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The Interdisciplinary Conceptual Design of Buildings

by

John Leslie Steele

A Doctoral Thesis submitted in partial fulfilment of the award
of Doctor of Philosophy of Loughborough University.

April 2000.

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Abstract

The Interdisciplinary Conceptual Design of Buildings

Design activity during the conceptual phase of building projects is dynamic, vibrant and as a result, chaotic in appearance. This problem is compounded by the fact that iterative, or cyclic, design progression is often criticised, with the concept of 'going round in circles' being one that is discouraged. However, design is a learning activity and, owing to the complexity of contemporary building projects, it is often only by moving ahead to improve knowledge, before taking a step back to re-address a problem with improved understanding, that the design process can progress. Today's design professionals are being urged to undertake early design activity in a more programmable, and thus manageable, fashion. As such, it is becoming increasingly apparent that designers have little, if any, shared understanding of what conceptual design actually involves, let alone a deeper knowledge of the structure of iterative progression. This can, and is, causing problems for the industry, as the lack of both common understanding and synchronisation in interdisciplinary thinking is resulting in design team fragmentation and adversarial relationships.

By modelling design activity it is possible to simplify, and thus ease understanding of, its complexities. The development and trialling of a generic framework of design phases and activities has allowed a simple graphical means of recording and displaying patterns of design progression to be devised. The models produced have been used to study and analyse the patterns of iterative working, the output of which has enabled a clarification of conceptual design practice to be achieved.

A web-based design system has been developed from the paper-based framework. This accords well with the richly iterative and often non-linear process which design typically follows and is intended to encourage creativity without imposing a rigid procedure. The tool offers alternative routes through conceptual design, and contains 'Team Thinking Tools' to help designers widen the solution space, set priorities and evaluate options. In addition, it promotes effective teamwork practices to help teams deal with social interactions. Also, at the user's option, the system can be used to capture, store and retrieve decisions made, and the reasoning behind them. This is of key importance in improving the performance of the industry as a whole, for it is only by understanding how the final product is influenced by early design activity, that the design process can be adapted to take account of these issues on future projects.

Acknowledgements

The research undertaken for this thesis would not have been possible without the help and guidance of many people, too many in fact for me to mention them all.

I express my sincere appreciation for the encouragement, intellectual guidance, and patience provided by my supervisor, Professor Simon Austin, without whose continuous support and expertise this research would have never been completed.

I am also grateful to Dr. Sebastian Macmillan of the Martin Centre, University of Cambridge, for his guidance, support, and friendship.

Special thanks go to Mr. Andrew Parker, for providing the seed from which this research grew, and Dr. Mike Murray, for his continuous advice and encouragement. I would also like to acknowledge the Engineering and Physical Sciences Research Council (EPSRC) for sponsoring the project.

Finally, I express my sincerest gratitude to my family: to my parents, for their interminable belief and encouragement; to my wife, Sara, for her understanding, patience and love; and to my children, Polly and Alfie, for providing the most welcome of distractions when they were needed most.

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Chapter One

Introduction to research and thesis structure

1 Introduction to research and thesis structure

1.1 Background

Since the origination of the 'Design methods movement' in the early 1960s, many design process models have been developed. These models can be categorised in many ways: Architectural, engineering, descriptive, prescriptive, and consensus. However, typically these are specific to a particular application and do not represent the amalgamated process of building design. Markus (1969), Maver (1970), French (1971), Archer (1984), Pugh and Morley (1988), Pahl and Beitz (1988) and Cross (1989) are just some of the many writers, from across the architectural and engineering design domain, who have attempted to generate standardised design procedures. Yet it is disturbing that, although the work of many of these writers has been utilised with varying degrees of success in a number of engineering domains, the construction industry has shown little interest in defining a procedure aimed at improving the efficiency of their design activity. This is not to say that the building industry has failed to benefit from the implementation of standardised procedure altogether, as the construction phase of any building project is planned thoroughly in a bid to improve efficiency and reduce time spans. So why has there been little transfer of this philosophy to the activity of design?

The lack of appreciation of the rewards that can be gained from planning design activity seems to owe much to the fact that design and construction are often perceived as being mutually exclusive activities. This is to say that the activity of designing was undertaken by a discrete group of individuals that would hand over their work to the construction engineers, at which point their input to the project would end. This resulted in the common misconception that design could be managed without the help of specific planning and management tools, whilst in construction there were clearer and more easily realisable benefits from improved planning (Austin, Baldwin, Li and Waskett 1999a). In addition, this lack of interest in design planning was compounded by design being: i) more complex, and thus more difficult to address, than construction; ii) undertaken, typically, in a far less pressurised environment in terms of completion deadlines; and iii) undertaken for a fraction of the cost of construction.

Today's lean construction environment has promoted the potential benefits of improving design planning. This owes much to the fact that: i) the activities of design and construction overlap; and ii) design errors tend to represent the major source of problems during construction (Glavan and Tucker 1991). Thus, the construction industry is increasingly recognising that efficiency and client satisfaction can be improved if design activity is planned and managed. Through the collaborative research work of a number of academic institutions, construction organisations and clients, attempts have been made to closely integrate all the phases involved in bringing a building to a customer. This research has resulted in the production of several standardised process maps, the most notable of which are the BAA Project Process (BAA Plc. 1995) and the Process Protocol (Kagioglou *et al.*, 1998). Yet, in spite of these investigations, at present the RIBA Plan of Work for Design Team Operation (RIBA 1969), which was developed some 30 years ago, remains the most widely used model of building design - although it has been revised recently (RIBA 1999) in light of these latest developments.

It has been documented that the existing systematic design procedures advocated by engineering researchers have rarely been subjected to any realistic evaluation in practice. Nevertheless, it is still claimed that their use will lead to better quality artefacts and/or shorter time to design completion (Minneman 1991). In the few instances that the earlier models have been tested on live projects their phases account for only a fraction of the actual activity that occurs (Hales 1987, Blessing 1996). For example, testing of Hubka's (Hubka 1982) model of engineering design failed to validate claims that design cycle time or artefact quality were positively affected by the use of systematic procedure (Minneman 1991).

The areas of building industry research documented above have focused on improving understanding of the entire design process but investigations have also been undertaken which concentrate on the individual stages of the process. These have resulted in the development of methods such as the Analytical Design Planning Technique (ADePT), which has focused to date on the development of models of the detailed design phase (Austin *et al.*, 1999b) and is currently being applied within the construction industry. It could be argued that these more detailed analyses are of more direct relevance to the industry as they de-mystify the intricacies of design activity at

a deeper and more detailed level. Moreover, it is only by understanding the activities involved within the individual stages of design that the interfaces between stages of work can be understood and subsequently managed. The more recently developed models of the design process, such as those generated using ADePT, have proven significantly more robust than the earlier counterparts, with models of the detailed design phase proving to be up to 90% generic in applications to date (Austin *et al.* 1999a).

Thus, this thesis documents a detailed investigation into one of the discrete components of the design process - the most vibrant but disorganised of the phases - namely conceptual design.

1.2 An overview of the research domain

The conceptual phase of any design project is potentially the most vibrant, dynamic and creative stage of the overall design process. However, it is at present the least understood. It is at this early stage that designers from all disciplines need to interact freely in a bid to achieve optimal design solutions that eliminate or reduce the need for compromise of design at a later, more critical period of the process.

As such, there is a need to develop a working environment that promotes creative and innovative interdisciplinary design within the building industry. This, along with a deeper understanding of business and design processes in general, can only enhance the design performance and wealth producing capabilities of the industry. Yet, at present, it appears that the opportunity to gain clarity within the building design process is being squandered, with the process of design being generally poorly understood (Hedges *et al.* 1993), which in turn leads to design teams often being poorly organised, having no real structure or common focus.

There could be many causes of these problems, one of which appears to be a lack of a shared understanding of what processes should be followed. Currently, design procedures 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. There seems to be an over-reliance on the experience of the designers to

'know how to design', which is generally an ill-founded assumption as there is no consistent approach to conceptual design by designers in the building industry and no real model or guideline to follow (Parker and Steele 1998).

There can be little doubt that, during the conceptual phase of a building project, there exists great potential for taking decisions that can result in significant reductions in project costs and increased customer satisfaction. The few researchers that have studied group design activity generally agree that shared understanding between the design team members can aid the decision-making process and is the key to successful collaboration. These researchers believe that a shared understanding can be achieved if all of the team members can agree on a shared design strategy, i.e. clarify and agree on the methods and processes of design to follow.

These differences in approach, and the resulting lack of a shared understanding of the respective processes, could go some way to explaining the confrontational attitudes which are apparent between disciplines in the contemporary building design environment. A lack of synchronisation causes serious problems for team members in both interactions and communications, and results in misunderstandings and uncoordinated actions (Valkenburg and Dorst 1998). According to Taylor (1993), an ordered approach to the design process is essential if people are to work together effectively towards common goals. To this end, it is apparent that for interdisciplinary design teams to work in a synchronised and efficient manner, an integrated design framework, sharing simultaneously the architectural and engineering approaches, is required.

Hales (1987) summarises the opinions of Bessant and McMahan (1979) in suggesting that the way for designers and design researchers to gain improved understanding of the design process is to move toward the development of flexible and adaptable models which take account of the dynamic nature of design activity. Evidence suggests that the designer is better able to cogitate on a particular problem when in possession of a general programme of events through which the activity is likely to pass than when no such structural concept is held (Archer 1984).

Additionally, design within the contemporary building industry involves teamwork, yet at present most of what is known about design activity in general comes from studies of individual designers (Cross and Clayburn-Cross 1996). Moreover, as has been stated previously, process models that are available to the team tend to outline technical procedures based on an individual's prescription of effective design. However, it has been argued that there should be a shift away from this description of design as a technical, rational process, towards that of design as 'a reflective conversation with the situation' (Schon 1983), as descriptive studies involving design teams make it clear that design is not only a complex technical process but also a complex social process (Blessing 1996).

Sir John Egan and his counterparts from the construction industry task force, in the document 'Rethinking Construction' (1998), argue that team design activity can be enhanced by applying a framework which outlines what is being worked on and what the work involves with respect to group design practice. Various current research projects (e.g. Process Protocol and ADePT) have demonstrated how this conjecture is being advanced within the industry. Any realistic framework of this type must include a collection of practices that designers can use in getting the social and technical work of design accomplished (Minneman 1991). Modern multi-disciplinary design demands that engineers work in teams (Brereton *et al.* 1996), a comment which holds true for all designers involved in team design activity, as to be successful the team has to reach some shared or commonly held understanding. As such, design methodology has now to address the design process as an integration of the technical process, the cognitive process, and the social process (Cross and Clayburn-Cross 1996).

It is difficult to achieve effective operation of a large interdisciplinary design team (Bessant and Macmahon 1979). However a way to improve this has been found to be the implementation of a design method, because it more or less imposes group dynamical effects and interdisciplinary co-operation (Blessing 1996, Pahl 1991). It is this conjecture, among others, that has prompted this research investigation.

1.3 Aims and Objectives

1.3.1 Introduction

The previous discussions suggest that there are very few models of the design process. This, however, is slightly misleading. In the fields of product, architectural and engineering design there have been many models generated to represent the design process. It is in the building design industry where research into process modelling has been left lacking. However, the University of Salford (Sheath *et al.*, 1996, Hinks *et al.*, 1997, Cooper *et al.*, 1998, Aouad *et al.*, 1998, Kagioglou *et al.*, 1998), Loughborough University (Austin *et al.*, 1994a, 1994b, 1996, 1998, Baldwin *et al.*, 1995, Newton 1995, Hassan 1996), and the University of Reading (Gray *et al.*, 1994, Fisher *et al.*, 1995, Farshchi *et al.*, 1998) appear to be notable exceptions to this rule. Salford has concentrated on the generation of a generic design and construction process protocol which defines a number of phases in a process framework, whereas work to date at both Loughborough and Reading has centred on design planning and management.

This particular research project however, differed from those mentioned above in that it aimed to generate a flexible and adaptable design model aimed at improving the effectiveness of interdisciplinary interaction and collaborative design activity during the conceptual design phase of building projects, and apply the model in practice as a means of developing a further understanding of the design activity of interdisciplinary teams. It defines a framework consisting of a number of phases, activities and design methods, which can be adapted to suit the specific requirements of the interdisciplinary design team members using it.

1.3.2 Aims

The aims of the research project were:

- a) To generate an adaptive contingency model, which represents realistically the conceptual design activity of interdisciplinary teams.
- b) To unite within the model the technical, social and cognitive elements of design at the conceptual phase with design techniques to support it, and investigate its applicability in practice.
- c) To develop the model into a suitable medium for delivery and assess its applicability and usefulness in practice.

In reaching the above stated aims, the project has contributed to the development of a working environment in which successful collaboration can flourish between all of the design stakeholders at the conceptual phase of building design projects.

1.3.3 Objectives

The following objectives were set to satisfy the above aims:

1. To gain a detailed understanding of writings on design processes and methods with particular focus on the discrete phase of conceptual design.

This objective was set in order to: i) identify gaps in existing knowledge with regard to the design models that are presently available; and ii) identify the phase of conceptual design in relation to the most commonly referenced process models.

Through the research undertaken to achieve objective one, it was found that the existing models of design from across the building design domain did not represent the conceptual design phase in similar terms. Thus, the remaining objectives outlined below focused on the conceptual design phase of building projects.

2. To understand the ways in which conceptual design activity is undertaken by teams of today's building design professionals.

Having developed an understanding of the full-phase design process from various perspectives, the second objective of the research was set in order to: i) understand the effects that social interaction have on early stage design; and ii) to identify and describe a number of design methods that could assist the interdisciplinary design team in overcoming both social and technical problems.

The research undertaken in achieving this objective highlighted the need for a generic model of the conceptual design process that was flexible to allow it to be adapted to various types of project and team. Additionally, it became apparent that for any model to be realistic and genuinely useful it had to account for the social dynamics of collaborative working. This led to the identification of the requirements of a model of the conceptual design process, and an appropriate modelling technique to represent it. Upon achieving this objective a model of the conceptual design phase could be constructed, this being executed through objective three.

3. To generate and verify a design framework aimed at assisting interdisciplinary design teams in undertaking conceptual design activity.

The phases and activities involved in conceptual design were to be established, along with details regarding the manner in which each of these components was addressed in practice. Then a framework was to be generated and its generic nature verified internally, followed by validation of the model through the representation of a range of building project processes.

Once developed, the framework had to be validated within the professional design community. This was undertaken through objective four.

4. To evaluate, review and improve the framework through its application in design workshops attended by practising building design professionals.

The testing of the design framework in an experimental environment would allow the manner in which team of designers progressed through the generic phases and activities to be mapped, and an improved design model to be generated.

In addressing this objective, insights were gained into how designers communicate and interact during early stage design. These insights would enable a basic functional specification to be developed to act as the basis of a computer-based version of the model, which formed the basis of objective five.

5. To translate the paper-based framework into a more applicable format, an interactive Web-based model, and undertake preliminary testing on a live design project.

The development of the preliminary framework into a prototype Web-based version would allow the model to incorporate an interactive team maintenance facility, thus allowing the social dynamics of the interdisciplinary design environment to be addressed. Additionally, it would enable the applicability of such a model to be tested subsequently in a live-design situation, which would allow objective six to be achieved.

6. To make recommendations for further research areas in the field of interdisciplinary building design and process-based computer support.

The findings obtained in achieving objective six would allow recommendations to be made for further development and refinement of the prototype Web-based support system in future research investigations. Additionally, the application of the system would allow further validation of the underlying framework structure by applying it in a live project and, ultimately, to gain further insights into interdisciplinary conceptual design in practice. Finally, the application of the design framework as a means of tracking and then understanding design progression would enable future research investigations to represent the conceptual design process graphically, thus allowing a deeper understanding of design activity to be developed.

1.4 Research output: The conceptual design framework and Web-based support system

The fundamental aim of this research project, which was to generate a flexible and adaptable design model aimed at improving the effectiveness of interdisciplinary interaction and collaborative design activity during the conceptual design phase of building projects, was achieved through the generation of a paper-based framework of conceptual design phases and activities.

The phase and activity structure of the paper-based conceptual design framework was used to track teams of interdisciplinary designers while working in practice, and from this a simple graphical means of recording and displaying the patterns of progression through the activities that the teams followed was developed. These maps were used to study and analyse interdisciplinary design activity in terms of the patterns of iterative working.

The notions of phases and activities of conceptual design have been embodied in a prototype computer-based interactive system that can be run over the World Wide Web (WWW). To ensure that the system supports the dynamic, highly iterative and non-linear process of conceptual design, 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. Provocative questions to the user are intended to discover

whether the team feel confident of having completed a particular activity and are ready to move to another. Whatever response the team gives to such a question, they remain at liberty to move to any other of the activities they choose. However, by default the system will guide them to the next activity in a stepwise progression. Once they reply that they are confident this next activity is complete, they will pass to the following one.

Where the team is not confident that it has completed an activity, the system offers assistance. This takes the form of a link to a set of 'Team Thinking Tools' embedded within the system. These are based on well-established design methods for:

1. widening the solution space through 'brainstorming' or the use of analogies
2. setting priorities among competing objectives
3. evaluation of options through ranking or weighting methods.

In addition to offering guidance and tools to the design team, the system has two further important components. The first of these is team management. A certain proportion of the time a team spends designing is used in social interaction - to negotiate roles and responsibilities. As such, the system attempts to support interdisciplinary team interaction and collaboration in the following areas:

- Working as a team
- Maintaining interaction between members
- Effective communication
- Team dynamics
- 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 reasoning 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 may 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.

Throughout the system development period there was a cyclic progression through the 'demonstration-idea-action' process. This resulted in the systematic crystallisation of the support system into a prototype version, and allowed the intended end users to provide useful feedback with which to improve the system. The demonstrations highlighted a number of perceived benefits that could result from its implementation:

Improved integration:

- Promotes an integrated interdisciplinary approach.
- Provides an activity framework (passive; knowledge store).
- Provides a mechanism for co-ordinating and aligning organisational processes.

Improved collaboration:

- Supports the social interaction which is critical to early stage design.
- Introduces a mechanism for the team to manage themselves.
- Provides a team-maintenance component to allow problems to be externalised and addressed.

Improved process understanding:

- Promotes process (as well as product) negotiation.
- Externalises the phase, activity, and type of thinking required by the team at any point during design activity.
- Allows the client to visualise and understand the reasoning behind iterative design progression.
- Provides a contingency process for undertaking the conceptual design activities (dynamic: guidance mechanism).

In addition to the outputs described above, a number of papers have, and are being, published from the research. These publications have served a dual purpose: i) to

subject the material to critical peer review; and ii) to disseminate the research material to a wide audience comprising both academics and construction industry professionals.

Writing these papers for critical review proved to be a highly beneficial exercise as it focused the thoughts of the author, enabling the material within this thesis to be refined and clarified in light of feedback from a number of experts in the field. A list of existing and forthcoming publications arising from this research is provided in Appendix I.

1.5 Thesis structure

This thesis has been compiled to reflect the manner in which the research investigation was undertaken. Thus, it has been divided into four discrete phases of inquiry (shown in table 1.1 below), with each phase comprising a number of chapters. This is illustrated graphically in figure 1.1.

Phase	Chapters	Focus of inquiry
1	One - Three	Introduction and overview of research domain
2	Four - Six	Development and testing of an improved conceptual design framework and model
3	Seven - Nine	Development and testing of a Web-based version of the model
4	Ten	Conclusions and recommendations for future work

Table 1.1 Structure of this thesis

The following summarises the purpose and content of each of the following nine chapters of this thesis.

Chapter Two: Research methodology

This chapter defines the methodology applied during this investigation to ensure that the findings of the research can be substantiated under the scrutiny of examination.

Chapter Three: Literature review

This chapter discusses the literature study that was undertaken to initiate this study. It discusses the various existing models of the entire building design process before focusing on issues relating to the conceptual design period specifically.

Chapter Four: Modelling conceptual design

This chapter discusses a number of structured analysis and design techniques used primarily in the information technology (IT) industry to generate models of complex systems or environments. The suitability of these techniques to developing models of the conceptual design phase are discussed and conclusions are drawn regarding the nature of the model.

Chapter Five: Development and verification of a generic model of the conceptual design phase

This chapter outlines the development of the preliminary conceptual design framework model. It describes a number of case study investigations that formed the datum from which the framework was constructed. A number of modelling approaches are also deliberated. The chosen approach, the categorical, or toolkit, approach is discussed in detail in the context of this research.

Chapter Six: Testing of the conceptual design framework

This chapter details the testing of the preliminary conceptual design framework in two experimental workshops. Maps of conceptual design activity, describing the manner in which the interdisciplinary teams progressed during the workshop, are discussed and analysed. The discussions describe the development of the framework into a revised generic conceptual design model.

Chapter Seven: Preliminary specification of a computer-based version of the conceptual design model

This chapter defines a functional specification for a computer-based version of the conceptual design framework based on the revised model discussed in the previous chapter.

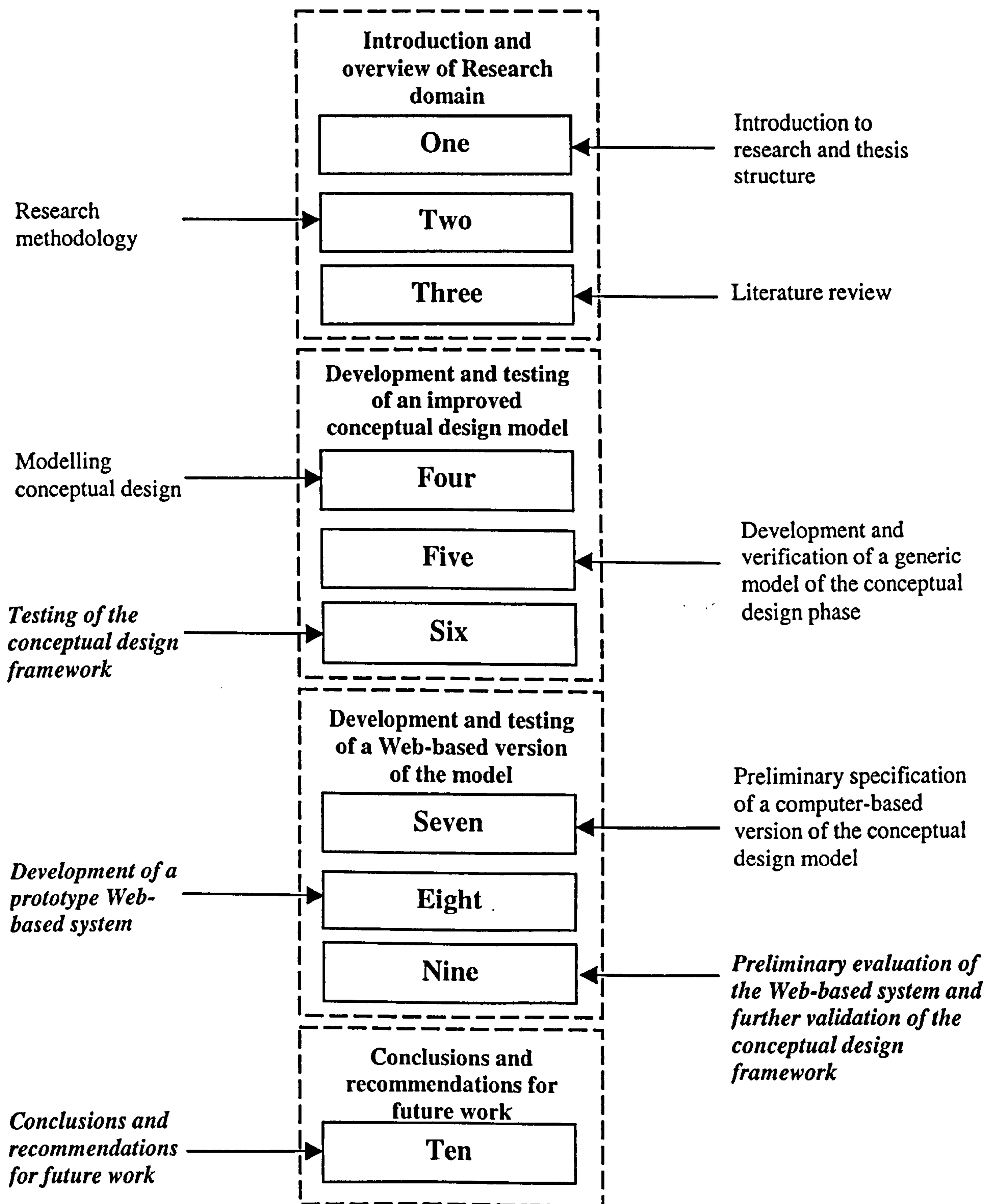


Figure 1.1 Breakdown of thesis

Chapter Eight: Development of a prototype Web-based system

This chapter discusses the development of the Web-based process-oriented conceptual design support system. It discusses the development of the various system attributes

and outlines the characteristics of the tool. The evolution of the system is discussed with regard to the input of the intended end-users.

Chapter Nine: Preliminary evaluation of the Web-based system and further validation of the conceptual design framework

This chapter discusses the trialling of the Web-based system on a live design project in industry. Details of the system application are described, while the feedback from the users is analysed, leading to suggestions for further refinement of the system. Further validation of the underlying framework structure is discussed and, ultimately, details are provided, based on the further insights gained into interdisciplinary conceptual design in practice, of the way in which the research findings can, potentially, be applied to improve both the execution and management of early stage design.

Chapter Ten: Conclusions and recommendations for future work

Chapter ten describes the conclusions that can be drawn from the research, and suggestions are made for future work that will be required to both develop and refine the system and further improve understanding of the interdisciplinary conceptual design of buildings.

Chapter Two

Research methodology

2 Research methodology

2.1 Introduction to the research design strategy

In order to ensure that the findings of any research work are valid, the researcher must first define the appropriate research methodologies to be implemented. However, it must be noted that, although this chapter identifies and defines the methodology that was applied throughout the research period, it is not intended to imply that the methods were preordained to enable the delivery of a predetermined output. The research investigation and the methodology with which it was undertaken were defined concurrently as an ongoing exercise.

This approach enabled the author to take the evolving findings of the study, analyse these in relation to the research objectives (as outlined in section 1.3), and then evaluate the optimum method of developing the investigation further. In this way the methodology evolved as the findings of the investigation were unearthed. As such, the defining of the methodology at the outset of the thesis is intended to ensure that the reader has a full and detailed understanding of the applied methodology prior to ingesting the details of the findings that resulted from its application (as will be outlined in the remainder of this thesis).

Research design goes far beyond creating a plan by which to work. It has several purposes: i) to assist the investigator in the avoidance of collecting data that does not relate to the research questions initially posed; ii) to ensure that data is collected in the appropriate manner; iii) to assist the investigator in the marshalling and analysis of the data.

Phillilier *et al.*, in Yin (1984), states that a research design can be thought of as a 'blue-print' of research, dealing with at least four problems:

1. What questions to study,
2. What data are relevant,
3. What data to collect, and
4. How to analyse the results.

Yin (1984), among others, has stated that there are five commonly utilised research strategies, with each having particular advantages and disadvantages in a particular situation or research scenario. The five strategies are experiment, survey, archival analysis, history and case study. The author suggests that two further strategies, process modelling and action research, should be included in this list. The choice of strategy to be implemented depends upon three conditions:

1. The type of research question,
2. The control the investigator has over actual behavioural events, and
3. The focus on contemporary, as opposed to historical, phenomenon.

Table 2.1 outlines the relevant situations in which one or several of the different research strategies could be suitable. ('What' questions, when asked as part of an exploratory study, pertain to all strategies).

Strategy	Form of Research Question	Requires Control over Behavioural Events	Focuses on Contemporary Events
Survey/Questionnaire	Who, what, why, where, how many, how much	No	Yes
Case Study	How, why	No	Yes
Modelling	Who, what, how many, how much	No	Yes / No
History	How, why	No	No
Archival Analysis	Who, what, why, where, how many, how much	No	Yes / No
Experiment	How, why	Yes	Yes
Action research	Who, what, how many, how much, why	Yes/No	Yes

Table 2.1 The research strategies applicable to design

The first and most important condition for differentiating between the various research strategies is to identify the type of research question being asked. In general,

'what' questions may either be exploratory, allowing any strategy to be used, or about prevalence, in which case, the analysis of archival records would be favoured. This particular research investigation focuses on 'How' and 'Why' questions, which are 'explanatory'. 'How' and 'Why' questions deal with operational links needing to be traced over time, rather than mere frequencies or incidence.

2.2 Literature survey

A literature survey was chosen to initiate the research investigation owing to the fact that it is the most efficient means of initial information gathering. Without undertaking a detailed survey of the existing material on the subject it would be impossible to ensure that the research was not duplicating work that has been previously undertaken.

A search of existing academic and industry literature was considered to be the simplest means of gaining as much understanding of the existing knowledge base of design and design research as possible. Additionally, it was perceived that the literature survey findings would highlight any gaps in existing knowledge and as such, direct and focus the research to progress toward addressing these inadequacies.

The initial period of the research was spent gathering literature on the subject of design. This component of the investigation is described in chapter 3. This data gathering exercise did not aim to concentrate solely on design within the building and construction industry or for that matter on the particular phase of conceptual design. Its aim was to provide the author with a detailed understanding of the ways in which the field of design had been explored previously. The findings of the literature search highlight the existing gaps in knowledge that the research project should aim to address. These findings, which provide evidence for the direction of the research, have been categorised into four areas:

1. the need for a model of the conceptual design phase of building design;
2. the need for a new model typology;
3. the need to introduce the social dimension of team interaction; and
4. the need to consider the applicability of design methods.

2.3 Questionnaire surveys

2.3.1 Introduction

There are several means of establishing attitudes and preferences in social research, for example: i) document analysis; ii) observation; iii) in-depth interviews; iv) structured interviews; and v) survey questionnaires. The most commonly used technique of these is the structured questionnaire. According to Eaton (1998) this type of survey represents an efficient method of collecting data of a general nature and allowing statistical analysis to be performed. The key to successful questionnaire design involves anticipating the research problem, what the concepts may mean and how the resulting data can be analysed. The questionnaire must reflect both theoretical thinking and an understanding of data analysis (de Vaus 1986). This is taken further by Brenner, Brown and Carter (1985) who suggest that the design of a questionnaire involves a process with several general stages: i) understanding the areas to be explored; ii) the question wording and sequencing; and iii) the physical design and layout. All of these factors were considered in detail during the development of the research questionnaires.

Questionnaire surveys were utilised during four periods of the research project:

- 1) During the preliminary investigations in order to develop the findings of the literature survey and establish the attitudes of industry professionals (see section 2.3.2).
- 2) During the experimental period (in the 'Designing Together' workshops – chapter 6), in order to elicit information from design teams regarding information relating to several specific research issues (see section 2.3.3).
- 3) During the initial period of evaluation of the prototype version of the Web-based design process model (see section 2.3.4).
- 4) During the trialling of the Web-based system (chapter 9) as a means of gathering feedback from the design team concerning information relating to the usefulness and applicability of the system in practice (see section 2.3.5).

Copies of the various questionnaires are provided in appendix II.

2.3.2 Preliminary investigations

The aim of this phase of the research was to take the findings of the literature survey and test their validity within building design organisations. A study of the attitudes of practising designers was considered vital in order to clarify what they believed were the major problems with conceptual design activity in the present design environment.

After much deliberation, it was decided that an amalgamation of two mechanisms would be introduced to undertake this activity: A questionnaire produced for completion by industry designers in face-to-face interviews. This allowed the author to explain and clarify any perceived ambiguities in the questionnaire itself while also allowing the respondents to elaborate on their questionnaire responses (see table 2.2 in section 2.4.5 for strengths and weaknesses of interviewing as a means of investigating the social sciences). This approach resulted in the collection of large amounts of qualitative data which may have been lost had the questionnaires been completed independently.

This structured form of data collection allowed interviewees to be asked similar, if not identical, sets of questions all based around the core questions laid down by the questionnaire itself. Utilising a questionnaire in this manner minimises the penalties imposed by failing to anticipate fully what information will be required when generating questions, as the interviewer can lead the questioning to extract any additional information as the interview progresses. As this phase of the research was introduced to collect both quantitative and qualitative data, this was considered the optimum means of data collection. The only real problem with utilising questionnaires in this manner is that the interviewer must be in contact with the respondent throughout completion of the questionnaire, either in person or by telephone, which can be a drain on resources in relation to both time and money. This is a requirement that is negated when a postal questionnaire is used. However, postal questionnaires have the disadvantage of appearing less important than formal interviews and as a result, the response rates to these tend to be greatly reduced.

2.3.3 The second experimental workshop

This stage of the research project was introduced in order to test and develop the preliminary version of the conceptual design framework. (A full description of the methodology is provided in section 2.7). In addition to monitoring the design teams, three questionnaires were developed as a means of eliciting detailed information from each of the participating designers.

Owing to the two-day time constraint of the workshop, in addition to the size of the sample, it was imperative that questionnaires were designed that could be completed quickly and efficiently, and could be self administered without the need for elaboration by the author. As such, the questionnaires were designed in a forced-choice, rather than open, format. This choice was made owing to the author's anticipation that the respondent's motivation would not be high at the end of an intensive two-day exercise. In this respect, forced, or closed, questions are ideal for this purpose, as they are quick to answer, requiring far less time for completion than open questions.

A Likert-style format of rating scale was chosen as the optimum response mode as it is recognised as a robust, yet simple, means of providing responses to forced choice questions. The Likert-style format is a general approach which involves providing people with statements and asking them to indicate how strongly they agree or disagree (de Vaus 1986). The format in which this is presented can be either verbal or diagrammatic. In this application, it was decided that the optimum format would be verbal.

The first of the three questionnaires, which concerned the design process, was adapted from one used by Preubler (1988) and subsequently Blessing (1994). This ensured that the questionnaire was tested and thus, dismissed the need for a pilot session. The second questionnaire, concerning the way the team perceived they had performed, comprised a number of questions highlighted in the Building Teams guidance manual (Palmer, Busseri, Macmillan 1998), and used the same format type and rating scale as the previous questionnaire. The third questionnaire concerned the applicability and usefulness of a number of design techniques (or team thinking tools). This was again formatted in a similar manner to questionnaire one, but also

included a number of open-ended responses to extract additional information. This mixing of open and closed questions is a recognised methodology in social surveying and according to Gallop (1947), the combination of a closed question (to see if the respondent has thought about or is aware of the issue), followed by an open question (to get at general feelings on the matter) is worth using for some key variables.

2.3.4 Preliminary evaluation of the Web-based system

This period of the research project was introduced to enable a preliminary evaluation of the Web-based version of the conceptual design framework to be achieved. Owing to the fact that the Web-based system was developed using Hyper Text Mark-up Language (HTML) – an internet based language that enables web browsers, such as Internet Explorer and Netscape Navigator, to be viewed over the WWW – the internet was utilised as a means of administering, and receiving feedback from, an evaluation questionnaire. The effectiveness of using surveying based around WWW technologies is becoming increasingly apparent (Pitkow and Recker 1999) and, at present, there are two recognised methods available for internet based surveying: e-mail surveys and web-based questionnaires.

E-mail surveys

Traditional e-mail based surveys require the user to perform multiple text entry, usually by either placing Xs in boxes or typing numbers, then posting the message to the surveyors personal address. This method requires the surveyor to send the message to the appropriate respondents, and then for the respondents to mail the reply. In other e-mail based surveys, the questions are posted to news groups, which then require the respondent to extract the message and proceed as above. Whichever of the e-mail based methods is used, once the responses have been submitted, the collation of the data can become problematic, since consistent structure within responses can only be suggested, not enforced. For example: if the question ‘*how old are you?*’ is posed the answer may lie on the same line as the question, two lines below, may contain fractions, an integer, or even a floating point number (Pitkow and Recker 1999).

Web-based questionnaires

The field of electronic surveying is a comparatively new means of data gathering in the social sciences. Web based questionnaires have several mechanisms that make them appealing to both researcher and respondent (Pitkow and Recker 1999). They:

- enable point and click response;
- provide structured responses;
- enable immediate data transfer and collation; and
- present the questions visually for re-inspection and review.

However, like e-mail surveying, the web-based survey suffers some problems, namely self-selection and sampling. Even when a person has been invited to participate in a survey, the individual can still choose not to submit their response (thus exercising the right of self-selection) (Kehoe and Pitkow 1996). This problem is still apparent in e-mail surveys. However, the contact is more personal and as a result, this problem may be reduced somewhat. The second problem emanates from the fact that non-random sampling is required in the context of this investigation. Thus, the targeted respondents must be told, or see announcements, of the survey in order to be able to participate. Obviously, only those who are made aware of the survey will ever have opportunity to respond. This problem owes much to the fact that at present the web has neither a broadcast mechanism nor a way of registering individual users (Kehoe and Pitkow 1996).

Choice of survey type

As can be seen, both Web-based and e-mail techniques are applicable in this particular application and each has similar disadvantages as a means of gathering user response data. The problems apparent with self-selection are symptomatic of all social surveying techniques to some extent, whether the targeted respondents hang-up during telephone interviews or neglect to return postal-questionnaires. However, the e-mail survey does have several significant disadvantages when compared to the Web-based survey in that a considerable amount of time and resource is drained in the sending of the survey and the collation of the data from an unenforceable response structure once returned. Moreover, the e-mail survey, although being more

personal, requires considerably more effort on the part of the respondent to submit the data, with the web-based survey requiring only a click on a 'submit' icon.

Additionally, as the Web-based system was constructed around HTML, it was possible to install a hyperlink to allow the users to link direct from the model into the survey questionnaire. To this end, the web-based questionnaire was chosen as the most suitable means of surveying the intended users in a bid to undertake a preliminary evaluation of the prototype version of the system.

Application

A number of designers from six construction industry organisations were contacted by e-mail and provided with a Web site address which would allow them to gain access to the system over the internet. The site, which was password protected, could only be accessed if the correct user-name and password were submitted. The site contained both a preliminary version of the Web-based system and an on-line questionnaire. The questionnaire was based on a Likert-style rating scale with the respondents being asked to record how strongly they agreed or disagreed with a number of statements regarding the Web-based system. A similar set of statements to those used in the second experimental workshop framework questionnaire were utilised, as the system had been developed to represent a Web-based version of the original paper-based framework. However, owing to the system being internet-based a number of additional statements were included in the survey. These related to each respondent's age, amount of computer usage, liking for the internet, and so on. These statements were utilised as a means of filtering responses to take account of the extraneous effects imposed by the survey medium. All told, the internet provided an efficient, simple-to-use, reliable and low-overhead means of surveying within the context of this period of the investigation.

2.3.5 Trialling of the prototype Web-based system

In order to gain feedback pertaining to the trialling of the system during the live-design project, a similar set of questionnaires were utilised as those described in section 2.3.3. These were combined with a further questionnaire that introduced the filtering statements used during the preliminary evaluation of the system within the

Web-based questionnaire (as described in section 2.3.4). The details and feedback regarding this period of the research are detailed in chapter 9.

2.4 Case study investigation

2.4.1 Introduction

As has been stated in chapter 1, the objective of this phase of the research was to test and develop the literature survey findings. Case study investigations are the optimum means of achieving this. A case study is an empirical enquiry that investigates contemporary phenomena within its real-life context, especially when the boundaries between phenomena and context are not clearly defined (Yin 1984). It is a perfect way of obtaining a clear contextual insight into the complexities of processes (Voyatzaki 1996), as it allows detailed descriptions of activity and interactions to be produced.

The case study allows contemporary events to be examined when the relevant behaviours of the participants cannot be manipulated and the investigator wants little or no control over events. It should be noted that it is actually possible to strategically design a case study that allows the investigator to manipulate the participant but, in this, the observation phase of the project, this was highly undesirable. In addition, case studies added two further possible sources of evidence which were vital to the project: direct observation and systematic interviewing. This gives case studies the unique advantage of allowing a full variety of evidence to be dealt with i.e. documents, artefacts, interviews and observation.

Another advantage of case studies is that they are most commonly utilised in topics involving decisions, organisations, and processes; which provides an insight into their usefulness in evaluation research (Palton 1980). Yin (1984) describes four different applications where case studies are most effective: i) (and most importantly) to explain the causal links in real-life interventions (which is the key aspect in mapping the complex cognitive processes involved in generating design concepts) and are too complex for the survey or experimental strategies; ii) to describe the real-life context in which an intervention has occurred; iii) when an evaluation can benefit (in a descriptive mode) from an illustrative case study of the intervention itself; and iv)

where they can be used to explore those situations in which the intervention being evaluated has no clear, single set of outcomes.

2.4.2 Qualitative versus quantitative evidence

Owing to the type of research questions being asked, the observation phase of the project enabled qualitative, rather than quantitative, evidence (in order to expose the processes behind conceptual design) to be gathered. It is important to understand that the contrast between the two types of evidence does not distinguish the various research strategies. This point is validated in the fact that case studies (fundamentally concerned with gathering qualitative data) can include, and even be limited to, the gathering of quantitative evidence. Qualitative research consists of two conditions: a) the use of close up, detailed observation of the natural world by the investigator; and b) the attempt to avoid prior commitment to any theoretical model (Van Maanen, Dabbs and Faulkner, 1982).

2.4.3 Validation of findings

According to Miles and Huberman (1984), in order to overcome common criticism of case study methodology, four components must be present within the investigation procedure. Voyatzaki (1996) describes these components as:

- **Internal validity:** research is internally valid when the inferences are correct. Data verification in qualitative approaches, which are fundamentally individual's interpretations of events and therefore cannot be differentiated in terms of levels of correctness, can be reached by attempting to discover similarities across accounts.
- **External validity:** research is valid externally when its findings can be generalised to some extent.
- **Reliability:** minimising errors and biases will help to achieve reliability of findings. Gathering rich documentation to support any findings can avoid errors (Yin 1984).
- **Construct validity:** research becomes increasingly valid when multiple sources of evidence are used to substantiate any findings. Ensuring that respondents are key

informants (integral players in the process) can increase construct validity (Yin 1984).

2.4.4 Direct observation of design meetings

Observation means any sensory perception, not only visual, of external cues that help us to understand human behaviour (Gorden 1980). Direct observation was used to monitor the live design activity of a single interdisciplinary team. This was complimented by the systematic interviewing of the design team members (see section 2.4.5).

It is a fairly difficult task to gain access to real-life projects, particularly within organisations whose projects tend to be of a reasonably confidential nature. Additionally, once this access has been granted, obtaining permission to record meetings using any recognised research mechanism, be it note-taking, audio-taping, or video-recording, represents another difficult barrier to overcome as this is seen as the antithesis of confidentiality.

After a number of discussions with representatives from one of the collaborating organisations, a suitable project was designated for monitoring. It was agreed that structured note-taking would be acceptable as a means of recording the team design activity in addition to audio-taping, providing that the tapes themselves did not leave the building and any transcription was undertaken on site. As such, the author was present at a number of design meetings throughout the conceptual design phase of the project.

