INTEGRATED PLANNING, CONTROL AND IMPROVEMENT OF BUILDING DESIGN

AUSTIN S.A, BALDWIN A.N, AND STEELE J.L

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

Abstract:

The construction industry is acutely aware of the need to improve the integration, planning and control of its design and production processes. A number of projects undertaken within Loughborough University's Department of Civil and Building Engineering, in collaboration with other academic institutions and construction industry organisations, are addressing this issue by investigating, and developing tools to assist, the design and construction process. Emerging from these projects is the common need for IT systems and support that will facilitate the capture, storage and retrieval of project knowledge. It is only by relating these compatible IT applications to a common and recognisable project process framework that construction industry organisations will be able to make optimum use of the available technological developments. This paper describes the development of techniques and strategies to support the integrated planning and control of design through the collaboration of the main designers, suppliers and contractor working on complex building projects, and discusses the relevance of clustering these in relation to the phases and activities of a generic model of design and construction.

Keywords: Integration, design, management, process, collaboration, web

1 INTRODUCTION

The construction industry is acutely aware of the need to improve the integration, planning and control of its design and production processes. This paper describes the development of techniques and strategies to support the integrated planning and control of design through the collaboration of the main designers, suppliers and contractor working on complex building projects. It focuses on the investigations of five research projects (funded by the Engineering and Physical Sciences Research Council, Department of the Transport and the Regions and many industrial organisations) undertaken by the Department of Civil and Building Engineering, Loughborough University in conjunctio with academic colleagues at Cambridge and Salford, and many industry organisations. These projects investigate: conceptual design amongst multi-disciplinary teams, Managing the Design Process (http://www-staff.lboro.ac.uk/~cvjls1/index.html); Integrated collaborative design within the supply chain, ICD, (http://www-staff.lboro.ac.uk/~cvjwh1/index.html); IT and tools to support construction briefing (CoBrITe), (http://www-staff.lboro.ac.uk/~cvmahh/cobrite.htm); The Design and Construction Process (Process Protocol II), (http://pp2.dct.salford.ac.uk); and Design Planning (ADePT), (http://www-staff.lboro.ac.uk/~cvprw/index.html).

Emerging from these design management projects is the common need for IT systems and support that will facilitate the capture, sharing, learning and feedback of project knowledge. This is the specific focus of our construction briefing project, CoBrITe, but is also an important requirement for the effective delivery of the benefits associated with all these research initiatives. Collaborative project environments, supplied via intranets, extranets or application service providers offer great potential. However, the research findings imply not only a need for new tools for undertaking design management, but also the need for changing roles within the team (including who should lead – e.g. it can facilitate contractor led design). Designers must improve their understanding of the process in conjunction with their roles and responsibilities within it. In the future, integrated virtual teams must achieve a collaborative, continuous-improvement culture of 'right on time, first time', which will require appropriate planning, change control and risk management strategies. It is on these issues that the research focuses. This paper will outline each of the research projects, before describing how they interface and align to support the design and construction process.

2 SUPPORTING BRIEFING (COBRITE)

The briefing stage of the design process is critical to the success of construction projects, but it is widely recognised that improvements are needed in this process in order to both reduce costs and optimise quality of building. Briefing involves understanding the client's needs and expressing them in a way that will ensure compatibility between the client's vision of the project and the resulting product.

There are several problems encountered in construction briefing which involve both clients and designers. These are that: i) there is little guidance and support for clients; ii) designers have difficulties both in capturing clients' needs and conveying conceptual design options to them; and iii) no common language exists between clients and designers, which impedes communication and the exchange of information between them. These problems are compounded by the fact that the construction industry is yet to exploit the potential of IT systems to assist the briefing process. This is in contrast to later stages of design and construction where computer-based techniques and systems are commonplace. The project, which uses a bottom-up, dynamic improvement approach, aims to improve the briefing process through more efficient and effective use of existing and emerging information technologies and builds on the recent Managing the Brief as a Process of Innovation project (Barrett and Stanley 1999).

The objectives of the project include: highlighting shortfalls and best practice; integrating recent/current briefing research projects; assessing potential users' needs; identifying promising systems/products and positioning them within the framework of the Process Protocol (see section 6); identifying specific IT tools and methods; and producing a prototype integration environment for the management of briefing and design information.

From an extensive literature review and the review of the work practice with the industry partners (Hassanen and Bouchlaghem 1999, 2000) the main characteristics of the briefing process and the requirements with regard to the information technology tools have been outlined. They include the following issues. Participants of the briefing process (i.e. client/user/brief-taker) are in general specialists, not experts in all the fields related to the project. In many cases they have to make decisions in areas out of their speciality. Many changes and revisions occur during the briefing stage; critical changes which affect the decision making, should be recorded and communicated to all relevant parties. The different parties involved in the briefing process are frequently geographically dispersed or reside in different organisations. The briefing stage is a critical stage with respect to the total cost and work programme – most decisions affect the total cost of the project and the work programme – any decision has to be properly monitored and its impact traced.

