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Application of the analytical design planning technique to construction project management

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Application of the Analytical Design Planning Technique to Construction Project Management

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ABSTRACT: Current construction project planning practice takes little account of the interdisciplinary, iterative nature of the design process. This, combined with work packaging devised to suit construction and other such influences on design planning, leads to a severely compromised design process containing inevitable cycles of redesign together with associated time and cost penalties. This paper describes the Analytical Design Planning Technique (ADePT), a project planning methodology which helps to overcome these problems by providing a logical, structured approach, based on information flow rather than the production of design deliverables. It takes account of the iterative nature of design and can enable fully co-ordinated, integrated design solutions to be developed within both budgetary and time constraints.

INTRODUCTION

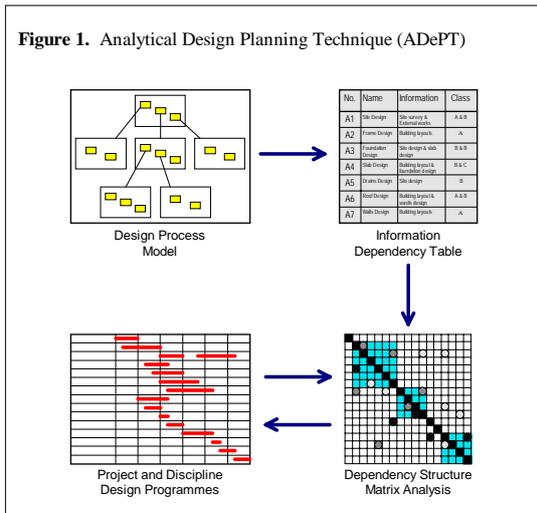
In recent times there has been a growing understanding of the importance of effective design management to facilitate a co-ordinated building design within budget, and to ensure the smooth running of the project. Construction industry clients are seeking major reductions in the cost of buildings, which can only be achieved by closer integration between the design and construction functions in the product cycle, as has occurred in other engineering sectors (such as the automobile and manufacturing industries). A key aspect is the capability to plan and manage design efficiently, taking into account the iterative nature of the process and changing needs of the client and contractor.

Current practice in the planning and management of the design process is focused on the design deliverables (e.g. drawings, bills of quantities and specifications) that are listed at the start of each stage of the design process. The tendency is then to plan the design process backwards from the date when these deliverables are due to be released to the client or contractor.

Typically a master programme is produced by the project manager (which includes global activities and milestone) and distributed to the leader of each design team, who then plans their work within the framework of the master programme. This approach assumes that design information is made available and communicated between the project participants as required, either informally or formally via drawings and design review. Experience shows that this is often not the case and that design should be planned around information flow, rather than deliverables, if a co-ordinated and effective solution is to be found. Network analysis and critical path methods are the generally accepted methods for the planning and scheduling of construction work on large to medium sized projects, but they are inappropriate for design management because of its ill-defined and iterative nature. Design managers now need equivalent tools to help them plan, manage change and integrate their role with the client, contractor and other parties.

The ADePT methodology shown in figure 1 has been developed over the last six years to help overcome these problems, and associated computer tools have been developed to facilitate more effective design planning and management of building projects. The first stage of the methodology is a model of the building design process, representing design activities and their information requirements. The data in this model is linked via a dependency table to a Dependency Structure Matrix (DSM) analysis tool (Steward 1981) which is used in the second stage to identify iteration within the design process and schedule the activities with the objective of optimising the task order. The third stage of the methodology produces design programmes based on the optimised process sequence. The technique requires some iteration between the DSM and programming stages.

Figure 1. Analytical Design Planning Technique (ADePT)



This paper overviews the complete methodology, including the establishment of a Design Process Model of the detailed stage of building design, the development of a DSM tool to suit the building design process, and the production of programmes of building design. The validation and testing of ADePT on current building projects is also described and an assessment made of its suitability as a project management tool. Detailed descriptions of the three stages of the ADePT methodology are given elsewhere (Austin et al 1998a, 1998b, 1998c).

THE DESIGN PROCESS MODEL

Prior to formulating the Design Process Model (DPM) in the first stage of the ADePT methodology, existing models of design and modelling methodologies were reviewed. This enabled a set of requirements to be established regarding the modelling technique adopted and the features of the DPM. The DPM was then produced with a proprietary Computer-Aided Software Engineering (CASE) tool.

