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IMPROVING BUILDING DESIGN THROUGH INTEGRATED PLANNING AND CONTROL

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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, Salford and Cambridge Universities, in collaboration with a number of 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

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) that have been undertaken at Loughborough, Salford and Cambridge Universities in conjunction with many industry organisations. These projects have investigated: conceptual design amongst multi-disciplinary teams, Managing the Design Process; Integrated Collaborative Design within the supply chain, (ICD); IT and tools to support construction briefing (CoBrITe), The Design and Construction Process (Process Protocol II), and Planning and Managing Design Activity using the ADePT methodology.

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 was the

specific focus of the Loughborough/Salford University-based construction briefing project, CoBrITe, but was 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 have implied 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. the facilitation of 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 focused. This paper outlines each of the research projects, before describing their interfaces and alignment to support the design and construction process.

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 utilised a bottom-up, dynamic improvement approach, aimed to improve the briefing process through more efficient and effective use of existing and emerging information technologies and expand upon the findings of the ‘Managing the Brief as a Process of Innovation’ project (Barrett and Stanley 1999).

The objectives of the project were to: highlight shortfalls and best practice; integrate the findings from several notable briefing research projects; assess the potential users' needs; identify promising systems/products and position them within the framework of the Process Protocol (see section 6); identify specific IT tools and methods; and produce 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 were outlined. They included 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 outside of their speciality. Many changes and revisions occur during the briefing stage; critical changes which affect the decision-making, must 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) were communication, information capture, information representation, information and change management, and information referencing. It was identified that the communication process is concerned, primarily, 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 e.g., a library catalogue; ii) create indexes of information; iii) can search these indexes and generate lists of appropriate information relating 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, was developed and trialled within the collaborating organisations. The shared workspace holds 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.

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. Yet, 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 at Cambridge University 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., 2001), and its subsequent development into a web-based design support system (please see www.arct.cam.ac.uk/mdp and enter user name: *mdp*, password: *hmitditw* if you wish to review the system and provide feedback).

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., 2001). Although each pattern was unique at an holistic level, many commonalities 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 was used on a component of a £100m airport terminal building, the feedback from which has been, on the whole, very positive. The system is available on the intranet of one of the industrial collaborators. On-going testing is enabling the system to 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.

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 also ensures 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 tool, PlanWeaver, 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 general 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 general 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 this ensures it can be applied to a wide range of projects. In applications to date, the general process model, which comprises some 150 diagrams, and represents 580 design tasks and 4600 information requirements, has been found to contain over 90% of the activities required to deliver project-specific models .

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 developed by BIW Technologies, PlanWeaver, has been developed to link the DSM to the model and programming stages of ADePT, and enable complex integration and analysis of process models to be undertaken quickly and efficiently (see www.adeptmanagement.com). The design process model and PlanWeaver software have been applied on numerous design and construction projects, the most recent of which was a complex £120 million Pharmaceutical laboratory. Prior to this, the research prototype software, Analytical Design Planner, was tested on the planning of detailed design work on three multi-million pound building projects. Matrix analysis of each design process demonstrated 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.

In total ADePT has 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 user 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 has shown 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 the associated software, Planweaver, is now commercially available. Additionally, through collaboration with the Lean Construction Institute (LCI) and the University of California at Berkeley, ADePT has been merged with Last Planner (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.

INTEGRATED COLLABORATIVE DESIGN (ICD)

Industry identified the need for the extension of ADePT into both the earlier scheme design and subsequent Production Information phase (involving suppliers). This has been undertaken in 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 were 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 also sought the earlier involvement of suppliers with design capability.

The aims of the ICD research project were to:

- i) develop a toolbox of techniques and strategies, combined with a collaborative working framework, that could help the construction industry optimise supply-chains;
- ii) integrate the proposed project and other 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 was divided into four components, two of which are outlined below. Further information is available at www.designchains.com.

Planning and integrating design processes

This component extended the design process models and ADePT design management tool to include the phases of schematic design and production information. The objectives were 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) could be used to improve decision making and activity scheduling.