The five key areas for technological improvement identified by the CoBrITe project (Bouchlaghem *et al.*, 2000) are communication, information capture, information representation, information and change management, and information referencing. The communication process is concerned with the exchange of information; this information must be captured and represented in order for it to be analysed and processed for the benefit of an organisation or project. The mechanisms used for information capture in the briefing process are largely dependent on the processes undertaken to communicate that information. These communication issues impact on all other areas of the process. Existing IT tools include: Email, encryption software, digital signatures, groupware solutions, document management systems, visualisation and workflow solutions.

In order to help ensure that relevant information is not overlooked during the decision making process, stored information should be referenced for easy access. Information technology for information referencing can be separated into several areas. These are tools that: i) maintain references between documents, like a library catalogue; ii) create indexes of information; iii) can search these indexes and generate lists of appropriate information related to a search term or terms; and iv) allow sections of documents to be referenced. The information, once created and stored, must be managed. It must be possible for personnel to access any information they need, and for authorised personnel to modify the information. Perhaps more importantly, information that should not be modified, or that should only be modified by a limited number of individuals, should be protected from unauthorised updates. Any technological solution to assist with information management and change management in the briefing process needs to consider the security of information, auditing of changes and versioning of information to prevent loss of data.

A web-based solution, which is built around a shared workspace and aims to assist in the briefing process, is currently under development. The shared workspace will hold all information concerning the brief as well as its evolution. The stored information includes bitmap images (representing the planned building), text documents, CAD drawings, detailed spreadsheets, and structured data stored in relational databases. A key component of the integrating environment is a process view of briefing (figure 1) to help designers locate relevant information and tools.

3 ASSISTING CONCEPTUAL DESIGN TEAMS (MDP)

The conceptual phase of any design project is possibly the most vibrant, dynamic and creative stage of the overall design process. At present it appears to be the least understood. The lack of understanding of the conceptual design process is due in part to the diverse range of disciplines and perspectives that result from collaborative working. The existing design procedures that are available to the interdisciplinary design team tend to be simply lists of deliverables rather than guidance documents providing design teams with an outline of what to do and by what method it should be achieved. In this respect, there seems to be an over-reliance on the experience of the designers to 'know how to design'. At present, no consistent approach to conceptual design exists within the building industry. The MDP research project aimed to generate a flexible and adaptable design framework, the application of which would serve to improve the effectiveness of interdisciplinary interaction and collaborative design activity during the conceptual phase of building projects. This was achieved through the generation of a paper-based framework of conceptual design phases and activities (Macmillan et al., 2000), and its subsequent development into a web-based design support system.

The phase and activity structure of the conceptual design framework was used to track teams of interdisciplinary designers and graphically represent their patterns of design progression (Steele et al. 1999, Austin et al. 1999). These maps (see figure 2) were used to study and analyse interdisciplinary design activity in terms of the patterns of iterative working (Austin et al., 2000). Although each pattern was unique at an holistic level, many commonalties were apparent within sub-sections of the maps. The framework has been transformed into a prototype web-based support system. To ensure that the system supports the dynamic and iterative nature of conceptual design activity, it has been developed to be both flexible and responsive. The system was devised to be capable of aiding the process without imposing a procedure. Questions, in the form of issues for deliberation, are prompted to assess whether the team feel confident of having completed a particularly activity and are ready to move to another. Where the team is not confident that it has completed an activity, the system offers guidance and assistance in the form of suitable 'Team Thinking Tools' (design techniques). These are based on well-established design methods for widening the solution space, setting priorities among competing objectives, or evaluation of options.

The system comprises two further components. The first of these relates to the proportion of time a team spends negotiating roles and responsibilities, i.e. social interaction. To account for this the system supports interdisciplinary team interaction and collaboration in the following areas: i) working as a team; ii) maintaining interaction between members; iii) effective communication; iv) team dynamics; and v) redirecting the team to maintain efficiency. The final feature of the system is the possibility of recording decisions during each of the stages or activities. The system allows, at the user's option, a record to be made of who took a decision, whom else contributed, and other associated explanatory material, such as the justification or rationale behind the decision. If this facility is used, a list of key decisions, who took them, when and why, will be available to the team in the future - and indeed to other teams within the collaborating organisations. Not only can the system help the users to avoid making unnecessary decision loops during the design activity, but capture, storage and retrieval of decisions during the process may also provide a means of performing follow-up reviews of the design process. In this sense the system offers the prospects of decision support, an audit trail, and improved knowledge management.