Existing Models of Design

Many attempts have been made to model design in general, engineering design and parts of the building design process. Most models represent the process at a 'high level', acting as an overview of the process, containing very little in the way of detail and describing the overall process in terms of the stages within it. Among the best known models is Pugh's 'total design' model, a generic model covering all design processes (Pugh 1986) and the Pahl & Beitz' (1988) design model representing engineering design. Pugh further developed his 'total design model' to produce a 'business design activity model' (Pugh 1990). This showed how the model could be made business or industry specific and by way of an example, he represented building design. This model shares the

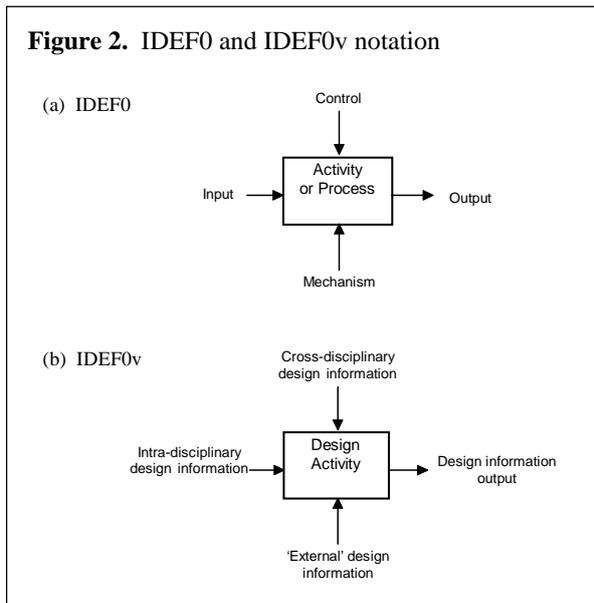
same features as the 'total design model' in that it is an overview of the process.

A widely used model of building design in the UK is the RIBA Plan of Work for Design Team Operation (RIBA 1973). This sets out the details of work to be carried out by each profession during each stage of the design process, but differs from most other models in that it does not show 'links' between activities to indicate how particular tasks are related. Sanvido & Norton (1994) produced a high level model of building design using an established modelling technique (IDEF0). Karhu *et al* (1997) also adopted the IDEF0 technique to model the building design and construction process at a high level. Data Flow Diagrams (DFDs), another recognised modelling technique, have been used in combination with the RIBA Plan of Work structure to produce information linked models of the building design process. Baldwin *et al* (1995) produced a model of the concept and scheme design stages of a project, while Austin *et al* (1996) developed a model of the architectural, civil and structural engineering elements of the detailed design stage.

Selection of Modelling Technique

A range of modelling methodologies have been examined to identify one that is most suited to representing information flow in detailed building design, including: data flow diagrams (DFDs); IDEF techniques; entity relationship diagrams; hierarchical plus input-process-output diagrams; Jackson diagrams; object-orientated modelling systems; and Petri nets. Each of these techniques has advantages in modelling certain types of activity or data. IDEF0 was identified as the most suitable technique to produce a model of building design for use in the wider context of the ADePT methodology.

The IDEF methodologies were devised in the 1970s for the U.S. aerospace industry and are now an established set of techniques which include IDEF0 for functional modelling (Marca & McGowen 1988). A process can be represented from the viewpoint of the information within it, rather than of its sub-processes, which has been identified as a requirement of a building design model. The technique is easy to use and understand, which is very important if the model is to be modified quickly at the start of a building project and maintained throughout. Each activity in the process transforms an information input into an output, and the internal mechanics of that transformation are not modelled. Figure 2(a) shows the notation of the IDEF0 technique. Each activity or process can be sub-divided to show finer detail on another diagram, ensuring a single diagram does not become too cumbersome.



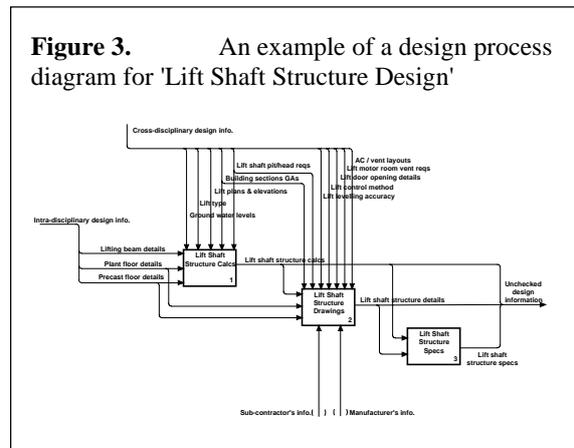
The review of the IDEF0 methodology found that although the technique is suitable to model the detailed building design process, some modifications could be made to the notation to enhance its advantages. The purpose of the ADePT model is not to indicate how each design task should be undertaken, so there is little benefit to be gained from representing process controls in the model. Also, activity mechanisms (architect, civil engineer, etc.) show nothing other than the discipline to which the activity belongs (because of the hierarchical structure of the design process). It was decided that better use could be made of the features of an IDEF0 diagram by distinguishing the information inputs that are from activities in the same discipline, from those in other disciplines and from external sources such as the client, a regulating authority or an earlier stage of the design process since these different types of information flow require different management priorities.

