it will enable design activities to be programmed and monitored based on the production of information rather than the completion of design deliverables such as drawings and specifications. The relative importance of information within the design process will be analysed allowing the process to be programmed in such a way that an optimum design sequence can be achieved and areas of work requiring tasks to be undertaken in an iterative manner can be identified. The allocation of resources and estimate of duration of tasks within iterative groups can then be undertaken more effectively. The methodology will also enable the effect of external influences, such as the procurement programme, on the design sequence to be analysed, and the overall process of design, procurement and construction to be reviewed.

Keywords: Design, management, matrix analysis, modelling, planning.

INTRODUCTION

In recent times, there has been a growing understanding of the importance of effective design and design management to facilitate a co-ordinated design, within budget, and as a result, the smooth running of the project on site. Traditionally, building design has been planned by the same methods used to programme construction and procurement. These techniques do not allow the effect of variations and delays to be fully understood within an iterative process such as design, and monitor progress based upon the completion of drawing work as opposed to the availability of key pieces of information.

Current research at Loughborough University aims to develop design process models and prototype software to enable design programmes to be produced, based on the production of information rather than deliverables such as drawings and specifications. The methodology is being developed in three stages, as indicated in figure 1. Firstly, a generic model of the detailed building design process has been produced showing the relationship between design activities based on the flow of information in the process. Secondly, matrix manipulation of a schedule of activities will identify an optimum sequence of tasks based upon the dependency and availability of design information as defined in the design process model. Finally, the matrix analysis will be linked to a programming tool so that design programmes can be produced when resources and duration of tasks are allocated to the re-sequenced activity schedule.

This paper describes how the methodology is being developed to model, first generically then specifically, the detailed design tasks for each discipline. It also

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discusses some of the requirements of the methodology to optimise design task order and produce design programmes, including the need to take account of the packaging of work during design, procurement and construction.