Prior to the first observation session the author introduced both himself and the reason for monitoring the project to the design team. This is recognised as being a key component of good observation technique as it put the team at ease and dispels any fear of ulterior motive. This small investment of time ensured the team recognised the author's agenda and as such, did not feel uncomfortable with the situation. In fact, the author's presence at the meetings aided the collection of complimentary data during the interviewing of the design team members, owing to their acceptance of this as part of the project environment.

2.4.5 Systematic interviewing of designers

The research interview is recognised as a means of serious data collection in the field of social science, although it is a reasonably complex undertaking. Interviewing allows the examination of human activities and explorations of them (Von Cranoch and Harré 1982), as individuals are treated as heroes of their own dramas (Brenner *et al.* 1985). In essence, although the handling of verbal data response is difficult, interviews provide a firm basis for understanding human experience.

The interview as a research tool is very flexible as it can deal with a variety of subject matter at different levels of detail and / or complexity depending on the methods implemented for the data analysis.

An interview is described as any form of interaction in which two or more people are brought into direct contact for at least one party to learn something from the other. For the interview to be used successfully as a means of data collection in a research context its particular qualities must be identified and its weaknesses obviated so that they can be minimised. These issues are highlighted in table 2.2 (adapted from Brenner *et al.* 1985).

Strengths	Weaknesses
Interviews allow both parties to explore the meaning of the questions and answers involved. In this way the responses can be negotiated.	The interviewer must train in order to achieve adequate results. This means the investment of time into the design of i) a suitable questioning structure; ii) an effective interviewing technique; and iii) a data collection programme (as they apply to the interview).
Any misunderstandings on the part of the interviewer or interviewee can be checked immediately in a way that is not possible with questionnaires or tests.	Owing to the fact that there is face-to-face contact between interviewer and respondent, there is opportunity for bias to occur (Hyman 1954).
Interviews facilitate rapid (immediate) response. This gives directness to this method of information gathering.	Verbal data, by virtue of its quality and varying degrees of structure, are particularly susceptible to error in interpretation.

Table 2.2 The strengths and weaknesses of interviewing

Adherence to three key issues ensured that effective interviewing was applied:

- The author undertook sufficient training in interview technique. To this end, the author, as the sole interviewer, utilised the interview training rules prescribed in Brenner *et al.* (1985) and an accompanying text (Brenner 1982). These were employed effectively in the context of the organisation and staff that constituted the research setting.
- The questions were relevant. That is they enabled the gathering of the relevant data from the respondents in a structured manner which related directly to the research focus.
- A high level of co-operation was obtained from all respondents during the interview sessions. As has been described in the previous section, this owed much to the fact that the author attended each of the design team meetings as a direct observer and, as a result, was seen as a standard component of the project environment i.e. the author's presence was seen as non-threatening.

These factors, as described in the social context of the interview, have been conceptualised visually in figure 2.1. This model, which has been adapted from Gorden (1980), depicts the interviewer, the respondent, and the questions asked, all being inextricably linked by communication (shown as C in the centre of the diagram).

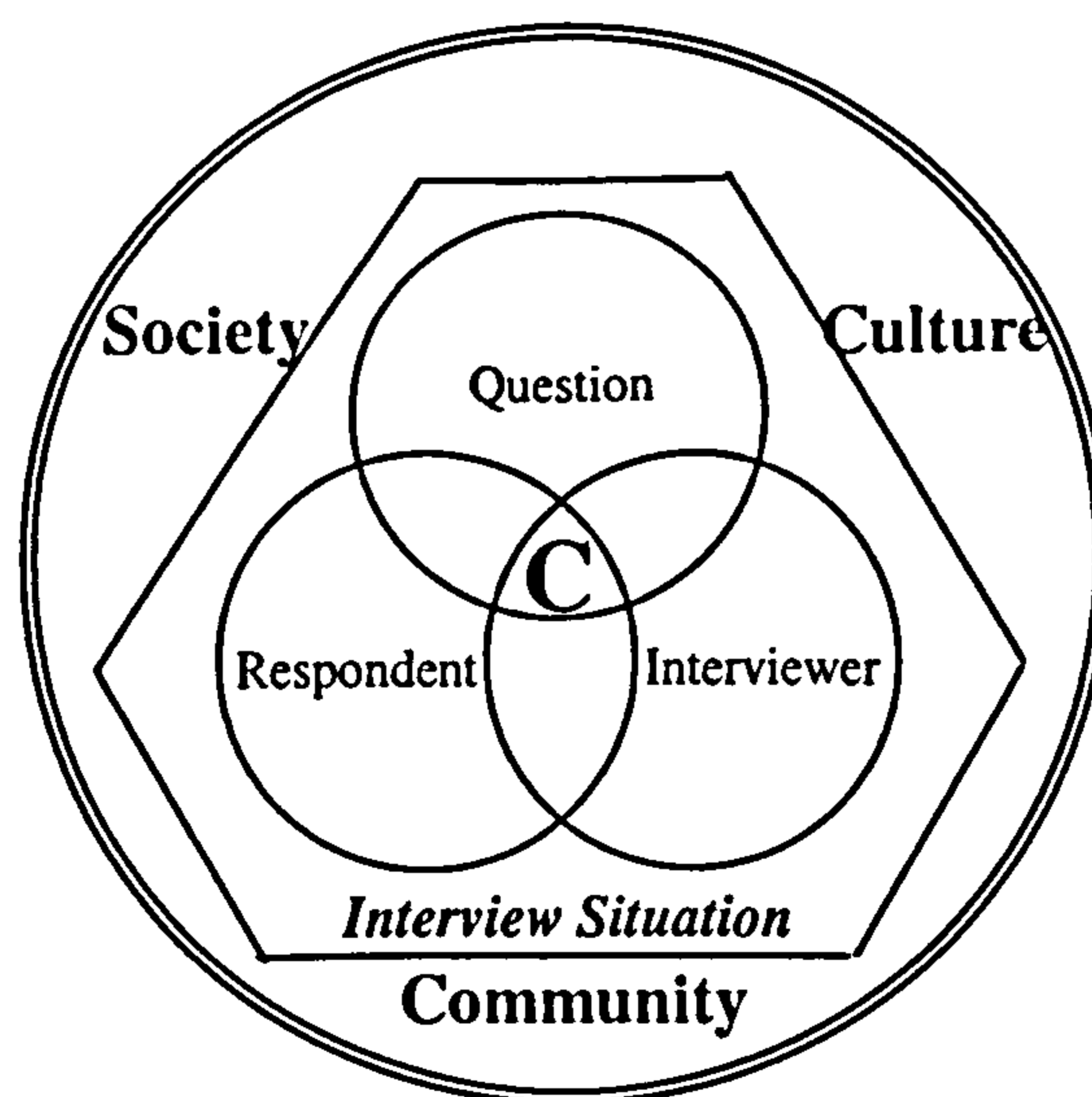


Figure 2.1 The triadic context of the interview environment

It is important to realise that this relationship is generated and manipulated prior to the start of the interview proper. As such, it can be seen that the planning of the

interview (as outlined above) becomes of even greater importance to the success of the technique as a qualitative data gathering methodology.

Each member of the design team was interviewed individually with respect to the processes followed, techniques implemented, and social interaction undertaken, during the course of the conceptual phase of the project. Although this multiple-interviewee approach can lead to contradictions in perceived occurrences, it was undoubtedly the optimum means of gaining an overall understanding of the project from an internal perspective.

When studying the role of situations in human behaviour, the gathering of several individual interpretations of events is highly important, as these can vary dramatically between players (Argyle, Furnham, Graham 1981). In this respect, the qualitative research interview cannot be objectively classified as either an objective or subjective method in the fact that objectivity can be incorporated on the part of the interviewer in structuring questions, but subjectivity must be expected, if not encouraged, from the respondent. Thus, the interview is neither an objective nor subjective tool, but must instead be characterised as intersubjective interaction (Kvale 1996). That is to say that a large number of interviewees reporting the same phenomenon in different ways does not mean that the data provided is incorrect or invalid, just as a large number of interviewees reporting the same phenomenon in the same way makes the observation correct and valid. As such, there will always be a certain degree of intersubjectiveness in any social survey.

The data gathered during the interview sessions, when combined with the direct observations made during live design activity, and further details gathered during this phase of the research allowed the author to develop a detailed understanding of the interdisciplinary conceptual design activity of teams. The information gathered allowed a number of hypotheses to be investigated and developed and also provided enough information to allow a number of structured analysis and design techniques to be applied and tested as suitable means of modelling conceptual design activity.

2.5 Modelling: simplified representations of reality

2.5.1 Introduction to modelling

For anything more than a superficial overview of the conceptual design phase to be gained, the complexities of the design activity had to be simplified to some considerable extent. As such, the generation of a model, which is, by definition, a simplified representation of a system or complex entity (*Oxford English Dictionary*), provides the ideal mechanism by which to achieve this.

Over the last 20 years several modelling techniques have been developed for use in either the structured analysis or structured design of complex systems. These are generally based on either charting or diagramming with the support of simple narratives and have been applied predominantly in the data processing industry. The basis of all of these techniques is that they provide a means of decomposing relatively complex systems into easily understood related elements that can then be represented in the form of diagrams and text. It has been stated that modelling the information flows within a particular system or process will lead to a greater understanding of that process (Austin *et al.*, 1993a).

2.5.2 Choosing the appropriate techniques

As has been stated above, there are many existing modelling techniques that can be applied to develop descriptions of design processes. The decision regarding which of the modelling techniques was most applicable to the conceptual design process involved several inquiries. These investigations involved: i) evaluating the existing modelling techniques available; ii) taking the most promising of these techniques and applying them, thus allowing models of conceptual design activity to be constructed; and iii) making a decision regarding the optimum means of delivery of the design model. The details of these investigations, along with a number of examples of models developed using the most applicable modelling techniques, are detailed in chapter 4.

2.6 Historic case study investigation with archive analysis

2.6.1 Introduction

An historic case study approach was utilised, in conjunction with some archival analysis where appropriate, as a means of developing the case study findings.

Several designers and design team leaders from a number of design and construction organisations were interviewed about the processes that were followed during the conceptual phase of previous projects in which they had been involved. This methodology is a recognised research strategy and allowed a wider view of the conceptual design process to be investigated, thus improving the qualitative nature of the observation period.

The historic case study phase of the research served two main purposes. First, to reinforce the findings of the literature search by gathering the views of a number of practising design professionals on various aspects of design practice. And second, to gather further information on how conceptual design activity is actually undertaken by interdisciplinary design teams on live projects, in order to allow a preliminary phase and activity model to be generated for testing in laboratory experiments. This phase of the research was aimed at gathering detailed information on the current practice of interdisciplinary building design teams.

Although this is a recognised method for gathering qualitative data in field research it does have several recognised flaws. One of these is that a history strategy generally deals with the entangled situation between phenomenon and context in non-contemporary events (Yin 1984). To be more specific, it is not a real time analysis technique and as such, results can be biased owing to the fact that descriptions tend to become over simplified, representing the interviewee's subjective perception of the proceedings. However, as the purpose of this phase of the project was to allow the author to gain a general understanding of conceptual design activity in practice in order for any high-level generic elements of the phase to be distinguished, this factor was not seen as being detrimental to the validity of the findings.

Over the course of this period of the research a total of 9 case studies were undertaken. These concentrated on investigating team design activity during the conceptual design phase of the projects only. These case studies varied in terms of client type, project type, project cost and phase duration and as such, allowed the way in which differing factors influence the processes followed during conceptual design to be investigated. The resulting analysis of this data is provided in chapter 5.

2.6.2 Open ended (semi-structured) interview

A number of designers and Design Team Leaders (DTL) from each of the six participating industrial organisations were interviewed by the author as a means of gathering information on how conceptual design activity is actually undertaken by interdisciplinary design teams on live projects. The reader is referred to section 2.4.5 for a detailed overview of the interview methodology implemented during these sessions. This data gathering exercise concentrated on outlining the way group design activity had been undertaken on previous projects. The technique of semi-structured interviewing was utilised for this observational exercise, based on details extracted from the literature survey regarding group design activity. This was reinforced with some detailed questioning to extract further information regarding particularly fuzzy areas of the described design activity. The interviews were recorded in note form however, to ensure that details were not lost during the course of the interview, the note-taking was backed-up with audio-taping.

2.6.3 Archive analysis

A history strategy also allows the investigation of documents (primary and secondary), cultural artefacts and physical artefacts as a major source of evidence. Thus, to support the details provided by each of the DTLs, additional material was collected in the form of documentation, meeting minutes and design reports. This material, when coupled with the data gathered during the interview sessions, assisted the author in developing several high level descriptive models of design activity.

2.7 Laboratory Studies – Experimental workshops

2.7.1 Introduction

The fundamental difference between experimental research and case study research lies in the fact that an experimental strategy allows the investigator to have some degree of control over the behavioural events involved. In other words, he can reduce the number of variables that may come into play, and as such, manipulate the environment to some extent, allowing him to focus more finitely on a particular area of interest. Conversely (as has been described previously), to undertake case study research the investigator does not require any control what so ever over behavioural events, as long as the participants are involved in activities directly pertaining to the research topic. In actuality, the investigators main aim is to observe phenomena as they occur in a real-life context. Yin (1984) reinforces this opinion in stating that ‘an experiment deliberately divorces a phenomenon from its context, with the context being typically controlled by the laboratory environment, so that attention can be focused on a few variables’. However, although this attempts to broadly define the nature of an experiment, it says little about what experimental design involves. As such, the author prefers to refer to experimental design as a plan, structure and strategy of investigation that allows the researcher to obtain answers to research questions while controlling variance (Lindquist 1956, Broota 1989).

2.7.2 Variance and variables in simple experimental design

The simplest type of experiment occurs when a single factor (variable) is controlled or manipulated by the investigator, leaving all other factors constant. In this case the manipulated factor is described as the independent variable and the effects of the manipulation on another variable (the dependent variable) are observed. By applying different levels (amounts) of the independent variable to different groups while all other factors remain constant, any differences observed in the dependent variable will, in all probability, be a result of the difference in the independent variable. This procedure allows the investigator to build knowledge about cause-and-effect relationships (functional relationships) in behaviour.

Johnson and Solso (1978) refer to this entire process as a ‘theory of control’, as attempts are made to control variables either by manipulation or by holding them

constant. Thus, it is understood that once this control is achieved or obtained, the determinants of behaviour can be discovered relatively easily. Additionally, the key to good experimental design requires that the only variable manipulated be the independent variable and that all other conditions be held constant for the various treatment groups (Johnson and Solso). However, the investigating body cannot account for all variables; the additional variables are defined as extraneous variables.

2.7.3 Extraneous variables

In addition to dependent and independent variables, which are the main ingredients of concern to the investigator, extraneous variables, which can influence the dependent variable in a number of ways, will almost always be encountered. These extraneous variables can mask the effect of the experimental variable and if left uncontrolled they will undoubtedly lead to experimental error or error variance (Broota 1989). According to Broota, two main sources of experimental error can be experienced:

- a) Inherent variability in the experimental units to which treatments are applied.
- b) Lack of uniformity in the experiment, i.e. lack of a standardised experimental technique (this also refers to error of measurement).

The existence of these extraneous variables, in addition to the other types of variable mentioned, highlight the main problem associated with researching the social sciences and the interdisciplinary design environment *per se*; the fact that so many variables are involved. As has been described above, the mixture of all these variables makes it very difficult to manipulate a particular experiment in a way that will provide any meaningful data. If two design teams are created and asked to solve the same design problem, then many varying elements come into play. One team may have very compatible members, one team may have more of a creative nature, and so on. All of these are extraneous variables that could change the outcome of the design solution, and will ultimately effect the success of the design team and the experimental findings.

The answer to this may be to use only one team but ask them to undertake one design problem using a structured prescribed procedure, and another without structuring their approach. However, as soon as the team has undertaken the first exercise the

nature of the team itself has changed and a new set of variables/constraints have been introduced. The team has worked together before and as such the members may have pre-conceptions about how one another works, they may begin to take on roles within the group, and they may adapt slightly to become a better (or worse) working unit. Thus, the original constraints and variables have changed and real comparisons cannot be made validly between the two exercises.

As such, the author could only control these elements by: first, ensuring that each of the extraneous factors was recognised and accounted for; and second, that the obviation of any of these factors was noted during passive direct observation thus allowing conclusions to be drawn regarding their effects on the experiment. It is believed that these factors, when combined with the standardised experimental procedures utilised, enabled meaningful data to be gathered around which valid findings were made.

To this end, the second phase of the research project employed an experimental approach to data gathering which involved a number of professional designers participating in specifically created 'Designing Together' workshops.

2.7.4 Designing together workshops

Two individual experimental workshops were held during the course of the research investigation. These, which are discussed in chapter 6, enabled real-time design activity of interdisciplinary teams to be monitored and a number of germane conclusions to be drawn. The first session, which involved designers from a single multi-disciplinary design and construction organisation allowed monitoring and direct observation of design activity to be undertaken and the usefulness of certain types of design techniques to be assessed. This data, when combined with the material from the case study investigations, lead to the development of a preliminary conceptual design framework and the refinement of a number of techniques for subsequent testing. The second session, which involved designers from a number of design and construction organisations, allowed a cause-and-effect experiment to be undertaken to provide hard evidence concerning the applicability of the design framework in practice and its effect on team performance and effectiveness.

In this second experiment the introduction of the conceptual design framework was classified as a treatment, that being the independent or manipulated variable within the experiment, whereas the team's progression and perceived performance were the dependent variables. Two teams were designated as test groups and, although both groups were provided with a copy of the preliminary conceptual design framework and tutored on its terminology and structure, each was given the treatment in a different form. One group was given the option to use the framework while a second group was asked to follow the framework. A third group, the control group, did not receive the treatment in any form, i.e. they were not provided with any formal framework. Instead, they were merely introduced to the project brief and asked to 'produce a design proposal'. To this end the control group provided a base line from which to determine the effects of the treatment on: i) each team's progression through the design project; and ii) each team's perceived performance.

A detailed account of this component of the research is provided in chapter 6.

2.7.5 Generality of findings in experimental research

One point that must be raised with regard to experimental research is; to what degree can the experimental results and conclusions be generalised?

This question of generalisation of results cannot be considered a criticism of the experiment as it enters into all areas of research at some time. What it does highlight is the fact that experimental investigations do have certain limitations. As will be seen in chapter 6, the author strove for control over the variables throughout the experimental phases in order to authenticate the validity of the findings. This control was achieved by maintaining a standardised approach to the experimental design by limiting the experiment to: i) a specific behaviour (Designing for the conceptual phase of a building project); ii) a specific time period and environment (two day workshop); iii) a specific sample of subjects (practising design professionals; and iv) specific techniques of measurement (observation and questionnaire).

While these techniques are recognised, and are essential to insuring the validity of the results achieved, they also raise questions over the generality of those results. This is why the experimental sessions must be recognised as being only a single component

of the overall research design. As such, these experiments represent building blocks from which the subsequent investigations, using an action research methodology, could be developed.

2.8 System development using action research

2.8.1 Introduction

Research involves the systematic and rigorous inquiry or investigation of phenomenon to improve understanding of the nature of problematic events (Stringer 1996). However, research can also include actions that attempt to resolve the problem being investigated. This type of investigation is known as action research.

Greenwood and Levin (1998) define action research as ‘social research carried out by a team encompassing a professional action researcher and members of an organisation or community seeking to improve their situation’. In essence, action research promotes stakeholder participation in the process of researching while supporting progression to a more satisfying situation for those stakeholders involved. This involves both the researcher and the stakeholders continually acting and then reflecting on that action, in order to maintain a change process by tracking what has been learned. This activity has been described as ‘reflection in action’ and ‘on action’ by Schön (1983) (the details of which are explored further in chapter 3), and according to Greenwood and Levin it is a ‘core feature of the praxis of action research’.

The evolution of the Web-based support system was driven by collaborative action research methodology to ensure that the needs and wishes of the end users were reflected in the final product.

2.8.2 The purposes and form of Action Research

The process involved in undertaking a research project using this type of methodology serves several purposes simultaneously: i) it develops the stakeholders knowledge and willingness to implement any change arising from the research; ii) it improves general practice within the organisation; and iii) it allows the development

and modification of research ideas via the direct input of the end users (Oja and Smulyan 1989).

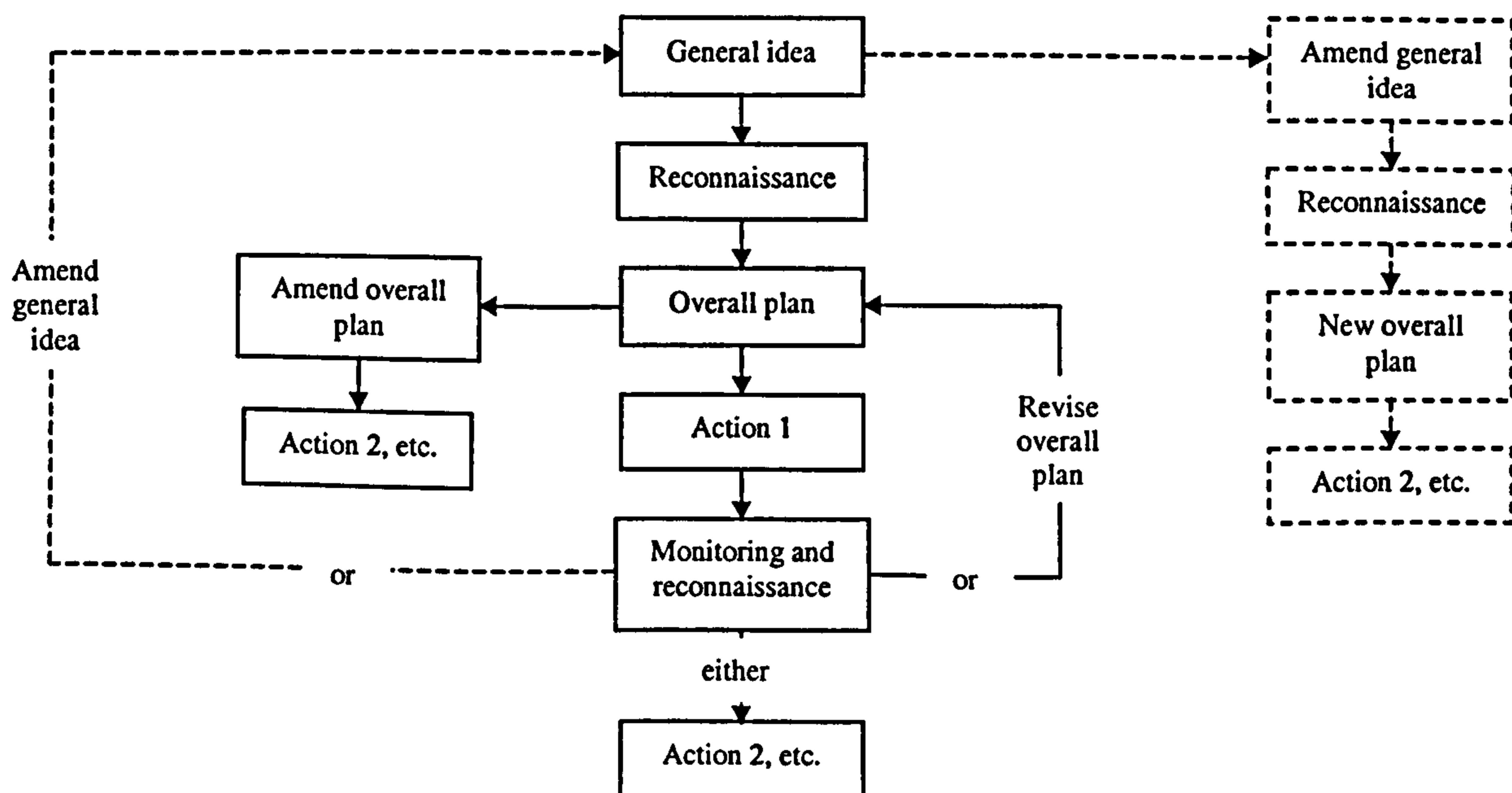


Figure 2.2 Cycles of action research (Ebbutt 1985)

Action research can take a variety of forms; the final form being dependent on factors such as the project emphasis and goals, the entire process used in carrying out the research and the degree of collaboration between the investigator and the organisation / practitioners (Oja and Smulyan). However, a generalised form of an action research process has been outlined by Ebbutt (1985) - shown in figure 2.2.

This model defines a cyclic 'idea - reconnaissance – action' process of progression through a number of stages of development. It is apparent that the process consists of two distinct phases: i) the clarification of ideas in the form of specific research questions; and ii) the continuation of change and understanding in the form of action. Thus, it can be seen that it is essential that the initial questions are continually reshaped to include newly discovered dimensions. However, what is conspicuous by its absence in this model is the critical relationship between the stakeholders and the researcher.

As such, it is important to put this model in the context of the organisation, or stakeholder group, with whom the research is being undertaken.

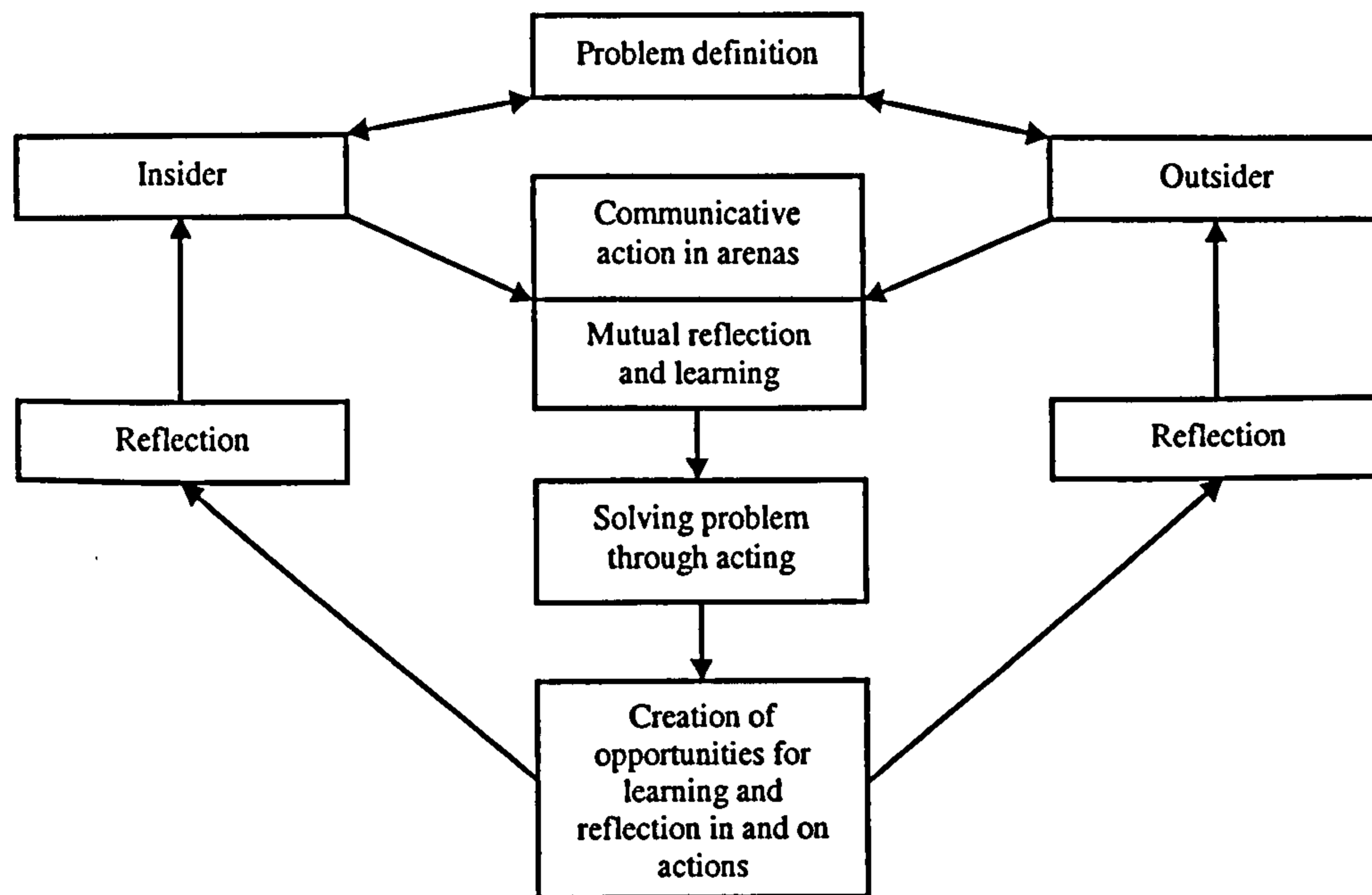


Figure 2.3 The cogenerative action research model

This interaction, which is a vital ingredient of the action research methodology, is better defined by the cogenerative action research model proposed by Greenwood and Levin (1998) - shown in figure 2.3. A combination of these two models acted as the basis of the development of the Web-based system. Details of this component of the research are described in chapter 8.

2.9 Conclusions

Flaws in design methodology can lead to the reaching of ambiguous and unsupported conclusions. It is only by developing a research strategy comprising robust and well grounded methods that the making of dogmatic statements can be avoided. This chapter has provided details of the methodology applied during this investigation. It is believed that the time and effort involved in compiling this research strategy has paid dividends in ensuring that the details outlined in the remainder of this thesis are both valid and verifiable under the scrutiny of examination.

Chapter Three

Literature review

3 Literature Review

3.1 Design and design process

3.1.1 Introduction

There have been a vast number of approaches taken to studying the field of design research and as a result, there is no lack of literature on the subject. For the enthusiastic researcher this is a fantastic discovery. However, the fact that there are so many differing fields of interest, which are all classified under the umbrella of design, makes the undertaking of a comprehensive literature survey of the subject an extremely daunting task. As might be expected, this wide field of interest has generated an even wider spectrum of views on the subject, which has resulted in many of the writings on design seeming almost contradictory at times.

Detailed literature searches, comprising numerous texts and academic papers, from many experts in the field have provided a plethora of differing opinions on many varying aspects of design research. Couple this with the fact that the subject of this thesis, the conceptual design phase of building projects, represents the amalgamation of several differing design approaches, and it becomes apparent that presenting a structured review of the area becomes an even greater challenge.

However, the following chapter attempts to provide the reader with an overview of the design process in its entirety. Its aims are five-fold: i) to categorise and describe the types of design model available; ii) to provide an overview of the many design models that have been produced to date; iii) to identify the discrete phase of conceptual design in relation to several of the more commonly referenced process maps; iv) to outline the effects of social dynamics during early stage design; and v) to provide a general description of the type of design method available for use by the designer.

3.1.2 A brief history of design

The activity of designing has been apparent in one form or another from the time Neanderthal man fashioned his first shelter. However, it was not until the rising of the Romans that Vitruvius (Vitruvius-translation Morgan 1914), architect to the Empire, recorded the earliest known writings on the subject of design. His 'Ten Books of

Architecture' were generated in a bid to have the art of architecture raised to the same level of status as music, painting and sculpture. This treatise represented the first distinction between design and construction.

There was little written about the 'art of designing' until the industrial revolution took place. History has shown that the majority of artefacts produced prior to the resulting mechanisation of manufacturing processes were not designed in the way that the term is now commonly understood. The artefacts evolved through a process of trial and error, a system that meant only through failure could a design be improved. Sturt (1923) reported in some detail how, over a number of generations, and a far greater number of failures, the wheelwright trade developed an in-depth knowledge of the proportion and shape of the farm wagon and its plethora of components.

In the majority of cases the craftsman who reproduced and modified the design of the artefact, be it a wagon or a cathedral, did not understand the reasons behind the modifications. All he knew was how to do them. This incapacity to understand why a particular artefact was built in a certain way lead directly to lack of progression of design until actual failure occurred. This owes much to the fact that failure was the only mechanism by which areas of weakness in the existing design could be highlighted and subsequently modified. However, it must be stated that the high level of component interaction, spatial relationship, and the usability of the artefacts produced by the craftsmen lays testimony to the usefulness of the evolutionary design approach, without which the world would have not reached the level of design understanding that it knows today. However, the size and complexity of the artefacts produced purely through the combined experience and expertise of the craftsman was very limited. Thus, it is apparent that, as projects became increasingly complex and the number of components and their interfaces grew, there was a need for robust methods to aid design.

Models of the engineering design process began developing in the early nineteen-sixties owing to the recognition, by many individuals in the design community, that there was no way of exercising control over the actual processes of designing. Jones (1992) explains how three British conferences on design methods, at London (1962), Birmingham (1965), and Portsmouth (1967) enabled the 'pioneers to become aware of

each others existence', and 'brought the subject to the notice of designers, design teachers and design students alike'.

As Evans, Powell and Talbot (1982) explain, 'For the first time 18 participants from such divergent disciplines as architecture, building, cybernetics, engineering, industrial design, graphics, painting, planning and psychology sat around a table to discuss their first-hand attempts to observe and analyse the design process'. Their discussions lead to a realisation that, as the complexity of real design problems increased, it became more and more difficult for the designer to generate optimum solutions. They attributed this factor to the mind's inability to handle information at such a complex level. As such, the participants arrived at the conclusion that the design process had to be structured in such a manner that the interaction of the many elements involved in design problems could be made easier to handle. Respected writers of the time such as Alexander (1963), Archer (1963) and Jones (1964) adhered to the belief that the application of scientific method was the key to solving problems of ever-increasing complexity. From that embryonic period on, many models of the design process, taking many forms, have been generated in an attempt to represent the process of design explicitly.

3.2 Existing models of design

3.2.1 Introduction

Design process models can merely provide a template for design and are inevitably idealised representations of the activities or steps involved in designing a product or artefact. Design in practice can be a disordered, perhaps even chaotic, process from which a product (a design) emerges and is notoriously difficult to observe (Taylor 1993). There can be no doubting the difficulty of endeavouring to extract the essence of what design involves, as is apparent in the fact that no single universally acceptable model has, as yet, been generated to describe the activity. Even so, many writers from a variety of fields have attempted to produce design process models with varying degrees of success. However, each model produced is equally valid in the respect that it works for that particular individual. The one clear purpose of all the models is to dissect the multifarious activity of design in order to improve understanding. The following sections outline several of these existing design models.

3.2.2 The decision-making process in design

In general, any attempt at producing a model of the design process has resulted in the production of a very linear sequence of activities. As has been previously explained, this is an explicit attempt at making the process of designing more scientific and rational in nature, thus transforming the almost mystical phenomenon of designing into a simple and easily understandable activity. This paradigm has resulted in the production of several very simple process models, which are described in further detail later in this chapter (section 3.6.6), such as:

- 1) Analysis, synthesis, evaluation. (Markus 1969)
- 2) Generator, conjecture, analysis. (Darke 1972)
- 3) Divergence, transformation, convergence. (Jones 1992)

And so the list goes on. But all of these may be better described as models of the decision-making processes that are undertaken throughout the activity of designing. Hickling (1982) has generalised around this theory and produced a basic process framework: observation, shaping, generation, comparison, and choice. Hickling has used this generic framework as a means of classifying processes from a wide domain (figure 3.1).

	Observation	Shaping	Generation	Comparison	Choice
Management	Information	Analysis	Alternatives	Evaluation	Decision
Science	Observation	← Interpretation →		← Theory →	
Medicine	Examination	Diagnosis	← Prognosis →		Treatment
Planning	Survey	← Analysis →			Plan
Design	Brief	Analysis	Synthesis	← Evaluation →	

Figure 3.1 Comparison of process across the domains

Hickling used this framework as a datum from which to move away from this linear type of process toward a model representing the continuous whirling process of decision-making in design (shown in figure 3.2). As can be seen, the description of

the design process in Hickling's framework was adapted from an early Markus and Mauer model (1970). This process was used as the basis for the RIBA 'Plan of Work' (shown in table 3.1) and is described in greater detail later in this chapter.

Unfortunately, owing to the fact that Hickling could identify no means of testing the connections between the elements of the model, their existence has never been verified. However, it is generally recognised that the main task of the designer lies in decision making, with every decision made during a project being of significant influence in the way in which a design will develop from that point on (Starkey 1992). As such, any model which even asserts the existence of certain connections is of considerable worth to the design community.

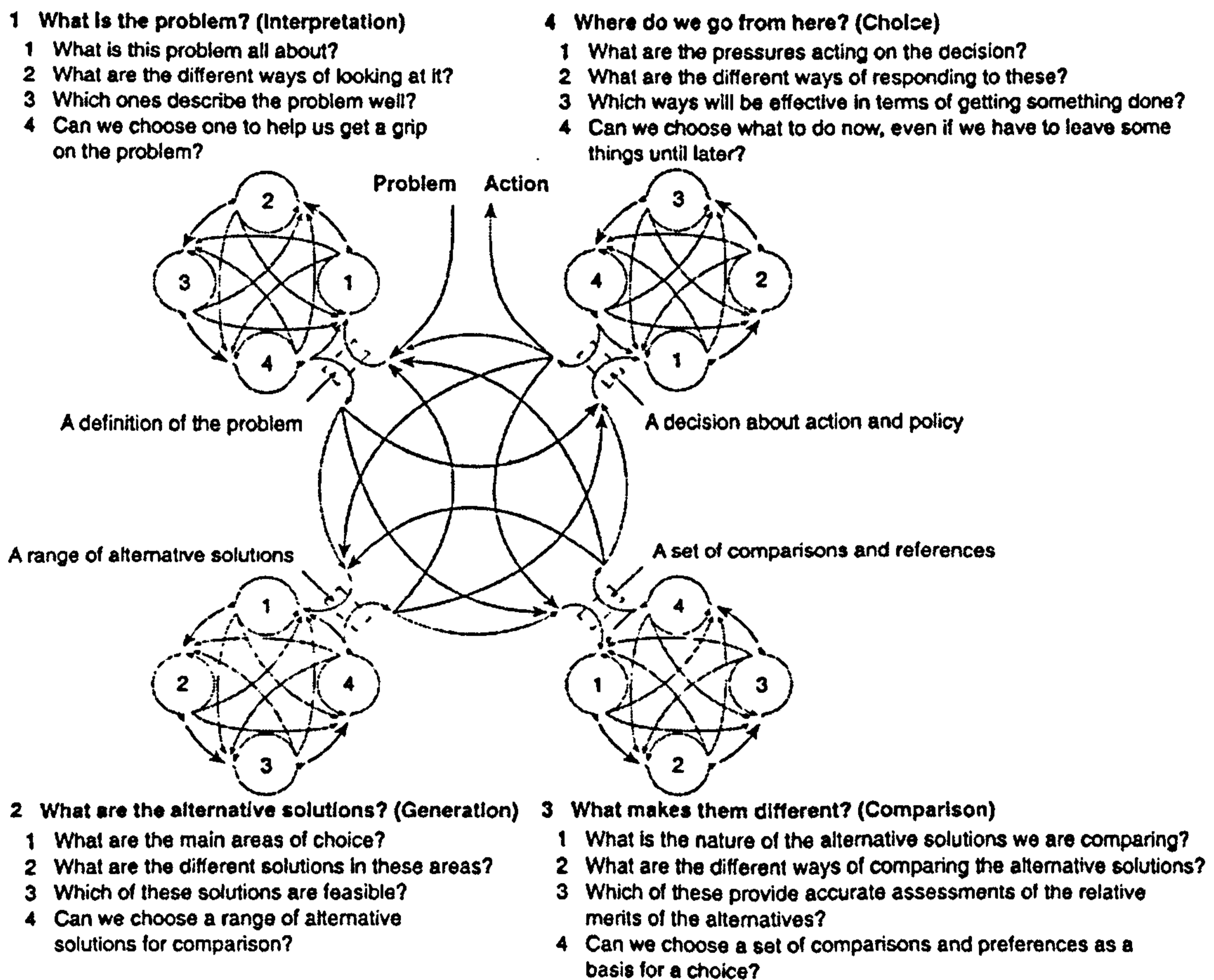


Figure 3.2 Hickling's (1982) '*continuous whirling process*' model of design (from Gray 1994)

3.2.3 Architectural design models

The Royal Institute of British Architects (RIBA) saw a need to set out a Plan of Work attempting to provide a model procedure for the design profession. As a result, the

RIBA Plan of Work (1964) was introduced, which is fundamentally an activity model of the building design process. It outlines twelve discrete stages describing the design procedure. These stages are categorised further into four individual phases (table 3.1).

<ul style="list-style-type: none"> A. Inception B. Feasibility C. Outline proposals D. Scheme design E. Detail design F. Production information G. Bills of quantities H. Tender action J. Project planning K. Operations on site L. Completion M. Feed-back 	<ul style="list-style-type: none"> 1. Briefing ↓ 2. Sketch plans ↓ 3. Working drawings ↓ 4. Site operations ↓
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Table 3.1 Stages of the RIBA Plan of Work

Lawson (1980) claimed that the development of the Plan of Work was purely a propaganda exercise on the part of the architectural profession, suggesting that it said more about the role of the Royal Institute of British Architects than it did about the nature of the architectural design process itself. It could be argued that, as the model is aimed at the architect primarily, it is slightly lacking in its representation of the design process in its entirety; though the Plan of Works does state that it represents purely an outline method of working. Unfortunately, from the outline of the process stages provided, it is all too apparent that it merely provides a description of the products of the design process rather than a model of the design process itself. However, the RIBA Plan of Work, which has recently been updated (RIBA 1999), is still the most commonly referenced document in the building industry, with its structured stages being cited by the few models of the construction process that are available today.

Markus and subsequently Maver elaborated on the original plan of work in the late 1960s and early 1970s respectively to develop the model of design shown in figure 3.3 below.