A prototype version of the system has been used on a component of a £100m airport terminal building, the feedback from which has been, on the whole, very positive. The system is about to be made available on the intranet of one of the industrial collaborators. With further testing it is hoped that the system will be improved in-line with the needs of the end users, and developed to a point that it can be adopted as an integral tool in supporting and managing interdisciplinary conceptual design activity.

4 PLANNING AND MANAGING DESIGN ACTIVITY (ADEPT)

The ADePT planning methodology provides a powerful, yet simple means of understanding the interdependencies between tasks in the design process. At a general level it challenges the way the product is viewed, placing greater emphasis on understanding and analysing the process of design. More specifically it offers a means of illustrating to the client, designers and building contractors, the importance of timely release of information, appropriate quality of information and fixing of design, and the resulting implications for cost, design flexibility and risk. 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. Variations can be assessed rapidly, allowing objective decisions to be made about the resulting changes to project duration, resource levels and engineering economics (Austin et al. 1999a). The ADePT methodology (figure 3) and associated computer tools have been developed to facilitate improved planning and management of design (Austin et al. 1998b). The first stage of the methodology is a model of the building design process. This data, which represents the design activities and their information requirements, are linked via a dependency table to a Dependency Structure Matrix (DSM) analysis tool which highlights blocks of interdependent activities and schedules the activities to optimise task order. The third stage produces design programmes based on the optimised task sequence.

The ADePT project has provided contributions to knowledge through the creation of the generic model of the detailed design process, development of a specification and prototype software to implement ADePT, and the conclusions drawn from the testing and application of the technique. The generic model, which has been developed using a variation on the IDEF0 notation, IDEF0v, is structured in a manner that reflects the discipline-based way in which industry currently works (representing architectural, civil and structural engineering, and mechanical and electrical engineering activities) and thus/this ensures it can be applied to a wide range of projects. The process model, which comprises some 150 diagrams, and represents 580 design tasks and 4600 information requirements, has been found to be generic to a level in excess of 90%, (i.e. over 90% of the activities required in the project-specific models were present in the generic model).

The stages of the ADePT methodology have enabled generic classifications to be compiled, indicating design tasks’ strength of dependency on information, based on the sensitivity of the tasks to changes in the information and the ease with which the task output can be estimated. Also generic deliverables lists and definitions have been produced to enable information to be located and retrieved more efficiently by users of the design process model.

A software tool has been developed to link the DSM to the model and programming stages of ADePT. The design process model and developed software were tested on the planning of detailed design work on three recently completed multi-million pound building projects. Matrix analysis of each design process has shown that, typically, around 60% of design activities are interrelated when applying the three-point information classification scale. Approaches for breaking down the large loops of iterative design tasks have been established which include examination of the design process at a system-level. The testing of ADePT has revealed a range of ways in which it delivers benefits, including: improved understanding of the optimal design programme; integration with the overall project programme (especially the construction stage); assessment of the effects of decisions on cost, risk and design flexibility;

and reduction in abortive work through the timely undertaking and approval of interrelated loops of design.

ADePT has also been applied to the planning of design work on seven live design projects (ranging in cost from £1m-£160m). Observations were made, and feedback was gained from discussions, questionnaires and a users' workshop, in order to judge the effectiveness of the technique, and the management, cultural and organisational issues related to its use. In summary, the feedback on ADePT shows that it is considered to be a highly effective means of improving the design process. It reduces waste from the process and improves the output from the design. The construction industry has shown considerable interest in ADePT, and discussions are now being held with a software developer to produce a commercial product. This should be available within the next 12-18 months. Additionally, through collaboration with the Lean Construction Institute (LCI) and the University of California at Berkeley, ADePT has been merged with LastPlanner (Ballard 1998) to produce an integrated planning, scheduling, and workflow management system for design (Hammond et al., 2000). This hybrid version, which exists as a research prototype and is to be tested on several large construction projects in both the UK and the US, has been named DePlan.

5 INTEGRATED COLLABORATIVE DESIGN (ICD)

Industry has identified the need for the extension of ADePT into earlier scheme design and the subsequent phase of production information (involving suppliers). This is being addressed by the Link IDAC 435: Integrated Collaborative Design (ICD) project and, as will be discussed in the following section, the IMI Process Protocol project. Both of these projects are driven by the need to develop new working relationships that integrate design and construction, and reduce constraints that have adverse effects on both sides. These research projects are also seeking the earlier involvement of suppliers with design capability.