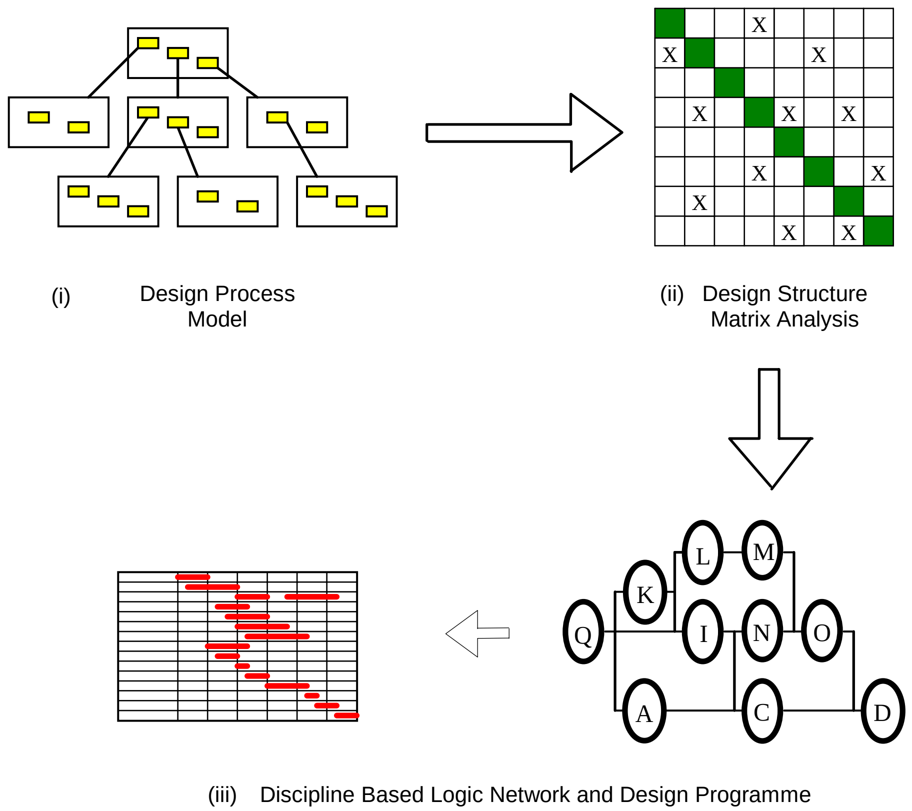

Figure 1 Prototype Design Planning Methodology

A PROCESS MODEL OF DETAILED BUILDING DESIGN

A range of modelling techniques have been adopted in the past to model the process of building design. See for example, Sanvido & Norton (1994), Austin *et al* (1995) and Ford *et al* (1995). Of the methodologies reviewed, it was concluded that IDEF0 diagrams (Integrated Computer-Aided-Manufacturing Definition, developed by the US air force) was the most suitable for the purposes of producing a model that could be linked to the later stages of the methodology. This is because IDEF0 diagrams allow a hierarchical process such as building design to be defined and they represent the process in terms of activities or sub-processes and the information flows between them. The higher levels of the detailed building design model see the overall process divided into the processes for each of the main design disciplines, namely architecture, civil engineering, structural engineering, mechanical engineering and electrical engineering. Figure 2 shows a part of the process hierarchy.

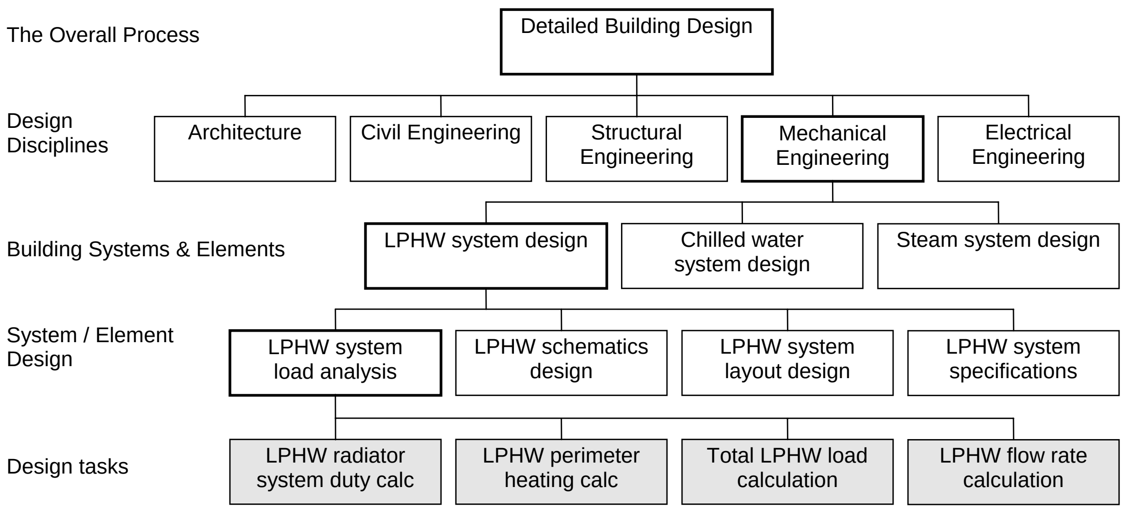

Figure 2 Part of the Detailed Building Design Process Hierarchy

The model of detailed building design has been produced using a variation of the IDEF0 technique: it was felt that no benefit could be made from showing the normal ‘mechanism’ (representing a resource) or ‘control’ that feature in an IDEF0 diagram so these have been replaced with inputs, effectively giving scope for three different types of input. This proves useful because the source of each information input to an activity can be indicated. Figure 3 shows the conventional IDEF0 notation and the modified notation to suit the requirements of the detailed building design process model.