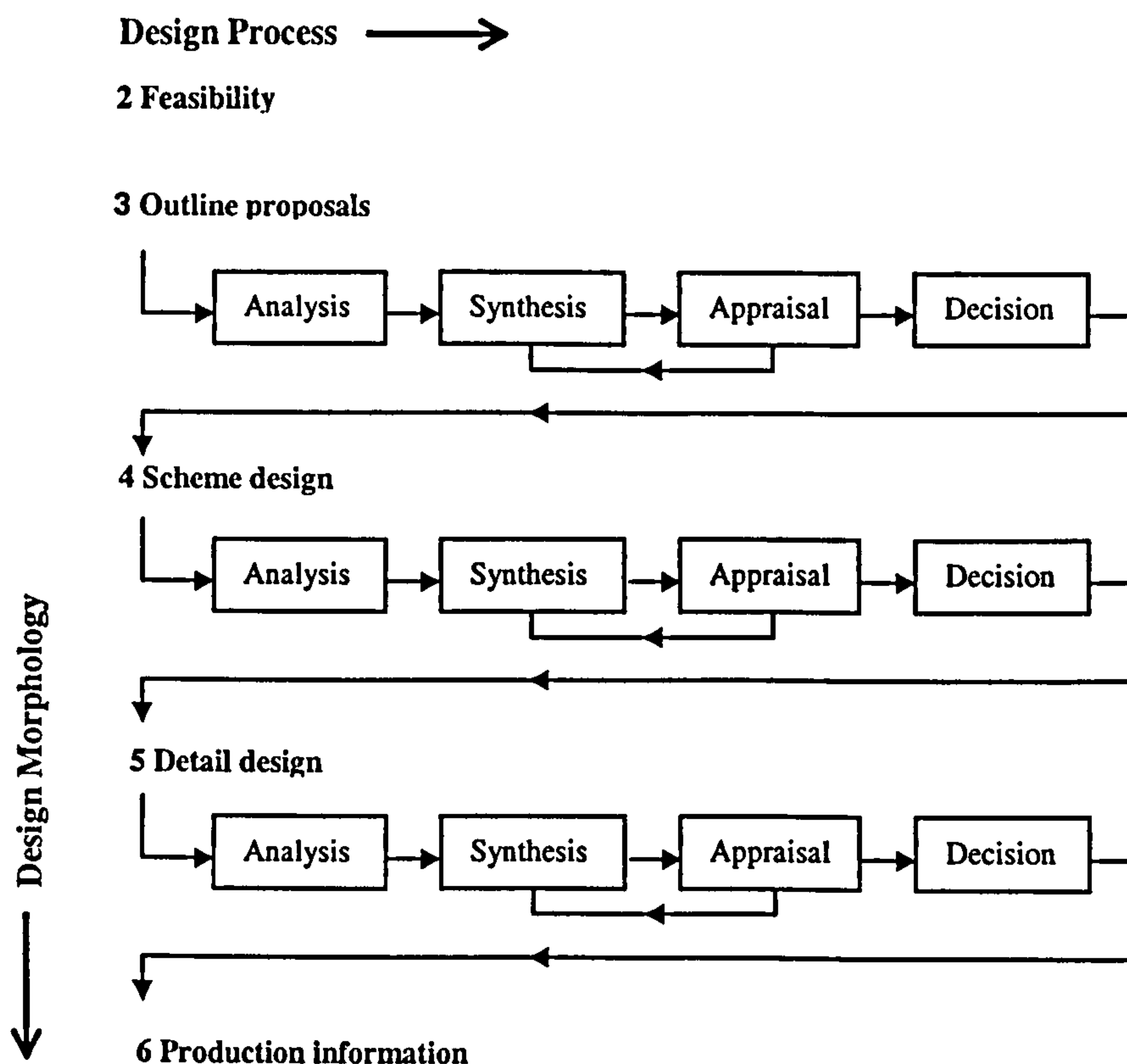


Figure 3.3 The architectural design process (Marcus and Mauer 1970)

3.2.4 The architects approach to design

Lawson (1980) discovered, through extensive testing, that architects tend to have a solution focused approach to problem-solving. Architects generally do not attempt to discover rules governing a problem, rather they adopt a solution focused strategy and are obsessed with achieving the desired result. In this respect the architect will acquire knowledge about the nature of the problem only as a result of attempting to generate possible, or what may prove to be impossible, solutions.

A principal characteristic of the architect's approach to design is the use of a few basic objectives to reach an initial concept (Darke 1979). Darke elaborates further in suggesting that the architect initially makes a conjecture or conceptualisation regarding possible solutions. The fact that this conceptualisation may be based on any one of a number of factors is irrelevant, as long as it promotes the generation of a concept or objective which could lead to a design solution. Darke describes this concept or objective as the 'primary generator'. It is a fact that designers must, and

do, pre-structure their problems in order to solve them (Hillier *et al.* 1972). As such, it is inescapable that designers will bring their prior knowledge of solution types with them in the form of pre-conceptions.

If we refer to the architect as an S thinker, that is he who performs problem-solving by using divergent, solution focused thinking, we can relate to the model constructed by Frost (1992) shown in figure 3.4. Frost explains how S thinkers 'tend to index stored knowledge in a goal-oriented way, which is honourably predatory and which transcends topic areas'. This is suited to the creative activity of recognising opportunities while attempting to generate innovative solutions to poorly defined problems.

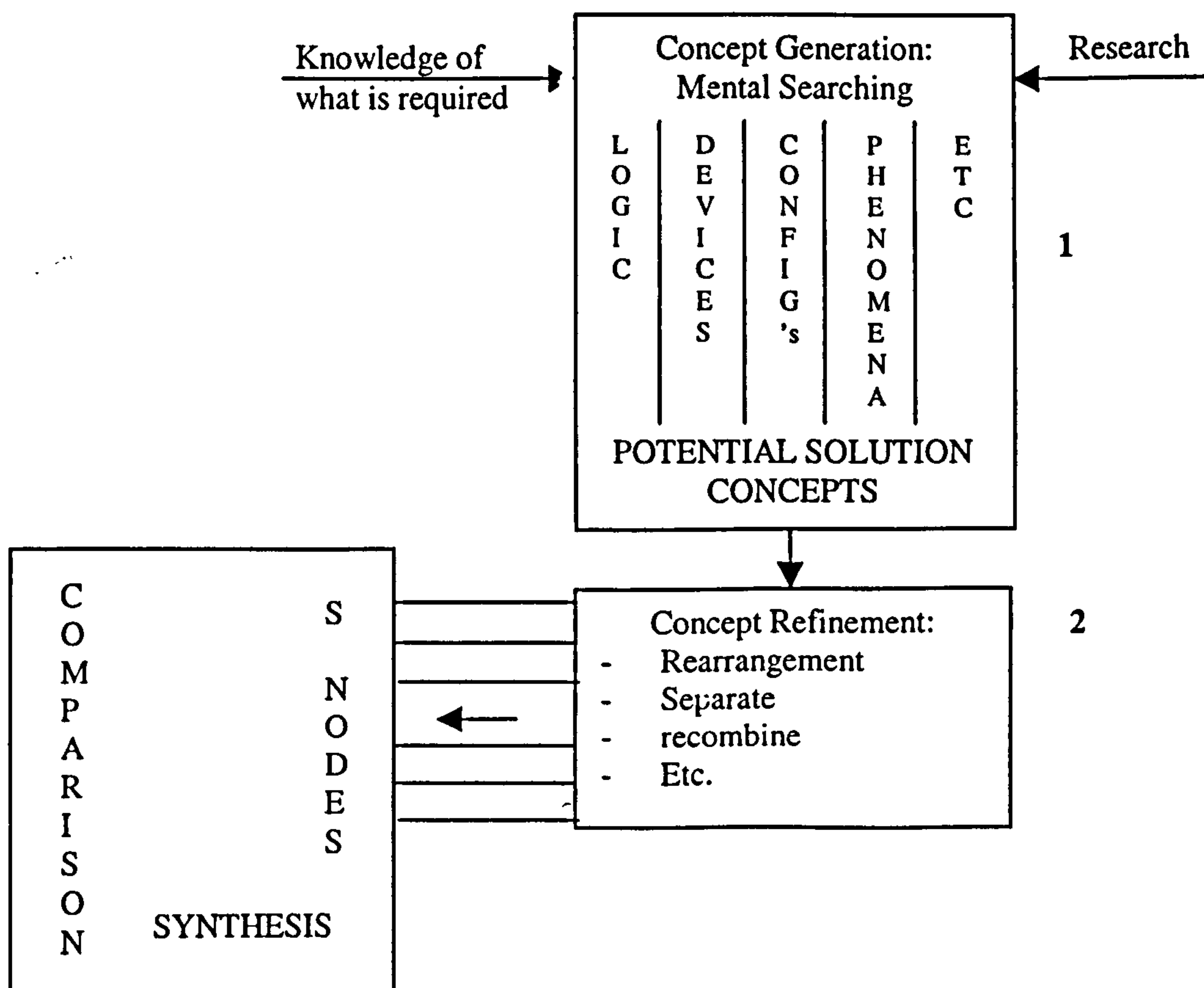


Figure 3.4 Solution focused approach to designing (Frost 1992).

3.3 Product and engineering design models

3.3.1 Introduction

This type of model does not attempt to provide a detailed description of the many elements involved in the actual activity of designing. Rather, they invariably take the

form of block diagrams representing the entire design process as a number of individual stages or phases of design.

3.3.2 Engineering models

Figure 3.5 illustrates a well-known model of the engineering product design process proposed by French (1971).

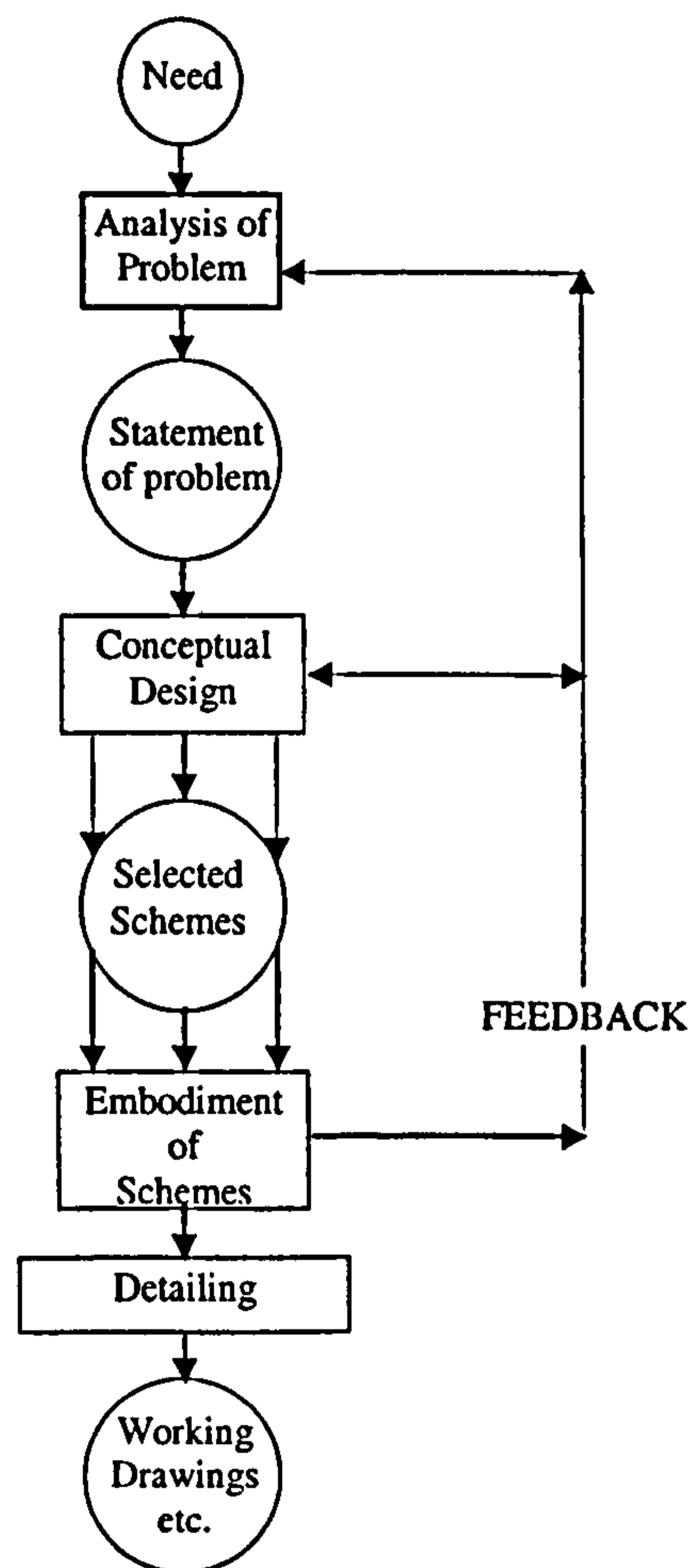


Figure 3.5 French's Engineering Design Process

In this particular model, important factors have been omitted such as, relationships with other activities like research and development, inputs of information, and so on (French 1971), which is generally the case with this prescriptive type of model.

Figure 3.6 depicts the German Verein Deutscher Ingenieure: (VDI) 2221 Guideline (1985) engineering design process model. This guideline suggests a systematic approach in which 'the design process as part of product creation, is subdivided into general working stages, making the design approach transparent, rational and

independent of a specific branch of industry'. The model, which Pugh and Morley (1988) have noted is very much associated with Pahl and Beitz (1988), and is based upon their work, promotes a purely problem focused - P thinking (figure 3.12) - approach.

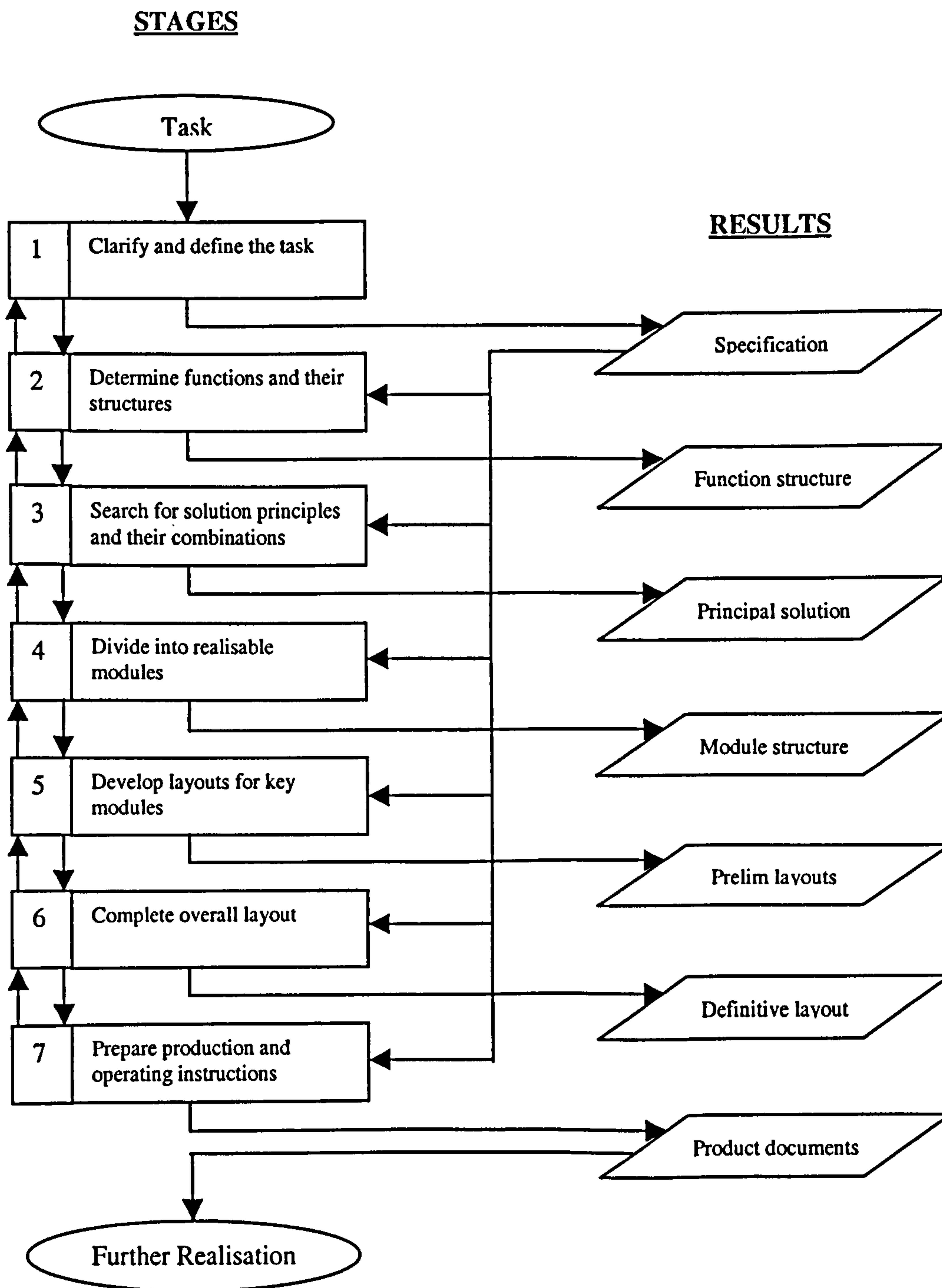


Figure 3.6 (VDI) 2221 (1985) engineering design process model

This model, along with the model generated by Pahl and Beitz (1988) (figure 3.7), fully represents the prescriptive systematic approach to design which personifies the German engineering design strategy.

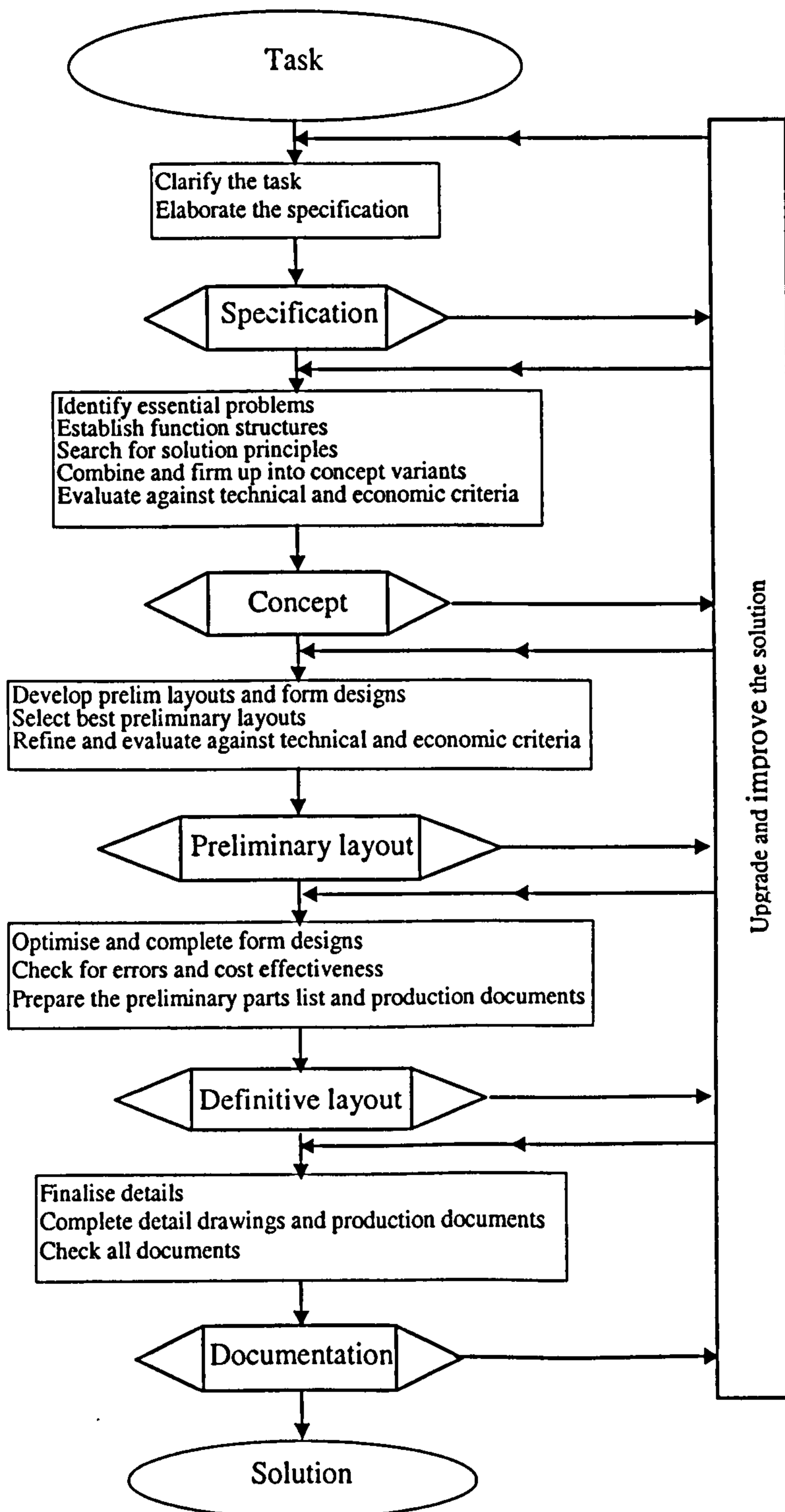


Figure 3.7 The steps of the design process (Pahl & Beitz 1988).

Pugh (1988) himself derived a design process model, which was later adopted by the Sharing Experience in Engineering Design (SEED) organisation, outlining six core phases of the total design activity (figure 3.8). Although originally aimed at product

design, the model is also valuable as a basis for teaching and discussing design, with its approach being generic and as such, easily transferable to other spheres (Taylor 1993). This becomes apparent in the following section.

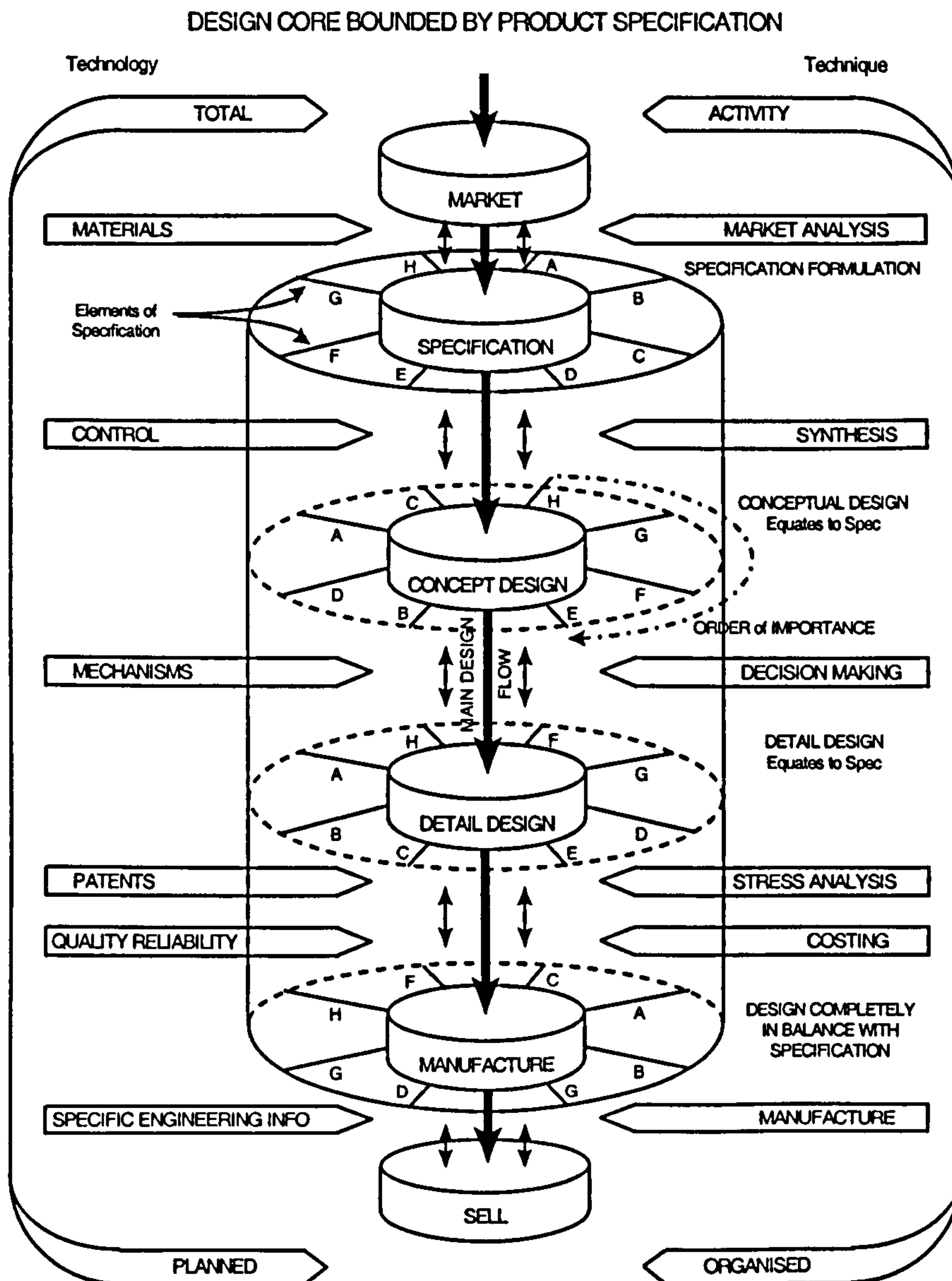


Figure 3.8 The SEED design process model

3.3.3 Descriptive models

This type of model simply describes the activities, or succession of activities, that will occur while in the process of designing based on previous observations. A descriptive model of the decision sequence that a designer follows is shown in figure 3.10.

This model, which was developed by Markus and Maver, merely represents the thought process undertaken by the designer and does not consider the process of

design itself. Markus and Maver both believed that a true depiction of design must relate a decision sequence to a design process i.e. a consensus must be reached.

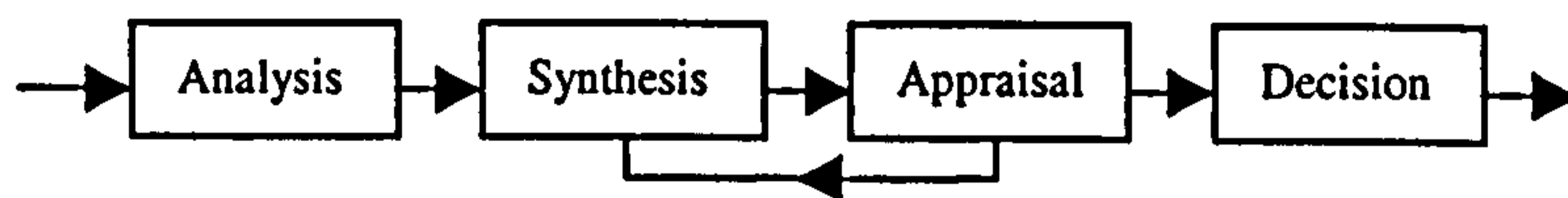


Figure 3.9 The Markus/Maver map of the Decision sequence.

As a result, Markus (1969) and subsequently Maver (1970) went on to develop the process map shown in figure 3.3 in an attempt to combine two of the Royal Institute of British Architects (RIBA) maps of designing.

3.3.4 Prescriptive models

This type of model attempts to prescribe, or suggest, what the creator considers to be an improved approach to the process of design. This type of model usually offers a more algorithmic, systematic procedure to follow... 'A better, more appropriate pattern of activities' (Cross 1989). Morris *et al.* (1998) have stated that, owing to its highly complex nature, the design process requires the fusion of individual's creativity through a number of interactions and exchanges and as such, any prescriptive model has its limitations. However, these models are still useful in providing some insight into the mechanics of the process (Morris *et al.* 1998). Many prescriptive models are hybrids, having both descriptive and prescriptive traits, expressing a prescriptive opinion based on descriptive studies or experiences (Blessing 1994).

Archer (1984) developed a model that actually prescribes the processes to be undertaken by the designer when attempting to solve a particular design problem. This model is shown in figure 3.10. French (1971) (figure 3.5), Cross (1984) (figure 3.14), Hales (1987), Pahl and Beitz (1988) (figure 3.7), and Hubka (1991) have all provided opinion on models of this type. As has been stated previously, the model generated by Pahl and Beitz was actually utilised by the German government and transformed into the engineering design work guideline known as VDI 2221 (figure 3.6).

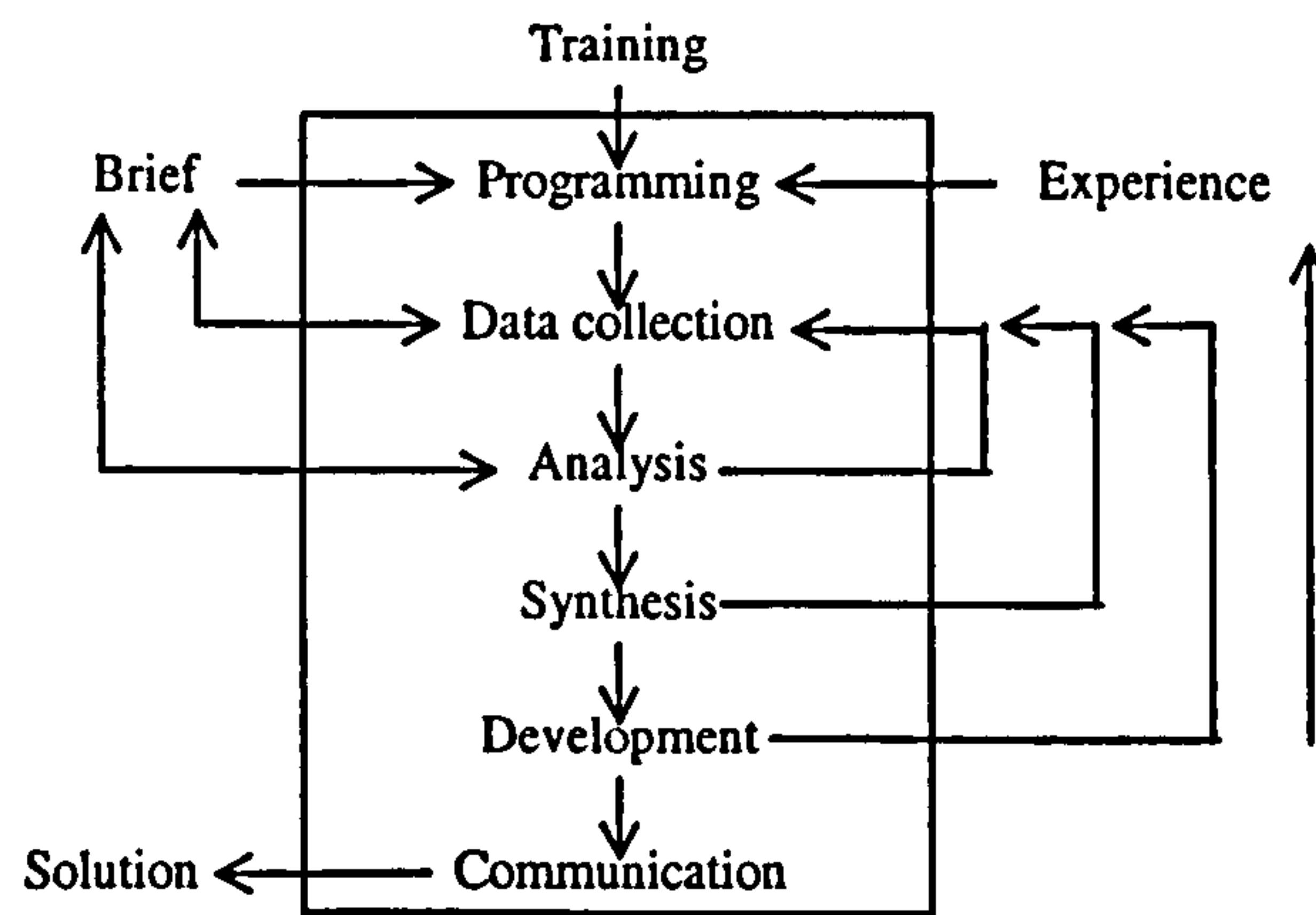


Figure 3.10 Archer's model of the industrial design process (1984)

According to Roozenburg (1991), it is imperative that designers who intend to use this type of design process model ensure that they realise that a prescriptive model only intends to structure, and not to predict, design behaviour.

Problem-oriented versus product-oriented prescriptive models

Blessing (1994) established that almost all of the engineering design models, in both the descriptive and prescriptive literature, divide the activity of design into a number of discrete phases or stages. Blessing discovered that three main stages could be distinguished:

- A problem definition stage resulting in a problem definition and a set of requirements.
- A conceptual design stage resulting in a concept (or solution principle).
- A detail design stage resulting in a full product description.

Upon analysing the numerous stage divisions, it was noted that two distinct types of prescriptive design models were apparent; problem-oriented and product-oriented. The problem-oriented models tend to focus on the analysis of the problem and are characterised by a number of abstraction steps. Whereas product-oriented models put more emphasis on analysing the product idea and as such, focus on the steps of analysis and evaluation (Blessing 1996). The two approaches are compared below (figure 3.11).

This difference relates to, and is consistent with, the P (section 3.2.4) and S (section 3.3.6) thinking approaches to design.

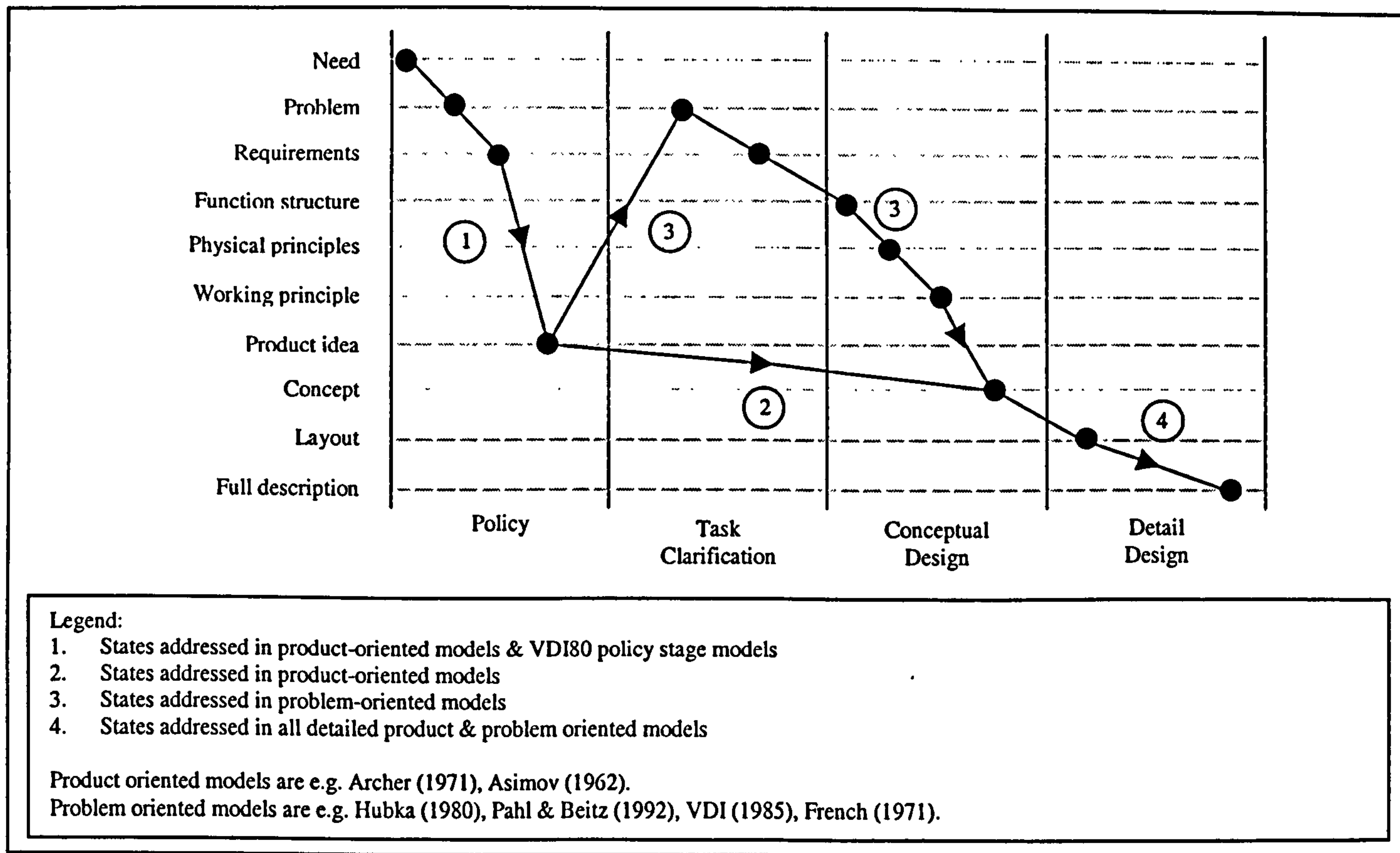


Figure 3.11 Problem states addressed in problem versus product oriented prescriptive models

3.3.5 Prescriptive versus descriptive models

The differences within the descriptive and prescriptive methodologies, when portrayed in the design literature, are fuzzy, and as a result the boundaries are fairly difficult to distinguish (Blessing 1994). However, according to Asimov (1962) prescriptive models generally have ethical content, while descriptive models generally having factual content. In actual fact, as has been stated previously, most models are based on a mixture of these two elements.

3.3.6 The engineers approach to design

Lawson (1980) discovered that, in general, the engineer's approach to solving design problems is far more scientific than that of the architect. Parker (1996) believes that engineers behave in this scientific manner owing to their theoretical training, and suggest that Lawson's (1980) hypothesis, relating to the manner in which different

designers think, holds true within multidisciplinary projects in which architects and engineers work together.

Pahl and Beitz (1988) explain how the engineering designer, referring to the P-thinker, attempting to tackle a particular problem, will have no ready solution, or only an inadequate one. Whether it is seen as a new problem will depend on his designer's experience, knowledge and familiarity with previous designs of this type. The initial clarification of the task using the specification will have provided some insight into the problems involved.

The engineering designer's first step as such, is to analyse the specification in respect to the required function and essential constraints. According to Pahl and Beitz; 'the functional relationships contained in the specification should be formulated explicitly and arranged in order of their importance'. This analysis, coupled to a step-by-step abstraction, will reveal the general aspects and essential features of the task (Pahl and Beitz 1988). In this respect the engineers systematic approach is to take the problem and divide it into sub-problems as a means of further understanding the requirements of possible solutions.

Lawson (1980), who explains that this approach 'sets out specifically to study the problem', further reinforces this view, i.e. a problem-focused strategy is followed. It is interesting to note that in stating; 'it is vital that the designer disregards any fictitious constraints and prejudices, which could lead to presuppositions', the systematic approach advocated by Pahl and Beitz sanctions the omission of any pre-conceptions. This is in stark contrast to the architects use of the pre-conception, or Darke's (1979) 'primary generator' (discussed in further detail in section 3.6.6), be it fictitious or factual, as a starting point from which to advance the design.

If we refer to the engineer/ scientist as a P thinker, that is he who performs problem-solving by using convergent, problem-focused thinking, we can relate to Frost's second model (figure 3.12). In general, P thinkers tend to be research oriented, and as a result, index in terms of well defined problems, attempting to deconstruct the problem into a number of discrete topic areas.

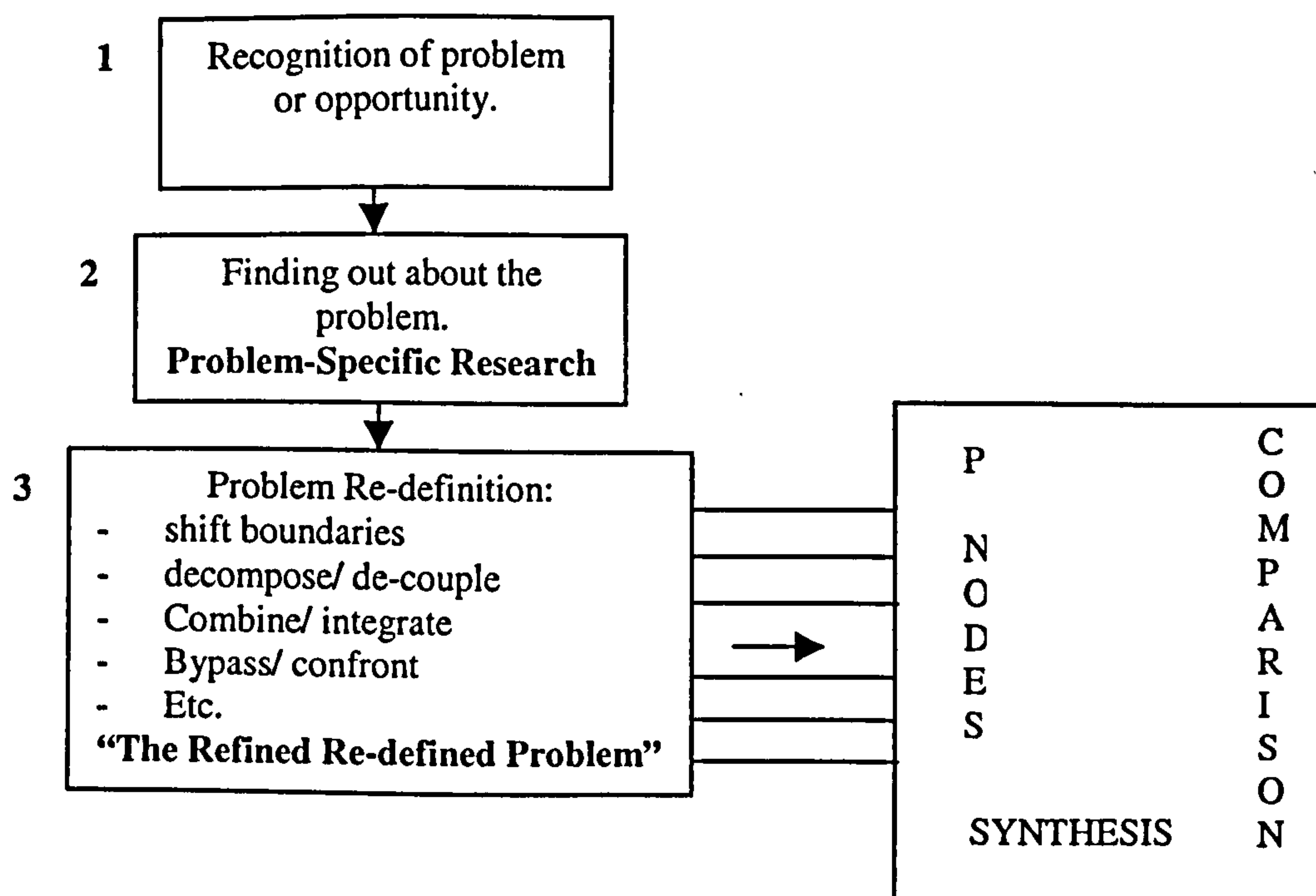


Figure 3.12 Problem focused approach to designing

3.4 Consensus models

3.4.1 Introduction

Roozenburg and Cross (1991) explain how the consensus model is based on the systems engineering approach to the development of complex technical and socio-economic systems, which structures development projects in two dimensions: vertical – corresponding to the origination phases in the life-cycle of a product (feasibility study, preliminary design, detailed design, planning for production, planning for distribution, planning for retirement); and horizontal – the problem-solving process that takes place in every phase of the vertical structure (analysing and defining problems, synthesising solutions, simulating/ predicting performance and evaluating and choosing the best system). The Roozenburg and Cross (1991) model is shown in figure 3.15.