Figure 2(b) shows the notation implemented in the detailed building Design Process Model (DPM), termed IDEF0v, which varies from the standard IDEF0 notation in the following ways:

- Intra-disciplinary inputs enter from the left
- Cross-disciplinary inputs enter from the top
- Inputs from external sources enter from the bottom

CASE (Computer Aided Software Engineering) tools that enable IDEF0 models to be constructed automatically distinguish between the different types of information input in a diagram. These tools allow a model using IDEF0v to be compiled and are able to distinguish between the different information inputs in their reporting facilities.

Figure 3 shows an example of a design process diagram from the DPM.



Discipline Specific Features

The building DPM has a hierarchical structure, the first level of which sub-divides the process into design undertaken by the professional disciplines: architecture; civil engineering; structural engineering; mechanical engineering; and electrical engineering. There are different characteristics for each discipline because of variations in the way they work. The DPM aims to describe the process at a non-specific level and consequently it represents the design of a typical building and its systems. The project planning of a particular building will entail some manipulation of the model to produce a project-specific process map. Some sections of the DPM will have to be deleted (for example, one of the options for 'foundation design'), some sections added and some altered (for instance, some information flows will need to be reviewed to account for the location of components in the building). This section describes the structure of the non-specific DPM within each discipline, summarising the breakdown into systems of the building and then into sub-systems and components.

The architectural design process activities relate to the design of systems and are closely associated with the production of drawings and specification as architectural development of the design is largely completed prior to the detailed design stage. This is markedly different to the engineering disciplines' design processes, where tasks are more concerned with the development of the design, and is a reflection of the way architects work. The four engineering processes are partitioned into the design of systems. The civil and structural engineering disciplines are sub-divided in a similar manner to architecture, the distinction between the two occurring at ground

level of a building. The design of the ground floor slab and systems beneath it are civil engineering activities, while the design of above ground systems are represented within the structural engineering model. A further feature of the civil engineering section of the DPM is that it contains 'options' for various systems of the building. For example, two options exist for the design of foundations: 'Piled Foundation Design' and 'Spread Foundation Design'.

The mechanical engineering section systems are decomposed further into 'Requirements and Load Analysis', 'Schematic Design', 'Plant Layout Design' and 'System Specifications' which are in turn broken down into individual design tasks. The electrical engineering section is represented in terms of 'groups' of systems such as 'Lighting Systems Design' and 'Communications Systems Design' before being decomposed further into systems such as 'General Lighting Design' and 'Emergency Lighting Design' and then into individual design tasks.

Cross-Disciplinary Characteristics

The non-specific DPM will need to be modified to create each new project-specific model. In some cases, more than these five disciplines may be involved in the design. For example, public health engineering and fire engineering are regularly undertaken by specialist consultants. These instances need to be noted at the beginning of a project so that they are included in the DPM. Also, in some cases it would be appropriate for the design of systems to be undertaken by designers in a discipline other than the one indicated by the DPM. Examples of instances where design could feasibly be undertaken by more than one discipline are: lifts (architectural or electrical engineering); foundations (civil engineering or structural engineering); and external works (architectural or civil engineering).

Each system within the building is represented once in the non-specific DPM. However, in some projects various parts of the building may be present more than once, for example, two or more specialist lighting systems may be required. Where this is the case, the relevant part of the DPM will need to be duplicated together with the corresponding information flows. The choice of some systems of the building is dependent on the construction methods being used, the site, the client and other influences. Therefore options for different types of system have been included in the DPM (including, for example a selection of different foundation, power supply, and lighting design activities) and any that are not required must be removed.