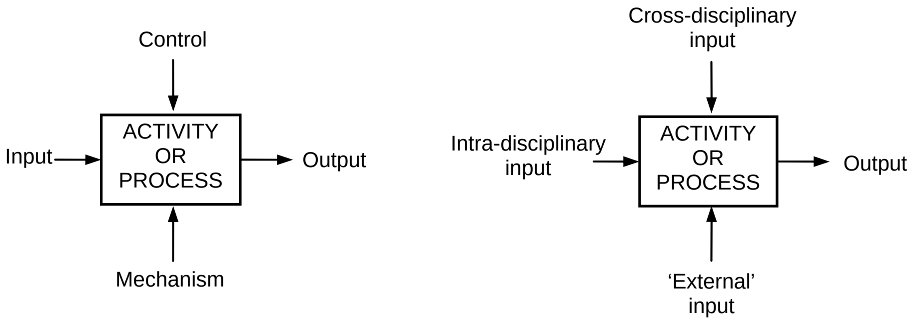

Figure 3 Conventional and Modified IDEF0 notation

This system of notation allows the different type of information flows to be quickly identified. This is advantageous because it enables the cross-disciplinary information exchanges, which are more difficult to manage, to be identified within the later stages of the methodology. The model in its entirety has approximately 800 activities at the lowest level of the hierarchy and in the region of 3500 information inputs, so by automatically identifying the source of each information flow, a substantial time saving could be made at the planning stage.

The 800 activity model is intended to be representative of the detailed building design process at a generic level. In other words the model should contain information to allow any project to be effectively managed. The data required to enable the model to be built was collected and verified by designers at Sheppard Robson, AMEC Design & Management, Ove Arup & Partners, Laing Management and Boots. This means that the generic model represents the way design work is carried out on the type of project most commonly undertaken by those companies. For this generic model to be more widely applicable, more organisations need to be approached and more projects considered.

For the generic model to be useful, it must be possible to manipulate it into a ‘project specific’ model. This means that those sections of the generic model not relevant to the project must be discarded along with the corresponding pieces of information. Also, there must be the scope to include sections and information dependencies into the model to allow for the peculiar details and features of each building.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
A													X			X
B	X				X								X			
C	X											X				
D			X												X	
E				X								X			X	
F																
G						X		X						X		
H													X			X
I								X			X					
J						X	X		X					X		
K						X		X	X							
L											X					
M								X				X				X
N											X	X				
O											X	X		X		
P								X								

	F	H	I	K	L	M	P	N	O	G	J	A	C	D	E	B
F																
H						X	X									
I		X		X												
K	X	X	X													
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J	X		X					X		X						
A						X	X									
C					X							X				
D									X				X			
E					X				X					X		
B							X					X			X	

Figure 4 Example of a Design Structure Matrix and its Manipulation

THE MATRIX ANALYSIS TECHNIQUE

The use of matrix manipulation techniques (or design structure matrix analysis), such as those devised by Steward (1981) and Eppinger *et al* (1992) have been proven by previous research at Loughborough University to be an effective system for optimising the sequence of activities within a building design process (Austin *et al* 1994, Newton 1995). This type of technique has yet to be proven to be workable on a process of such magnitude as detailed building design. Figure 4 shows how the information within the design process model can be represented in matrix form and also, the outcome of manipulating (or partitioning) the matrix to achieve the optimum design sequence, for a simple example. The premises are that the tasks within the matrix are undertaken in the order represented down the side or along the top, and that a mark in the matrix indicates that the task on the left-hand side is dependent on some information from the task at the top of the matrix. For example, it can be seen that task B is reliant on some information that is produced by tasks A, E and M.

The manipulated matrix now gives the optimum design sequence. The shaded area within the manipulated matrix indicates a ‘loop’ of tasks where either work must be undertaken in an iterative manner or estimates of unavailable information must be made in order for the design to proceed. Computer code is currently being written to partition a matrix that contains 800 tasks or groups of tasks within a matrix of that size.

The nature and exact details of an item of information required by an activity, although shown in the design model, cannot be shown on the matrix. What can be indicated however, is the importance of the information to the task that is dependent upon it. The benefit of doing this is that the matrix can then be partitioned to ensure that where the information is absolutely necessary for a task to be carried out, the re-sequencing of the two relevant activities can be given priority over others where the information requirement is less vital. The relative importance of each of the information flows within the design process model are being collected through interviews with practising designers. This is being done on a three point scale: A, B and C, with A representing a piece of information that is not easily estimable, and on which the task is highly dependent and sensitive to the information, and C representing the opposite extreme. If then the 800 task matrix is manipulated under the assumption that any dependency with a C rating is ignored because the required information can be reasonably estimated, the resulting matrix will give the optimum sequence of design activities, and highlight the areas of the design where tasks will need to be undertaken in an iterative way. We would expect these loops of design tasks to correspond with systems and elements within the building that require close co-ordination with one another.