In essence the consensus model provides a representation of the kinds of design activities involved in designing, while simultaneously outlining the actual design phases which make up the process itself, i.e. it combines the characteristics of both descriptive and prescriptive models into a single entity. The model does not restrict designers to just one way of working - a characteristic that should be displayed by all

realistic and genuinely useful models. Instead it tries to organise their problem solving behaviour to such an extent that it is more effective and efficient than other intuitive, unaided, unsystematic ways of working can provide. The RIBA 'Plan of Work' (table 3.1) was developed with this in mind. Pugh (1986) and Hubka (1980) (figure 3.13) have also outlined further examples of Consensus models which aim to describe the activity of design in a less systematic manner. Hubka's model, for example, indicated the extent to which the design knowledge space expands through the cycles of iterative design progression (Hubka, 1980).

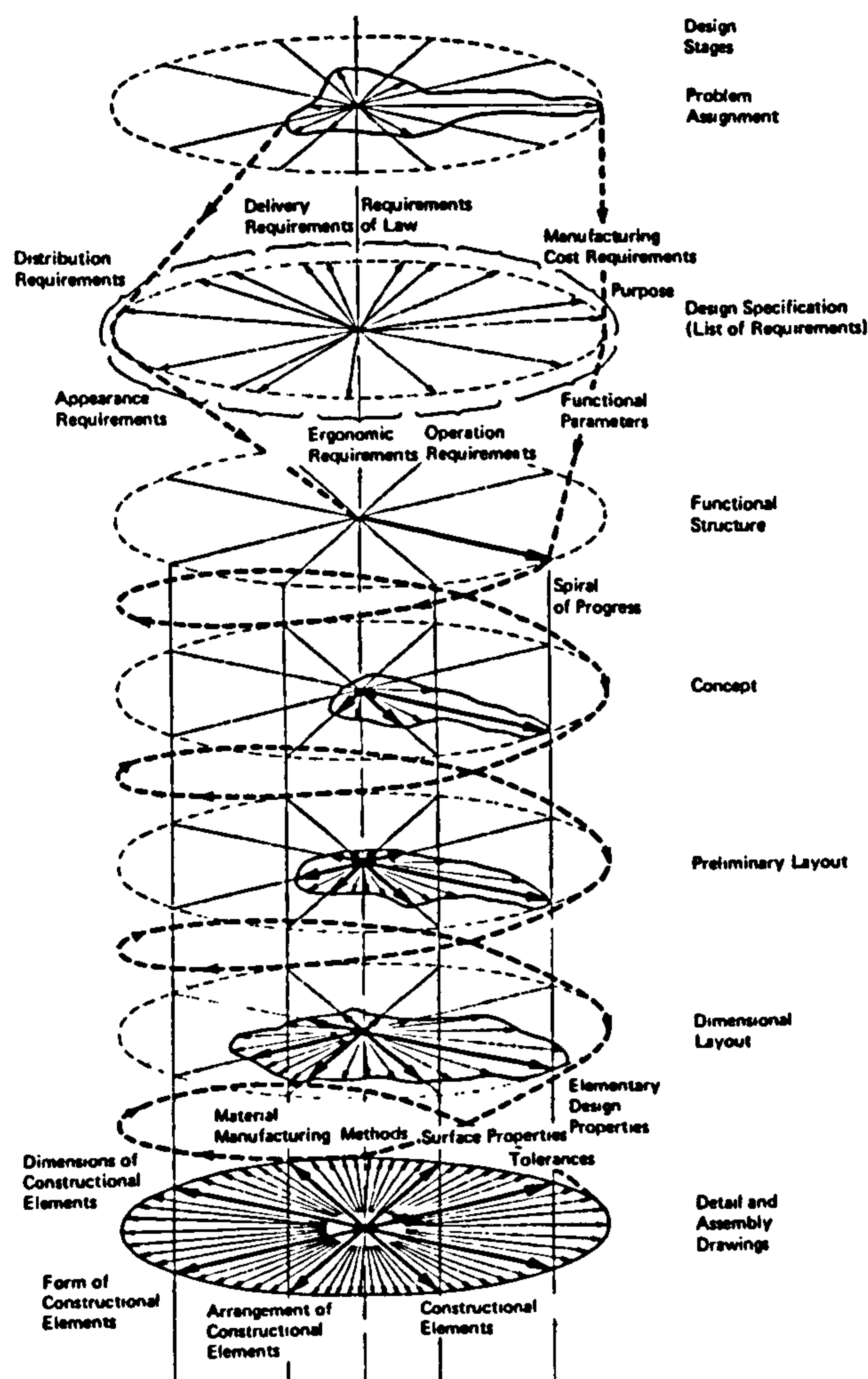


Figure 3.13 Hubka's model on the application of the degrees of completeness
(Hubka 1980)

3.4.2 Consensus of design approaches

As the design methodologists of the sixties developed their ideas on design, the number of models being constructed grew and a definite split of opinion became

apparent. Architectural methodologists began to criticise the shared view of the design process and real differences between the architectural (section 3.2.4) and the engineering (section 3.3.6) approaches were recognised (Roozenburg 1991).

A consistent approach to designing is integral to both improving the quality of design solutions and in educating the designers of tomorrow. According to Taylor (1993), 'an ordered approach to the design process is clearly essential if people are to work together effectively towards common goals'. This is a critical issue as far as building design is concerned as it represents the amalgamation of not just engineers and architects, but a number of other key disciplines, into a single interdisciplinary design unit.

3.4.3 The Convergence of the approaches

To briefly reiterate the two design approaches; Frost (1992) claims that architectural designers largely perform problem solving by the use of divergent, solution focused thinking - S thinking - in which intuition and exploration are essential in the generation and synthesis of concepts which are potentially useful as the solution to the problem or to some part of it. Most design problems do not permit such a clear-cut definition as to allow a direct progression to a solution. Indeed, a design problem itself may need to be redefined somewhat in the light of what turns out to be feasible as a solution develops. This type of problem, which is inherently ill-defined and as a result generally complex, has been described by Rittel and Webber (1973) as a 'wicked' problem.

Lawson (1984) recognised that scientists (the engineers) largely perform problem solving by the use of convergent, problem focused thinking - P thinking - in which the problem itself is analysed in the hope that it will reveal cues or guidelines for its own solution. This is due to the fact that the majority of pure engineering problems are capable of relatively clear definition.

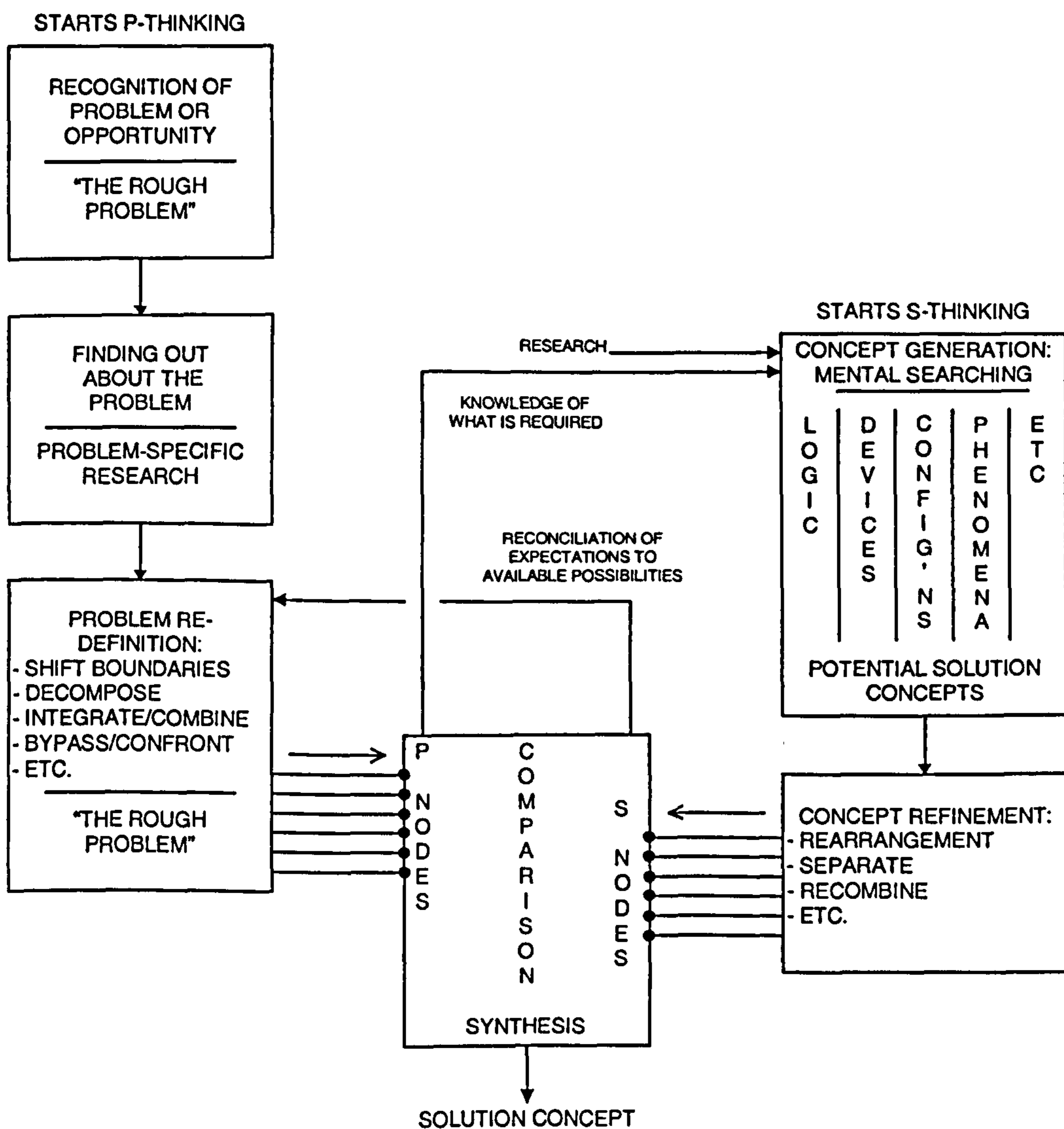


Figure 3.14 Combined model of the P thinking and S thinking stages of the design process (Frost 1992)

The aim of outlining these two approaches is not to suggest that one is better than the other, but rather to advocate the notion that both are required when attempting to generate a balanced building design. In the design of the contemporary built environment the knowledge of both engineers and architects is essential. A shared understanding of design processes and techniques would enable the use of these different types of thinking to be optimised (Parker 1996). Thus it must be concluded that more developed, generalised models of the design process would integrate the strengths of both design approaches. According to Roozenburg (1991) the relationship between problem and solution (and sub-problem and sub-solution) is symmetrical, which demonstrates that problem definition is often dependent on solution concepts (i.e. making solution conjectures often helps clarify the problem). Frost (1992) explains that 'the process of selecting an appropriate combination of S nodes to

satisfy the requirements of all the P nodes in efficacious interaction is the act of synthesis. If all the P nodes can be satisfied in this way, then the problem has been solved, at a conceptual level at least'. Thus, Frost produced a convergent model of the designers thought process (figure 3.14), which accounts for solution focused and problem focused thought simultaneously, and as such, provides an idealised prescriptive/descriptive hybrid representation of the iterative design process undertaken by the expert designer.

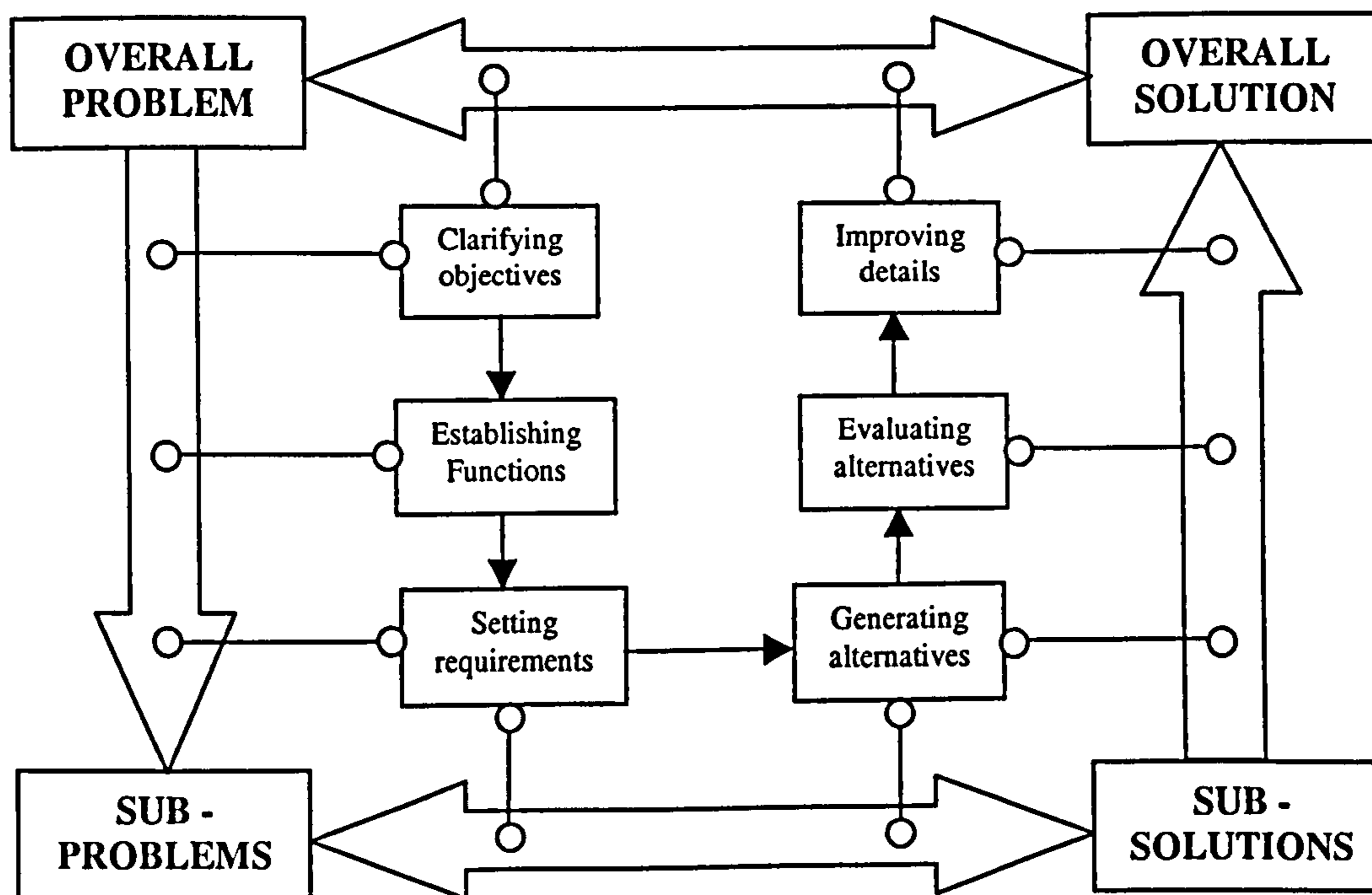


Figure 3.15 The Cross (1992) descriptive/prescriptive design process model

Cross (1992) not only acknowledges that Frost's model is a valid representation of both problem and solution based thought in unison, he also introduces another element into the model; a proposed set of design activities (shown as the core of figure 3.15). These activities promote and assist the design process, whether this is in exploring the problem-solution relationship, decomposing problems into sub-problems or synthesising sub-solutions (Roozenburg and Cross 1991)

The design methodologists have been particularly concerned with the development of a consensus model owing to the obvious educational benefits it could offer. A designer with a knowledge of the general nature of the design process is better equipped to undertake the activity (Maffin *et al.*, 1995). The complexity of the designers task owes much to the unlimited number of considerations involved in the

synthesis and evaluation of solutions (Taylor 1993). The parallel nature of design must not be overlooked as ‘reconciling the fluid nature of the human design activity with the systematic and rigorous procedures essential to modern design in a way that maximises overall design effectiveness’, is the key challenge in educating today’s designers (Taylor 1993).

3.5 Building Design Models

3.5.1 Introduction

Many may suggest that it is infeasible for the building and construction industries to look to product and manufacturing based industries for design process models and techniques, as they possess entirely different cultures in terms of final product (Parker and Steele 1998). Although there can be no denying that they are different, Kline *et al.* (1992) outline many generic similarities between them, such as:

- The technologies utilised are rapidly changing.
- Processes are becoming increasingly complex.
- People skills are becoming more and more important to success.
- The marketplace for both is extremely competitive.

Owing to the generic nature of Pugh’s ‘Total design model’ (figure 3.8), its form was utilised in considering how the process of design fits within the wider context of the business activity of an enterprise or firm, be it manufacturing, construction or any number of others (Pugh and Morley 1988). Figure 3.16 represents the dynamic concept model for business design with respect to the construction industry. Pugh classified this type of model as a ‘Business boundary model’ as it explicitly attempts to manage the activities in the design core, so that they are given a structure, and provided with appropriate information, resources and support. It has been suggested that the task of management is to give the design core an anatomical structure that will be the carrier of certain desired properties (Pugh and Morley 1988). This introduces another important aspect into the design equation; the importance of management.

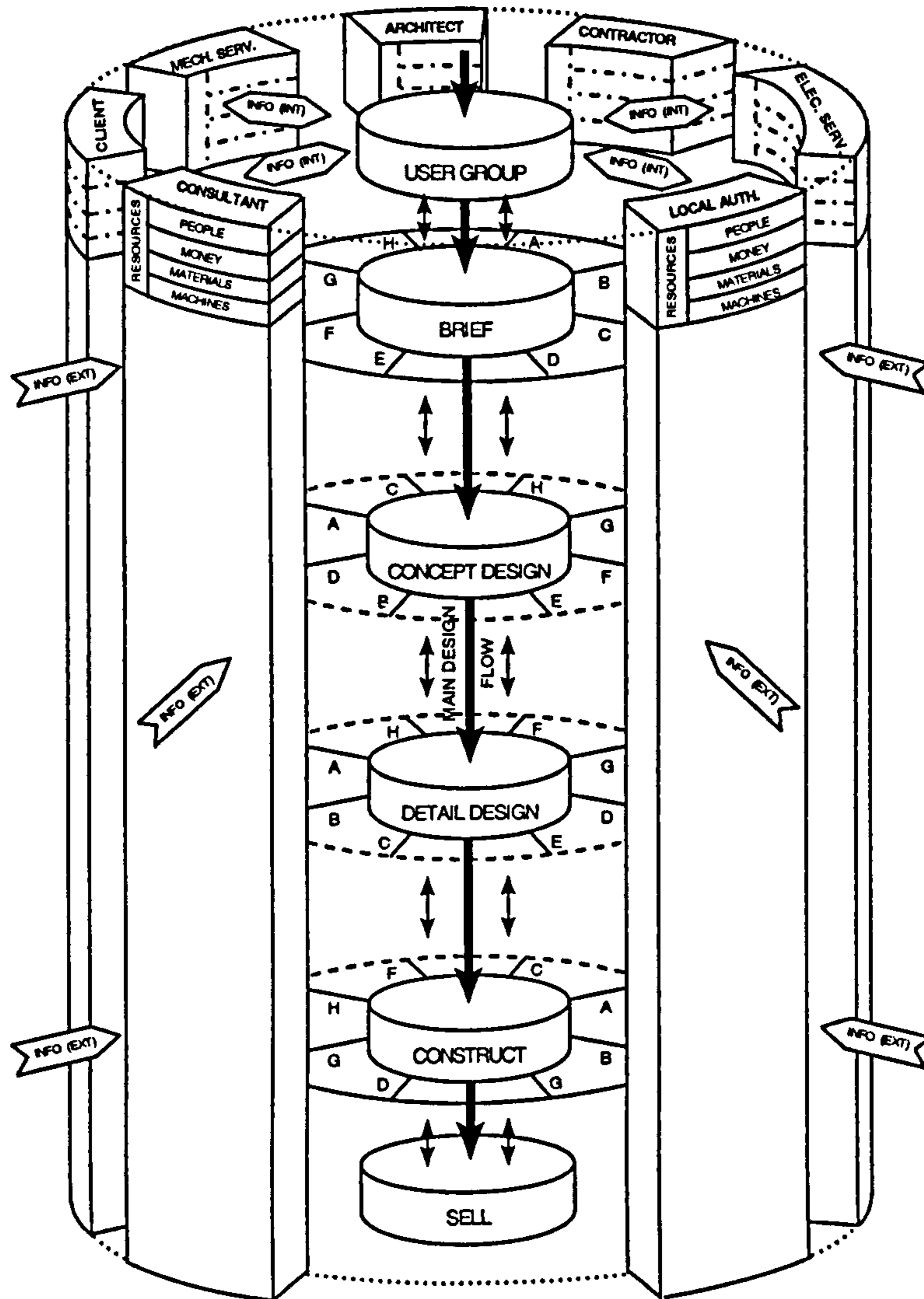


Figure 3.16 Pugh's construction industry model

Probably the most regularly referenced process model in the contemporary building design industry is the RIBA Plan of Work (outlined previously in this chapter). However, a number of organisations have developed design process models that offer a different perspective on the way building design is undertaken in current practice.

3.5.2 Generic Design and Construction *process protocol* (GDCPP)

Researchers at University of Salford have created a generic design and construction *process protocol* (table 3.2) which defines the entire design procedure, and has been received with great interest by both industry and academia. This model was built from a very solid datum, referencing descriptions of the design and construction process laid down by Walker (1989) and Hughes (1991) plus reviews of other published

models such as the RIBA Plan of Work (1969) and the BAA Plc Project Process map (section 3.5.3) (Sheath *et al.*, 1996).

The *process protocol* model breaks down the design and construction process into ten discrete phases, which are then further categorised into four broad stages of design.

Phase Number	Phase Description	Stage Categorisation
Zero	Demonstrating the need	Pre-project
One	Conception of need	
Two	Outline feasibility	
Three	Substantive feasibility study and outline financial authority	
Four	Outline conceptual design	Pre-construction
Five	Full conceptual design	
Six	Co-ordinated design, procurement and full financial authority	
Seven	Production information	Construction
Eight	Construction	
Nine	Operation and maintenance	Post-construction

Table 3.2 Phase and stage descriptions of GDCPP

It is important to understand that this process map not only describes the physical stages of the process, but also addresses the additional factor of the management of design. Pugh (1988) makes it explicit that this is an integral component in achieving design success and Salford have adhered to this view, outlining eight key management areas, requiring full consideration at each design phase:

1. Development management
2. Project management
3. Resource management
4. Design management
5. Production
6. Facilities management
7. Health and safety, statutory and legal management
8. Process management

The overriding aim of the map itself is to improve the collaboration between companies in the traditionally fragmented construction industry. However, it also attempts to provide a standard framework for clients around which they may enhance the effectiveness of their work (Sheath *et al.*, 1996).

3.5.3 BAA Plc project process

BAA Plc have been continually striving to improve their design process through collaboration with several academic institutions, including the University of Salford. This has culminated in the production of the BAA Plc project process, first published in 1995. This model outlines seven discrete phases that make up the design process:

1. Inception
2. Feasibility
3. Concept design
4. Co-ordinated design
5. Production information
6. Construction
7. Operation and Maintenance

As with the *GDCPP*, the importance given to managing the process is explicitly apparent, and has been fully integrated into the design procedure. Once a stage is considered complete, it must be signed off at an *Approval Gate* before the next stage can commence. This 'stage gate' review and approval between each phase enables the design output to be frozen at each stage, thus enabling more efficient control of the process. The major benefit of this freezing of the design is the improved communication and co-ordination it promotes between the project's participants as they pass through each phase (Sheath *et al.* 1996)

Any final approval to continue will only be given if the design to date has satisfied the eight key interrelated sub processes of:

1. Development management
 2. Evaluation and approval
 3. Design management
-

4. Cost management
5. Procurement management
6. Health and safety
7. Implementation and control
8. Commissioning and handover

Each sub-process is conducted, in some form, throughout the process and it is this grouping of activities that is promoted as ensuring the effective execution of the process. According to Sheath *et al.*, 'even though the BAA model is robustly developed, its applicability at a generic level may be questioned, as it was developed from the client's perspective, i.e. the sub-processes identified relate specifically to key functions within the BAA organisation'. Consequently, the model takes little account of the improvements that could be implemented from other perspectives.

Driven by the recommendations of Sir Michael Latham (1994) and, more recently, from an internal perspective via Sir John Egan (and the report of the construction industry task force 1998) BAA Plc have attempted to produce long term relationships between designers and contractors, with a view to creating contracts of a non-adversarial nature while promoting a working environment of continual improvement. However, even though the BAA Plc project process does outline the stages of the design process, as does the RIBA Plan of Work and the GDCPP, none of these models actually define the design processes followed within each discrete stage of the process.

3.5.4 Additional process perspectives

Managing design

The British Standards Institute (BSI) have produced a document referred to as the 'Guide to managing product design' (1989). In Section 4 of this document, entitled 'Managing the design activity', there are guidelines for those who manage design. As such, an idealised design process has been mapped. This document references the work of Pugh and Morley (1988), and Pahl and Beitz (1988), and their influence is apparent in this BSI model.

Planning design

Potter, in the Construction Industry Research and Information Association (CIRIA) special publication - number 113: 'Planning to build?' (1995), states that all projects go through the same basic processes. According to Potter, the type of procurement route taken is irrelevant to the project procedure, as the processes will always remain the same, with the only variants being their sequence and the individual responsibility taken for each stage. This suggestion that the sequence of phase progression will change for each new project is one that the models described previously within this section have not stated explicitly. Given this concept that high-level design progression is non-linear dismisses the opportunity to utilise the stage-gate routine proposed by BAA Plc, and subsequently, Salford's GDCPP.

3.5.5 Relating and comparing models of the entire design process

The previous sections have provided an overview of the design process in its entirety and many of the existing design models have been reviewed and described. As such, several differences and similarities within the existing models have been made apparent. Table 3.3 compares a number of these models. The most obvious difference between the models is the lack of synchronisation across the phases of design activity, with each model defining the discrete phases in different ways. However, there are a number of other conclusions that can be drawn from this comparison.

Model Name	Inception		Feasibility		Concept design		Co-ordinated design		Production information
	Demonstrate the need	Conception of need	Outline feasibility	Substantive feasibility & outline financial authority	Outline conceptual design	Full conceptual design	Co-ordinated design, procurement & full financial authority	Production information	
BAA Project Process (1995)									
Salford Process Protocol (1998)									
RIBA Plan of Work (1969)	Inception			Feasibility	Outline proposals	Scheme design	Detail design	Production information	
MOD 'Working Document' (1997)	Inception		Definition & qualification		Concept design			Detail design	
C'IRIA 11.3 (1995)			Feasibility and briefing		Scheme design			Production information	
BS: 7000 (1989)			Feasibility		Concept design	Embodiment design	Detail design	Design for manufacture	
Hubka (1982)			Elaboration of assigned problem		Conceptual design	Laying out		Elaboration	
Pahl & Beitz (1988)			Planning and Clarification of the task		Conceptual design	Embodiment design	Detail design	Detail design	
VDI 2222 (1973)			Planning		Conceptual design	Embodiment design	Detail design	Detail design	
French (1971)			Analysis of the problem		Concept design	Embodiment of schemes	Detailing	Detailing	



Table 3.3 Comparison of full-phase models of design

Each model:

- describes a sequence of phases which, typically, imply iteration within phases but not between one phase and another;
- shows progression from broad outline to elaboration of detail;
- implies starting with an analysis of requirements before the generation of possible solutions (even though much design work involves the modification of existing solutions, not the invention of new ones); and
- has comparable, though not identical, terminology.

Typically, although there are exceptions, the models:

- set out only what should be undertaken, not why or how it should be done;
- do not define what is to be done separately by different team members and what needs to be done in collaboration;
- limit their concerns to the problem requirements and their solution;
- do not address the social aspects surrounding team-working, such as the selection and involvement of team members at various stages, the exchange of information, or the promotion of effective collaboration.

Also, the building design models include an initial feasibility phase – which engineering models seem to exclude.

To understand the intricacies of the design process each discrete phase must be explored in detail. It is only by undertaking these more detailed investigations that the understanding of design will be improved. Table 3.3 highlights an area relating to one of the phases involved, conceptual design. This represents the pivotal topic of the remainder of this thesis.

3.6 Models of the conceptual design phase

3.6.1 Introduction

The major difficulty in attempting to describe rationally the process of conceptual design lies within the very nature of this intuitive, creative, innovative, heuristic, cognitive, and inspiration driven stage of the design process. The fact that a team of

individuals are brought together for the purpose of generating a design solution to a particular problem, in a particular environment, over a given period of time, allows a tip of the ice-burg glimpse of the diverse range of variables and unknowns which can come into play, and must therefore be considered, when trying to create a structured model of the conceptual design process in generic terms. Jones (1992) suggests that another difficulty in designing lies in making the intangible, tangible. He states that 'designers are forever bound to treat as real that which exists only in an imagined future and have to specify ways in which the foreseen thing (the concept) can be made to exist'.

The conceptual portion of the design process is particularly difficult to specify because it is not an isolated activity. Conceptual behaviour in design requires complex cognitive information processing, including knowledge and information acquired from outside of the particular design project at hand. Conceptual activities are also those activities most likely to involve elements of creativity (unique ideas) and consequently represent the most difficult portion of the design process to automate (Newsome and Spillers 1988).

The key to designing on a conceptual level lies in the understanding that conceptual activities are highly ambiguous, being very much dependent on creativity, and as such, providing more than one solution to a design problem is not only acceptable, but also highly desirable. According to Schon and Bucciarelli (1988); 'Designing is different from problem solving, though to design one must solve problems'. Practically speaking, design problems are inexhaustible (French 1971). Unlike a crossword puzzle or mathematical problem, which has a single correct solution, the design problem can be solved in a number of alternative ways, of which one or all may prove feasible. As such, there can be numerous solutions to a problem, and therefore scope exists for better designs to be produced if more ideas are explored (Chakrabarti and Bligh 1994). Suh (1990) takes this further by introducing the paradigm of linking functional requirements with the design parameters. Suh defines design as 'the creation of synthesised solutions in the form of products, processes or systems that satisfy perceived needs through the mapping between the functional requirements in the functional domain and the design parameters of the physical domain, through the proper selection of design parameters that satisfy functional

requirements'. Suh continues in suggesting that 'this mapping process is non-unique; therefore, more than one design may ensue from the generation of the design parameters that satisfy the functional requirements; in other words, the actual outcome depends on a designer's individual creative process. Therefore there can be an infinite number of plausible design solutions and mapping techniques'.

3.6.2 Towards a universal definition of conceptual design

It is extremely difficult to define conceptual design in a single universal term. There seem to be almost as many derivatives of the description of this phase of design as there are writers about it: Hill (1970), French (1971), Olson (1976), S.E.E.D (1985), Spillers & Newsome (1988), Pahl & Beitz (1988), Hales (1992). Chakrabarti & Bligh (1994), Blessing (1994), Andersson (1996), Parmee (1996), and Ullman (1997) provide a taste of those authors, the majority being based in the engineering design domain, who have attempted to define the conceptual design phase. (Each of the definitions provided by the above mentioned authors, in addition to a number of those generated by government and private sector organisations, can be referenced in Appendix III).

3.6.3 Model Typology

Hales (1987) summarises the opinions of Bessant and McMahon (1979) in suggesting that the way for designers and design researchers to gain improved understanding of the design process is by moving toward the development of flexible and adaptable models which take account of the dynamic nature of design activity.

However, there is a division between the typology of the existing models of conceptual design activity. A number of authors, predominantly from the engineering design domain, adhere to the belief that the process can be described systematically and sub-divided into a multiple number of sub-phases or activities. This prescriptive type of model is characterised by both the entire design process (figure 3.7) and the conceptual design process (see figure 3.17) models proposed by Pahl & Beitz. The second type of model is characterised by the simple three-phase models, generally advocated by the architectural design authors. These appear far less rigid and represent a broad categorisation of the sub-phases of design.

3.6.4 Systematic Multi-phase models

Pahl & Beitz (1988) describe a systematic approach to the process of concept generation. As has been stated previously, this approach provided the datum from which a basic model of the steps of the conceptual design process was conceived (figure 3.17)

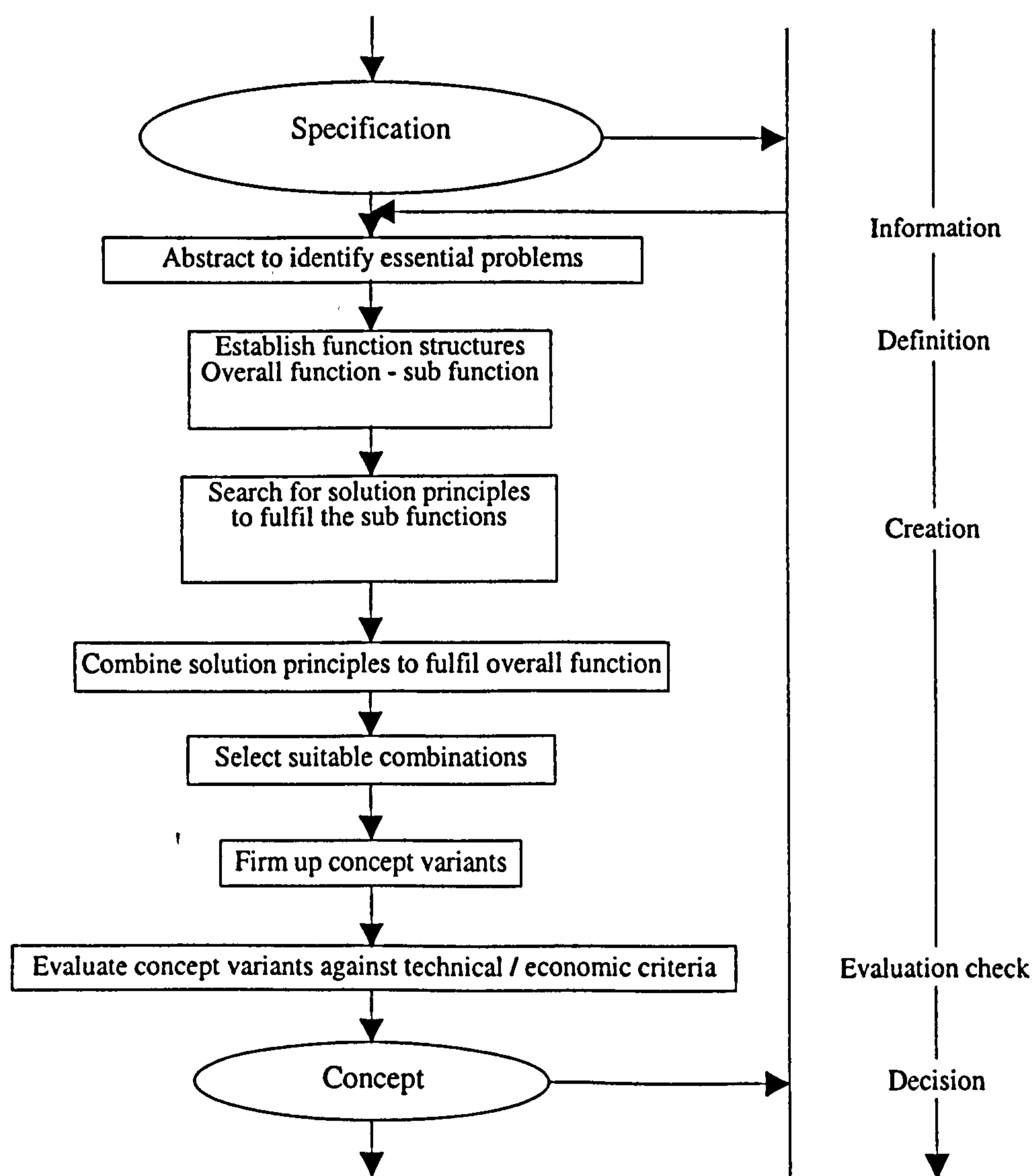


Figure 3.17 The conceptual design process model of Pahl and Beitz

As can be seen, the Pahl and Beitz approach describes seven discrete stages through which the designer must pass in order to produce a design concept. This model is an explicit attempt at providing a thoroughly systematic procedure for designers to follow during conceptual design activity. Cross (1982) also produced a prescriptive model of conceptual design activity (figure 3.15), which adheres to the Pahl & Beitz,

VDI approach to sub division of problems into sub-problems, in a bid to reduce the complexity or 'Wickedness' (Rittel and Webber 1973) of the problem (see figure 3.18 below). As could be expected given details outlined earlier in this chapter, it is the writers from the engineering design field that are the largest exponents of the systematic processes, whereas the writers of the simple three-phase models tend to have a more diverse field of design interest.

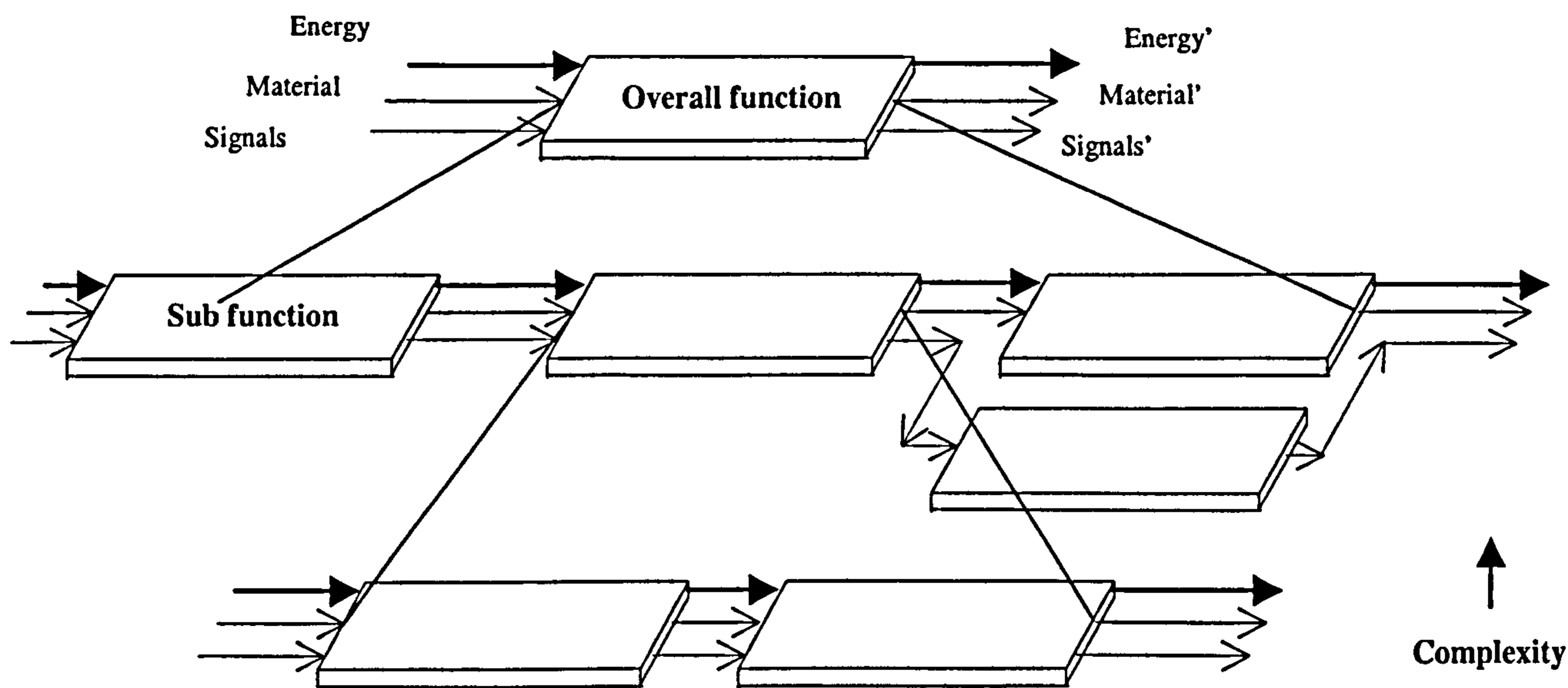


Figure 3.18 The principle of sub-division of functions

3.6.5 A Critique of the systematic Approach

According to Minneman (1991), the majority of the criticism of the systematic approach to design comes from those individuals who feel that design is akin to art and as such, that designing is an intuitive, individual centred, act that cannot be subjected to a systematic approach. Minneman introduces a number of arguments and counter arguments from a number of sources that are summarised below:

- The systematic approach presumes a well-known and well-described design situation (technical problems, requirements, stakeholder needs, and so on must be known for the design to proceed). Conversely, Cross and Nathenson (1980) argue that in reality little, if any, of this information is known at the outset.

- The systematic procedures have seldom been subjected to realistic evaluation in practice, yet their advocates claim their use will lead to better quality artefacts and/or shorter times to design completion. The authors make no apologies for this.
- When the design model of Pahl and Beitz was tested by Hales (1987) in a live project, the activities that were accounted for by the model made up only 47% of the design team's work. The single most prevalent activity, reviewing and reporting, was not evident in the Pahl and Beitz model.
- A similar testing of Hubka's model (Hubka *et al.*, 1988), like that of Hales, failed to provide any indication that design cycle time or artefact quality were positively affected by the use of a systematic procedure.

As such, claims that adopting the prescriptive systematic procedures will improve the design process, shorten the design cycle time, or produce higher quality artefacts still remain unproven (Minneman 1991).

3.6.6 Designing as a three-stage process

The following models of design provide an overview of the differing perspectives on the activity of designing. They outline differing subjective opinions on the way that design is undertaken in practice and as such, the reader should be aware that they appear to be contradictory in parts. The difference between this type of model and the systematic procedures is that they provide a loose framework to describe the designers progression, rather than a tight procedure that must be adhered too. This is not to say that the advocates of system do not allow iteration in their models, it merely provides the reader with a view of the opposing end of the scale as far as definition of discrete phases and stages is concerned.

Analysis, synthesis, evaluation

According to Jones (1992); 'the simplest and most common observation about designing, and one upon which many writers agree, is that it includes the three essential stages of analysis, synthesis and evaluation'. The nature of this design model, which was generated in the 1960s, is based firmly on novelty within design (Evans *et al.*, 1982). It is generally accepted that this approach will be utilised regardless of how much prior knowledge of a particular type of problem the designer has, or how much information the client has provided.

The affect that the stakeholder(s), or stakeholder organisation(s), input can have on the design process is a key issue, and as such, is one that must be investigated further during the course of this thesis. It is without doubt an issue of major importance, as the stakeholders initial input will predetermine the constraints on the solution domain by setting the design space boundaries. Morris *et al.*, (1998) describe how clients, being principle stakeholders, commonly vary in levels of experience and expertise, but they additionally vary 'in their desire to be actively involved in the decision making process and the extent to which functional requirements are known and understood'. Moreover, some clients have detailed understanding of what they require while others simply recognise that they have a business need. When the client tends toward the latter position the reasoning behind the client's decisions will be captured within the design briefing process as the designer will work in partnership with the client to elicit, identify and ultimately meet the clients needs (Morris *et al.*, 1998). However, when the client provides a detailed and very much predefined and absolute statement of his requirements, the opportunity to utilise any of the designer's creative input is lost, relegating his role to one of purely design progression. One, or a combination of, these three phase frameworks will be followed in one form or other during design activity.