The project also modelled 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 have afforded opportunity to evaluate how information flows from early stage design through into production information and onto fabrication. As such, this research has allowed: i) an optimisation of the design process to a level far beyond that which was previously achievable; and ii) the eradication of 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 recognised that designers lacked 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 that was traditionally performed was, and still is on the whole, a separate, post-design activity (resulting in large design iterations) rather than being an inherent culture in the design process. Timing is therefore 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 of this component was the development of a VE culture within a design organisation - which 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 had 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

The main ICD project output for industry is in the form of a handbook (Austin *et al* 2002) which has received significant attention in the construction industry. It proposes the concept of a design chain in which companies can understand each other to develop sustainable relationships that reflect design complexity. The approach emphasises the flow of design solutions within short-term project teams and the assembly and maintenance of long-term business relationships, using key principles and supporting strategic, tactical and operational practices (Figure 4). ICD is currently being utilised as the basis for the delivery of several high profile bids for the Ministry of Defence.

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 5). This was 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 led to the development of an IT map which mirrored, and mapped 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. Testing suggested that the application of such a Process Protocol could help deliver 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 was also funded by the EPSRC under IMI but represented a collaboration between industry, the University of Salford, and Loughborough University, aimed to achieve this (see www.processprotocol.com). Process Protocol II involved 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 were met. These included: 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 were adopted and incorporated in the maps, with industry concerns (such as ISO 14001 and the environment, supply chain networks to improve collaboration and reduce non-value adding tendering activities) being highlighted.

A total of fourteen workshops were held, with each involving industry experts in the respective fields, to validate the sub process maps for each Activity Zone. Upon completion of all sub process maps, the Process Protocol Level II was implemented on several construction projects in the UK, enabling validation of the approach. A major component of the project was the measurement of performance – both of the construction project and of the impact and effectiveness of the Process Protocol itself. The pilot projects, which were completed in September 2001, provided a clear picture of how the Generic Design and Construction Process Protocol assisted in improving the efficiency and effectiveness of the construction industry.

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

INTEGRATION AND ALIGNMENT OF THE PROJECTS

In developing the projects described above the potential for linking them and creating synergy was recognised. 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, as the projects developed it became clear that there was an opportunity to incorporate the projects into a common structure. This demanded full consideration of the interfaces between the research projects. The immediate beneficiaries of this were the research community, as the interconnections and gaps in research focus enabled the identification of the requirements for collaboration and future research investigations. However, construction organisations have also benefit greatly from having access to the 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 each of the projects discussed had a different focus and accompanying set of objectives it was 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 can be applied 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 existed 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 became apparent that the Process Protocol was not only a suitable vehicle for illustrating the connections between the research (figure 5), it also offered 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 was 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 served to ensure that the stable of work undertaken at Loughborough, Salford and Cambridge Universities was integrated and aligned, not only with one another, 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 was the common need for IT systems and support that would facilitate the capture, sharing, learning and feedback of project knowledge. This was the main focus of the construction briefing project, CoBrITe, but was also an important requirement for the

effective delivery of the benefits associated with each of 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 in future research projects.

CONCLUDING SUMMARY

This paper has described several research projects which aimed 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. It is now imperative that integrated, virtual teams must achieve a collaborative, continuous-improvement culture of 'right on time, first time'. This requires the application of appropriate planning, change control and risk management strategies. It is this that the design management work at Loughborough, Salford and Cambridge Universities aimed to accommodate.

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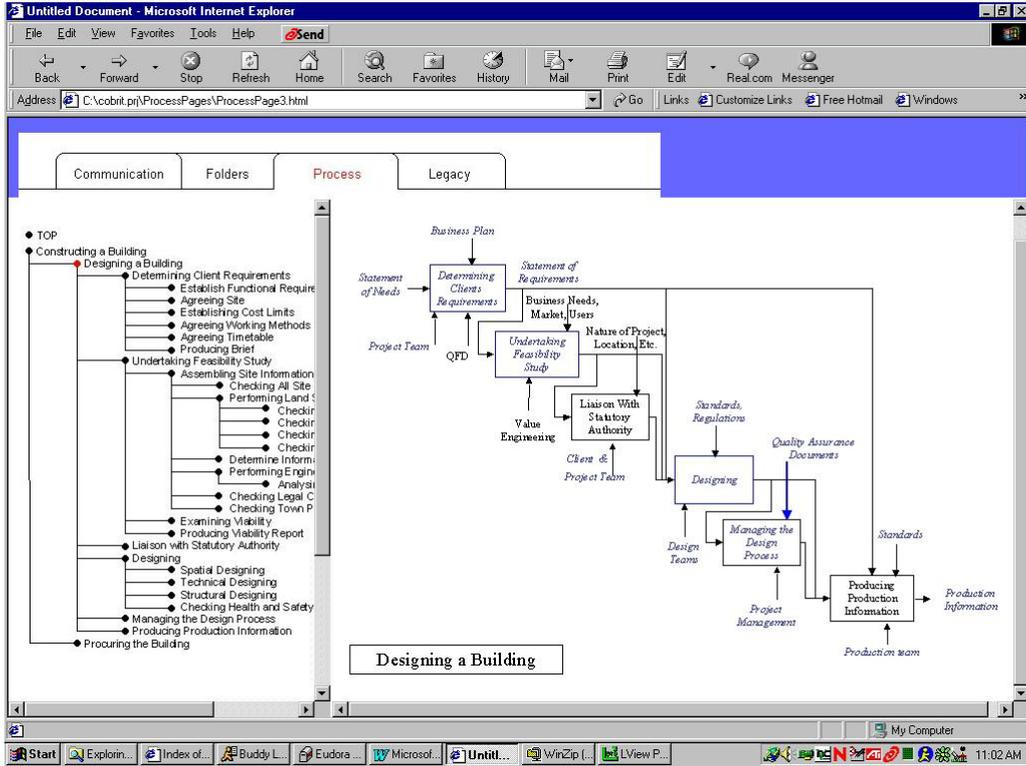