IMPOSING EXTERNAL INFLUENCES ON THE DESIGN STRUCTURE MATRIX

The development of the detailed building design process model and its interface with a design structure matrix analysis technique will result in the optimum sequence of design activities for either the generic model or for a specific project. Unfortunately (as far as a designer or design manager would be concerned), the optimum design sequence can only very rarely be undertaken because of the influences of external forces upon the design. This research project gives us the opportunity to investigate exactly what the effects of these external pressures are upon the design process.

Discussions with design planners and managers have highlighted a range of issues that have a bearing on the process of detailed building design. For example, the presence of a client’s design department will often result in information being released to the consultant in phases as and when it is produced, rather than being available at the beginning of the project and therefore whenever it is required. A further example of an external influence upon the design process is the delay incurred by the consultant in waiting for confirmation of details from contractors, and then in checking and approval of contractor’s information. A final example, and one that more often than not has a fundamental affect on the design process, is the scheduling of work into packages to meet a procurement strategy and construction programme. The first two examples of external influences on the design process given above, are representative of the sort of problem that could have been overcome through accurate programming at the start of the project and swift and effective management during it. The methodology being developed through this research will allow the direct effect on the design team and programme of communication breakdowns and delays to be assessed. The final example given above highlights an area where the design programme is compromised prior to the beginning of the design rather than during it. In other words, the optimum sequence of design activities has been lost at the stage where the programme is being devised.

Previous research at Loughborough University (Austin *et al* 1994) has shown that by rescheduling the optimum design sequence, the process starts to contain very large loops of iteration making it unmanageable, or it requires extensive over-engineering to take place. This is needed where it is important that the process is not held up and accurate estimates of required information are difficult to make. Figure 5 shows, for the simple example, the effect of compromising the optimum design schedule. It can be seen that by promoting two of the activities within the overall process (tasks E and B) almost the entire process is engulfed in an iterative loop, making it very difficult to manage. This would mean that some of the information flowing between activities would need to be assumed. For example, by making an assumption of the information required by task E from tasks O and D, and by task B from task A, the iterative loop would be made much smaller. Unfortunately, these items of information may not be easy to predict and therefore, some over-engineering will be required.

	F	H	I	K	L	M	P	N	O	G	J	A	C	D	E	B
F																
H						X	X									
I		X		X												
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O				X	X			X								
G	X	X						X								
J	X		X					X		X						
A						X	X									
C					X							X				
D									X				X			
E					X				X					X		
B							X					X			X	

	F	H	I	K	L	M	E	B	P	N	O	G	J	A	C	D
F																
H						X			X							
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G	X	X								X						
J	X		X							X		X				
A						X			X							
C					X									X		
D											X				X	

Figure 5 Compromising the Design Sequence

One of the aims of this research is to use the developed methodology to fully analyse the effect of scheduling the design process to satisfy the programmes of procurement and construction activities that exist on a project. The optimum design sequence is usually affected by the division of the elements and systems within the building into ‘work packages’ to suit the construction and/or procurement of the building. This means firstly that design work is programmed in terms of the construction work packages, and secondly that because of this, the optimum sequence of activities across more than one package is very rarely achieved. The methodology being developed will not only allow the effect of programming design activities to suit procurement and construction to be assessed, but will enable the procedures by which buildings are procured to be reviewed.

It is proposed that by identifying the key requirements to provide close design management and the affects upon the design programme (and thereby, the ease with which it can be managed) of packaging the work to suit procurement and construction, the packaging of work could be revised to better suit the design process. It is seen that if this were to happen, the design process would be easier to manage, resulting in less abortive work being done and fewer technical queries and variations being raised while the building is being constructed. The overall effects would therefore be, a time saving on site, a reduction in the number of disputes arising and a cost saving for all the parties involved. One way in which the design process could be divided, is to separate out the loops of iterative tasks. These loops will, as often as not, contain the requirement for co-ordination across a number of disciplines. If this work were to result in the production of a defined package of information and deliverables, then the management and programming of that package would be easier.