Generator, conjecture, analysis

Darke (1979) made explicit her view that in general the designer *must* utilise a few simple concepts or objectives regarding possible design solutions as a starting point when attempting to generate feasible concepts. Darke's investigations were attempting to provide much needed empirical evidence to validate the findings of Hillier *et al.*, (1972), who had produced the thorough theoretical basis for the model, and on whose work Darke built the concept of the generating principle.

The work of the eminent science philosopher Karl Popper has been based on the paradigm that the key to furthering knowledge is through criticism. As such he is of the opinion that the logic of scientific discovery lies purely in the process of refutation, the testing of scientific theories, where as the process of conjecture, the inventing of them, follows no pattern of logical reasoning and should therefore be relegated to study by psychologists. According to Evans *et al.*, (1982); 'The principle

underlying this is that we can never prove a theory with certainty; we may always find a counter example. So the hallmark of a good theory is one that is eminently testable and has stood attempts to refute it’.

There is an apparent connection here to the conceptual phase of the design process. It is generally recognised that, with the exception of absolute innovation, designers tend to produce outline ideas fairly quickly by adapting previous designs to suit the problem at hand. As a result, they spend relatively small periods of time analysing the problem. According to Evans *et al.*, (1982); ‘the assumption is that analysis occurs on the basis of some analytical framework, some conjecture about what should be analysed which will be part pre-conception based on the past, part innovation. So instead of cycles of analysis-synthesis we have cycles of conjecture-analysis’. This opinion is adhered to in the generator-conjecture-analysis model. Lawson (1980), explains how this process should be approached by the designer; ‘First decide what you think might be an important aspect of the problem, develop a crude design on this basis and examine it to see what else you can discover about the problem’.

Divergence, transformation, convergence

In naming the three stages divergence, transformation and convergence, Jones (1992) refers more to the problems inherent in system designing rather than the actual approaches believed to be followed by the architect or engineering designer - which appears to be the focus of the processes outlined previously. (The differences in the approaches of these two discrete groups have been outlined earlier within this chapter). Jones (1992) himself stated that it may seem confusing and unhelpful to a professional designer to think of these stages as being separate. For example, if we take the extreme case of a wholly prefabricated search design strategy (i.e. design activity that would be undertaken in familiar situations, where a predictable number of tried and tested actions are followed), the act of converging onto a final, evaluated and detailed design proposal, is considered to be the fundamental overall aim of the design activity. However, as Cross (1989) explains; ‘within the process of reaching that final design there will be times when it will be appropriate and necessary to diverge - to widen the search or to seek new ideas and starting points’.

Thus, it is apparent that the overall design process is convergent, but it will contain periods of deliberate divergence (figure 3.19). However, there is little doubt that the separation of the three phases of divergence, transformation and convergence is prerequisite to whatever changes of methodology are necessary at each stage before they can be reintegrated to form a process that works well at the systems level.

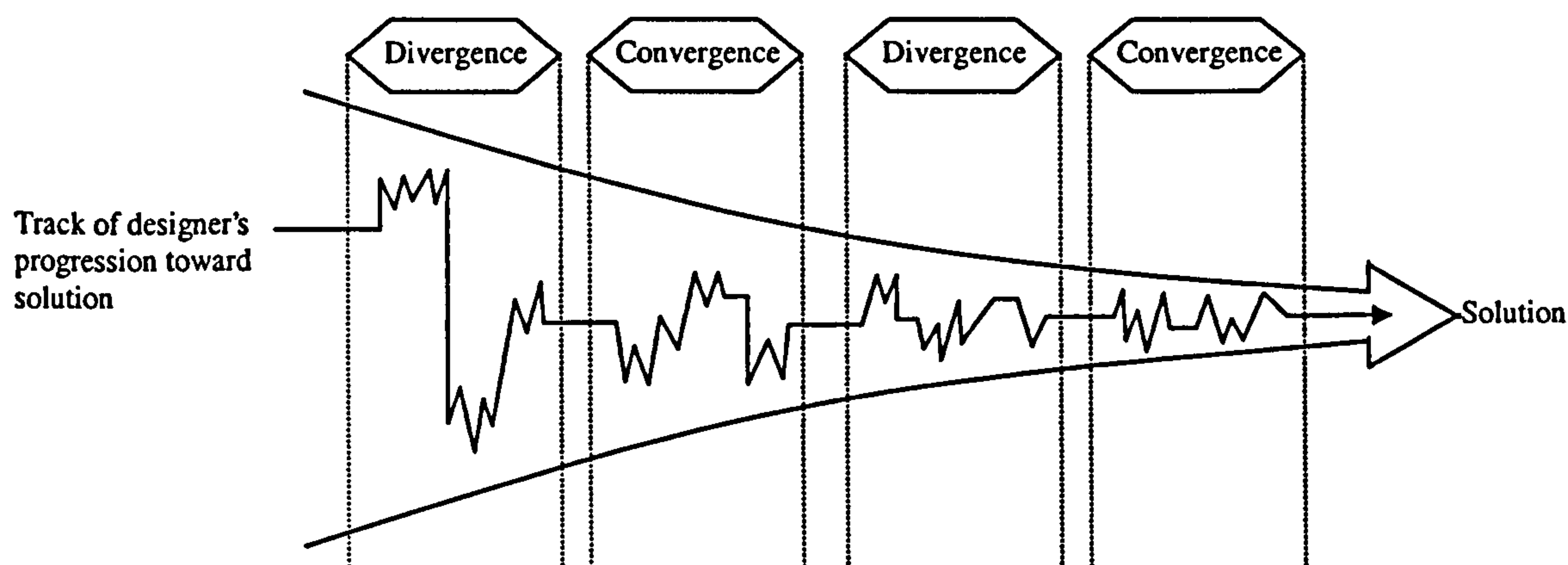


Figure 3.19 Illustration of Divergent and Convergent search in design (Cross 1989)

3.6.7 Relating and comparing models of the conceptual design process

Table 3.4 relates and compares the Pahl and Beitz model with several other systematic models of conceptual design proposed by such authors as Cross (1989), Hubka (1982) and Jones (1992). These have been cross-referenced with the three-phase model of Analysis, synthesis and evaluation and the Ministry of Defence building design procedure; 'Building down the barriers' (1994).

From this comparison it is again apparent, as was the case with the full phase models, that although there is some consistency in terminology, there is a lack of synchronisation across the various sub-phases identified. Additionally:

- All the models start by an analysis of requirements – none starts by taking an existing concept and modifying it to suit new needs;
- Few of the models explicitly encourage the generation of alternative concepts for evaluation – most imply convergence to one solution quite early in the process;

- Engineering models subdivide the concept phase into a number of sub-phases to be undertaken sequentially; in contrast, building design models do not have the sub-phases mapped; and
- No reference is made about how to generate concepts - none of the models makes explicit reference to techniques for stimulating a wider solution space, or to formal measurement, evaluation or assessment methods.

Additionally, none of the models of the building design process succeeds in capturing ways to help a new design team overcome the stimulating but potentially chaotic period at the start of a project when team members have conflicting aims, priorities and expectations, and need to find ways to construct shared goals, objectives and problem-ownership. This element of social interaction and sharing understanding is of critical importance to successful team-based conceptual design activity. As such, the following sections discuss teamwork and collaboration within design.

3.7 Teamwork in design activity

3.7.1 Introduction

Simon (1969), one of the design methodologists, attempted to apply 'science' to the study of designers and design problems. Simon suggested that design problems could be solved systematically through the application of scientific techniques and theories; this was described as 'technical rationality'. Schön (1983) suggested a shift toward what he refers to as 'reflection-in-action', e.g. adapting to the situation. Schön, basing his work on case studies from architecture, psychotherapy, engineering, scientific research, and the general field of management, discovered a common vein running among all the participants. Schön describes the way designers work in an almost 'intuitively-knowing' manner as being 'the artistry' of design, which he classifies into five components:

- Knowing-in-action
- Reflection-in-action
- Conversation-with-the-situation
- Reflecting on the situation
- Reflective conversation with the situation

The reader is referred to Dorst and Dijkhuis (1996) for a detailed comparison of the paradigms for use in describing design activity.

Over the last two decades an increasing number of empirical investigations into design practice have been conducted. Radcliffe (1997) differentiates between these studies in terms of those that have been conducted in natural settings (e.g. Hales 1987, Bucciarelli 1988, Minneman 1991) and those that have been conducted in experimental environments (e.g. Tang and Leifer 1991, Radcliffe and Lee 1990, Christiaans and Dorst 1992). Despite these studies most of what is commonly known about design activity in general has emerged from studies of individual designers (Cross and Clayburn Cross 1996). However, Valkenburg and Dorst (1998) describe the development of a new description method based on Schon's theory of reflective practice that describes the nature of team designing. According to Valkenburg and Dorst, effective interdisciplinary team design activity relies on the team members supporting one another. They suggest that this support should be provided through the answering of questions directed at a particular disciplinary issue as well as from each member picking up and building on the line of thought of another. They explain that the key to undertaking successful team design activity lies in the synchronisation of the thoughts and activities of each team member, stating that a lack of synchronisation in focusing on a collaborative goal 'can cause serious problems for team members in interactions and conversations and lead to misunderstandings and uncoordinated actions'. A team's design progression involves the establishment of shared meaning about both the problem and the possible ways of solving it. This can be achieved by categorising the activity and applying suitable design methods as appropriate (Hubka and Eder 1997).

3.7.2 Design as social interaction

Minneman (1991) generated a new methodology for undertaking design studies, which he then utilised to observe and record group design activity in practice. The resulting observations adhered to the work of Cuff (1982), which had been built on Rittel and Weber's (1973) theory of architectural design as a process of interest driven argumentation. The findings of Cuff, which were the result of her attendance at a vast number of architectural practice design meetings, showed that design emerged from negotiations between the architect and the client, rather than from a flash of creative

genius on the part of the architect. According to Minneman (1991); 'this emphasised the fact that design emerges from social interaction'. Minneman describes two components that, if introduced to teams of designers, will help improve social interaction and, thus, group design activity:

- A framework for the content of the work that generally expands the accepted notions of what is being worked on in a group design practice; and
- A collection of practices that designers can be seen to use in getting the social and technical work of design accomplished.

According to Minneman; 'designers are using the collection of communication practices to accomplish the social work of establishing, developing and maintaining a shared understanding. That shared understanding not only encompasses the object of their design work, but also the processes of its creation and the relationship among all of those involved in the effort'. In order for interdisciplinary teamwork in design to be maintained, a flexible structure or framework must be constructed and shared among the team to mediate distributed collaborative design development via co-ordination and negotiation among team members (Peng 1999). However, although Minneman recognised this connection between the need for a shared datum for the social and technical elements of the design process, his work only contributed fully to the social element.

Blessing (1994) also reached a similar conclusion regarding the need for improved understanding of the social aspect of design activity, stating that 'descriptive studies involving design teams make it clear that design is not only a complex technical process but also a complex social process'. Blessing's investigations have shown that the prescriptive and descriptive literature barely addresses the effect of group social interaction on the design process, concluding that, 'a model of the design process should include the notion of teamwork...'

3.7.3 Team member interaction

Brereton *et al.*, (1996), also adhere to the findings of Minneman. They suggest that modern interdisciplinary design demands that engineers learn to work in teams. This teamwork requires individuals to express ideas and misgivings, listen, negotiate, and so on, i.e. they must collaborate. They explain how the individuals involved in the design activity must be aware of various characteristics of collaboration so that they can recognise both successful and poor strategies and as such, ‘...carefully moderate their commitment to ideas to remain amenable to negotiation’. According to Brereton *et al.*, a design progresses as the design team focuses and makes transitions from topic to topic. These transitions will occur when:

- Team members seek to shift debate to another topic.
- Team members seek to change the process.
- Team members are prompted by related topics.
- Topics lose steam.
- Processes lose steam.
- Team members stop to seek information.

They state that collaboration will only be successful if the team members are well balanced in their roles and manage their negotiations well.

3.7.4 Toward a team design process

Teamwork is of substantial importance in normal professional design activity. Working in a team introduces problems and possibilities for the designer in comparison with working alone (Cross and Clayburn-Cross 1996). Cross and Clayburn-Cross explain that ‘the ill-defined nature of design problems means that analysing and understanding the problem is an influential part of the design process. Individual designers can form their own, possibly idiosyncratic understanding of the problem, but a team has to reach some shared or commonly held understanding...a disadvantage of teamwork is likely to be that conflicts will arise between team members’. Only recently have studies begun to observe the social interactions that influence the activities of teamwork in design. The writers of these studies suggest that designing is a social process and, as a result, design methodology must address

the design process as an integration of the technical process, the cognitive process, and the social process (Cross and Clayburn-cross). Blessing (1994) refers to the findings of Bessant and Macmahon (1979) and Pahl (1991) stating; ‘...it is rather difficult to achieve the effective operation of a large interdisciplinary design team [however] a way to improve this and the flow of information in a company was found to be the implementation of a design methodology, because it more or less imposed group dynamical effects and interdisciplinary co-operation’. According to Archer (1984), even where problems are handled intuitively, a designer is better able to cogitate on a particular problem when in possession of structural concepts of the logic of the general class of problems into which the problem falls, and of the general program of events through which the activity is likely to pass, than when no such structural concept is held.

The majority of authors that have actually studied team design activity as a social as well as a technical process have come from the engineering design domain, e.g. Hales (1987), Minneman (1991), Blessing (1994). If the activity of designing is ever to be aided, it is necessary to understand the interrelation of the different factors involved in the technical, as well as the social, processes of design, as the way in which a group discusses and solves conflicts and makes decisions may increase or decrease the performance of its members (Gunther *et al.*, 1996). According to Goldschmidt (1996); ‘teamwork in design is a relatively recent phenomenon, emanating from the scope and complexity of many design tasks and the need for multiple expertise and labour division’. Goldschmidt’s work promotes the concept of the designer as a team of one, rather than the design team resembling different aspects of the individual designer.

Bearing these discussions in mind it is imperative that any investigation into the conceptual design phase of building projects must take into account the extensive and far reaching effects that social interaction can have on design activity. This has been recognised previously, and as a result a number of methods and techniques have been developed to assist in team working in design. These design tools are discussed in the following section.

3.8 Design techniques

3.8.1 Introduction

Section 3.1.2 described how three British conferences on design methods held in the 1960s resulted in the emergence of the design methodology movement. The design methodologists were not only interested in attempting to define structured design procedures, they were also concerned with generating strategies and tactics for the designer to implement when faced with a particularly taxing problem. These strategies have come to be known as design techniques or design methods. The key objective of nearly all these methods was to improve the efficiency of the design process through a more systematic and rational approach (Evans *et al.*, 1982).

3.8.2 Methods, techniques, tools

Design methods are tools that can be applied at particular stages of design, to assist in the progression of the process. These instruments and methods of analysis provide a means of managing the many difficulties unearthed when addressing complex design problems.

In this respect, the terms design technique and design method are one and the same in that they describe any tool, procedure or aid that assists the designer, or design team, in undertaking a design task. In fact, any identifiable way of working, within the context of designing, can be considered to be a design technique (Cross 1989). It must be made absolutely clear that design techniques will never be able to replace the gifts of the talented designer, or provide step by step instructions for the production of wonderful designs. However, they may: i) improve the quality and speed of the able designers work; ii) increase the magnitude of the tasks that can be handled; and most importantly iii) improve the co-operation of the essential specialists inside and outside the design office (French 1971).

3.8.3 The traditional methods

The most common design methods are, typically, designing-by-drawing, modelling, and calculation (Cross 1989). The old adage – a picture is worth a thousand words – illustrates the effectiveness of drawing as a means of simplifying and transferring the conceptual thoughts of the individual designer to the many disciplines involved in the

fragmented interdisciplinary design environment that is common place today. However, when used in isolation, the technique has several inadequacies:

- The drawing cannot convey anything about the needs of the users or the problems that could be discovered in manufacturing the artefact.
- Only one person can produce scaled drawings at a time and as such, the situations which it is to fit must be envisaged in a single mind (Jones 1992).
- Sketches cannot provide any means of testing material types and strength in the context of a real-life application.

The difficulties of mentally assessing the suitability of proposed designs using drawing alone can be overcome to some degree by making models and prototypes that are tangible and, as a result, can be tested. Utilising sketching and modelling together when generating and progressing concepts introduces some key benefits (Dorner 1997):

- They clarify the characteristics of the concept.
- Sketches and models may additionally serve the purpose of forming a protocol or logbook of the whole solution generation process, so that the early stages of the development path of ideas are accessible for future reference.
- The sequence of sketches and models is not only a thesaurus of ideas, but acts as a good basis from which to reveal the mechanics of one's own thinking by implementing a form of cognitive mapping procedure around the causal reasoning behind particular decision paths.

In addition to the benefits outlined above the designers task can be eased further by making calculations to check the performance of critical parts (Jones 1992). In utilising calculation procedures the designer is able to model and test a design concept before it has even left the drawing board. This means that the behaviour of a component, or set of components, can be simulated to a reasonably high level of accuracy and as such, allow evaluation to be undertaken in terms of expected performance, in addition to aesthetic quality.

3.8.4 The alternative design techniques

It has become increasingly apparent that the traditional design techniques mentioned above, which were the only real tools of the designer for a number of years, are not sophisticated enough (when used in isolation) to cope with the highly complex interactive design problems experienced today. As such, the design theorists set about creating and archiving a number of alternative design techniques, which were aimed at addressing more fully the changing face of the design industry as a whole. Authors such as Alexander (1963), Jones (1963), Archer (1965) and Beer (1966) advocated the use of alternative techniques to aid the designer in a world of growing design complexity. The majority of these new and alternative design methods were intended to enable the use of many minds during design activity (Jones 1992). The alternative techniques, which generally consist of a number of systematic procedures, are aimed at achieving specific goals throughout the differing stages of the design process.

Parker (1996) proposes several reasons why the implementation of the new and alternative design techniques into the contemporary design culture could prove to be beneficial:

- To allow increased numbers of options to be considered.
- To help facilitate teamwork.
- To aid in overcoming blocks.
- To reduce the cost of errors.

Cross (1989) reinforces these opinions, with his observations summarising the commonality of the nature of the alternative design methods. Cross states that two principle common features are apparent in all of the new design techniques available, one being that 'design methods *formalise* certain procedures of design', and the other being that 'design methods *externalise* design thinking'. This owes much to the fact that one of their main aims is to ensure that the designer does not overlook any factors that are key to design progression; thus avoiding the occurrence of oversight. Additionally, Cross suggests that 'the process of formalising a procedure tends to widen the approach that is taken to a design problem'. If the initial concept that comes

to mind is automatically chosen as the design solution, the probability that a number of more inventive solutions have been left unconsidered is vastly increased.

This point also relates directly to the second common feature of the alternative design techniques, that of externalising the thoughts and thinking processes of the designer, allowing them to be recorded explicitly in a number of ways i.e. in charts, matrices and diagrams. As Cross explains; 'This externalising is a significant aid when dealing with complex problems, but it is also a necessary part of teamwork'. This owes much to the fact that, in order for all the team members to contribute to the development of a design concept, the concept must first be transferred out of the head of the individual and reproduced on paper.

The alternative design methods tend to fall very broadly into two discrete groups; those that are creative and those that are rational.

The Creative Problem Solving Techniques (CPSTs)

Probably the most influential writer on creative thought is Edward de Bono (1967, 1969, 1986, 1992), who has generated many techniques to aid in the promotion of lateral thinking. Rickards (1980) has described these techniques as CPST's (creative problem solving techniques). According to Cross (1989), CPST's 'generally work by trying to increase the flow of ideas, by removing the mental blocks that inhibit creativity, or by widening the area in which a search for solutions is made'.

CPST's are sets of procedures that can be deliberately introduced as an attempt to stimulate novel and relevant ideas or solutions to problems during individual work or as part of a meeting (Rickards 1980). According to Rickards for a technique to be truly creative, it must meet the following criteria:

- The method should be of use primarily in the creative mode of thinking
- The method should prescribe certain steps that should be taken
- The processes used in the application of the method should be consistent with accepted concepts concerning the nature of the creative process

- Provision should be made for holding the judicial or analytical modes of thinking in abeyance while new ideas are given the chance to emerge and to be elaborated on
- Divergent thinking should be encouraged. Provisions for a wide range of solutions or ideas should be made
- Urgency should not be permitted to cause the immediate selection of the first solution. Time to toy with the concepts should be provided
- Enjoyment of the process should be encouraged and tolerated
- The methods should provide certain unique operational mechanisms that facilitate the production of new ideas
- There should be enough history behind the method for its utility to have been tested.

Appendix IV provides a brief listing of a number of creative design techniques.

The Rational design techniques

The rational design techniques encourage a more stringent and systematic approach to design activity. However, this does not mean to say that the creative design aids described previously should be considered the exact opposite of the rational techniques. In fact, 'rational methods often have similar aims to the creative methods, such as widening the search space for potential solutions, or for facilitating team work and group decision making' (Cross 1989), and therefore, creative methods and rational methods are complementary aspects of design (Jones 1992).

Many of the more creative designers are unsympathetic towards rational techniques, as they feel that they can constrain innovative thought (Jones 1992). Rational decision, it is argued, can be undertaken by a computer, and as such 'the picture of the rational, or systematic, designer is very much that of a human computer; A person who operates only on the information that is fed to him, and who follows through a planned sequence of analytical, synthetic and evaluative steps and cycles until he recognises the best of all possible solutions' (Jones 1992). However as Cross explains, 'this is a complete misunderstanding of the intentions of systematic design, which is meant to improve the quality of design decisions, and hence the end product'.

Appendix IV provides a brief listing of a number of these rational design techniques that cover all aspects of the design process.

3.8.5 Critique of the design techniques literature

For all stages and activities of the design process methods have been developed to support the designer solving the problems related to that specific stage or activity (Blessing 1994). However, Minneman (1991) has noted that the design methods theoreticians provide little, if any, evidence of using any form of observational technique in the derivation of these prescriptive methods. In fact, extensive discussion of the origins of the prescribed design methods is largely absent from their presentation in the literature (Synectics (Gordon, 1961) being a notable exception). Laying this point aside; of those methods that are prescribed, none could ever be described as being complete. It is apparent that the successful designer will always have to apply some degree of individuality, in terms of rationality and intuition, if any design problem is ever to be solved. The way in which the mixing of judgement and calculation is to be achieved depends upon the quantity of objective evidence available and upon the skill and experience of the individuals (Jones 1992). As such, it becomes apparent that the individual designer, or the design team members, must generate a design strategy that works for them, and ensure that it is integrated successfully into the design activity. Parmee (1996) has shown that there are several predominant problems in attempting integration of a design strategy into group design activity.

The proposed use of design techniques is aimed at harnessing the expertise of the entire team rather than simply that of a few of its members. However, it has been shown that there is no hard and fast combination of design techniques that will work for all designers, on all problems (Rickards 1981). Rickards has stated that, in order to create the optimum design strategy, a matrix should be created of 'techniques against problem types to suggest combinations in complex situations. Selection will be influenced by the nature of the problem, but also by the time available, degree of training, and size and composition of the group'.

Thus, for team working to be most efficient, a flexible design strategy in the form of a number of methods that seem most appropriate to the design problem as it evolves should be at the team's disposal. As such, a design strategy should comprise two things (Cross 1989):

1. A *framework* of intended actions within which to operate; and
2. A management *control* function enabling team members to adapt their actions as they learn more about the problem and its responses to their actions.

However, at present there is not enough known about the behaviour of designers, or design problems, to attempt an explanation of the effectiveness of certain techniques over others through observation or experiment (Jones 1992).

3.9 Concluding discussion

This chapter has described many facets of design from many differing perspectives. Initially, a number of the existing full phase models of design were discussed. Although these were very similar in terms of their general arrangement, it was apparent that the boundaries between the phases of the models were misaligned and distinctly fuzzy. However, this investigation served to identify the phase of conceptual design as described within the existing professional and academic literature.

Once identified, models of the conceptual design process were investigated and compared. It became apparent that the systematic engineering design models subdivided the concept phase into a number of sub-phases to be undertaken sequentially; whereas, the building design models (being far fewer in number) did not have any sub-phases mapped.

Additionally, none of the models of the building design process captured ways to help a new design team overcome the problems associated with collaborative working. This component of design activity is of major importance in ensuring that the vagaries of human interaction do not have adverse effects on the development of designs. A subsequent discussion of the role of teamworking in design highlighted that realistic

models of conceptual design had to account for the social, as well as the technical and cognitive, processes involved in design activity.

Additionally, none of the models of the conceptual design phase made explicit reference to techniques for stimulating a wider solution space, or to formal measurement, evaluation or assessment methods. Thus, in the penultimate section of this chapter, the design methods literature was reviewed. This investigation highlighted the benefits that could be gained from applying design tools within the teamworking environment. However, it was also made apparent that very few of these methods had been subjected to formal evaluation and as such, these benefits could only be asserted, and not fully substantiated.

Thus, to conclude, the investigations of the existing design literature described herein provided a datum from which the remainder of this thesis was developed. The following chapter describes the preliminary step in the development of an improved model of the conceptual design phase of building projects; an evaluation of methods for modelling design processes.

Chapter Four

Modelling conceptual design

4 Modelling conceptual design

4.1 Introduction to modelling design processes

It was stated in chapter 1 that one of the objectives of this research investigation was to gain an understanding of the ways in which conceptual design activity is undertaken by teams of today's building design professionals. There can be little doubting that the complexity of the building design process, both holistically and at sub-phase level, does not make this a simple task. Thus, it was apparent that, for anything more than a superficial overview of the conceptual design phase to be gained, the complexities of the design activity had to be simplified to some considerable extent. The generation of a model, which is, by definition, a simplified representation of a system or complex entity (*Oxford English Dictionary*), provided the ideal mechanism with which to achieve this.

This chapter investigates the applicability of existing modelling techniques as suitable means of generating descriptions of the conceptual design phase of building projects. These investigations involve: i) evaluating the existing modelling techniques available, ii) taking the most promising of these techniques and applying them, allowing models of conceptual design activity to be constructed; and iii) making a decision regarding the optimum means of delivery of the conceptual design model.

4.2 Structured modelling techniques

4.2.1 Introduction

Over the last 20 years several modelling techniques have been developed for use in either the structured analysis or structured design of complex systems. These are generally based on either charting or diagramming with the support of simple narratives and have been applied predominantly in the data processing industry. The basis of all of these techniques is that they provide a means of decomposing relatively complex systems into interrelated sub-elements that can be represented in the form of diagrams and text, thus making them far simpler to assimilate. It has been stated that modelling the information flows within a particular system or process will lead to a greater understanding of that process (Austin, Baldwin and Newton 1993a). These models can then be applied by designers to help avoid the careless processing of

incomplete or inaccurate information during the development of design solutions (Kraol 1983).

Many modelling techniques are described within the data processing industry literature, several of which appear to have the appropriate attributes to facilitate the modelling of the conceptual phase of the building design process. These techniques are: Directed graphs, Data flow diagrams (DFD), Entity relationship Diagrams, Hierarchical plus Input-Process-Output Diagrams (HIPO diagrams), IDEF diagrams, Jackson diagrams, Object-oriented modelling, and Petri-nets.

On further investigation of the applicability of these various techniques it became apparent that several were wholly inappropriate. These techniques and the reasons behind the unsuitability are described below:

Jackson diagrams

Jackson diagrams take the form of structured trees that indicate the relationships between various activities within a process or system. However, owing to the fact that the technique functions on the premise that the structure of a model corresponds to the structure of the information it produces (Brookes, Grouse, Jeffrey, Lawrence 1982), which is not always the case, the method, although potentially useful, is not commonly applied in practice (Waskett 1999).

Hierarchical plus Input-Process-Output Diagrams (HIPO diagrams)

HIPO diagrams were developed by IBM to allow the functionality of complex systems to be structured, and thus understood. In addition to inputs, processes, and outputs, the technique, which is represented by several components, provides details of the media on which they occur (Davis and Burk 1983). However, as each component of the technique is represented graphically within a model the number of diagrams required to describe a system or process are many; thus reducing the ease of which information flow within the system can be tracked. For this reason it must be discounted as a potential notation with which to develop the conceptual design model.

Object-oriented modelling

Object-oriented techniques enable representation of dynamic circumstances in terms of the processes that are performed and the nature of the data stores (Wang 1994). They are also capable of scheduling when timings are simulated within the processes (Waskett 1999). However, according to Sarshar (1993) object-oriented modelling techniques are in need of significant development before they are capable of dealing with the complexities of information flow within the construction industry *per se*, let alone the mass, transient flow which has been shown to be the case during the conceptual design phase. Consequently, they must be disregarded as a suitable modelling notation.

Having dismissed these techniques the suitability of those which remained had to be assessed. Thus, the rest of this chapter examines, evaluates and, ultimately, applies the most promising of the existing modelling techniques, in a bid to assess if modelling can be utilised to improve understanding of conceptual design activity.

4.2.2 Review of suitable techniques

The modelling techniques available all provide a means of undertaking structured analysis and design of complex processes. However, there are some differences in their appearance, application and use. These differences, although subtle, need to be recognised and understood in order to identify the optimum technique for modelling the conceptual design phase.

Directed graphs

Directed graphs can represent design processes as series of nodes (representing design activities) connected by the flow of information that occurs between them. A simple structure is shown in figure 4.1 below.

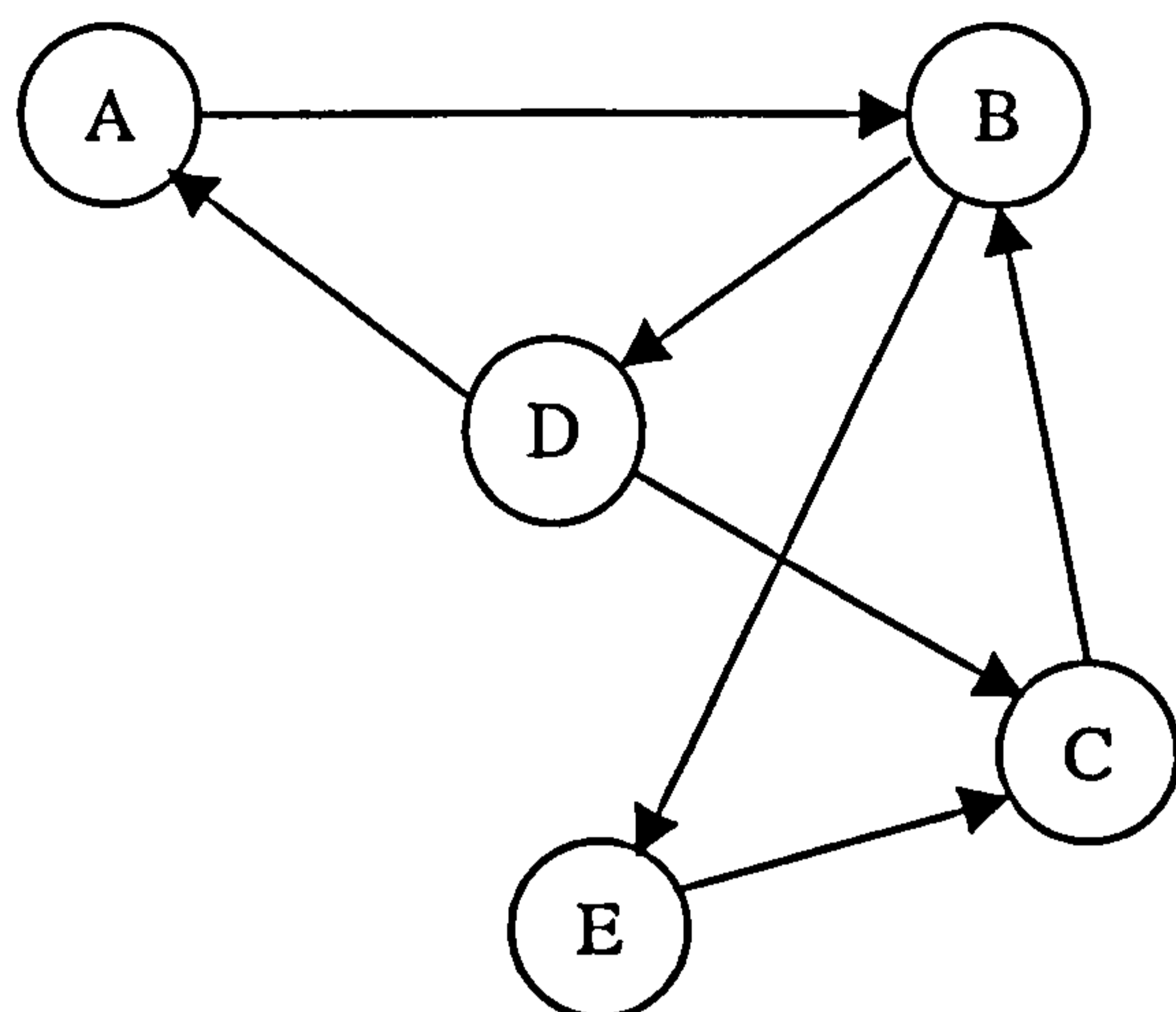


Figure 4.1 A five activity Directed graph

Although this technique does not portray details of the nature of the information flow, it does provide a graphical representation of the information dependency between certain activities. In this respect it is very effective as a means of understanding the iterative nature of design processes. However, the arbitrary positioning of the various activities means that the model cannot reflect hierarchical structure within a design process.

Data Flow Diagrams (DFD)

Data flow diagrams (DFD's), although similar in appearance to Directed graphs, differ in the fact that; i) they represent a hierarchy of activities; and ii) the information that is received and produced by the activities is made explicit within the models produced. Several methodologies exist (Gane and Sarson 1978, DeMarco 1979, Ward and Mellor 1986), which are all variations on a theme, with each containing the same basic elements of information flows (data), processes, files, and information sinks (see table 4.1 for the respective notations employed).


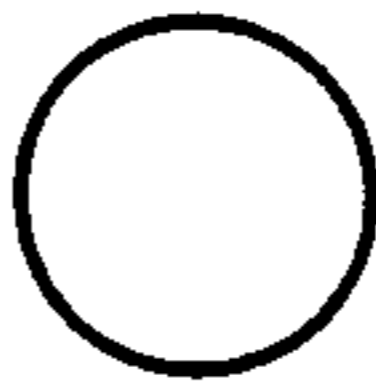
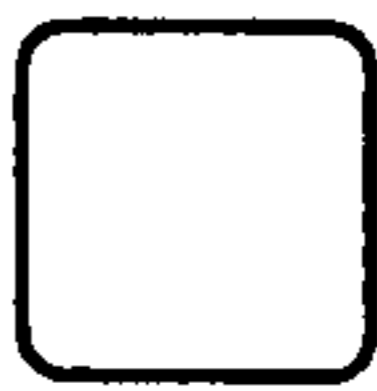




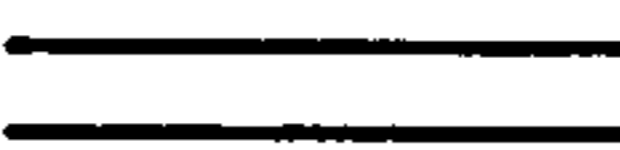
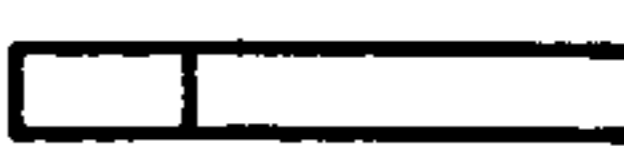

Symbol name	Description	flowcharting symbols	de Marco (1979) notation	Gane & Sarson (1978) notation
Activity or process	A function that the system carries out, transforming inputs into outputs.			
Information flow	Data in movement (arrow shows direction)			
Information file or store	Information or data at rest			
Sink or source	External entities with which the system communicates		Not used	Not used

Table 4.1 Symbols used in data flow diagramming (Bingham & Davies 1992)

DFD's facilitate the structuring of activities with respect to the information which flows between them. As such, they have been used extensively by design researchers (Hedges, Hanby and Murray 1993, Sanvido and Norton 1994, Newton 1995, Hassan 1996, Pabon 1987) for developing simplified representations of complex processes. Three significant characteristics make DFD's appropriate to modelling systems comprising of tasks and interfaces: i) they view systems from an information (data) perspective; ii) they treat each process or activity as a 'black box' which does not require a definition of the actual process involved; and iii) they are hierarchical in nature and allow 'top-down' analysis (Austin *et al.*, 1993b). It is this focus on the combination of the logical processes and data flows which makes the DFD such a powerful analytical tool (Bingham and Davies 1992).

Entity relationship diagrams (ERD)

ERD diagramming, or entity modelling, is a structured technique for generating graphical representations of the data used within an organisation and the relationships between that data (Bingham and Davies 1992). The ERD is used to model high level data and, as its name implies, depicts entities (the things we wish to store data about) and the relationships among them (Topper, Ouellette and Jorgensen 1994). Figure 4.2 (adapted from Newton 1995) describes the ERD notation and the various relationships that can be held between entities.

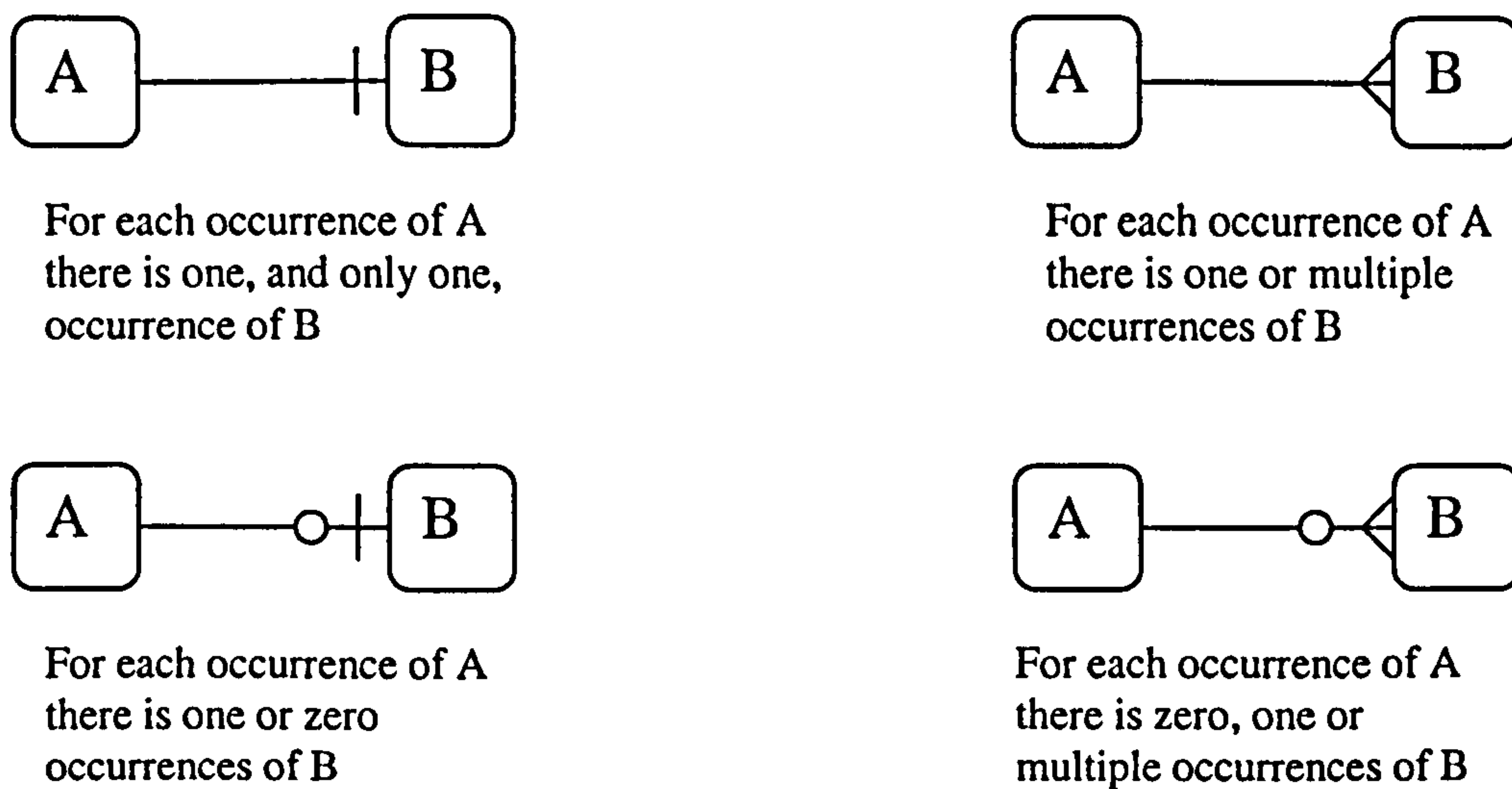


Figure 4.2 ERD notation and the various entity relationships

Owing to the fact that ERD's depict entities, as opposed to processes, they provide no means of representing information flow. Thus, the information dependencies between interdependent tasks or design options cannot be modelled and as such, ERD's must be considered inappropriate to modelling building design processes (Newton 1995).

Petri nets (PN)

PN's were developed in the early 1960s as a means of representing manufacturing processes graphically. The notation used in modelling the design process comprises a number of elements: i) Transitions – representing design activities; ii) Places – representing states of readiness; iii) Tokens – representing resources such as people, equipment, or design information; and iv) Arcs – indicating the direction of flow of sources through the process. The standard elements of the Petri Net are shown in table 4.2.

PN's, although not designed specifically for use in the building industry, are described as useful constructs in modelling construction processes (Wakefield and Sears 1997). PN's are a very useful modelling technique because of their power and flexibility.


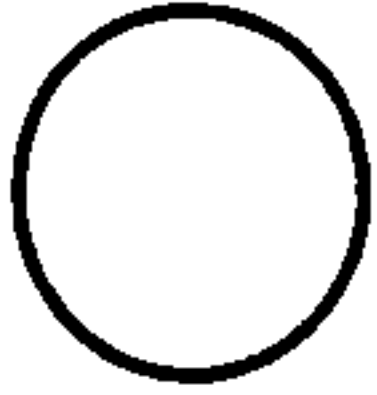


Element	Symbol	Description
Transition		An action or operation that changes the state of the system
Place		Indicates a state of being (e.g. a state of readiness)
Token		Resources required to undertake a transition (e.g. materials, information, etc)
Arc		Indicates the direction of tokens when a transition takes place.

Table 4.2 Elements of a Petri Net model

However, owing to the lack of hierarchy in their construct they can become cumbersome when applied to large complex problems (Waskett 1999).