The aims of the ICD research project are to: i) develop a toolbox of techniques and strategies, combined with a collaborative working framework, that can help the construction industry optimise supply-chains; ii) integrate the proposed project and other recent/on-going research initiatives (investigating client/main contractor partnering, design and supply chain management); and iii) allow inexperienced, one-off clients to benefit, not just large, regular procurers. To meet these aims the ICD project has been divided into four components, each of which has made significant contributions to knowledge. A brief outline of two of these components is provided below.

Planning and integrating design processes

This component is extending the design process models and ADePT design management tool to include schematic design and production information stages. The objectives are to: i) model the exchange of information between the design team and suppliers undertaking the fabrication activities, at all stages in the supply chain; ii) evaluate both traditionally let work packages and more innovative methods of procurement; and iii) identify how the process model and associated analytical techniques (including DSM) can be used to improve decision making and activity scheduling.

The project is now modelling the exchange of information between the design team and suppliers undertaking the fabrication and construction activities, at all stages in the supply chain. The models will afford opportunity to evaluate how information flows from early stage design through into production information and onto fabrication. As such, this research will allow an optimisation of the design process to a level far beyond that which may currently be achievable, remove unnecessary projects costs in terms of: reduced prime cost to the client; higher fee profit for designers; and reduced effort and abortive work which benefits all parties.

Value engineering

Value Engineering should be seen as distinct from Value Management (the latter being associated with supplementing the briefing process); Value Engineering is intrinsically linked to the client criteria which are defined during the Value Management stage. Value Engineering is concerned with the design process itself and how multi-disciplinary teams can ensure the developed solutions provide the best possible value to the client in terms of economy, quality, procurement and buildability.

The project's industrial collaborators recognise that designers currently lack the awareness of design to provide commercially focused solutions, both in terms of the client and the potential benefits to the design organisation(s). Also, the limited value engineering currently undertaken is a separate, post-design activity (resulting in large design iterations) rather than being an inherent culture in the design process. Timing is thus crucial and hence there is a strong link to the process integration component and the application of the techniques to be delivered to help schedule VE activities.

The key aim is the development of a VE culture within a design organisation - this is a question of both incentivisation (to realise benefits from their contribution to improved efficiency) and learning how, where and when to use appropriate VE techniques (Austin and Thompson 1999). The research therefore has the following objectives: i) to evaluate VE techniques (including those from other industries) in design and construction, making use of the new process models and produce a VE toolbox; ii) to identify the commercial benefits to clients and design management contracting organisations: and iii) to initiate a programme of cultural change to ensure that all parties to the design are able to embrace these new techniques within their work procedures

6 THE PROCESS PROTOCOL

Introduction to the Process Protocol

A research team at Salford University used construction and manufacturing experience as a reference point for the development of a Generic Design and Construction Process Protocol (GDCPP) (figure 4). This Process Protocol was researched and developed over two years with the support of the EPSRC under the IMI Construction as a manufacturing Process sector. Although the work was undertaken in close collaboration with a wide spectrum of construction industry organisations, the GDCPP was developed from a client perspective, with the main focus being the uneducated or one-off client as this client type tends to require most assistance in undertaking construction projects (Kagioglou et al.1998). However, the generic nature of the model not only ensures that it can be applied by a variety of client types on a variety of projects, it also allows organisations to adapt and modify it, thus enabling bespoke models to be generated, which reflect the internal cultural idiosyncrasies and working practices of specific organisations, without losing the common structure of the generic framework. The research also investigated the relationship between process implementation and the use of IT. This has lead to the development of an IT map which mirrors, and maps onto, the GDCPP, to allow co-ordination of the relevant IT mechanisms in relation to the needs of specific phases of the design and construction process. Preliminary testing has suggested that the application of such a Process Protocol can result in overall project improvements. It has been indicated that through the combined use of a generic process and co-ordinated IT the cost savings for a project would be approximately 18%. These figures are based on the facts that a decrease in the number of claims is obtained, the supply chain is managed more effectively, and a better communication environment is achieved.

The Protocol Development: Process Protocol II

Although the Process Protocol work developed a foundation from which to develop research and process in the construction industry, it was recognised that the phases of the generic model required further investigation and definition. The Process Protocol level II project, which is also funded by the EPSRC under IMI but represents a collaboration between industry, the University of Salford, and Loughborough University, aims to achieve this. Process Protocol II involves the development and definition of sub-processes for each phase of the protocol while specifying the most appropriate IT support mechanisms. In achieving this, the IMI's construction as a manufacturing process sector objectives will be met. These include: i) aiding the identification of the client's needs; ii) improving the management of the design and construction process through the adoption of a common framework; and iii) aiding the integration of technology into the design and construction process.