Figure 1 The CoBrITe tool process view of briefing

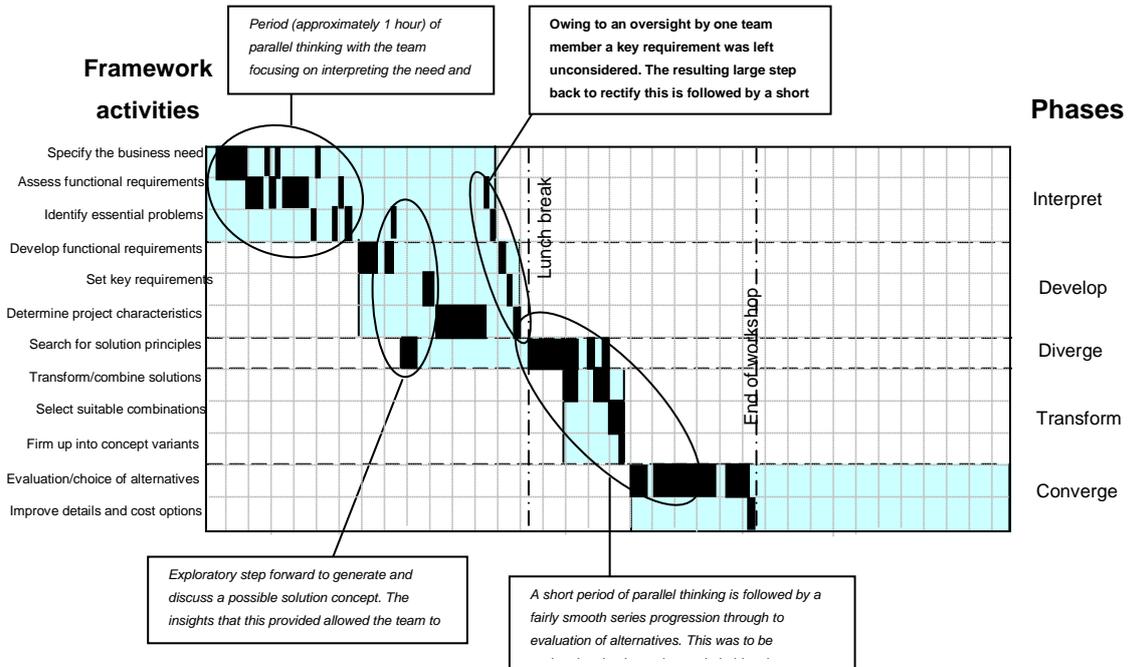


Figure 2 Example of design phase progression (MDP project)