Structured Analysis and Design Technique (SADT)

Ross and Schoman (1977) developed SADT in the mid-1970s as a mechanism for analysing manufacturing in a bid to improve productivity. SADT allows the rigorous expression of high level ideas, a factor which is of major importance in the areas of problem analysis, requirements definition and functional specification (Ross 1985). The technique was adopted, and subsequently developed, by the United States aerospace industry, where it was renamed the Integration definition language for function modelling (IDEF or IDEF0).

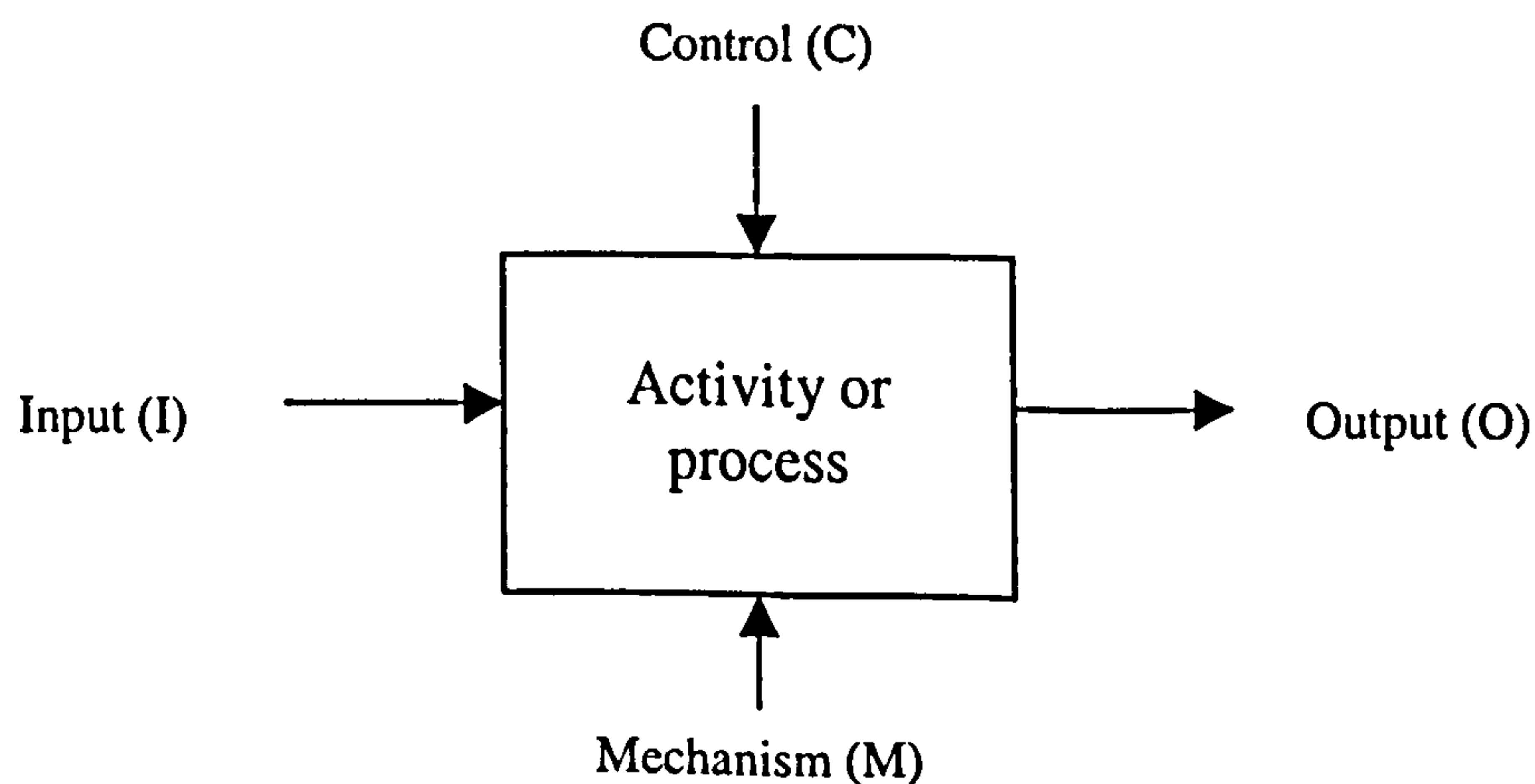


Figure 4.3 Standard IDEF0 notation

IDEF0 models comprise a hierarchy of related diagrams; each based on a diagonal row of boxes (activities) connected by a network of arrows (information or object relationships). The direction of entry of an arrow into a box designates the information type (see figure 4.3 for standard notation). Each box within a diagram has a node reference which designates its relationship in the hierarchy of the diagram. The reader is referred to Colquhoun, Baines and Crossley (1993) for a comprehensive review of the IDEF0 technique.

Austin, Baldwin, Li and Waskett (1998), after attempting to apply the technique to building design problems, made some modifications to the notation in order to enhance its use.

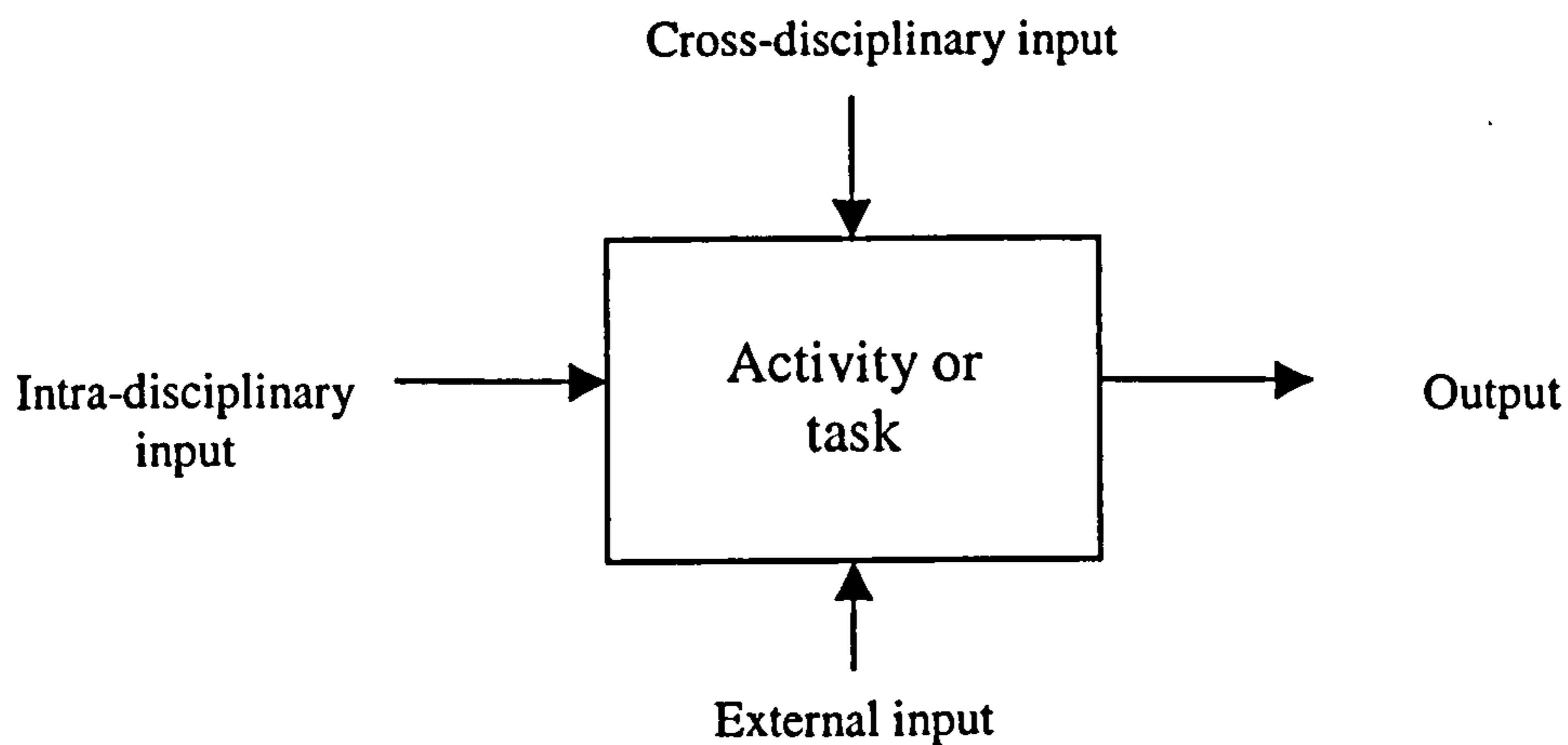


Figure 4.4 IDEF0(v) notation

It was discovered that, in the design of buildings, it was more beneficial to distinguish between information inputs in terms of activities in the same discipline, those in other disciplines, and those originating from external sources (Austin *et al.*, 1998). This variation on IDEF0 has been named IDEF0(v). The IDEF0(v) notation is illustrated in figure 4.4.

4.2.3 Evaluation and choice of modelling techniques

In the preceding section the most promising of the existing modelling techniques have been described and investigated in a bid to assess their applicability to modelling the conceptual design phase of building projects. Each technique has certain advantages and/or disadvantages in particular scenarios. The techniques must now be compared as a means of evaluating and choosing the most appropriate to apply. Table 4.3 below

describes a previous comparison of techniques undertaken by Court, Culley and Macmahon (1996).

Modelling techniques	Engineering information components requiring modelling											Model features					
	Process activity	Input/output – role in activity	Transforming elements – role in activity	Transforming elements - structure	Show interrelationships between entities	Hierarchical breakdown	Represent information transfer mechanisms	Represent information storage mediums	Represent information storage locations	Represent communication mediums	Represent format of design information	Aid clear thinking	Aid computer manipulation	Readable by user	Provide a basis for communication	Ability for ease of drawing	Consistent notation
Directed graphs	Y	Y	Y	Y	Y	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y
Data flow diagrams	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
IDEF0	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	Y	Y	Y	Y	Y	Y
Entity relationship diagrams	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Petri-nets	Y	Y	Y	Y	Y	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y

Table 4.3 Comparison of modelling techniques (Adapted from Court *et al.*, 1996)

As can be seen, although each technique is applicable, the comparison undertaken by Court *et al.* suggests that the most appropriate techniques for modelling *per se* are Data flow diagrams and Entity relationship diagrams. However, ERDs, as has been described previously, do not facilitate the modelling of interdependent tasks or design options and must therefore be discounted as a means of modelling building design processes (Newton 1995). Petri-nets, although meeting many of the required criteria, must also be discounted owing to their inability to represent complex systems (Waskett 1999) and information flows (two intrinsic components of the conceptual design process). As such, three suitable structured modelling techniques remain: Directed graphs, DFDs and IDEF0 models.

The remainder of this chapter discusses: i) the data gathering strategy employed to enable construction of models of interdisciplinary conceptual design activity; ii) the manner in which the three techniques were utilised to model the conceptual design processes based on the data collected; and, finally, iii) an evaluation of the appropriateness of the techniques for developing a generic model of conceptual

design. The following section describes the first of these elements: data gathering within a case study project (chapter 2, section 2.4 provides details of the methodology applied).

4.3 Data gathering: Direct observation case study and interview

4.3.1 Strategy

Case studies are most commonly utilised in topics involving decisions, organisations, and processes. They provide a perfect means of obtaining a clear contextual insight into the complexities of processes (Voyatzaki 1996) as they allow detailed descriptions of activities and interactions to be produced. The Case study can comprise several techniques for gathering evidence. In this particular case direct observation and systematic interviewing were employed, supplemented by an additional information requirements table, as will be described in section 4.3.4, which allowed a wider variety of evidence to be dealt with, i.e. documents, artefacts, interviews and observation.

4.3.2 Direct observation

The first step in the data gathering involved the direct observation of an interdisciplinary team during the conceptual design of a large office development. The author was present at each of the design team meetings in a bid to record activities, information transfers and decisions in note form. This note-taking was supplemented with audio-taping. However, owing to the level of confidentiality that the project demanded, these were transcribed on site, with the tapes themselves never actually leaving the building. Additionally, members of the design team were shadowed intermittently over the duration of the conceptual design phase. Historical analysis of the design activity was also undertaken once the conceptual phase of the project was complete. This involved the investigation of meeting minutes, completed documentation, and drawings, all of which served to reinforce the live observations.

As the aim of this phase was not only to gather enough information to apply one of the modelling techniques, but also to gain a deeper understanding of the mechanics of conceptual design activity *per se*, the observations allowed the generalities of the phase to be obviated. These features are outlined below:

- Design proposals of the individual disciplines tend to be compromises rather than designs to ensure optimisation of the overall design strategy. In general, the architects appear to drive the initial designs.
- Experiences and pre-conceptions are used as starting points for the generation of design solutions. These are then challenged and transformed to suit the problem at hand. An observation reinforced by Robinson (1986).
- Designers do not appear to follow any rigid sequence of design decision-making procedure at the conceptual design phase. Lera (1982) elaborates on this, stating that, in addition, designers are 'unlikely to find acceptable any rigid process during the conceptual design phase'.
- The flow of information between designers appears to be unstructured, if not chaotic. Ideas, thoughts and assumptions are externalised rapidly, resulting in mass information flow, and doubtless loss of important concepts. In this respect the observations matched those of Newton (1995) who found it impossible to track the flow of verbal and informal information transfer at the conceptual design stage.
- Teams tend not to record formally the progression of their design decisions in detail, preferring instead to trust memory to stop them taking the same decision-loops time and time again.
- Designers tend to focus on specific parts of the design problem in detail, while ignoring other parts for extended periods of time. This does not appear to adversely affect the team's progress.
- Designers tend to reflect on their own, or others, previous experiences of similar design problems, as a means of developing design solutions. This occurrence avoids 're-inventing the wheel' time and time again.
- Designers use few, if any, design techniques. Those that are used are applied in an unstructured manner. There was minor use of sketching during the session, and checklists were apparent throughout. These were the only design techniques as such that were used.

4.3.3 Systematic interviewing of the design team members

The interview as a research tool is very flexible as it can deal with a variety of subject matter at different levels of detail and/or complexity depending on the methods implemented for the data analysis (chapter 2, figure 2.1 provides a graphical representation of the interview environment).

When studying the role of situations in human behaviour, the gathering of several individual interpretations of events is highly important, as these can vary dramatically between players (Argyle, Furnham and Graham 1981). Thus, each member of the design team was interviewed individually with respect to the processes followed, techniques implemented, and social interaction undertaken, during the course of the conceptual phase of the project. Although this multiple-interviewee approach can lead to contradictions in perceived occurrences, it was undoubtedly the optimum means of gaining an overall understanding of the project from an internal perspective.

4.3.4 Determination of tasks and information requirements

As has been described above, the systematic interviewing of the design team members allowed the respective disciplinary tasks within the overall conceptual design process to be identified and recorded. The next stage of the data gathering exercise involved collecting details of the information required to enable the designers to perform these pre-defined tasks. In section 4.3.2 it was stated that it was almost impossible to track the flow of verbal and informal information transfer during real-time design activity. As such, an alternative methodology was applied as a means of gathering the relevant information. This methodology, described in some detail by Austin *et al.* (1998), was well tested, having being utilised previously to gather data during investigations of both the scheme design (Pendlebury 2000) and detailed design (Waskett 1999) stages of building projects. The methodology comprised two stages: i) the identification of the conceptual building design hierarchy and tasks, and; ii) the determination of the information requirements of the respective tasks. These individual stages are described briefly below (the reader is referred to Austin *et al.* (1998b) for a detailed description of the methodology in its entirety).

Identification of design hierarchy and tasks

During discussions with practising design professionals it was discovered that design activity *per se* (i.e. across all phases of design) is seen as a number of processes and sub-processes which can be regarded hierarchically. Although this has been proven to be the case in the later phases of design (Waskett 1999), it is a hypothesis which has not yet been tested at the conceptual design phase. Thus, through a number of structured interviews with a full compliment of building designers, a hierarchy of activities was established which represented the processes undertaken within the conceptual design phase. The structure of the hierarchy, an example of which is provided in figure 4.5, represents individual disciplines at the highest level, and partitions down into systems, sub-systems and then components.

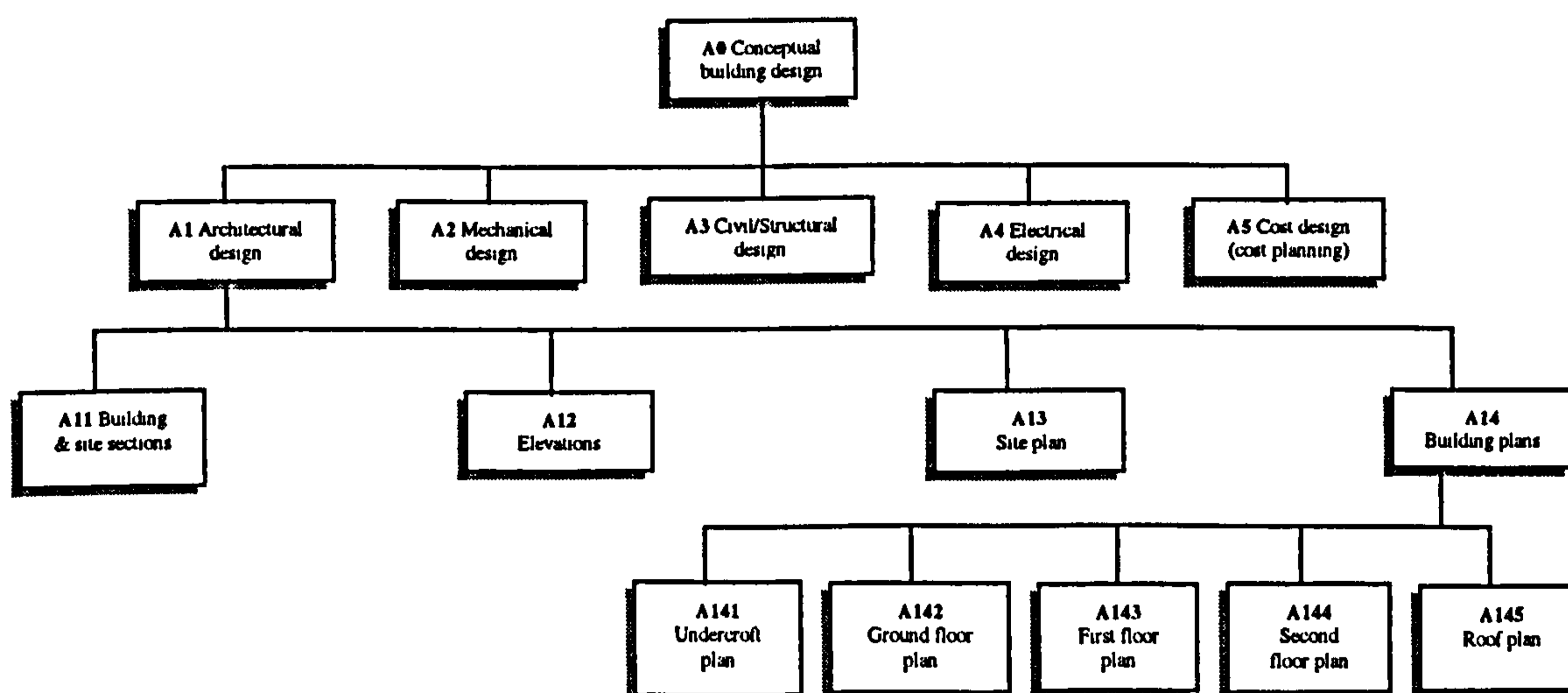


Figure 4.5 A section of the conceptual design building process hierarchy

The project designers verified the diagrams by checking them for internal consistency. Once the integrity of the hierarchy was confirmed, designers who had not been involved within the project on which the model had been based were asked to validate its structure and components. Typically these checks lead to only minor, if any, changes being introduced. Once complete, the hierarchy represented a web of entangled tasks and as such, the next step in the methodology involved making explicit the interconnectedness of the discrete tasks in terms of their information dependencies.

Determination of information requirements of tasks

It has been stated previously in section 4.3.2 that it was impossible to track the flow of verbal and informal information transfer at the conceptual design stage.

DESIGN TASKS		INFORMATION REQUIRED		TRANSFER OF INFORMATION	
Name of overall deliverable to be produced	Names of Sub-deliverables	Information required to generate deliverable	Source of that information	How was the information transferred	Was the transfer formally recorded

Table 4.4 Data collection table

Thus, a simple data table was utilised to gather the information requirements of each of the tasks. These data tables (a typical example of which is shown in table 4.4) were allocated to each of the designers working on the observation project. The designers were asked to record details of design tasks, the information required to allow them to undertake the respective tasks and finally, the nature of the transfer mechanism. Once this data had been gathered, each of the techniques outlined as applicable to modelling the conceptual design process were applied. The details of this modelling are outlined in section 4.4, while the findings and conclusions are described in section 4.5.

4.4 Model generation using the respective techniques

4.4.1 Directed graphs

The model shown below in figure 4.6 provides a detailed representation of the conceptual design process undertaken during the observation project.

This model indicates how the design activity undertaken during the conceptual phase of a building project relies on the mass flow of information between all stakeholders. It is apparent that modelling this flow using the directed graph technique produces a number of tasks with numerous information arrows representing levels of interdependence. This type of model describes the phase wonderfully, but it is of little use in allowing the designer to gain a further understanding of the dynamics of the

interaction or the design processes involved in the conceptual design phase. Likewise, a model of this nature does little, if anything, to identify the phases and sub-phases which define the process.

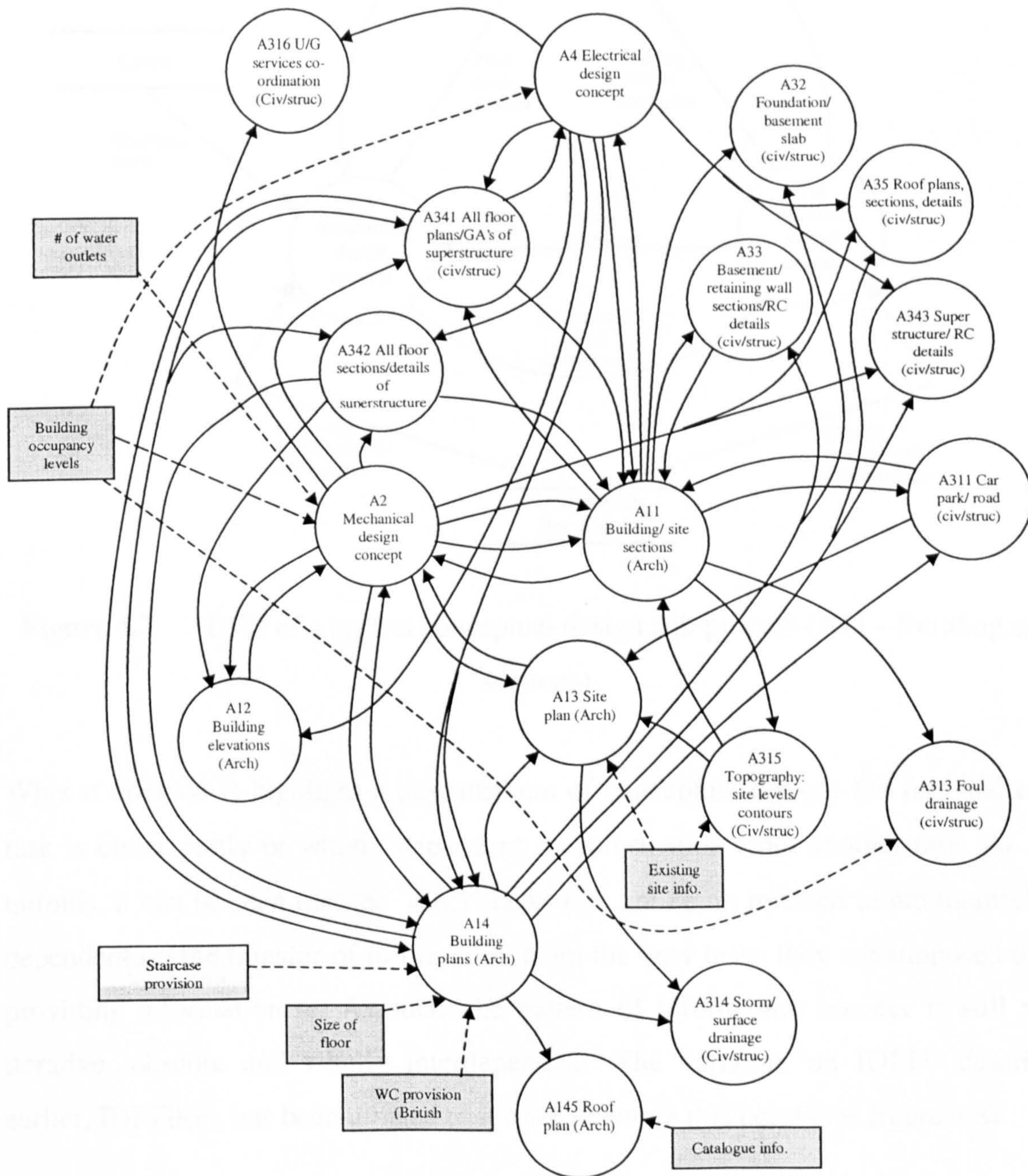


Figure 4.6 Section of directed graph of interdisciplinary interdependence of A0

4.4.2 Data Flow Diagrams

In referring to the Data Flow Diagram (DFD) in figure 4.7 it can be seen that this type of model does simplify the process to such an extent that it becomes understandable. However, like the directed graph, it does not allow the conceptual design process to be understood at its basic level.

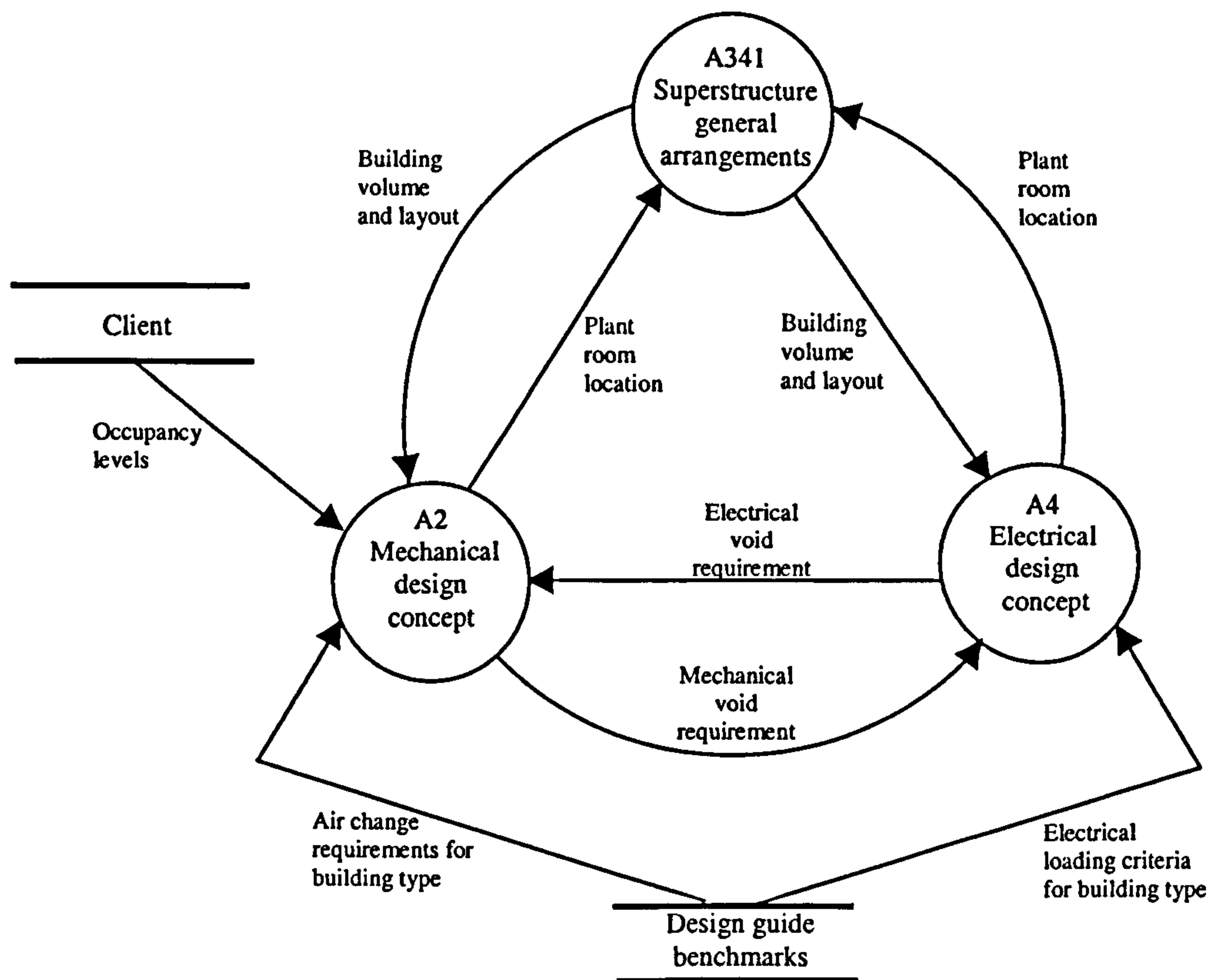


Figure 4.7 DFD of a typical conceptual design sub-process (A11 - Building site sections)

What it does do is highlight a key attribute of conceptual design: the fact that each task is either partly or wholly dependent on information from another task. As this unfolds, it can be seen that the 'other' tasks that are being referred to are themselves dependent on the transfer of information from the very tasks they are supposed to be providing information to. As such, the pattern of information transfer is still very iterative, obscure and wholly interdependent. The variation on IDEF0 described earlier, IDEF0(v), has been utilised to further illustrate this point (see figure 4.8).

4.4.3 IDEF0 (variant)

As can be seen from figure 4.8, the IDEF0(v) technique, when compared to directed graphs and DFDs, does improve the readers understanding of the hierarchical structure of the concept design phase. However, rather than it allowing the generalities of the phase to be obviated, it merely reinforces the earlier observation of the interdependence of the various activities, and the iterative nature of the phase in general.

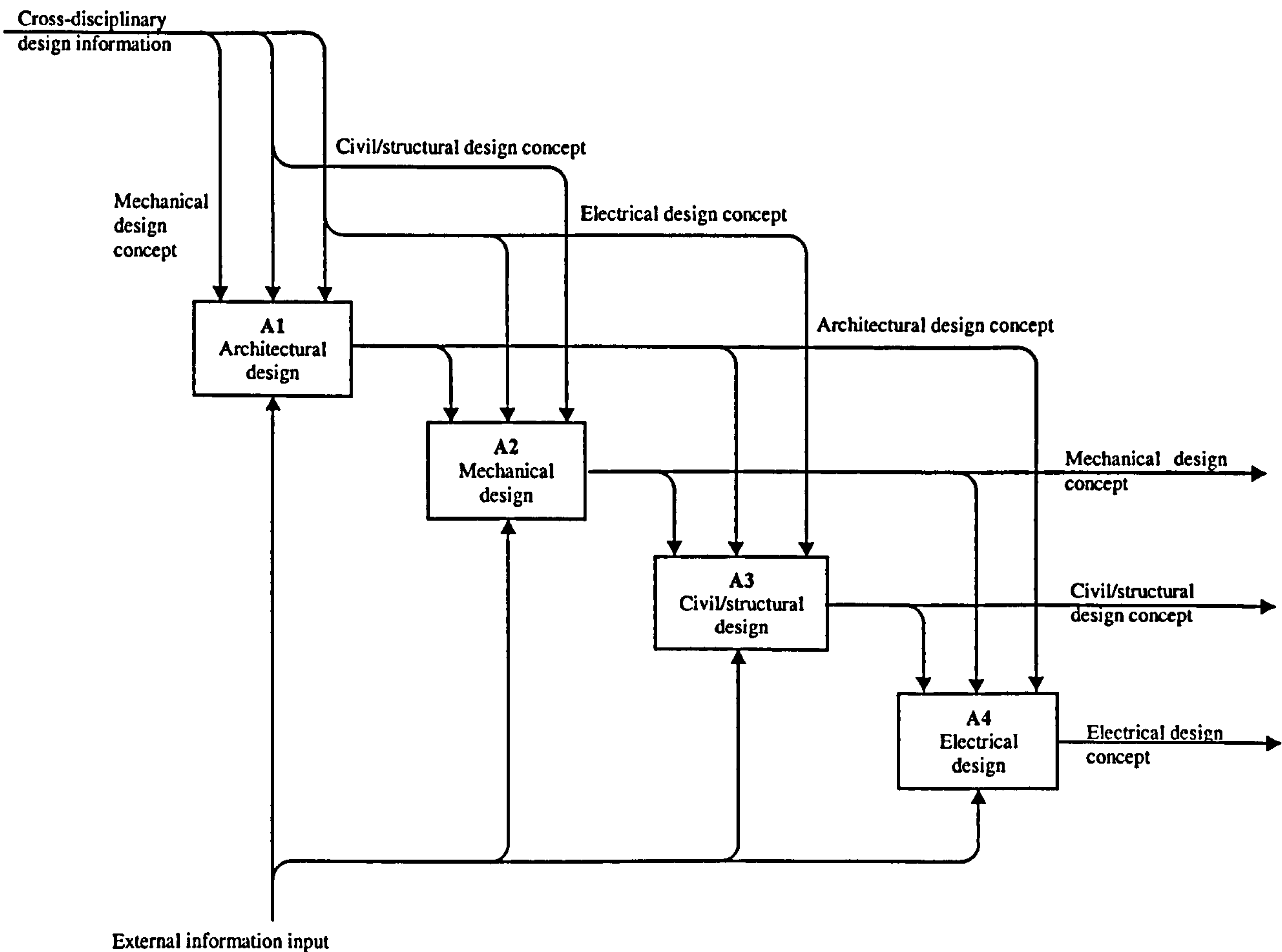


Figure 4.8 IDEF0(v) model of interdisciplinary interdependence A0

The IDEF0(v) technique makes explicit, in a far more structured manner than the other techniques, the relationships between sub-elements of the process – figure 4.8 makes it clear that a number of internal interconnections rest within a higher level of interdependency - and the hierarchical nature of their connectedness. As such, within the concept design phase it must be concluded that although IDEF0(v) is the most promising of the structured techniques, it is more appropriate for describing the intricacies of the interaction, rather than allowing a basic understanding of the sub-phases of conceptual design activity to be gained.

4.5 Conclusions

4.5.1 Observations from the models

In referring to each of the models there is a key point that is very conspicuous by its absence: the fact that few of the designers who provided the information stated that there was any information transfer within their own individual discipline. Thus, where

such flows of information can be seen (in figure 4.6) the author has assumed that some flow must have occurred in order for the second task to be accomplished.

Upon contemplation, considering the nature of the phase, this is not as surprising as it appears. Designers tend to work either individually or as co-ordinators of the work of a single designer within their own discipline during this period of design. Given this scenario, there will be no formal (tangible) transfer of one piece of information in order for another element of the design to be produced (an activity that we know must occur in order for the interdependent deliverables to be produced). Within the context of this case study investigation it is the author's suggestion that this transfer of information is not referred to owing to the fact that it takes place within the mind of the designer in question and is thus intangible, i.e. it is not passed using any formal/tangible medium. This difficulty in making the intangible, tangible owes much to the fact that designers are forced to treat as real ideas that live only in their imaginations and subsequently identify ways in which those ideas may be brought into existence (Jones 1992). This activity is in effect an iterative decision making process that is undertaken rapidly, sometimes instantaneously, in the mind of the experienced designer, i.e. at a cognitive level.

This would suggest that, even though the information flows depicted in the models are already vast, they only represent a portion of the actual information transfer that occurs. Thus, all that is represented in this type of model are the processes involved once the concepts of the individual designers have been filtered internally and then externalised. As such, several key phases of actual design activity will be inevitably disregarded from any model generated using one of the previously mentioned modelling techniques. Thus, for a model of the conceptual design phase to be generic it must be applicable at a cognitive, as well as a project, level.

4.5.2 Nature of the model of conceptual design

It cannot be doubted that the unstructured mass flow of information should be encouraged to ensure that the design has gained optimum input from all design stakeholders. However, the key to optimising time spent on design conception is to ensure that this activity is promoted during specific phases of conceptual design only. Mass information flow and iteration undertaken across specific phases of design

activity are key factors in achieving optimum solutions. Those models generated using the very structured techniques outlined here are valid and realistic representations of the conceptual design process. Unfortunately, they do not appear to be particularly helpful in aiding the interdisciplinary design team to align and synchronise their design processes. It is apparent that the tasks comprised within the models are correct and appropriate, and as such will be taken forward to enable derivation of the model (see chapter 5). However, the flow of information between tasks, which in this model is specific to the project from which the data was gathered, is ephemeral and, although there is some structure to the connections (as will become apparent in chapter 6), can change considerably between projects. Again, this is not detrimental to the design process as, even though the same tasks can be connected by differing information flows during the conceptual design period, equally valid proposals can be delivered irrespective of the sequence in which the tasks are addressed. As such, it must be concluded that the structured techniques described are appropriate to modelling the later design phases, which, by the very nature of the information flow, have a highly detailed structure. However, although the flow of information is equally vital to all stages of design, the fact that it is so vast, chaotic and transient during the conceptual design phase means that representing it in a structured manner simply over emphasises its complexity. Thus, the chaotic nature of the information transfer, which is integral to the development of ideas and concepts, cannot provide the basis of a useful model of the conceptual design phase.

Thus, the next stage of the research, which is described in the following chapter, focused on the collection of details of the high level activities of conceptual design rather than details of the information flows that inter-connect them. As will be described in chapter 5, this approach enabled the development and verification of a model of conceptual design to be achieved.

Chapter Five

**Development and verification of a generic model
of the conceptual design phase**

5 Development and verification of a generic model of the conceptual design phase

5.1 Introduction

The objective of this phase of the research, as described in chapter 2, was to gather information on how conceptual design activity is actually undertaken by practising interdisciplinary design teams in order to generate a preliminary design model. The purpose of producing the model was to allow the conceptual design phase to be simplified to some degree, allowing the details of design activity during this period to be represented graphically, thus making them simpler to understand in a rational manner. The initial case study, which has been outlined in the previous chapter, served as a pilot study, its purpose being to obviate the level of detail which had to be explored to allow a meaningful and genuinely useful model of conceptual design to be developed. The conclusions from this study emphasised the fact that it is unrealistic to use the vibrant and chaotic nature of information exchange as the basis of a model of the conceptual design phase. As such, it was decided that the data gathering should focus on the collection of high-level design activities rather than details of their interconnectedness. For this, several recognised methods of data gathering were utilised: i) historic case study; ii) the analysis of available archived documentation where appropriate and; iii) an experimental session in the form of a designing together workshop. This chapter describes the first two of these data collection methods in detail (the third being detailed in chapter 6) and the subsequent development of a generic model of the conceptual design phase of building projects.

5.2 Methodological considerations

5.2.1 Introduction

The conceptual stage of the design process is particularly difficult to specify because its phases cannot be described as isolated activities. Instead, they represent clusters of different activities that are performed during periods of design progression. Additionally, the way in which activities are described is highly ambiguous, with individuals from various disciplines using a variety of terminology to recount the same occurrence. However, although any attempt at collecting data relating to the conceptual design process can be both a difficult and time-consuming task, the research interview is recognised as an effective means of data collection in the field of

social science. To this end, a number of designers and 'Design Team Leaders' (DTLs), representing a full compliment of disciplines from six construction industry organisations (collaborating organisations), were interviewed about how group design activity had been undertaken on previous projects. Although the handling of this type of verbal data response is fairly difficult, the interview provides a means of gaining a detailed understanding of a social situation; a factor which owes much to its flexibility in dealing with a variety of subject matter at different levels of detail and complexity (Brenner *et al.*, 1985).

5.2.2 Systematic interviewing

The technique of open-ended, systematic interviewing was utilised for this observational exercise based on details extracted from the literature survey regarding group design activity. The reader is referred to sections 2.4.5 (figure 2.1) for details regarding the interview approach and the interview environment. Open-ended interview responses were followed up by structured questioning to extract further information regarding particularly fuzzy areas of the described design activity. The interviews were recorded in note form. However, to ensure that details were not lost during the course of the interview, the note taking was supplemented by audio-taping.

The interview as a method for gathering qualitative data has both strengths and weaknesses in field research (see section 2.4.5, table 2.2 for details). One of its main flaws is that it is not a real time analysis technique and as such, results can be biased owing to the fact that descriptions tend to become over simplified, representing the interviewee's subjective perception of the proceedings rather the idiosyncratic activities of design that actually took place. However, as the purpose of this phase of the project was to gain a general understanding of conceptual design activity in practice, in order for any high-level generic elements of the phase to be distinguished, this factor was not seen as being detrimental to the validity of the findings.

Over the course of this period of the research nine case study investigations were undertaken (section 5.3.1). These inquiries, which involved interviewing a total of 30 design professionals, focused primarily on the examination of design activity during the conceptual design phase of the projects. However, owing to the fuzziness of the boundaries between the early phases of design, there was, inevitably, some overlap

between them. As such, it is important to note that the term ‘conceptual design phase’ was never used in the interview sessions as it was felt that this title did not represent the same period of design activity for all individuals. Instead, the interviewer stated that the design period being investigated started as soon as a decision was made that the business need could only be fulfilled through construction, and ended at the point when the client's preferred concept(s) were signed off for further development.

5.2.3 Archive analysis

To support the information gathered during the interview sessions, the author was given access to archived data. This data, comprising various types of documentation such as meeting minutes, early design drawings, project design notes and concept design reports, had been generated over the course of each of the respective case study projects. The collection and subsequent analysis of the accumulated documentation, which amounted to over 40 individual documents, together with the information gathered during the interview sessions, allowed the elements of team design activity to be recorded in reasonable detail. Additionally, the documentation proved important as a means of confirming the reasoning behind the progression of activities described by the interviewees.

5.2.4 Designing Together workshop

During the course of the case study period an experimental session was held, which took the form of a ‘Designing Together’ workshop in which the real-time conceptual design activity of three individual teams was observed and recorded as they worked on an artificially constructed design problem.

The workshop, which involved fifteen participants from a leading multi-disciplinary practice, involved the design of a window façade system for the re-cladding of 1960s office buildings. During the design exercise detailed notes were made with regard to both the manner in which the teams progressed and the activities and phases that were undertaken. These observations were later used to develop detailed maps of the design progression of each team (chapter 6, figures 6.2 - 6.7). Additionally, upon completion of the exercise, each team was asked to describe the manner in which they perceived they had progressed through the design activity. The data, as will be described in section 5.3.3, assisted in the development of the preliminary model (figure 5.5). This

period also served to both enhance and verify the case study findings. Full details of this, and a second similar workshop which served to validate the findings, are provided in chapter 6.