The Process Protocol II project commenced with information gathering, in the form of literature reviews and interviews with more than fifty industry experts from over thirty organisations. These data were used to develop initial sub-process maps for the different Activity Zones within the Process Protocol, i.e. Design Management, Resource Management, Development Management, etc. Each map expanded the outline provided by the GDCPP, providing more detail on the activities and information requirements likely to be found within the respective Activity Zones for each phase of a construction project. Various methods and approaches found in manufacturing have again been adopted and incorporated in the maps, with current industry concerns (such as ISO 14001 and the environment, supply chain networks to improve collaboration and reduce non-value adding tendering activities, etc) being highlighted.

To date, eight Activity Zone workshops have been held, involving industry experts in the respective fields, to validate the sub process maps for each Activity Zone. A further six workshops are planned before September 2000, with the output from each workshop being incorporated into subsequent revisions of the sub process maps. Following completion of all Activity Zone sub process maps, the Process Protocol Level II will be implemented on one or more construction projects in the UK to validate the approach. A major component of the project is the measurement of performance – both of the construction project and of the impact and effectiveness of the Process Protocol itself. The pilot projects, due for completion in September 2001, will provide a clear picture of how the Generic Design and Construction Process Protocol can be used to improve the efficiency and effectiveness of the construction industry.

Process Protocol II will also contribute to culture change by improving communication and process management between the fragmented groups within the construction industry. In particular, it will provide a common language by which all parties can 'locate' themselves and their processes within the project organisation as a whole. It has already been adopted by several major UK construction organisations as a vehicle for investigating their processes or addressing the specific requirements of PFI projects.

7 INTEGRATION AND ALIGNMENT OF THE PROJECTS

In developing the projects described above we have recognised the potential for linking them and creating synergy. However, given that each of the projects had different foci, with some being phase specific, it was questionable whether a definitive interfacing strategy could be developed until the projects had made substantial progress. There was a preference for a bottom-up approach, in which useful links would emerge naturally, rather than being imposed by a top-down, pre-defined solution. However, the projects have now progressed to a stage where clear opportunities have arisen to incorporate the projects into a common structure. This demands full consideration of the interfaces between the research projects. The immediate beneficiaries of this will be the research community, as the interconnections and gaps in research focus will identify the requirements for immediate collaboration and future research investigations. However, construction organisations will also benefit greatly from a framework of research outputs in the form of tools and techniques to support, plan and manage the design and construction process, a system architecture, and better understanding of information management requirements.

Assimilating phase interfaces

Given that the nature of each of the projects discussed has a different focus and accompanying set of objectives it is difficult to understand the interfaces without defining their position in relation to a common framework. As has been discussed, MDP and ADePT focused on discrete phases of the design process, CoBrITe has potential for application throughout the design and construction process, whilst the components of ICD are representative of each of the above. Moreover, as has been demonstrated in the use of the ADePT methodology as a mechanism of application in the ICD project, opportunity exists for integration and application of the research methods and outputs in areas other than those initially suggested by the research focus. Thus, as the definition of the projects increased and, consequently, the interfaces between the projects gained clarity it has become apparent that the Process Protocol is not only a suitable vehicle for illustrating the connections between the research (figure 5), it also offers great potential for delivering the research outputs in practice.

In adopting the Process Protocol as a framework within which to categorise and store the various research components it has been possible to satisfy one of the key objectives of the Process Protocol research project; that being to specify, and populate the model with, suitable IT support systems. Additionally, the interrelations of the various research projects has served to ensure that the stable of work being undertaken at Loughborough is truly integrated and aligned, not only with each other, but also in relation to satisfying the wider needs of the construction industry.

Implications for technology application and working practices

Emerging from these design management projects is the common need for IT systems and support that will facilitate the capture, sharing, learning and feedback of project knowledge.

This is the main focus of the construction briefing project, CoBrITe, but is also an important requirement for the effective delivery of the benefits associated with all these research initiatives. There are a number of ways in which an organisation can commercially embrace the IT systems and tools to improve their working practices and the efficiency of construction projects. Research has, for some time, investigated the opportunities offered by the Internet, while industry and business in general has begun to recognise the potential benefits of adopting the technology. As a result, software companies have started to introduce IT systems that can be utilised and thus fully integrated as web-based applications. The collaborative project environment demands that designers and manufacturers from different organisations, who may reside in geographically dispersed locations, work together in teams. The web not only offers an environment that allows access to information, IT applications and shared databases, but also enables real-time computer supported collaborative working to be undertaken. There are still a number of important questions to be addressed in relation to ownership of knowledge, e.g. how much cross-organisational transfer of knowledge is allowable before it becomes detrimental to the business. However, the issues of ownership and control of information repositories is an issue that will be investigated further as the research proceeds.