DEPENDENCY STRUCTURE MATRIX (DSM) ANALYSIS

Scheduling Design Work

Management of design is influenced by contract procurement, the level of expertise of the client and the structure of design team, and encompasses information exchange management and quality management. However, the fundamental activity in the project management of design is the planning and control of work. In current construction industry practice, design is planned by the same techniques as site construction, including network analysis (Alkayyali *et al* 1993). However, network analysis techniques and tools were designed to represent sequential processes and cannot easily account for a process containing iteration, such as design (Austin *et al* 1996). This results in the unwanted omission of logic or information links between activities. In building design, this problem is particularly prevalent when considering information exchanged between design disciplines because of the disparate manner in which they undertake their work and its planning. In the 1960s, Steward developed a theory that a complex problem such as design could be solved more efficiently by representing the interrelationships between activities in the form of a matrix (Steward 1965). This matrix could decompose the problem, thus establishing the contributing sub-problems. The approach was termed Design Structure Matrix analysis, although more recently it has been termed Dependency Structure Matrix (DSM) analysis, reflecting its application outside design (Browning 1997). DSM forms the second stage of the ADePT methodology and involves analysis of the design activities and information dependencies in the Design Process Model (DPM) in order to find an s sequence.

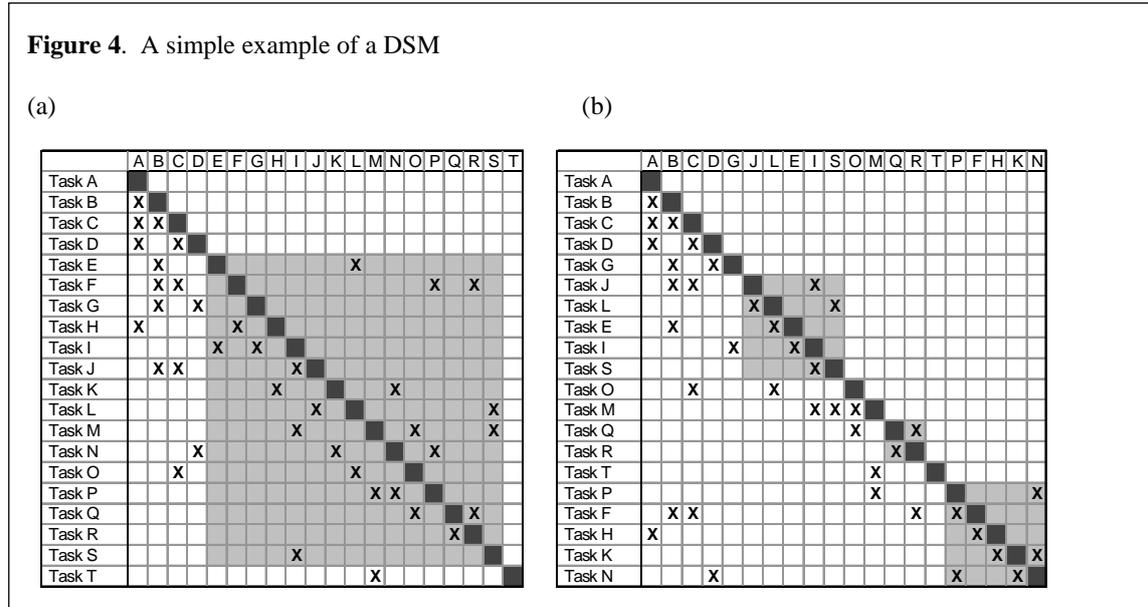
DSM Methodology

Figure 4(a) shows a matrix for a very simple design problem which contains 20 activities, listed arbitrarily down the left hand side of the matrix. The same activity order is also listed across the top of the matrix. An assumption is made that the activities are undertaken in the order listed within the matrix, starting from the top. A mark in the matrix indicates that the activity on the left hand side is dependent upon the activity at the top of the matrix. In the assumed order of activities, a mark below the diagonal shows that an activity is dependent on information which has been produced by a previous activity, whereas a mark above the diagonal indicates that a activity is dependent on information that has yet to be

produced. The latter can be overcome by estimating the information that is as yet unavailable and then verifying the estimate once the information generating activity has been undertaken. For example, in figure 4(a) it can be seen that activity E depends on some information from activity L that at the time has not been undertaken. If this information is estimated, activity E can be carried out and then activity L, following which the estimate can be verified. It may be that the activity dependent on the estimated

information (activity E) has to be redone if the original estimate was not accurate, resulting in an iterative loop of design activities. In this case it involves at least eight activities (E to L), but possibly up to 15, with nine information estimates, as activity L in turn requires an estimate of information from activity S (hence the shaded block of tasks).