5.2.5 Type of modelling approach

A choice needed to be made as to the most appropriate modelling approach to utilise in developing the preliminary design model. The investigation of available modelling techniques (chapter 4) concluded that structured representations of design activity based around information flow between tasks at the conceptual phase were overly complex and cumbersome. However, by representing only discrete sections of the information flow between tasks rather than the whole, design activity could be simplified. Unfortunately, once reduced to this level the models become fragmented and as a result, provide little, if any, understanding of the sub phases through which the design activity should progress. However, the observations made during both the case study and experimental investigations, as will be described in section 5.3, highlighted the fact that generic activities, representing the objective of performing a cluster of tasks, were apparent across the projects. Bearing these factors in mind, three modelling approaches were considered: project specific, global, and categorical.

Project specific

A project specific approach would require the collection and archiving of models from individual projects, which would then be referenced and examined as a means of predicting and defining the tasks involved in a project of the same type. This type of approach has both advantages and disadvantages:

Advantages

- True and accurate representations of previous projects can be generated.
- A store of these projects could be generated from which the most applicable could be chosen as a basis for predicting design activity in future projects of a similar nature.

Disadvantages

- To produce models of all permutations of all projects likely to occur in the design of a building would be both time consuming and unrealistic (Newton 1996).
- Large parts of each model would be similar with only small differences distinguishing individual models. However, there would be differences and these would have to be accounted for.
- Projects evolve from the unique environments in which they are developed and are a result of the personalities of the participants and the social conditions. As such, applying a specific model of a successful project to a new environment would not guarantee a successful result.

Global

A global approach would involve representing all possible design occurrences on all types of building design project in a universal model. The major advantage of using this approach is that a new project could be represented by simply removing those elements of the model that were not applicable to the particular project at hand. However, this approach too has a number of recognised disadvantages:

- It would be practically impossible to represent all possible eventualities that could occur during the course of the conceptual design phase of all projects. This owes much to the fact that the conceptual design phase cannot be viewed as a history of various responses to one and the same problem but as the history of a problem which is evolving and whose solution is changing with it (Eaton 1998).
- The model would be awkward and unmanageable, possibly with large parts being redundant for each proposed project (Newton 1996).

Categorical

A categorical approach would involve the development of a tool kit model comprising two basic elements: i) a standard framework describing the various phases that are generic from one project to the next; and ii) at the lowest level, it would provide a structured set of activities. This level of the model would enable project specific knowledge, data and models to be stored rationally. This type of approach allows flexibility and adaptability to particular types of project, client, and design

environment while offering a structure to which project specific sub-models can be connected. As such, this type of approach has several distinct advantages over both the project specific and the global approaches:

- It would allow sub-models developed using the structured modelling techniques to be integrated into the wider picture and their interfaces to be aligned across the generic phases.
- It would describe the phases of design activity that will be undertaken by the design team, albeit at a high level of abstraction, without constraining the manner in which they are undertaken.
- It structures the conceptual design period without over systematising the details of the actual design activity involved.

Nevertheless, this approach also has a recognised flaw:

- The user must generate sub-models of design activity and insert them into the framework if an increased level of detail is required. As such, the users must generate their own project-specific models as described above.

However, considering the above factors, the categorical, or tool-kit, approach was chosen as the most suitable means of developing the preliminary model of the conceptual design phase. For the purposes of this investigation a model is defined as a simplified representation of a system or complex entity, while a framework is defined as a structural plan or basis for a project. Owing to the nature of this type of modelling approach it was considered appropriate to classify the product as a framework rather than a model: with the framework being a structure in which project specific models can be located. From this point forward the product will be defined as a framework.

5.3 Development of the preliminary framework

5.3.1 The case study projects

Nine projects were examined during this research period in order to gain an appreciation of the similarities and differences in the tasks undertaken during the conceptual design of buildings.

The case studies represented an investigation of the ways in which differing factors can influence the activities involved in the conceptual design process. These particular projects, which are described and contrasted in table 5.1, were chosen specifically to ensure that such variables as i) type of building; ii) client; iii) time periods for phase completion; and iv) cost, were accounted for.

As can be seen, the projects varied in a number of ways. This variance in the nature of the projects was seen as being beneficial to the research as it ensured that a realistic cross-section of design approaches was considered. However, the nature of the projects available for study was constrained to some degree by the fact that there were only six industrial collaborators directly involved in the research.

Project	Project type	Client type	Phase duration	Building cost (budget)	Method of study	No. of tasks described
A	Airport pier	Airport authority	12 weeks	£21.5m	Interviews; Archive analysis.	36
B	Airport terminal (refit/extension)	Airport authority	12 weeks	£51m	Interviews; Archive analysis.	41
C	Airport terminal (refurbishment)	Airport authority	8 weeks	£12m	Interviews; Archive analysis.	30
D	Office building refurbishment	Pharmaceutical organisation	6 weeks	£16.7m	Interviews; Archive analysis.	32
E	Laboratories, offices (new build)	Pharmaceutical organisation	20 weeks	£137m	Interviews; Archive analysis.	58
F	Laboratories, offices (new build)	Pharmaceutical organisation	12 weeks	£30m	Direct involvement; interviews; archive analysis.	40
G	Corporate offices (new build)	Property developer	8 weeks	£28m	Direct observation; systematic interviewing; archive analysis.	42
H	Operations centre	Rail company	5 days	£20m	Interviews; Archive analysis.	27
J	Production facility/ office headquarters	Private client	2 weeks	£2.5m	Interviews; Archive analysis.	45

Table 5.1 Comparison of case study projects

5.3.2 Observations from case study data

The various sources of data, relating to each case study project, were compiled and cross-referenced. A synopsis of each case study was generated, in addition to a list of the design tasks that were involved in each of the respective projects – an example of which is provided in figure 5.1 below.

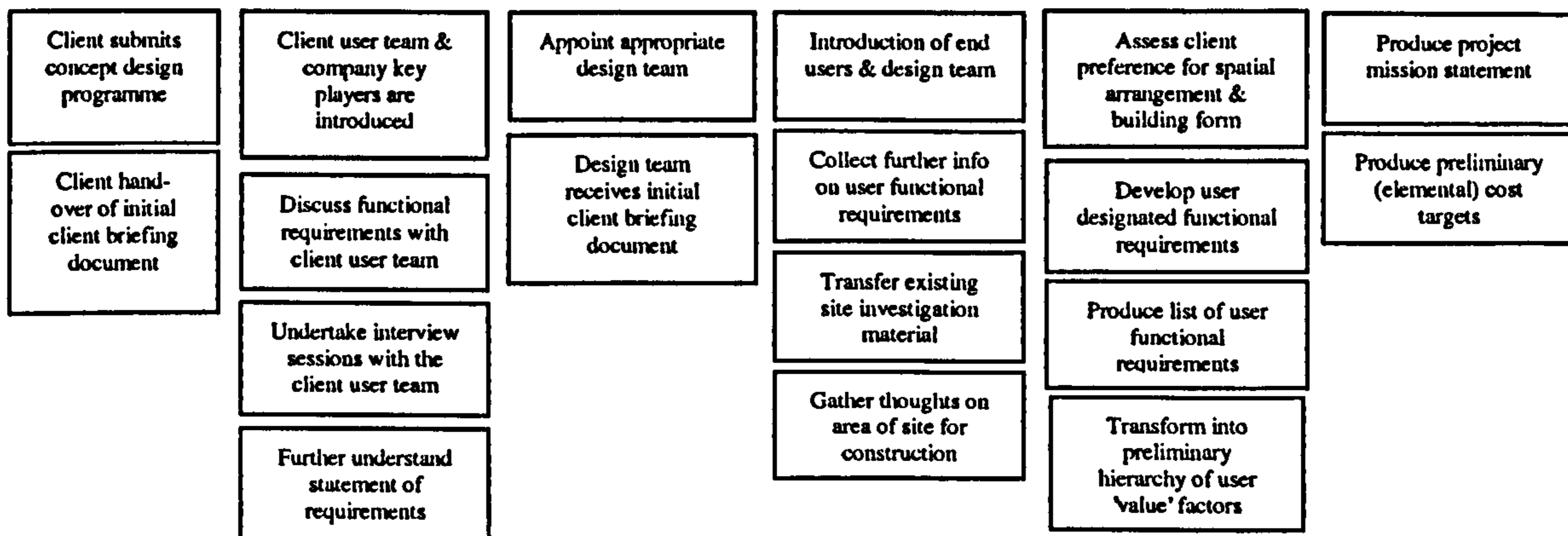


Figure 5.1 Section of task list from case study E

Subsequently, each of these documents were passed to those individuals who provided the information for verification of data. In this manner, errors in the descriptions were highlighted and amended quickly and efficiently. This procedure allowed the generation of a robust and detailed description of the various design tasks involved during the conceptual phase of each of the projects. This allowed a number of general observations to be made, the most germane being:

- There was a variation in the number of tasks that were identified in each project (table 5.1). This difference was recognised as being the result of either: i) individual perception and subjective interpretation of the situation; or ii) differences in the processes involved. However...
- Within the high level details of tasks it was apparent that some were common to all projects, while others were very much project specific. There was no evidence of correlation between these similarities and differences in terms of project type, duration, or cost.
- There was little, if any, explicit recognition of iteration within or across the identified tasks, with descriptions tending to be systematic and linear

representations of design progression. Interviewees acknowledged that iteration had occurred across tasks however, they could not recall the manner in which this iteration had occurred. As such, only basic progression through tasks could be identified (a recognised problem in historic investigations).

- It was apparent that each project involved a period of understanding the project requirements prior to any generation of concepts. This implies that conceptual design activity involves high-level phased progression to some extent
- It was possible to compile tasks into a number of discrete groups (activities), with each group having a similar objective across every project (see section 5.3.5). Although the tasks within each project contained similar and disparate tasks, the objective of each activity could be described in generic terms.

In addition to these direct observations, the interviewees were asked to divulge information regarding any problematic areas they had encountered during the conceptual phase of the projects (table 5.2). No form of pre-structured questioning was utilised to gather these details, with the responses shown in table 5.2 being purely the spontaneous retort of the individual respondents.

		Project								
		A	B	C	D	E	F	G	H	J
Problematic areas	Confusion regarding direction of progression	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Team members rushing ahead of one another during design process	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Late changes in requirements and design aspirations causing difficulties	✓		✓	✓				✓	✓
	Construction not directly considered in concept development	✓				✓		✓		
	All team members not told about design changes			✓	✓				✓	
	No consistent level of detail to be reached for concept proposal				✓					
	Little user involvement during conceptual design activity	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Expectation that all requirements can be satisfied equally	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Lack of cohesion between design stakeholders		✓	✓						✓
	Wrong people involved in initial briefing sessions	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 5.2 Problem areas in conceptual design phase

These details were required to allow a further understanding of the nature of the phase to be gained. Predictably, there were several distinct problems that were common to each project:

- There is a need for each design team member to understand what others are doing as they progress through the phase. Without this shared understanding the team becomes inefficient. Consequently...
- There is a tendency for individual members of the team to try and 'rush ahead' in design terms, with designers tending to try and develop some elements in detail before many other issues have even been discussed broadly.
- There is little user involvement in design meetings. This is critical as it would allow them to participate actively in the concept development and ensures that the final proposal meets their requirements. This involvement would improve the decision making process and reduce the problem of having to wait for client input and changes before the design activity can progress.
- At present, initial briefing sessions tend to involve the wrong people. Instead of the client outlining what is required, the design process would be simpler and contain less iteration if the building users were involved from the outset. However...
- It is very difficult to accommodate the requirements of everybody involved in a project not least because some requirements conflict. This also leads to problems when trying to provide different people with robust information; 'they must appreciate the fuzziness of this stage of design'.

These findings allowed the intricacies of the conceptual design phase to be elaborated while providing a platform from which a design framework aimed at overcoming these problematic areas could be constructed. Additionally, the problem areas that were described acted as a means of categorising unclassifiable design time during the observation of the two subsequent experimental workshops.

5.3.3 Designing Together workshop observations

This first experimental session provided the opportunity to gain an appreciation of the similarities and differences in the activities undertaken during the design of a building

component. As described previously, this designing together workshop involved three teams of five industry professionals working on the design of a window façade system.

Upon completion of the exercise the design teams were asked to provide a presentation outlining not only their proposals but also the processes involved in reaching them. These processes, which were described both graphically and verbally, represented each team's own interpretation of the design activities they had followed during the course of the exercise. Details of these descriptions are provided and compared in table 5.3.

Initial proposal for activity terminology	Team A	Team B	Team C
Understanding the briefs requirements	Task debate	The Task	Common understanding of brief
		Brainstorm design features (introduced by brief)	
Generating a mission statement	Vision statement	Mission Statement	Mission statement
	Mission statement		
Identifying design process to follow and allocate time periods to each phase		Time Evaluation	Identify activities to be undertaken
			Order activities chronologically
			Allocate days, times, responsibilities
Assessing and developing design factors/ requirements	Critical success factors (What are the issues?)	Existing methods of fulfilling the design brief	
Identifying design drivers and constraints	Design Basis/ constraints		
Prioritising factors/ requirements			Weight factors from brief
Generating design concepts/solutions	Concept drawings	5 Concept solutions	Brainstorm concepts to address factors: -External visual impact Internal considerations
Grouping/combining solution concepts		Evaluation (of preliminary proposals)	Group factors to allow scoring of schemes
Selecting suitable options		2 solutions	Identify broad options
Evaluating/choosing options	Select design	Detailed review of solutions	Use 'pros and cons' to assess options
		Preferred scheme	Choice of option
Developing, improving and reviewing of final option	Resolve issues with design	Detailed design review	Develop option
	Assign tasks for deliverables		
	Generate deliverables		
	Final internal design review		
	Final amendments		
Presenting final proposal	Present design proposal		

Table 5.3 Comparison of design processes outlined by the teams

Within table 5.3, the left-hand column represents the authors initial proposal for terminology to define, in generic terms, the activities comprised within each teams process description. It was apparent that, as with the case study projects, the elements of each team's process description (although the terminology is different) could be compiled into a number of discrete groups (activities), with each group having a similar objective (identified by this initial proposal for activity terminology).

From Chapter 3 literature review (section of larger comparison – table 3.4)				Workshop descriptions	Case study projects	Proposed generic model
Hubka (1982)	Pahl & Beitz (1988)	Cross (1989)	Jones (1992)	Proposal for terminology	Task grouping	Actual framework terminology
				Understanding the briefs requirements	The clustering of tasks from the case study projects was undertaken with the aspects of the prior investigations in mind. Thus the genesis of the preliminary design framework from the case study tasks was grounded in the authors synthesis of available data	Specify the need
				Assessing and developing design requirements		Assess the requirements
	Identify essential problems	Clarifying objectives		Identifying design drivers and constraints		Identify essential problems
Establish function structure	Establish function structures	Establishing functions	Design situation explored			Develop the requirements
Establish technical process						
Apply technical systems and establish boundaries		Setting requirements	Problem structure perceived and transformed			Set key requirements
Establish groupings of functions		Determining characteristics		Prioritising factors and constraints		Determine project characteristics
Establish functional structure and represent						
Establish inputs and modes of action	Search for solution principles	Generating alternatives	Boundaries located, sub- solutions described and conflicts identified	Generating concepts		Search for solutions
Establish classes of function carriers				Grouping/combini ng solution concepts		Transform and combine solutions
Combine function carriers and examine relationships	Combine solution principles					Select suitable combinations
	Select suitable combinations		Sub-solutions combined into alternative designs	Selecting suitable options		Firm into concept variants
Establish basic arrangement	Firm into concept variants		Alternative designs evaluated and final design selected	Evaluating/choosi ng options		Evaluation and choice of alternatives
	Evaluate against technical and economic criteria	Evaluating alternatives				
		Improving details		Developing, improving and reviewing of final options	Improve details and cost options	

Table 5.4 Genesis of the preliminary conceptual design framework (phase and activity model)

Within the investigation of the existing design literature (chapter 3) a detailed comparison of existing conceptual design process models was undertaken in a bid to align the terminology from the various design sectors, where possible, with the construction industry (section 3.6.7, table 3.4). Thus, a process of iteration and reasoning from this detailed review of the existing literature and the empirical data lead to the development of the new framework, its terminology, levels and hierarchical structure. Table 5.4 illustrates the combination of sources and empirical data to demonstrate the genesis of the preliminary design framework. This process, in relation to the grouping of the case study design tasks, is described in the following section.

5.3.4 Generation of the preliminary design framework

The development of the framework involved a bottom-up approach to grouping the design tasks from the various case study projects in the light of the results from the literature search and the workshop process descriptions (table 5.4). This procedure has been represented graphically in figure 5.2.

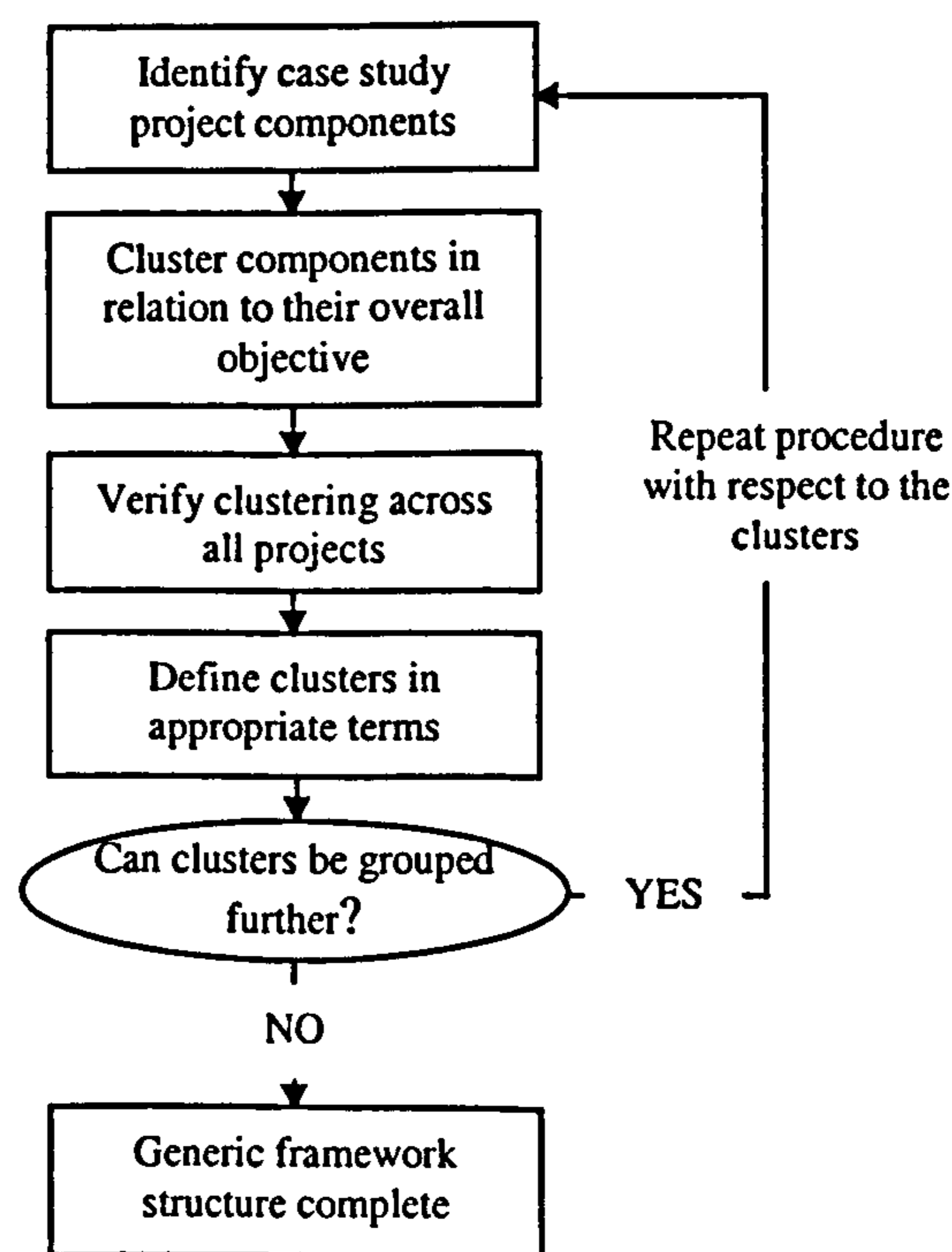


Figure 5.2 Procedure utilised to generate preliminary framework

In essence the approach involved the generation of a framework hierarchy, with the project-specific tasks acting as the basis of development, and the clustering of these

tasks in relation to their combined objective representing the generic group characteristics (figure 5.3). These groups of tasks were termed activities. Once defined, each activity was correlated with the conceptual design activity described by each team at the end of the designing together workshop (table 5.3). The combination of these two individual sets of descriptions allowed the bottom level design activities to be identified.

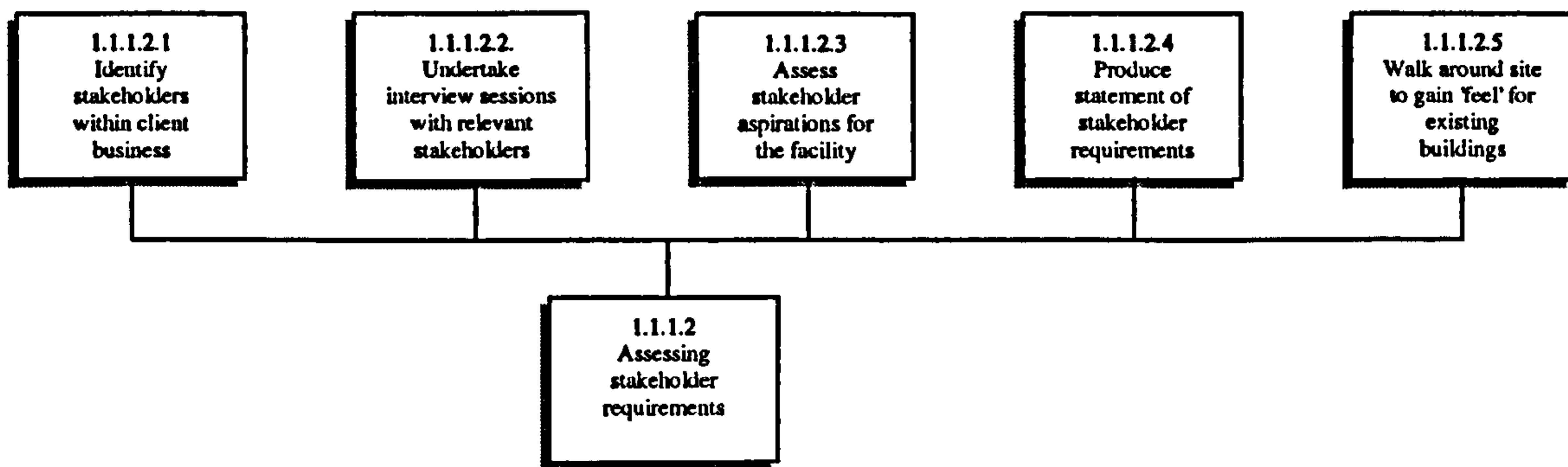


Figure 5.3 Section of bottom level of project specific framework hierarchy

Once these bottom level activities had been distinguished, the procedure was repeated. However, this second stage of development grouped the activities in terms of their overall phase objective as a means of developing the next level of generality.

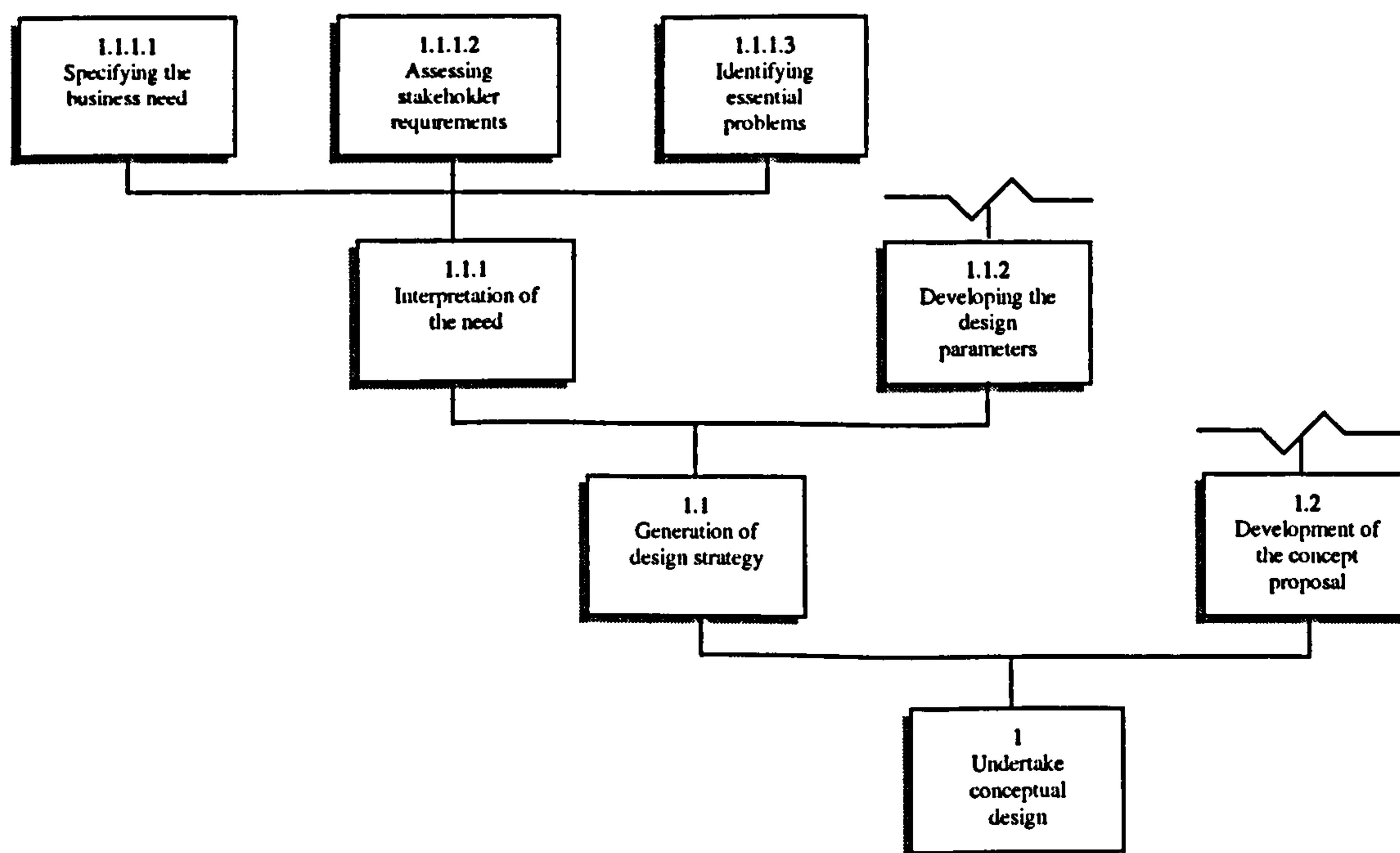


Figure 5.4 Section of the conceptual design framework hierarchy

This procedure was repeated until the only way in which the components could be grouped was under the objective: 'Undertake conceptual design'. Thus, when the framework was at the required level of detail in generic terms (figure 5.4) a five-levelled hierarchy had evolved.

Once complete, this hierarchy represented a generic building design framework in which each of the case study projects and the designing together process descriptions could be contained. The framework comprised four levels of definition; with the second containing two stages, the third containing five phases, and the fourth and final level containing some twelve generic activities (table 5.5).

Level 1	Level 2 (stages)	Level 3 (phases)	Level 4 (activities)	Level 5 (tasks)	
Undertaking conceptual design	Developing the business need into a design strategy	Interpretation of the need	Specifying the business need	Specific to project	
			Assessing stakeholder requirements		
			Identifying problems with existing solutions		
	Developing the design parameters	Developing requirements	Setting requirements		
			Determining project characteristics		
			Generating initial concepts		
	Developing the design strategy into a concept proposal	Divergent search	Transformation/combination of concepts		Selecting suitable combinations
					Firming up into concept proposals
		Convergence to proposal	Evaluating and choosing proposal		Improving detail and costing proposal

Table 5.5 Basic framework structure

5.3.5 Definition of level four activities

The fourth level activities had to be defined in a manner which outlined the nature of the group without being over descriptive of the actual tasks involved.

It was recognised that, without defining the activities of the framework, it would be impossible for it to be implemented in either a live design project or an experimental workshop; two exercises that would enable validation of the framework and lead to its

subsequent improvement. Thus, the tasks involved in each of the activities were considered in some detail and a generic definition of each was produced (table 5.6).

Activities	Definition
Specifying the business need	Once approval from the client is received that the only way to satisfy a certain business need is to construct, this basic need must be recognised. The manner in which the need is specified, be it formally in a design brief or verbally through a brief conversation with the client and his representatives, is irrelevant. The nominated interdisciplinary design team must fully appreciate and understand this need before any attempt can be made to address it. This can usually be achieved by gathering the information available and then generating a project mission statement to define broadly what is required.
Assessing functional requirements	This activity involves taking the specified business need and attempting to elicit information from the client or the client brief concerning aspirations for the project in terms of requirements for functionality. The search space must be given boundaries. The first step in achieving this is to assess the client's own requirements. If these are not met, the design solution will be unacceptable. The client's requirements should be extracted and recorded.
Identifying essential problems	Here the design team should develop some idea of the constraints of the problem at hand. This should help to both clarify the problem and promote some solution-focused thinking. The fact that a new design is required shows that there are problems with the products or systems already available. As such, these problems should be identified and used to guide the design by setting some design drivers and constraints.
Developing functional requirements	The design team members must attempt to extend the acceptable solution boundary. This can be achieved by identifying the 'real' users of the facility or system and questioning them as a means of understanding their value requirements. This activity also provides the design team with the opportunity to introduce their combined experience and expertise into the design environment. The client's requirements must still be adhered to, but the introduction of more innovative requirements may force the designers to uncover more innovative and fresh proposals. This activity allows the design team to contest both convention and the client's wishes as a means of developing a function structure.
Setting key requirements	This activity involves the production of a list of all the requirements that have been both stated by the client and introduced by the design team. Each of these requirements should then be defined in a few words. The definitions should be defined narrowly enough to give the design team direction, while still being broad enough to ensure that a wide search space is apparent. Similar requirements should be combined while those that are unrealistic should be discarded or reassessed. The requirements that remain should be set as key to the project.
Determining project characteristics	The pre-set requirements define the boundaries of the search space. At this stage of the process the requirements list needs to be developed in to a value tree. This will require the design team to rank the requirements in order of their perceived value, and thus importance, to the success of the project. This value hierarchy will define the project characteristics and will set the value datum against which the conceptual design proposals will be assessed.
Search for solution principles	This activity is where initial attempts are made to generate solutions. These solutions can be developed based on requirements or abstract ideas. Designers must be creative and uninhibited in proposing solutions. The key here is to use creative thinking in conjunction with experience and prior knowledge as and when they are required. Once externalised the ideas should be recorded in a structured manner to ensure that no scrap of ingenuity is lost, however useless or unrelated it may initially appear. Several 'creative' tools have been developed to assist in undertaking this phase.
Transform/combine solution principles	At this point a number of concepts should have been generated that address the problem holistically and/or at sub-system level. These solutions however, may well be unusable in their present form, having being generated as the result of uninhibited thought. As such, this period of design activity should concentrate on developing, transforming and combining individual proposals in a bid to mould them in to a number of usable proposals, at an holistic and/or sub-system level, that more realistically address the functional requirements.
Selecting suitable combinations	The number of solution concepts must be reduced as early as possible. However, care must be taken not to dismiss valuable concept principles before the opportunity to combine them with other concepts, to generate an advantageous overall solution, has been missed. There is no fail-safe procedure that facilitates this choice, but the decision must be democratic. Firstly, elimination of totally unsuitable proposals must be undertaken. After this, it is a matter of giving preference to those remaining solutions that are patently better than the rest.
Firming up into concept proposals	Those concepts that remain may satisfy the requirements superficially. However, the generation and selection procedure to date may well have revealed gaps in information about important elements of the design that mean that not even a rough and ready decision, let alone a reliable evaluation, of the proposals is possible in their present state. In building design this tends to manifest itself in the co-ordination of the disciplinary components. As such, important aspects of the working principles in terms of performance, space requirements, pinch-points in structure, services co-ordination, and so on must be known at least approximately. More detailed information need only be gathered for promising proposals.
Evaluation and choice of alternatives	This activity involves the solution proposals or concept variants being evaluated by the interdisciplinary design team so as to provide an objective basis for decisions. The subjective views of the individuals must be introduced into a democratic decision making mechanism. There are several evaluation procedures that have been developed to satisfy this design activity, all of them developed to allow objective evaluation of concept variants as well as of solution principles in every phase of the design process. The evaluation procedures allow the concept variants to be gauged against one another, an imaginary ideal and/or the pre-set value hierarchy of design characteristics and requirements.
Improve details and cost options	This activity requires the improvement of details and the costing of the proposals. The costing of proposals should be an ongoing exercise throughout the design activity, but at this juncture a detailed costing of the proposals is imperative. This activity actually involves developing the chosen proposal to a level that allows the critical unknowns to be improved to the point where they pose little or no risk to the subsequent development and success of the project. The pinch points should be detailed enough to ensure that co-ordination can be facilitated in the later stages of design. This activity, along with the entire conceptual design phase, is complete when the chosen proposal is documented in a way that the client can fully understand it and as such, agree that with further development it will sufficiently, if not optimally, satisfy his need

Table 5.6 Definitions of level 4 framework activities

5.4 Verification of the preliminary design framework

5.4.1 Verification versus validation

Verification represents an internal check of both model integrity and logic based on the projects studied. This involved checking that each of the components of the preliminary framework were representative of the conceptual phase of building design and that, in combination, they characterised the elements of design activity described during each of the case study projects.

Validation involves an external check of correlation between the model and reality. This activity involved applying the framework to real-time design activity as a means of confirming its applicability to building design. This would allow both the ratification of the existing framework components and provide critical feedback for the subsequent development and improvement of the preliminary version.

5.4.2 Verification

To enable the framework to be verified among the collaborating parties it was transformed from the early hierarchical form in which it was derived initially. This revised version was based on the initial hierarchy, however the subtle modification served to smooth its appearance and reduce the overly-structured appearance of the framework hierarchy. This alteration to the model was made owing to the belief that, for any model of the conceptual design process to be realistic and widely acceptable to industry, it should not appear overly systematic (Blessing 1996). The revised framework model is shown in figure 5.5.

This revised framework, along with the activity definitions (table 5.6), were sent to those design professionals who had been involved directly in the collation of the case study project data. Short interviews were held with each individual, both face-to-face and by telephone, to elicit their opinions on the appropriateness of the framework as a reflection of their respective descriptions.

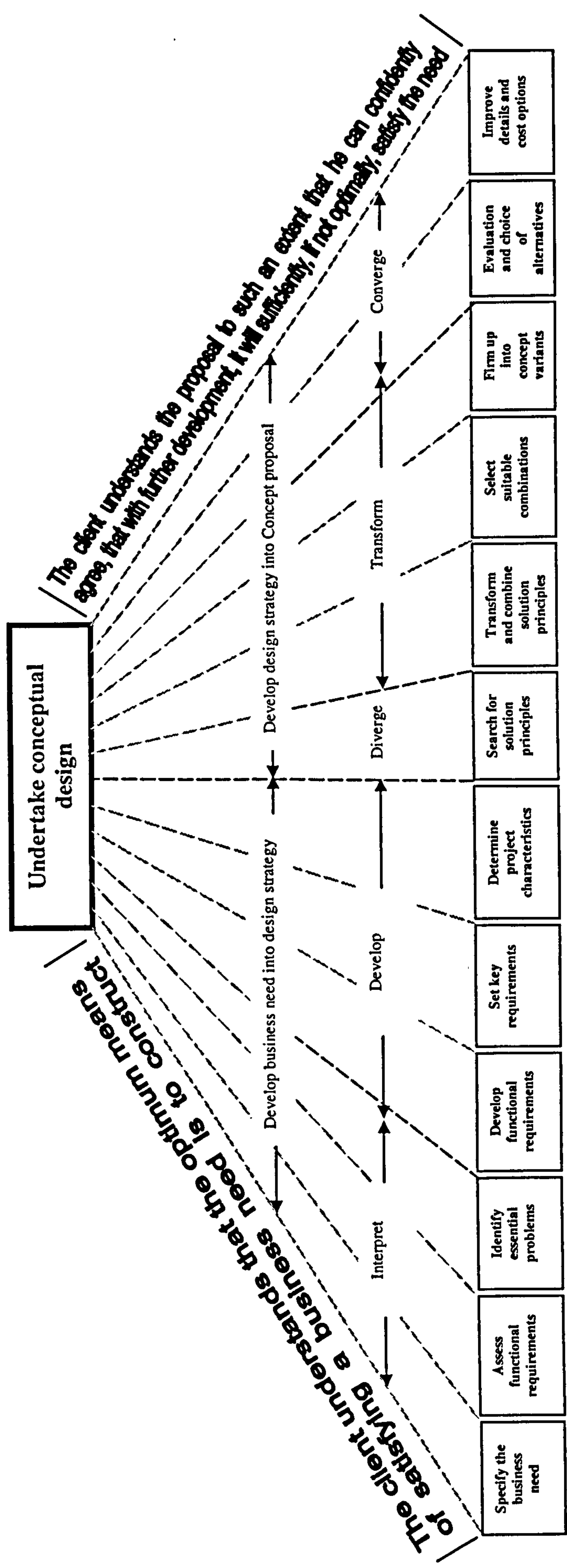


Figure 5.5 The revised version of the preliminary conceptual design framework

The result of these sessions was, without exception, very positive across all the interviewees. A synopsis of the key comments is provided below:

- All interviewees agreed that the design activity undertaken during the conceptual phase could be classified and grouped into the proposed activity and phase structure. However...
- Although the framework could be used to describe the case studies, it did not indicate the order in which the activities were undertaken i.e. No representation of the way the design actually advanced is provided.
- The phase description (level 3 in table 5.5) was deemed more appropriate as a means of guiding design progression in practice, with this sequence of progression being more akin to the way the design had actually advanced during the design activity.

In order to reinforce and further verify the remarks of the case study interviewees, the revised framework was sent to each of the lead contacts from the collaborating organisations who were asked to check that: i) the nature and structure of the framework hierarchy was applicable to conceptual design activity from their individual disciplinary perspective; and ii) the framework components were representative of the manner in which their respective organisations undertook conceptual design at a generic level.

These individuals then participated in a half-day round table discussion of the framework's veracity. The extensive discussions resulted in several points of agreement being reached:

- As with the case study interviewees, the participants agreed that, in general, the design activity undertaken during the conceptual phase of building projects could be classified and grouped into the proposed framework.
- The phases outlined in the framework were described as being 'understood intuitively by professional/expert designers'. (This is an interesting comment that

is discussed further as a result of the experimental investigations outlined in chapter 6 and the live trialling of the framework in chapter 9).

- In this respect it was suggested that the framework phases could be utilised as a training aid for new designers; with the model being used to develop graduate understanding of how design is actually undertaken. (It should be noted that the architects among the group considered this to be already understood among graduates within their discipline).
- The framework's focus on outlining activities and phases would make it more acceptable to designers working in practice as, rather than structuring conceptual design systematically, it suggests a direction for progression. However, ...
- There was a split of opinion between the activities and the phases with regard to the most appropriate/acceptable level to utilise in directing design activity.

All told, the response confirmed that the framework was both concise and clear and, more importantly, that the combination of phases and activities within the framework were acceptable to a sample of the professional design community.

5.4.3 Validation

The optimum means of validating the framework was to apply it to a real-time conceptual design project. However, it was wholly unrealistic at this stage of its development to expect the collaborating organisations to endorse the use of an as yet untested research model on a live design project. Likewise, introducing the preliminary framework to practising designers in the high-pressure environment of a live design project, while expecting them to apply it with full conviction and enthusiasm, was impractical. Additionally, it is questionable whether anything useful could be gained from testing a preliminary version of the framework without first developing and refining it in an initiatory session. As such, it was decided that an initial validation of the model could be achieved to an acceptable level by applying the framework in an experimental environment; the detail of which is the focus of the following chapter.

5.5 Conclusions

Chapter 3 identified that there is no model available at present to guide an interdisciplinary design team through the conceptual stage of the building design process. Additionally, it was suggested that for any such model to be realistic and widely acceptable to industry, it should not prescribe a systematic procedure, but be a contingency model that can be adapted to suit the team and the project. These hypotheses, among others have driven the development of the preliminary conceptual design framework.

A number of case study investigations have been described which involve a variety of project types, costs, and client. The most pertinent of the case study conclusions were:

1. A number of problems encountered by design teams were common across all projects, while others were specific to the project in question.
2. Similarly, some tasks were common across all case studies, although many others were project specific. However...
3. The tasks identified in each case study could be grouped with respect to their combined objective; these have been defined as generic activities.
4. After an investigation of the available modelling approaches, it was decided that the optimum means of delivering the framework would be in the form of a categorical (or toolkit) model. A model developed using this type of approach not only allows the team to decide at which level they work, it also permits them to define their own pattern of progression through it.
5. Additionally, this system provides a structure in which more detailed and constrained project specific models can be stored and aligned.
6. A generic conceptual design framework has been generated and verified. The author believes that this model is adaptable and flexible to fit the needs of all

teams and all project types, and it structures conceptual design activity without prescribing a systematic procedure.

Chapter 6 of this thesis describes the subsequent period of the research project. This involved the employment of an experimental approach (methodology outlined in chapter 2, section 2.5) as a means of validating the preliminary conceptual design framework. This session, which was the second of two (both of which are discussed in the following chapter), involved a range of the relevant design disciplines from across a number of professional organisations. It allowed a cause-and-effect experiment to be undertaken to provide hard evidence concerning; i) the validity of the framework phases and activities; ii) the applicability of the design framework in practice; and iii) its effect on team performance and effectiveness. Additionally, both designing together workshops allowed the effectiveness of a number of design techniques, such as brainstorming, forced analogies, and ranking and weighting, to be tested. This work also provided insights into the manner in which conceptual design activity is actually undertaken by teams of practising designers. Details of both experimental workshops, in addition to the conclusions drawn from the sessions, are provided in the following chapter.

Chapter Six

Testing of the conceptual design framework

6 Testing of the conceptual design framework

6.1 Introduction

This chapter describes the testing of the preliminary conceptual design framework (shown in figure 5.5), the development of which has been described in the preceding chapter, in two individual experimental ‘Designing Together’ workshops. These experimental sessions were held in a bid to both verify the framework structure and ensure that its components were subjected to rigorous testing in a live design environment. They also served several other key purposes, namely: i) to test the applicability and validity of the preliminary conceptual design framework; ii) to provide another opportunity (in addition to the case study design meeting observations) to monitor interdisciplinary design teams in practice; iii) to compare and contrast the effectiveness of different types of design team; and iv) to test a number of ‘Team Thinking Tools’ that had been identified over the course of the research.