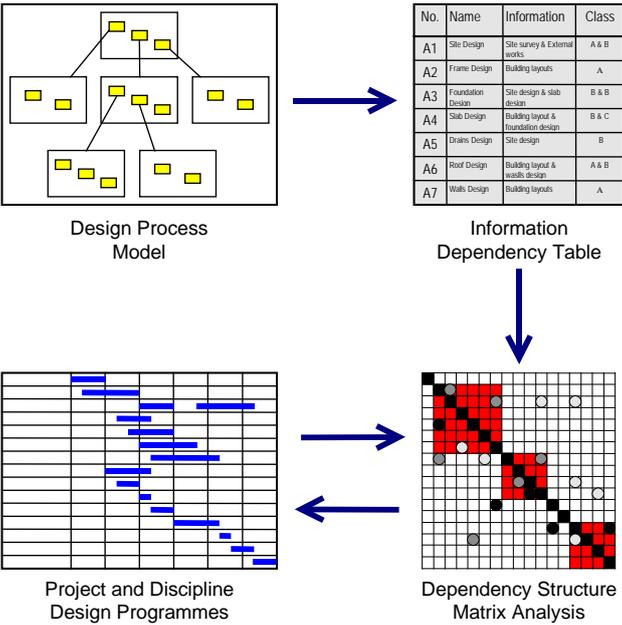


Figure 3 The Analytical Design Planning Technique (ADePT)

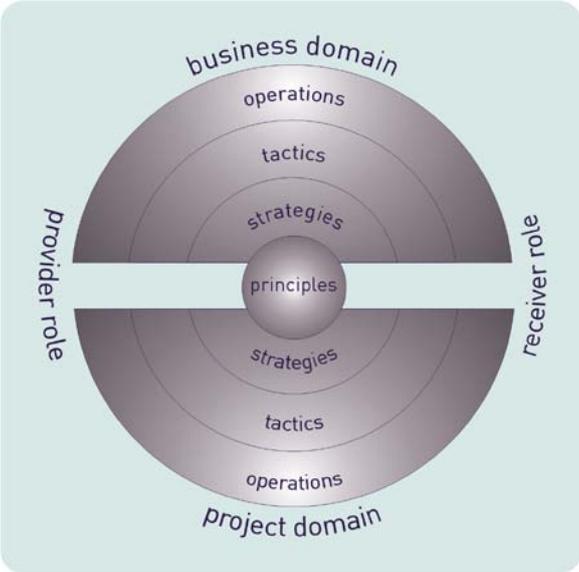


Figure 4 The ICD approach



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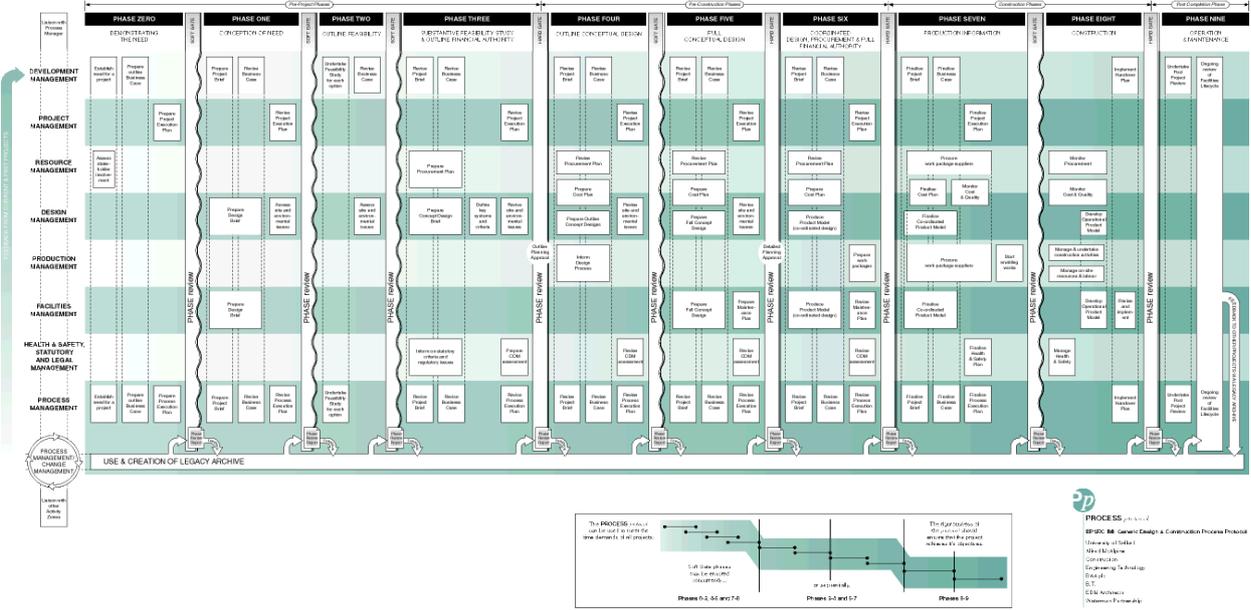


Figure 5 The Process Protocol

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