Figure 4. A simple example of a DSM



The need to estimate information and then carry out activities more than once results in the process being inefficient. It is desirable to reduce the need for estimates and therefore iteration within the process. This can be achieved by reordering the activities within the matrix (termed partitioning) so that the marks are below the diagonal or as close to it as possible, thus producing the optimal sequence of activities. The purpose of partitioning a matrix is to maximise the availability of information required, and minimise the amount of iteration and the size of any iterative loops within the process. Figure 4(b) shows the partitioned version of figure 4(a). It can be seen that the sequence is altered and that twelve activities contribute to three iterative loops which in turn require five information estimates. In this improved order the estimate of the information from activity S for L will only involve the reworking of five tasks, as opposed to 15 in the original order. Partitioning a matrix sequences activities that do not contribute to iterative loops, identifies the activities that are within iterative loops and the loop's location in the overall order,

but does not sequence the activities within the loops. This is because the activities that contribute to a loop are all interrelated and any of them can be the first activity undertaken in the completion of the loop. It is also desirable that the activities within a loop be ordered to reduce the number of estimates that must be made. This forms the first part of the further process of tearing.

Tearing a loop means reducing the size of the iteration by minimising feedbacks and identifying estimates that can be made with some confidence and that therefore do not need to be revisited as part of the design process. The first stage in tearing is the scheduling of activities within the loop to reduce the number of estimates that are required and identify a starting point. The second stage is the removal of feedbacks from the loop. A decision is required by the user before a tear is made. This means that a knowledge of the problem is required so that an assessment can be made regarding the feasibility of each tear (Steward 1993). There are many information dependencies between activities in complex problems such as building design, which can be clarified by accounting for different levels of information importance (strengths of

dependency). This can be done by classifying the dependencies within the matrix and using a partitioning algorithm that can prioritise the sequencing of activities accordingly. Following the classification of information in a matrix, further tearing may be necessary in order that the highly complex design process is decomposed into manageable sub-problems.

The classification of information within a matrix is a subjective exercise. Austin *et al* (1996) described a three point scale of classifications, used in ADePT, which is based on the strength of dependency of information, sensitivity of activities to changes in information, and the ease with which information can be estimated within the building design process (Figure 5). To determine each information classification, three separate subjective judgements must be made and the resulting classification is given a rating of either 'A', 'B' or 'C' (where 'A' = strong 'C' = weak). The philosophy adopted by ADePT is that weak dependencies can be omitted from the matrix partitioning (because an accurate estimate can easily be made), and therefore the size of iterative loops can be reduced and the design process clarified.

Figure 5. The basis for allocating information classifications

Information flow	Task is	Task is	Information is
Class A	↑ INCREASINGLY DEPENDENT	↑ INCREASINGLY SENSITIVE	↓ INCREASINGLY ESTIMABLE
Class B			
Class C			

Application of DSM

Interest shown in DSM has been largely limited to academia. Although the theory of DSM has been applied in a number of circumstances, analyses are only just now being undertaken in practice. Much of the work to date has focused on the optimisation of design problems in engineering applications.

Rogers and Padula (1989) at the NASA Langley Research Centre have demonstrated how DSM could be applied to the scheduling of problems with up to 50 activities at the conceptual phase of the design process. Eppinger and co-researchers at MIT have applied DSM to a number of engineering problems involving up to 100 activities, including: the processes of

semiconductor design for Intel Corporation, and an automotive brake system and engine design for General Motors. (Eppinger *et al* 1994 and McCord & Eppinger 1993); and the design process of a climate control system for the Ford Motor Company (Pimmler & Eppinger 1994).

The application of DSM to problems in the construction industry has been limited to research work at Loughborough University and VTT in Finland. The former started in 1992 (Newton 1995) and produced the first version of the ADePT methodology. Austin *et al* (1994 and 1996) describe the use of DSM in a simple building design problem comprising some 50 activities across the architectural, civil engineering and structural engineering disciplines. This work led to the conclusion that DSM is a tool that could be used to demonstrate areas in a design that need to be undertaken in an iterative manner. In the simple example considered, these areas of iterative work reflected the parts of the building that would typically require close co-ordination and redesign to be undertaken. Baldwin *et al* (1995) described how DSM could be applied to problems in the scheme stage of a building's design and hence simulate the affects of changes in the design with regard to the overall duration and resource allocation of the process. At VTT in Finland, Huovila *et al* (1995) demonstrated the application of DSM on a design problem in construction, comprising some 30 design activities and it was concluded that the technique can be effectively used in construction to find better sequences of design tasks. Further uses of DSM have been demonstrated at VTT, such as the application of the technique to schedule work at an overview level across all stages of a construction project (Vahala 1997).