8 CONCLUDING REMARKS

This paper has introduced and discussed several research projects which aim to improve the planning, control and management of building design. These projects have been categorised in relation to a generic model of the design and construction process. This has illustrated the benefits of recognising the interfaces and overlaps in the IT tools which are available to support specific stages of the process. The research findings imply that there is a need for tools for undertaking design management that account for and address the need for changing roles within the team (including who should lead – e.g. contractor led design can be facilitated). Designers must improve their understanding of the process, together with their roles and responsibilities within it. Contractors must be provided with an improved understanding of design and how it interfaces with construction. In the future integrated, virtual teams must achieve a collaborative, continuous-improvement culture of ‘right on time, first time’, which will require appropriate planning, change control and risk management strategies. It is this that the design management work at Loughborough University aims to accommodate.

9 ACKNOWLEDGEMENTS

The authors would like to acknowledge all their academic colleagues at Loughborough, Cambridge and Salford and the many industrial organisations who have collaborated with the research programmes. All these research programmes have been funded by the Engineering and Physical Sciences Research Council with additional financial input from the Department of Transport and Regions.

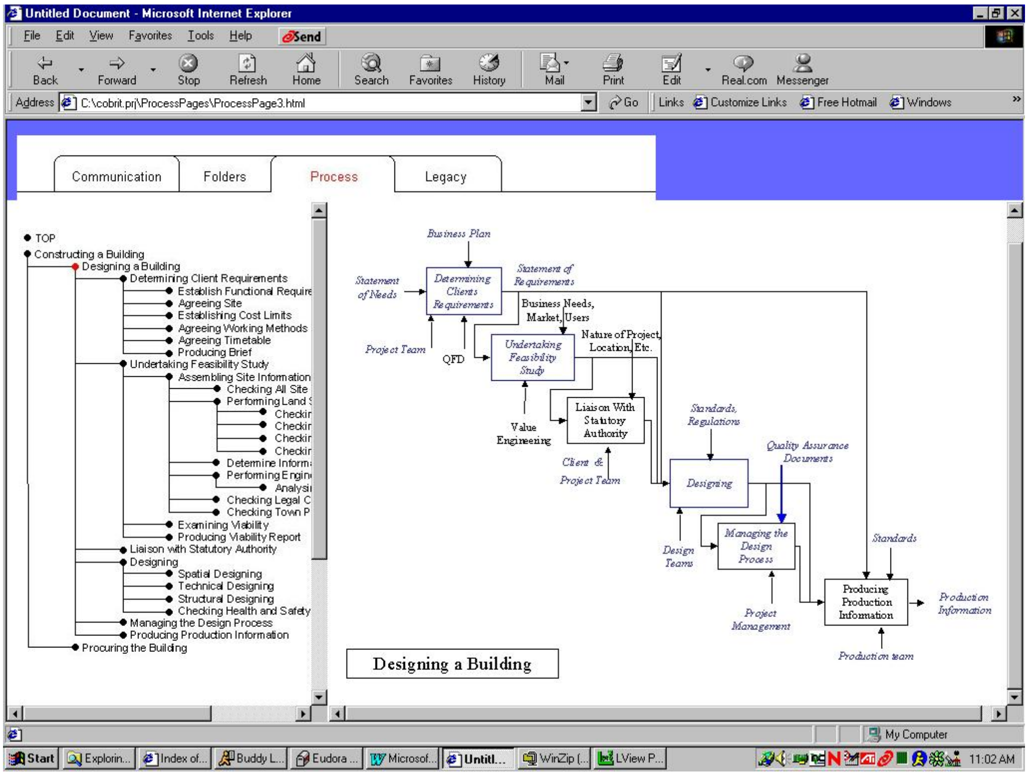

Figure 1 The CoBRITe tool process view of briefing

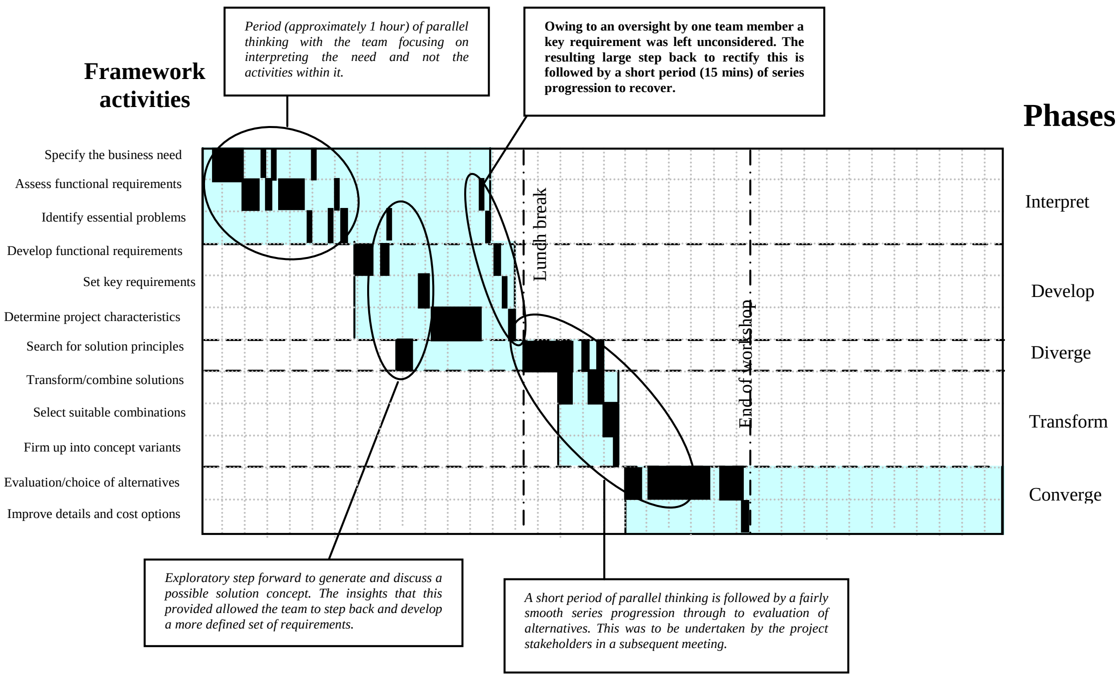

Figure 2 Example of design phase progression (MDP project)

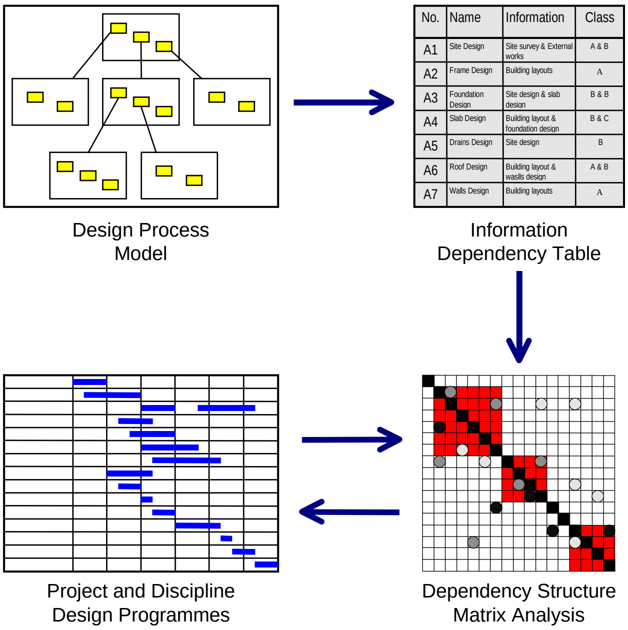

Figure 3 The Analytical Design Planning Technique (ADePT)