Unfortunately, the packaging of work within a project could not be achieved to ideally suit the design process without unreasonably compromising the construction process (for example, to satisfy the design process, the foundations would be the final element to be designed), however it is envisaged that a balance could be struck between packaging the work to suit procurement and construction and design.

PRODUCING LOGIC NETWORKS AND DESIGN PROGRAMMES

In order for the design sequence, as determined by the design structure matrix analysis, to be meaningful, it needs to be represented on design programmes with durations and resources allocated to the tasks. The aim of this part of the methodology is to have a direct link from the matrix analysis to an existing tool that allows logic networks and programmes to be developed. Discussions with practising design planners have highlighted the flexibility within the system that can be achieved by producing logic networks of the design process. It is felt that by allocating resources and durations to the groups of design tasks within a logic network, rather than the individual tasks within the design process model, a more accurate estimate of the time taken to complete tasks within an iterative loop can be made. This is because the loop itself can be thought of as one design and co-ordination activity rather than a series of design tasks each of which is undertaken a number of times within the loop. Figure 6 shows an example of a logic network for the manipulated design process represented in matrix form in figure 4. It can be seen that the iterative loop of tasks within the matrix is indicated as a block of interdependent tasks within the logic network. Resources can then be allocated to this block rather than the tasks within it and, having identified the need for close co-ordination between activities, a reasonable estimate of the time taken to complete the block of tasks can be made. This is a highly beneficial method of design programming, allowing cross-disciplinary activities to be programmed, and enabling them to be managed more effectively.

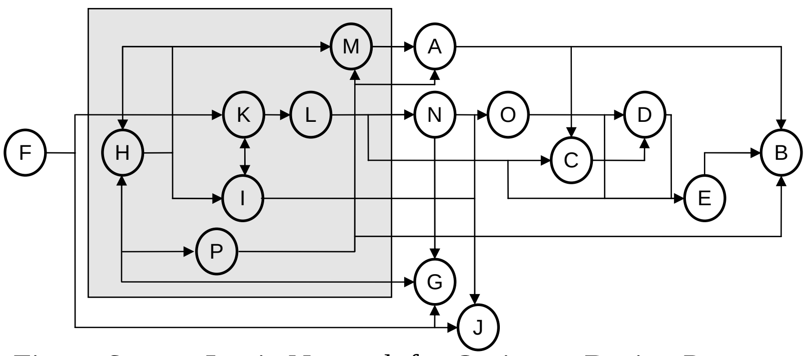

Figure 6 Logic Network for Optimum Design Process

Following the establishment of a logic network and the allocation of resources and time, design programming software will produce a design programme. The programme, like the matrix analysis and logic network, will highlight the iterative loops of design tasks, but more importantly it will enable the process to be monitored based on the production and transfer of pieces of information rather than on deliverables.

CONCLUSIONS AND FURTHER WORK

The prototype methodology that is being produced through the research aims to ensure that the process of detailed building design is better understood by those involved in it, and can be more competently managed. Through the use of process modelling, design structure matrix analysis and the production of design programmes, the planning of building design can be approached in a more systematic manner compared to that which is widely adopted at present.

Through an analysis of the affect of external influences on the design process, and in particular the procurement strategy and construction programme, a greater appreciation of the ways in which design can be more effectively planned should be reached. It is hoped that this will then enable the overall process of design, procurement and construction to be planned in such a way that conflict can be reduced and clients given better value for money.

A significant part of the ongoing research involves the validation of the design process model followed by testing of the methodology on a number of past and current projects. This will enable potential problems, difficulties and benefits to be identified. By producing design programmes based on the matrix manipulation, we will be able to determine the areas where the design process is poorly planned and is most heavily compromised in practice. Using the matrix analysis technique and then developing logic networks and design programmes will enable the methodology and its requirements to be refined throughout the research. This will then lead to the identification of a set of functional requirements from which a professional planning tool could be developed. We also anticipate that the research will identify changes in industrial work practice that will be needed if this approach to design planning and management is to be successful.

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