A prototype DSM tool

Two readily available DSM tools have been reviewed through their practical application to simple design problems. These tools are the Problem Solving Matrix (PSM) and Design Manager's Aid for Intelligent Decomposition with a Genetic Algorithm (DeMAID/GA).

PSM was developed by Steward and operates in a Windows environment, matrices being set up through either the direct input of activities and dependencies, or by importing the data pre-configured in a matrix form. The program can manipulate large matrices: testing has shown that a design process in excess of 700 activities can be analysed, and information dependencies can be input with a ten-point range of classifications. DeMAID/GA is a tool, developed at the Langley

Research Centre at NASA (Rogers 1996), that operates in Macintosh and UNIX environments and can analyse matrices of up to 85 and 200 activities respectively, with a seven-point information classification system. Data is input via the compilation of a text file describing features and relationships of each design task, which is not a particularly simple process because it involves the transfer of data between files. The operation and presentation are different to the PSM program in that it uses a genetic algorithm to sort the tasks and then represents them in a matrix to achieve as few dependencies as possible below the diagonal. Thus feedback loops in the design process appear below the diagonal rather than above it as in conventional DSM analysis. Dependencies are not shown by a mark in the matrix, rather by the intersection between a horizontal line from one activity and a vertical line from another to indicate an output from the first activity is required as an input to the second.

Our review of DSM techniques led to the production of a specification of a matrix analysis tool to suit the characteristics of the design process in a construction project. The Algorithmic Matrix Manipulation Program (AMMP) has been developed at Loughborough University, although to date some of the features identified in the specification have not been incorporated in the tool. An example matrix from AMMP which is capable of dealing with a design process comprising over a thousand activities is given in figure 6. Data is input to the matrix via a spreadsheet (the ADePT dependency table) containing details of activity relationships and information dependency classifications. Information can be transferred quickly from the Design Process Model (DPM) to AMMP and additional dependencies can be added directly through the user interface if necessary.

Further enhancements to AMMP currently under development include a user interface that allows it to be fully integrated with the process model, dependency table and programming stage of ADePT. This will allow the effects of changes to the design to be reviewed on either the matrix or programme, and changes imposed on the matrix to be more easily viewed on a design programme.

Figure 6. A matrix produced using AMMP

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1 Task A		A																		
2 Task B		B																		
3 Task C			B	B																
4 Task D				B	B															
5 Task E					B								A							
6 Task F						A	C									A		A		
7 Task G							A	C												
8 Task H								A												
9 Task I									C											
10 Task J										B	B									
11 Task K												A								
12 Task L													A							
13 Task M														A						
14 Task N																				B
15 Task O																				
16 Task P																				
17 Task Q																				
18 Task R																				
19 Task S																				
20 Task T																				

Application of DSM to the detailed building design process

Both AMMP and PSM have been evaluated as part of the application of the ADePT methodology to several building projects.

DSM analysis of large scale design problems has shown that, on the basis of the information classifications established prior to the analysis, the process contains a large loop of iterative work. In some cases this loop can consist of around 60% of the tasks in the process and must therefore be broken down to represent design problems of a more manageable size. This is achieved through tearing of the loop. This approach means that some information that had been deemed necessary (classified 'A' or 'B') must now be estimated (classified 'C'). So that these estimates do not need to be revisited during later stages of the design (i.e. we do not allow them to be responsible for the production of large iterative loops), they must incorporate an appropriate margin for error.

Establishing the effects of tearing an information dependency can prove difficult when a loop consists of a large number of tasks and interrelationships. The DSM can be viewed at an abstract level so that the interrelationships between elements of the building can be more easily understood.

Analysis to date has shown that the iterative loops within matrices relate to co-ordination issues to be dealt with during the design, such as ceiling, underground services and perimeter structure co-ordination. The formatting of information in a matrix prior to its representation on a programme accounts for the iteration in the process and ensures that tasks in a loop are programmed to be undertaken concurrently so that co-ordination can be achieved.