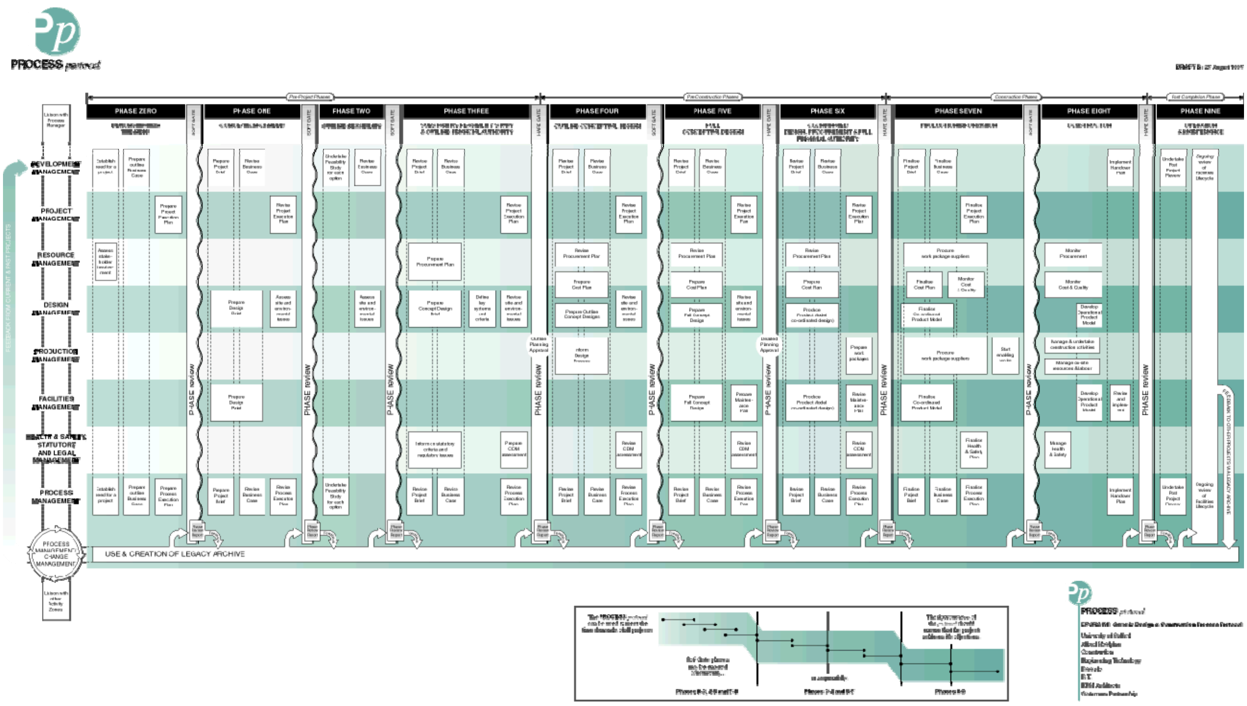

Figure 4 The Process Protocol

REFERENCES

Austin S, Steele J, Macmillan S, Kirby P, Spence R (1999). 'Using training workshops to map interdisciplinary team working'. *Proceedings of Chartered Institute of Building Services Engineers National Conference 1999*. Harrogate, UK. pp. 38-49.

Austin S, Steele J, Macmillan S, Kirby P, Spence R (2000). 'Mapping the conceptual design activity of interdisciplinary teams'. Accepted for publication in *Design Studies*.

Austin, S., Baldwin, A., Li, B. & Waskett, P. (1999a) 'Analytical Design Planning Technique: A Model of the Detailed Building Design Process'. *Design Studies*, Vol. 20, Issue 3, April, pp 279 - 296.

Austin, S., Baldwin, A., Li, B. & Waskett, P. (1999b) 'Analytical Design Planning Technique for Programming the Building Design Process'. *Proceedings of the Institution of Civil Engineers, Structures and Building*, Vol. 134, Issue 2, May, pp 111-118.

Austin S A and Thomson D S (1999), 'Integral value engineering in design', *Proceedings of COBRA 99 Conference*, RICS, Salford, 1-2 September 1999, vol. 2, pp 1-10.

Ballard, G. and Howell, G. (1998). 'Shielding Production: An Essential Step in Production Control' *ASCE, J. Constr. Engrg. and Mgmt*., Vol. 124 (1) pp. 18-24.

Barrett, P. and Stanley C. (1999) *Better Construction Briefing*, Blackwell Science Ltd, UK.

Bouchlaghem D, Hassanen, M, Rezgui Y, Rose D, Cooper G, Barrett P and Austin S (2000), 'It tools and support for improved briefing' Proceedings of *Construction Information Technology 2000*, CIB W78 and IABSE, 28-30 June, Reykjavik.

Hammond J, Choo H J, Tommelien I, Austin S, Ballard G (2000) 'Integrating design planning, scheduling and control with Deplan', *Proceedings 8th Annual Conference of International Group for Lean Construction*, Brighton, July 2000.

Hassanen, M., and Bouchlaghem, D. (1999) *Briefing Practices and Links with other Relevant Projects*, CoBrITe Interim report, Loughborough University.

Hassanen, M., and Bouchlaghem, D. (2000) *Current Use of IT in Construction Briefing*, CoBrITe Interim report, Loughborough University.

Kagiogou M, Aouad G, Cooper R, Hinks J (1998). The Process Protocol: Process and IT modelling for the UK construction Industry'. *Proceedings of The Second European Conference on Product and process modelling in the building industr'*. Amor R (ed.). pp. 267-276. BRE, UK. 19-21 October.

Macmillan S, Steele J, Austin S, Kirby P, Spence R (2000). 'Development and verification of a framework for conceptual design'. Accepted for publication in *Design Studies*.

Steele J, Austin S, Macmillan S, Kirby P, Spence R (1999). 'Interdisciplinary Interaction During Concept Design'. *Proceedings of the 15th Annual Conference of the Association of Researchers in construction management 1999*. Liverpool, UK. pp. 297-305.