DESIGN PROGRAMMING

Representing the design process on a programme

In order for the DSM to be used as a means of controlling the design process, the information it contains must be represented against a time scale. In the third stage of ADePT the partitioned matrix is linked to a proprietary design planning tool to reveal a programme for the design activities. This process raises a number of issues.

Conventional programming tools represent sequential processes and do not allow elements of work containing iteration to be programmed. Thus, in current practice, feedback is not identified, resulting in co-ordination failures and rework. In this work we wished to link the output from the DSM analysis to a proprietary project management tool in order to demonstrate that ADePT can be integrated with existing construction planning systems and to use a form of representation familiar to design planners and managers. The output from a partitioned DSM must therefore be entered into a programming tool in a manner that incorporates the iteration within the process, but does not stop it functioning. This is done by grouping tasks that form a loop under a 'rolled up' activity and removing interrelationships from within the loop so that they can be programmed to occur in parallel. The group's relationships with previous and subsequent tasks remain. The overall duration of the group of tasks must allow for the necessary information exchanges within it, even though they are not shown on the programme and therefore accounts for the time necessary to achieve co-ordination.

The design process model, and therefore the DSM, are deliberately restricted to the representation of design work and exclude management activities such as design review meetings and approvals. Whilst it is possible to include the latter, the philosophy adopted in ADePT is that these management and co-ordination activities are best programmed after the establishment of the optimal design sequence. For example, it is logical to programme a design review meeting following the completion of a loop of iterative design so that all relevant co-ordination issues can be reviewed, client approval obtained and then that element of design fixed. The Design Process Model also identifies information that is required by the design from external sources such as regulating bodies, local authorities and the client. The optimal design programme assumes that this information is available when required, but in practice there is often a delay in obtaining this type of information, or it is released to the design team

in stages. A schedule of the information required from external sources can be produced from the DPM, and the programme can show the timing of these requirements.

In current practice, design is largely programmed to release information to suit the construction stage. The proposed approach is fundamentally different in first producing an optimal programme to suit design, which is then modified as it is integrated with a procurement and construction programme. This initially involves the addition of tender dates, tender periods and other exchanges with contractors to the programme, and then the determination of the procurement work package (WP) to which each design task contributes information. Having established the tender dates of each WP on the procurement programme, the design programme can, where appropriate, be rescheduled to ensure that these dates are met, a process that means reducing the duration of some WP designs. This rescheduling can be achieved by either changing the duration of some tasks, with corresponding allocation of resources, or by changing the sequence of tasks and estimating or fixing some information dependencies that are now above the diagonal in the DSM to avoid potential iteration. Some of these cannot easily be estimated (those classified 'A' or 'B') and particular care must be taken over their estimation and fixing. Proposed changes to the optimal design programme during its integration into a project programme can be reviewed to establish the ease with which task duration and resources can be reallocated, and the most suitable pieces of information to estimate and fix. Also, the additional cost incurred through over-designing these elements of the building can be compared to the costs of extending the duration of the corresponding work packages.

Implications of planning with ADePT

The adoption of ADePT as a design planning tool, will require some changes to current planning practice. Revised procedures necessary to produce an effective design programme using the technique have been developed through its application to a range of projects. These cover the programming of iterative loops and integration of the optimal programme with procurement and construction programmes. Some of the other main differences with current practices occur prior to the production of the programme, when the design activities and information requirements are identified. This is done through the production of a project-specific DPM and the allocation of information classifications. These procedures are described elsewhere (Austin *et al* 1998b, 1998c) together with the time required to undertake them

effectively. It is necessary to spend more time than is typical in current practice in order to produce a meaningful programme with ADePT. Testing of the tools has shown that 5 to 10 working days is required to produce a project-specific model, DSM and detailed programme (including management tasks and integration with procurement and construction programmes). In some cases, this represents considerably more effort compared to that expended in current practice, but the cost to the project will be insignificant compared to the savings that will result from the design being undertaken more efficiently and the reduced rework and problems on site. This is, in effect, the main premise of the ADePT methodology - that the conventional way of programming design to suit construction is superficially attractive but fundamentally flawed. This is because it makes the design process inefficient which results in poorly co-ordinated solutions that are eventually resolved, at high cost, on site.

In order to further understand the implications of adopting the technique, and its effectiveness, additional validation of the tools is currently being undertaken.

VALIDATION OF ADePT

All stages of ADePT have been validated through their application to a series of building projects under construction. These were a pharmaceutical research facility, a railway station and an office development comprising some 350 to 400 design tasks and 2400 to 2800 information dependencies (Table 1). The DPM has been validated by producing project-specific models and a broad range of design work has been embraced. The first task in formulating each project-specific model is to ensure that the model content and structure is appropriate. This requires the deletion of design activities from the generic model that are not relevant to the project, and the addition of tasks associated with features of the building not already included. The validity of the model was confirmed by the relatively small number of additions and the largely repeatable nature of its structure, evident from the suitability of a high proportion of tasks and associated information flows to a diverse range of projects, as can be seen in table 1. The low number of civil and structural tasks applicable to all of the projects is due to their different structural form (foundations, ground floor slab, frame, etc.). Table 1 shows that despite this, relatively few additions were necessary to compile the model during its testing on the three projects, as various choices for different structural systems are included in the non-specific model. The second task in modelling each project was to review the information requirements of all design tasks, which

again involved deleting (and on occasions, adding or redirecting) information flows in the model. This was also accomplished with little difficulty.

The output from the DSM tools and corresponding design programmes have been compared with the planning that was undertaken in practice. This has shown that the programmes used in practice did not take full account of the iteration within the design process, and that the design had been planned almost entirely to suit the construction process.

Table 1. Results of applying ADePT to three building projects

Project		A	B	C
Description		Pharmaceutical laboratory	Railway terminal	Office development
No. of design tasks	Deleted	207	261	242
	Added	35	36	6
	Total	410	357	346
Number of tasks in each discipline common to all projects	Architecture	51		
	Civil Eng.	9		
	Struct. Eng.	26		
	Mech. Eng.	91		
	Elec. Eng.	104		
Proportion of model common to all		69%	79%	81%
No. of data flows		2406	2804	2656
Hours to generate		16	20	12

FURTHER WORK

One of the projects on which testing has been carried out, a £30M pharmaceutical research laboratory, is being reviewed with respect to changes that occurred during the design. These are being simulated on the DSM and the resulting changes to the design programme assessed. This work will give an insight to the effectiveness of ADePT to represent changes throughout the course of a project. The same test project is being examined with consideration to problems that occurred during the design (following its initial planning) and construction. These problems are being reviewed to determine whether they could have been avoided through more effective design planning. The ADePT programme will then be reviewed to determine whether it highlights the corresponding design activities as being in need of special attention with regard to information estimates or whether they are within an iterative loop that was not identified in practice.

ADePT is also being applied in the planning of the detailed design of a £160M hospital project. Work to date involves the development of a project-specific model, DSM analysis and the production of a design programme which is currently being integrated with a procurement and construction programme. The ease with which the

project-specific model was formulated (approximately one working week) and the range of building systems that it incorporates, further indicates the level of detail in the generic model.

To date, ADePT has been used to examine the detailed design stage of projects. Other research is underway to model the concept and scheme design stages of building design. ADePT will be used to optimise the way the design is undertaken in these stages, and integrate the planning of these stages with that of detailed design to facilitate more effective overall design planning.

CONCLUSIONS

The technical feasibility of the ADePT tools to plan and manage building design has been established. Initial testing confirms the viability of such tools and a number of conclusions can be drawn from the work that has been undertaken in modelling the design process and developing and testing a matrix analysis tool and programmes. The detailed DPM and DSM tool offer an effective means of scheduling a design process based on the flow of information through a project rather than on the production of deliverables. The matrix indicates groups of tasks that are interdependent and therefore require careful co-ordination. A proprietary project management program can show the optimal design sequence (as determined by the matrix analysis tool) in the form of design programmes. These programmes highlight the iterative task groups identified by the matrix and ensure that they are scheduled to take place in parallel, thereby reducing the likelihood and scale of redesign and associated construction problems. The programmes produced using the ADePT tools can be presented in a number of ways to reflect different levels of detail and activities, thus making them as flexible and versatile as those currently produced in practice. The tools can be used to analyse the affect of construction influences on design, in order to produce programmes that best suit the entire design, procurement and construction process.

The ADePT planning methodology provides a powerful, yet simple means of understanding the interdependencies between tasks in the design process. It offers a means of illustrating to the Client, designers and constructors, the importance of a timely release of information, appropriate quality of information and design fixity. It should also ensure that the appropriate information is exchanged between members of the design team and that the problem of information overload is minimised. By providing a logical, structured approach to planning, based on information flow rather than the production of deliverables, and

taking account of the design process' iterative nature, ADePT can enable fully co-ordinated, integrated design solutions.

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