6.2 Overview of the workshops

6.2.1 Workshop format

Each workshop involved 15 design professionals working over a two-day period to design a window façade system. The first involved designers from a single multi-disciplinary construction organisation; the second involved designers from six construction industry organisations.

The format of the two-day workshop was derived from that used in the University of Cambridge Interdisciplinary Design in the Built Environment (IDBE) course. Initially on day one the teams were asked to introduce themselves and carry out a preliminary exercise for the design of a newspaper, which was aimed at encouraging team member interaction in readiness for the main exercise. The main exercise involved the design of a window façade system for the re-cladding of 1960’s office buildings (see appendix V for windows project design brief). Each team was asked to design an adaptable and flexible modular window system that could be used to reclad existing office buildings. The brief stated that the system should be a manufactured product, available virtually from stock, and should enhance the environmental performance of the building. A number of design requirements and parameters were outlined, which

provided the teams with some initial constraints. A half-hour presentation was given to introduce the cladding exercise, which comprised a wide-ranging and well illustrated review of the function and history of the window. This presentation drew examples of many types and forms of window and introduced a number of passive environmental conditioning strategies such as the use of brise-soleil and low emissivity glazing. At this point the designers were introduced to a number of design techniques, which they were asked to apply during the course of the exercise (a different combination of techniques was introduced at each workshop – see tables 6.2 and 6.4 for details). These techniques, which were discussed in chapter 3, were introduced in the design literature in the 1960s as tools to broaden the number of solutions designers might consider and to help them evaluate alternative potential solutions more rigorously. A brief presentation of these tools was provided, which gave the delegates an insight into how to apply and use the tools and which particular periods of design each tool was developed to assist.

On completion of the main exercise on the second day, each team was given half an hour to present their design proposals to the entire delegate group and a panel of critics. Additionally, the teams were asked to describe the design processes followed and discuss the use, if any, they had made of the design techniques. Although it was not a pre-requisite, each team member presented an element of the proposal, typically those elements that fell within their own professional territory. Three experienced judges provided the teams with feedback about their proposals.

6.2.2 Workshop 1: Teams from a single organisation

Three teams of five designers (table 6.1), all from a single construction industry organisation, were asked to undertake the exercise without being given any form of pre-structured design process to follow. The design techniques that were introduced in this workshop are shown in table 6.2.

The design activity of the teams was monitored throughout the session, with detailed notes being made of both activities undertaken and team member interactions. During the final presentation each team was asked to describe the design process that they followed during the course of the exercise.

Team (A)	Team (B)	Team (C)
Mechanical services engineer	Principal quantity surveyor	Senior project engineer (structural)
Senior controls engineer	Senior architect	Principal mechanical services engineer
Structural engineer	Graduate mechanical services engineer	Process consultant
Graduate mechanical services engineer	Graduate electrical services engineer	Structural engineer
Senior architect	Structural engineer	Graduate architect

Table 6.1 Team member disciplines in workshop 1

The design processes that were described both graphically and verbally during the final presentations, representing each team's own interpretation of the phases of design they followed during the design exercise, are shown in chapter 5, table 5.3. These details, when combined with findings made during the literature survey and the case study period, permitted the development of the preliminary conceptual design framework (shown in figure 5.5).

Stage of design that technique is intended to assist	Design technique	Aim of technique
Conception	Brainstorming	To stimulate a group of people to produce many ideas quickly.
	Synectics	To stimulate ideas by encouraging comparison with unrelated items.
Structuring	Mind-mapping	To direct the thought process, allowing leads to be investigated without breaking the designer's or design team's original train of thought.
	Six thinking hats	To promote fuller input from more people and separate ego from performance.
Evaluation	'Pro's & con's' with weighting	To allow a number of feasible options to be listed in terms of their respective benefits and inadequacies, and ultimately evaluated using a simple weighting procedure.
	Paired comparisons	To permit a systematic evaluation of feasible options by comparing each option in turn with one of its counterparts.

Table 6.2 Design techniques introduced at workshop 1

Once generated, the framework was used to analyse the data gathered during the monitoring of the workshop. This then allowed the generation, and subsequent comparison, of the patterns of actual design progression for each of the teams (see section 6.3). As will be made apparent in the remainder of this chapter, there were

significant differences between the manner in which the teams perceived they had progressed and the manner in which they had actually progressed.

6.2.3 Workshop 2: Teams from several organisations

This workshop also involved three teams of five designers. However, the teams comprised designers from a number of construction industry organisations, with each organisation being represented once in every team. This ensured that each team had a full compliment of the relevant building design disciplines, namely architects, building services engineers, civil/structural engineers. This also reflected the way in which teams are newly formed in practice (discipline and allocation in teams is shown in table 6.3).

Team (A)	Team (B)	Team (C)
Structural Engineer	Structural engineer	Structural engineer
Architect	Project manager	Electrical services engineer
Mechanical services engineer	Senior Architect	Architect
Senior Architect	Graduate mechanical services engineer	mechanical services engineer
Electrical engineer	Structural engineer	Senior mechanical services engineer

Table 6.3 Team member organisations in workshop 2

Two teams were given the preliminary conceptual design framework, with one team being given the option to follow it and the other asked to follow it. They were then tutored on its terminology and structure. The third team was asked to solve the design problem without being introduced to the framework (as in workshop 1). In this way, the first two teams were designated as test groups, and the third as the control group. During actual design activity, a member of each team recorded the phases of design as they were being undertaken and the design activities performed. This recording was undertaken at five-minute intervals throughout the duration of the exercise. To verify and support this self-assessment, the author monitored each team and made notes of both the time and activities being observed. This provided additional

information regarding the design activity and also acted as a means of verifying the self-assessment records.

The designers were provided with a booklet (shown in Appendix VI) of 'Team Thinking Tools' (design techniques such as synectics (forced analogies) and mind mapping – full list provided in table 6.4) which they were asked to use during the exercise.

Nature of design technique	Design technique	Aim of technique
Creative	Synectics	To stimulate ideas by encouraging comparison with unrelated items.
	Six thinking hats	To promote fuller input from more people and separate ego from performance.
	Mind-mapping	To direct the thought process, allowing leads to be investigated without breaking the designer's or design team's original train of thought.
Rational	Isolated option testing	To find the limits within which an acceptable solution lies as a means of testing a single option against a set of criteria
	Ranking and weighting	To compare a set of alternative designs through the application of a common scale of measurement
	Analysis of interconnected decision areas	To identify and to evaluate compatible sets of sub-solutions to a design problem

Table 6.4 Design techniques introduced at workshop 2

Upon completion of the exercise, the individual team members were asked to complete questionnaires. Teams A and B completed questionnaires relating to the design framework model, the respective team performance, and the usefulness of the design techniques. Team C completed the latter two only. All questionnaires are provided in Appendix II.

The information provided by these questionnaires, combined with the observations made during the course of the design activity, allowed a number of preliminary findings to be drawn. Again, the data recorded during this session allowed each team's individual pattern of design progression to be produced.

6.2.4 Nature of the problem

This particular design problem, although appearing to be relatively simple, has the advantage of requiring input from each of the design disciplines. Those teams that realise the need for integration of the disciplinary issues into simple systems tend to be most successful. Each of the teams produced appropriate concepts that they believed could be subsequently developed into working systems. However, the manner in which the teams worked and the nature of the proposals produced were quite different. The remainder of this chapter describes the variations in the design processes followed by the workshop teams and concludes by suggesting a generic model of the conceptual design phase of building projects.

6.3 Findings from workshop 1

6.3.1 Introduction: Theory versus practice

Conventionally, models of the design process based around a sequence of related activities imply that one activity follows another, and that each is of broadly equal duration and importance. In referring to the descriptions of the design processes provided by the teams in workshop 1 (see chapter 5, table 5.3), this concept, which has been represented graphically in figure 6.1 below, would seem to be reinforced.

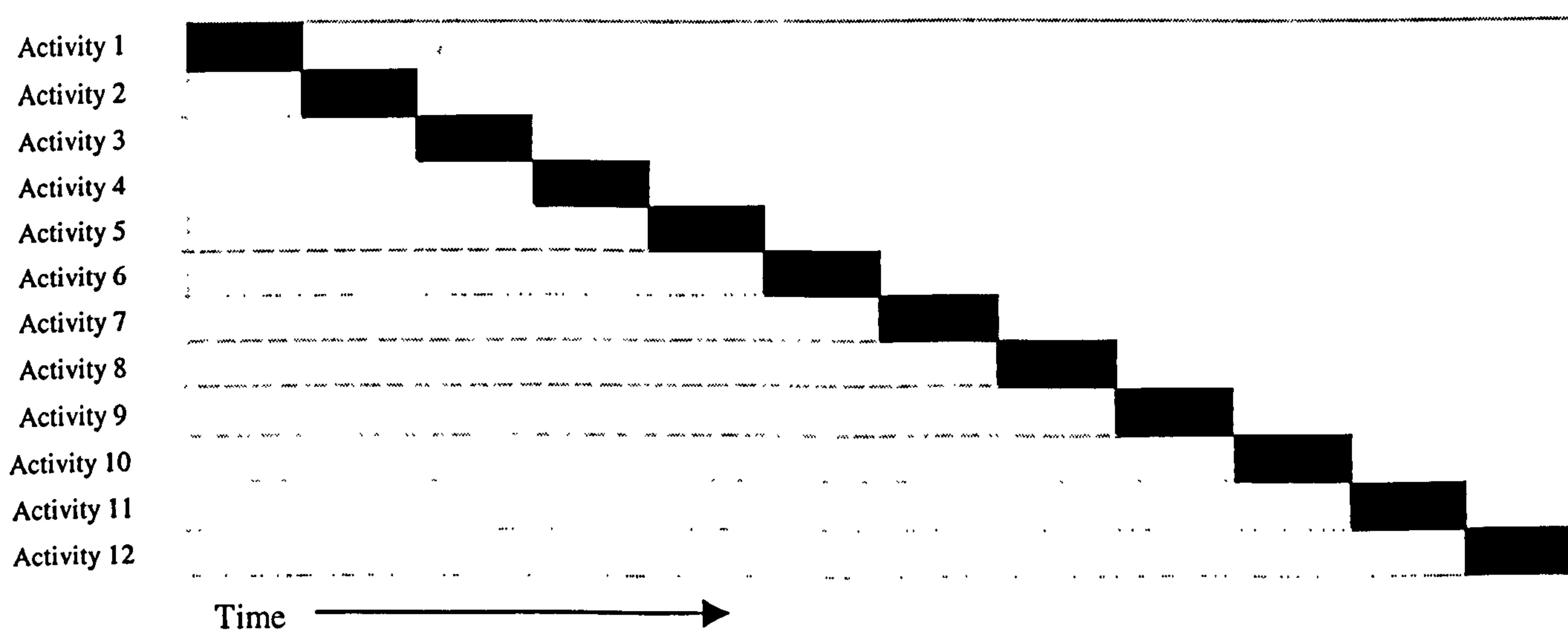


Figure 6.1 Theoretical representation of activities of the design process

However, when the phases and activities of the conceptual design framework are used as a structure with which to analyse the monitored data from the design teams we discover a more complicated picture of the activities and the relationship between

them. Details of the actual design activity undertaken by the teams during the design exercise as defined by the framework model are provided in the following sections.

6.3.2 Team A1 - Observations

Team A1 spent approximately 310 minutes designing over the course of the workshop. Although a linear sequence of phases was pre-defined by team A1 it is apparent that the design actually progressed linearly but in a number of iterative bursts. Two iterations were performed to establish requirements while developing a design strategy, after which a period of concept generation and transformation took place. Then the team iterated twice again to arrive at the final proposal; once to generate and choose the primary concept and again, to conceive and crystallise sub-elements of the proposal.

The team members collaborated successfully throughout the exercise with no real disagreements between individuals. There did not appear to be any single team leader but instead, the leadership and responsibility for decisions was shared equally between the members. Any differences of opinion were discussed and a consensus was negotiated without disruption to the design activity.

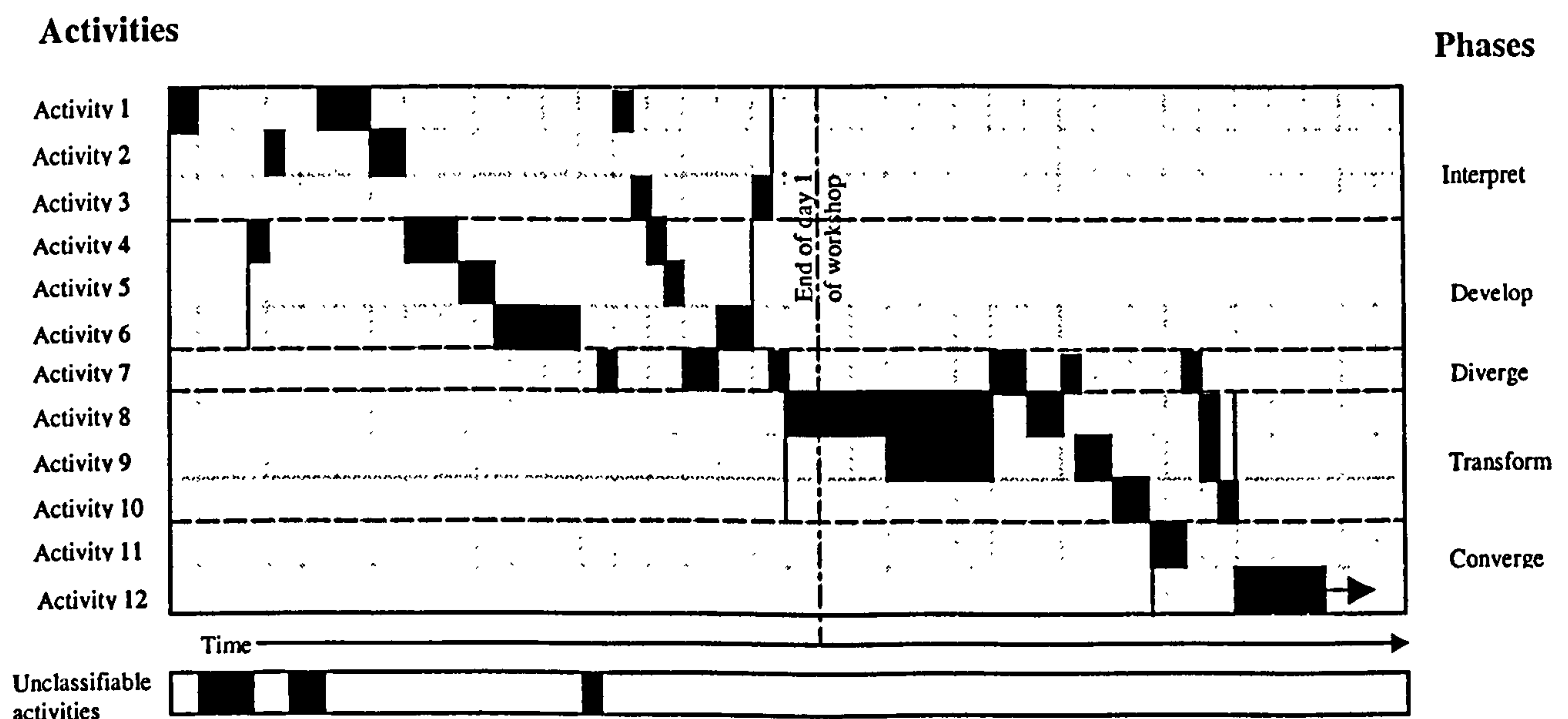


Figure 6.2 The actual design activity of team A1

Over the course of the workshop the team spent approximately half an hour undertaking activities that could not be classified by the conceptual design framework.

6.3.3 Team B₁ - Observations

Team B₁ spent 255 minutes designing over the course of the workshop. The pattern of design progression over the majority of the exercise lacks the linear iterative form portrayed by team A₁.

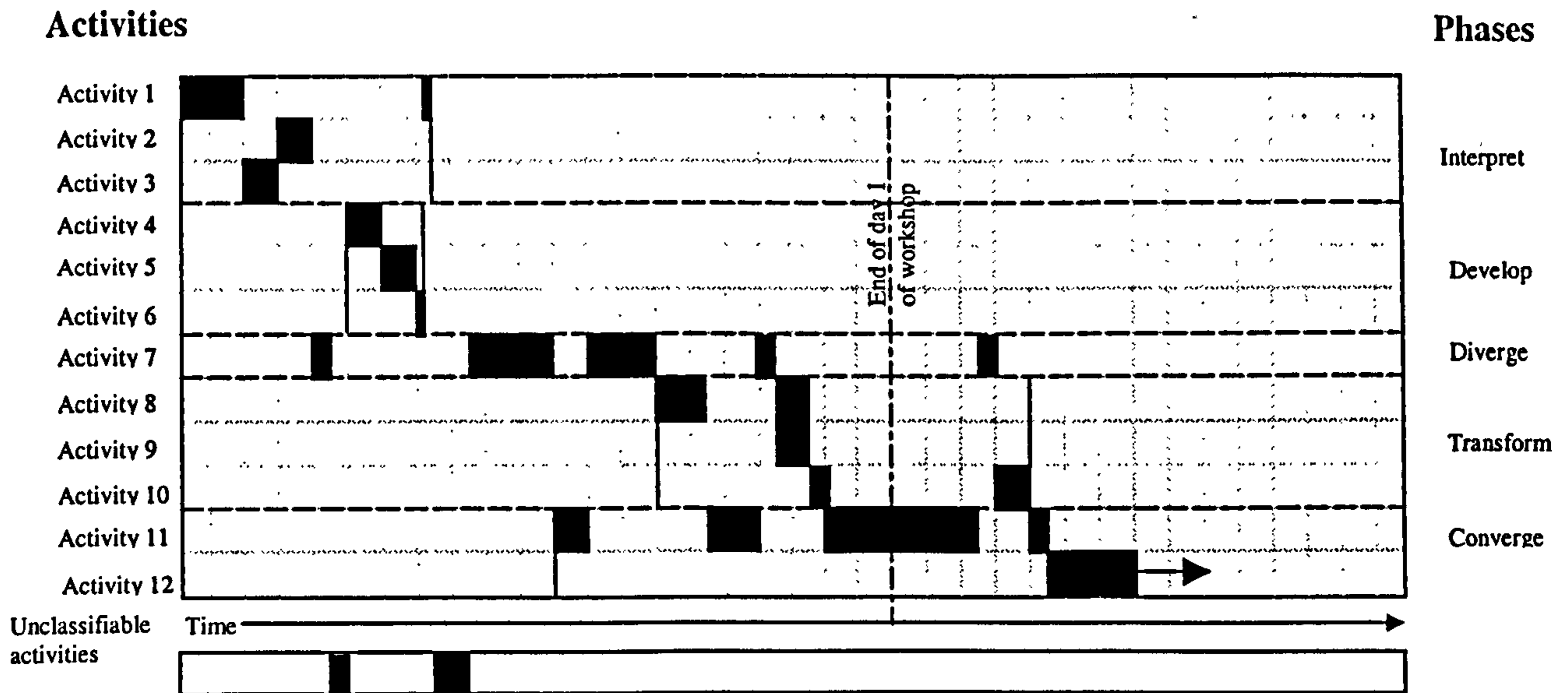


Figure 6.3 The actual design activity of team B₁

This pattern appears to owe much to the team's decision to agree on the direction of progression as and when they saw fit, rather than pre-defining a design process. This *ad hoc* approach resulted in the team making tangential forays into peripheral issues at times. However, this did not cause problems as the team members soon identified any inappropriate design activity and redirected their progression accordingly.

The architect led the team from the outset and, although never formally discussed by the team members, the team appeared to be happy with this arrangement. The team members appeared to be compatible and as a result, collaborated well throughout the course of the exercise. It is important to note that that only 15 minutes (approximately) of design time could not be classified within the proposed framework.

6.3.4 Team C₁ - Observations

Team C₁ spent 260 minutes designing over the course of the workshop. The team spent a long period of time pre-structuring their design process at the early stages of the design exercise (which could owe much to the influence of the process consultant

in the team). The team progressed linearly through the design process in the early part of the exercise. This appears to suggest that the time spent defining a design process was not wasted, as progression was made quickly, efficiently and without incident.

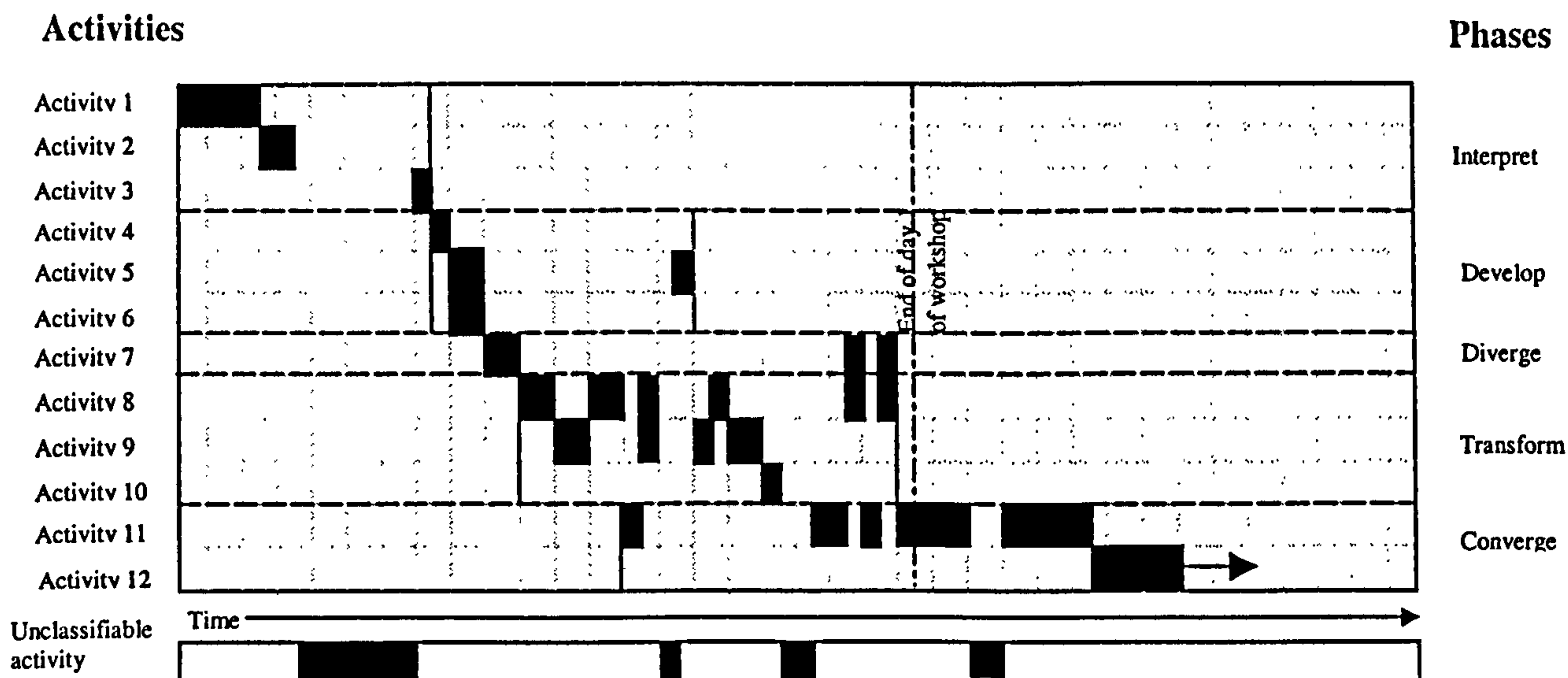


Figure 6.4 The actual design activity of team C₁

However, after an initial period of concept generation and transformation, the team faltered when faced with the task of evaluating their proposals. This occurrence is reflected in the jumps between searching for solutions (activity 7), transformation/combination of solutions (activity 8) and evaluation/choice of solutions (activity 11) after the initial period of linearity.

This activity was the result of confrontation between two team members; a graduate architect and a senior mechanical services engineer. The conflicting opinions of these team members meant that consensus could not be reached. This resulted in a lot of material being produced in an attempt to reach consensus without any final evaluation or choice of single options ever being undertaken.

Again, it was apparent that a considerable period (approximately 55 minutes) of the design time of team C₁ could not be classified within the proposed framework.

6.3.5 Synopsis of design proposals

This design problem was chosen specifically because of the fact that, for it to be addressed effectively, it requires input from each of the design disciplines. As has

been stated previously, the more successful solutions are generally those which recognise the need to integrate the various disciplinary issues into a single solution concept. The three teams in workshop 1 all produced valid proposals for the window system. Each system utilised various forms of natural ventilation strategy, with the architectural and services elements being fused where appropriate. Brise-soleil and light shelves had been utilised to both improve the internal environment and enhance building aesthetics. Teams A₁ and B₁ proposed single systems that were flexible and adaptable to the needs of any client. Team C₁ generated a 'kit of parts' proposal, which allowed the client to purchase a bespoke system assembled from any permutation of standard components. The team members stated that they felt this was the optimum proposal of those they had produced but added that they were forced into this decision because time was running short and they were having difficulties making a final evaluation of the concepts.

Intriguingly, there appears to be a clear connection here between the process and the product. Inability to agree a single 'integrated' solution was resolved by designing a kit of parts where each team member contributed to a part of the solution. The judges who evaluated the designs at the end of the workshop considered that the final proposals of each team were equally valid in terms of their adherence to the requirements of the brief.

The following section describes the design activity of the teams in workshop 2. In analysing the data from this workshop it became apparent that the manner in which a team performs is inextricably linked to the composition and nature of the team.

6.4 Findings from Workshop 2

6.4.1 Team A₂ - Observation and team member perception

Team A₂ was given the option to use the framework as a guide to the design stages but were not encouraged to use it as a systematic procedure. The team spent 305 minutes designing over the course of the workshop. Figure 6.5 provides a detailed outline of the activities undertaken and the time spent within each activity and phase of the framework.

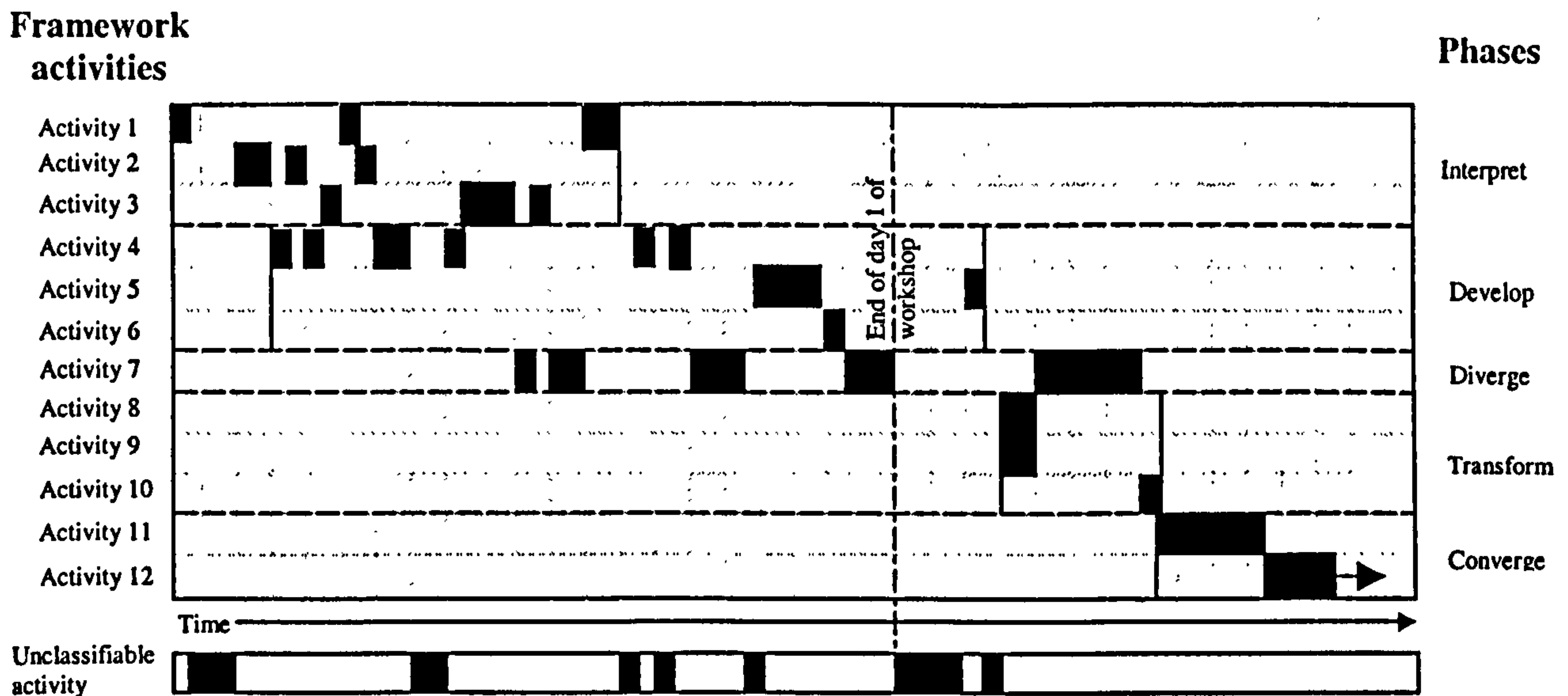


Figure 6.5 The design activity of team A2

Team A2 produced a 'kit of parts' solution to the problem, which comprised a number of interchangeable, standardised components from which a client could select the most applicable arrangement. The phrase 'kit of parts' not only describes the solution but also the way in which the team worked. The group did not interact well. Instead, each member looked at a different element of the problem, with these partial solutions being brought together at the end. There was little, if any, integration between the disciplines despite the fact that the disciplinary components were connected.

The team leader (who had assumed this role) appeared to guide the group through the design activity without agreeing this direction with the remainder of the team. It was commented that 'the design appeared to be a vehicle for the leaders enthusiasms'. Later, the leader commented that he had taken control because the team was too timid as a group, with no one being prepared to take the lead role. As such, the leader progressed through the activities without consulting the other team members.

This opportunistic design progression led to discontentment between members of the team, and resulted in a confrontational atmosphere and lack of cohesion between individuals. To this end the team in their own words 'sometimes lacked direction', with a 'split in focus of team members' and as a result, the team members 'grew frustrated'. One team member stated that the lack of common agreement on how to

progress was the basis of the team's problems. Even though the team discussed the lack of cohesion felt by some of the design members at the start of the second day; no action was undertaken to address it. However, the dissatisfied team members felt that 'the design collaboration improved' to some extent, thus they bought back into the design progression. However, there were 'still undercurrents of a lack of collaboration' and as such, team members soon fell back into their disciplinary sub-teams as the work progressed. The divisions remained apparent throughout the exercise. It was also noted that there was a clash of personalities within the team; a factor that did not aid the situation.

Team members reported that the framework could guide the design process if the entire team would agree to follow it (findings would suggest that agreement on any procedure would improve team interaction, collaboration, and resultantly, team effectiveness). The early jumping between activities did not help the team, making the individual members frustrated. Interestingly, it was stated that because the framework was not followed in sufficient detail, being referred to after the fact, it was not used as it should have been, e.g. as a guiding principal. Additionally, it was stated that 'someone needed to catch the process, as [the team] tended to jump around the process rather than use it as a [sequential] process'. Several team members agreed that concerns were not aired at an early enough time in the process to enable the team to make changes and remedy the situation.

6.4.2 Team B2 - Observation and team member perception

The members of team B2 spent 250 minutes designing. The team members were encouraged to follow the framework's activities sequentially with a minimum of iteration (figure 6.6).

After beginning the exercise by progressing sequentially through the activities, one member of team B2 undertook an opportunistic advance to search for solutions (activity 7). The remainder of the members opposed this individual's transgression of the proposed use of the framework and after a brief discussion it was decided that the team should progress in unison. Thus, this step was disregarded during a subsequent analysis of activity dependency (as will be described in section 6.6.3). After reconvening at activity 1, team B2 followed the framework fairly rigidly for the

remainder of the exercise. Again, it was noted that approximately 10% of design time, (30 minutes) could not be classified by the framework activities.

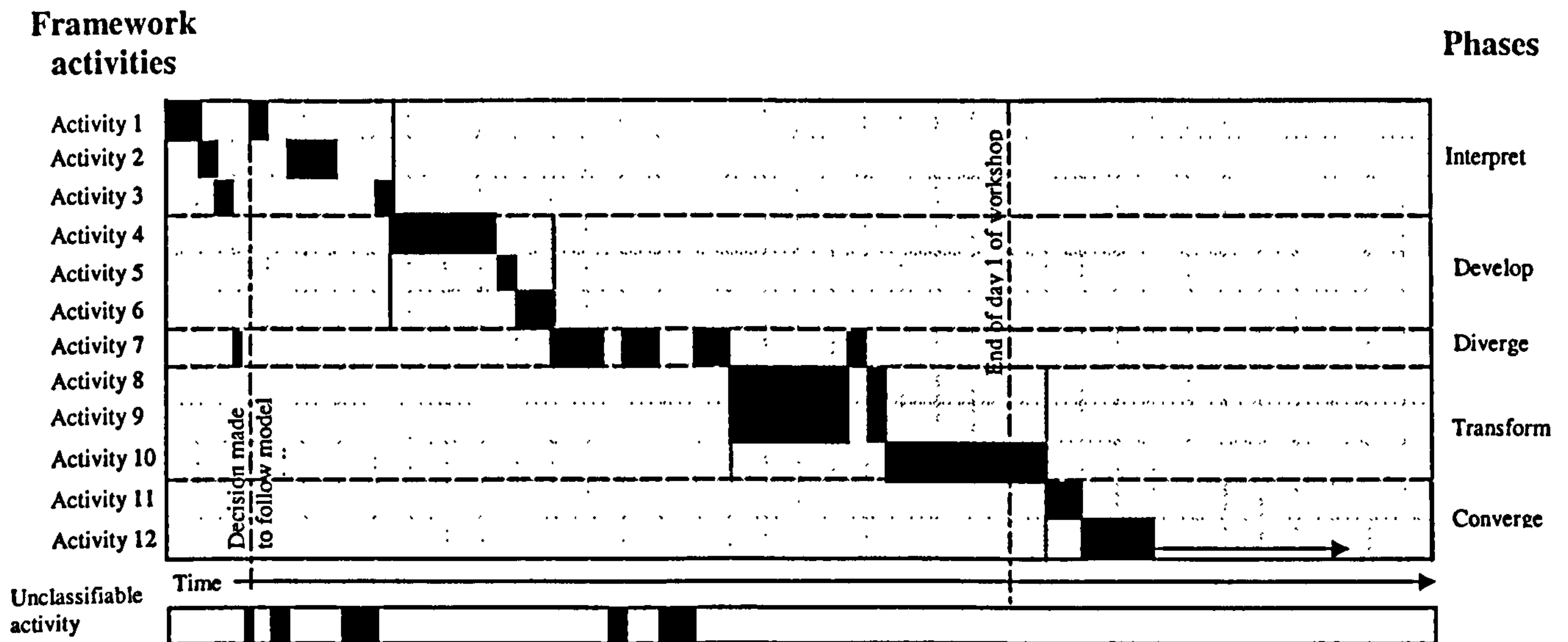


Figure 6.6 The design activity of team B2

The concept generated by team B2 was based around a clip-on spandrel of limited use in terms of either aesthetics or shading. The design concept was generally undeveloped, with the concept tending to re-create the type of environmental problem that it was attempting to remedy.

The crudity of the solution seemed to be the result of a mistaken belief that the problem was simple. Generally, a high level of cohesion was apparent within the group but, though the team interacted well throughout, the resulting concept was judged fairly poor by the expert assessors.

The team members discussed their roles in advance of the design activity and, with one exception, were happy about their positions, with individuals being flexible in their approach to forwarding ideas across the boundaries of the disciplines. The objector, whose background was in project management, felt that the leader had assumed sole responsibility for the position, and had not let the other team members become involved in progressing the design. However, on reflection, no other member of the team stated that they had wanted to 'lead' the design at any time before, during or after the exercise. In fact, one individual stated that 'the group worked together very well right from the start, but became even more organised as time went on'.

It was suggested that the team selection is a key factor in the success of design activity. One suggestion for getting the interaction element correct was to let the team members pick themselves. One team member felt that there was too much interest in details, rather than in ensuring that the strategy/concept was defined.

6.4.3 Team C2 - Observation and team member perception

Team C2, who had not been given a copy of the design framework, coincidentally undertook each of the activities that were outlined by the document. This acted as further validation of the proposed framework. However, the design activity was undertaken in a different fashion from the other teams (figure 6.7), although in a similar time period (245 minutes) to team B2.

Team C moved through the activities very quickly in a fairly rigid fashion to the point at which a number of alternatives needed to be evaluated. In attempting to evaluate these alternatives it became apparent that none was felt to satisfy fully the requirements of the brief and in consequence, the team came to an abrupt halt.

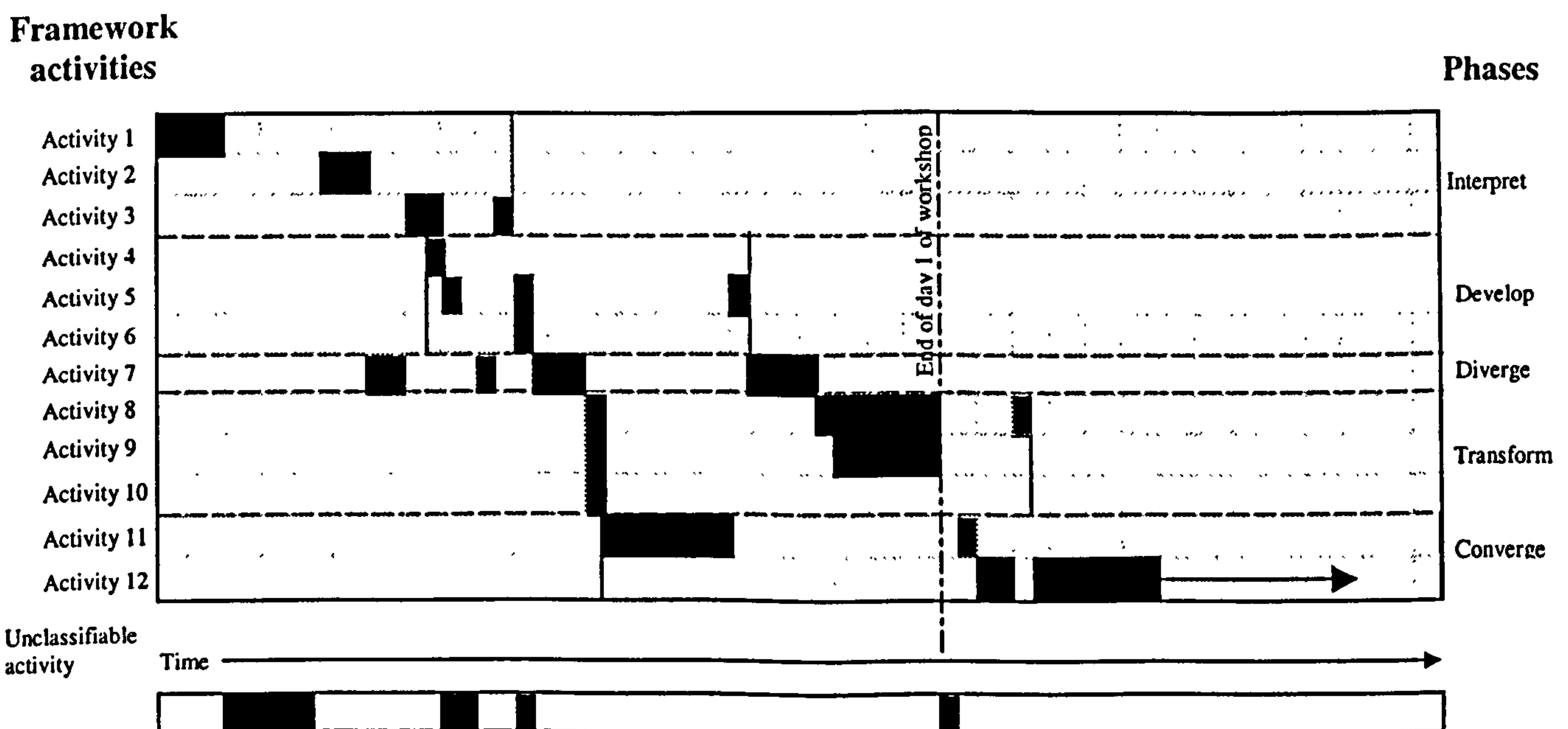


Figure 6.7

The design activity of team C2

The author then interjected and facilitated the use of one of the team thinking tools. This resulted in the team jumping back a number of stages and recommencing their

design activity from an earlier phase (see double iteration in figure 6.7). Again, a considerable amount of time (40 minutes) was not classifiable.

Although the team's concept design was not quantified fully, it was judged to be imaginative and to have recognised the areas of incompatibility between sub-elements of the problem. It was apparent that the team had differentiated between interconnected and unconnected characteristics. Thus, the solution was fairly simple, while still addressing the requirements of the brief.

The team highlighted their frustration at not having any certain direction during the design exercise. The group attributed this to not having been given, nor defining for themselves, a process to follow prior to commencing the design activity. As such, they approached the design activity in an *ad hoc* manner; a factor that the team believed led to a 'general lack of direction' and caused frustration. Even so, the team generally followed the activities outlined in the conceptual design framework that the other teams were given.

One team member stated that the team 'often lacked guidance and little process [was] used'. He felt that the team avoided confrontation and generally agreed on the way forward, but '[they] stumbled forward in design terms'. Additionally, it was felt that there was a need to capture and record ideas as they came; a lack of this combined with a lack of an agreed process caused frustration. However, despite some individuals having doubts about the potential contribution that they could provide in the early stages of the activity, a full team effort did occur later in the process.

Another team member held a similar view, stating that 'at the beginning of the exercise the team members did not really gel'. It was felt that this initially caused different stances to be taken by individuals during the idea development stages. This individual suggested that the problem would have been overcome if they had had a process, either imposed or self generated, with which to harmonise their activity.

6.4.4 Critique of the three schemes

In the critique held at the end of the design period team C₂ was adjudged to have produced the best proposal. This appeared to owe much to the team sharing the

leadership, with each member tending to advise and then ask for comment, instead of simply dominating the flow of work. The negative aspect of this was the occasional lack of leadership, with no single member being willing to take the lead in times of dispute (the group was too polite to allow that to happen). The key to the success of the proposal seems to be that they had a wide knowledge base and were willing to listen to one another.

6.4.5 Questionnaire responses

The information gathered from the design framework and team performance questionnaires is shown below. A five point Likert scale was applied with 5 and 1 representing the maximum positive and negative responses respectively and 3 as neutral. Figures 6.8 and 6.9 provide an overall team response to each question. The team responses have been plotted against one another to allow a comparison to be drawn.

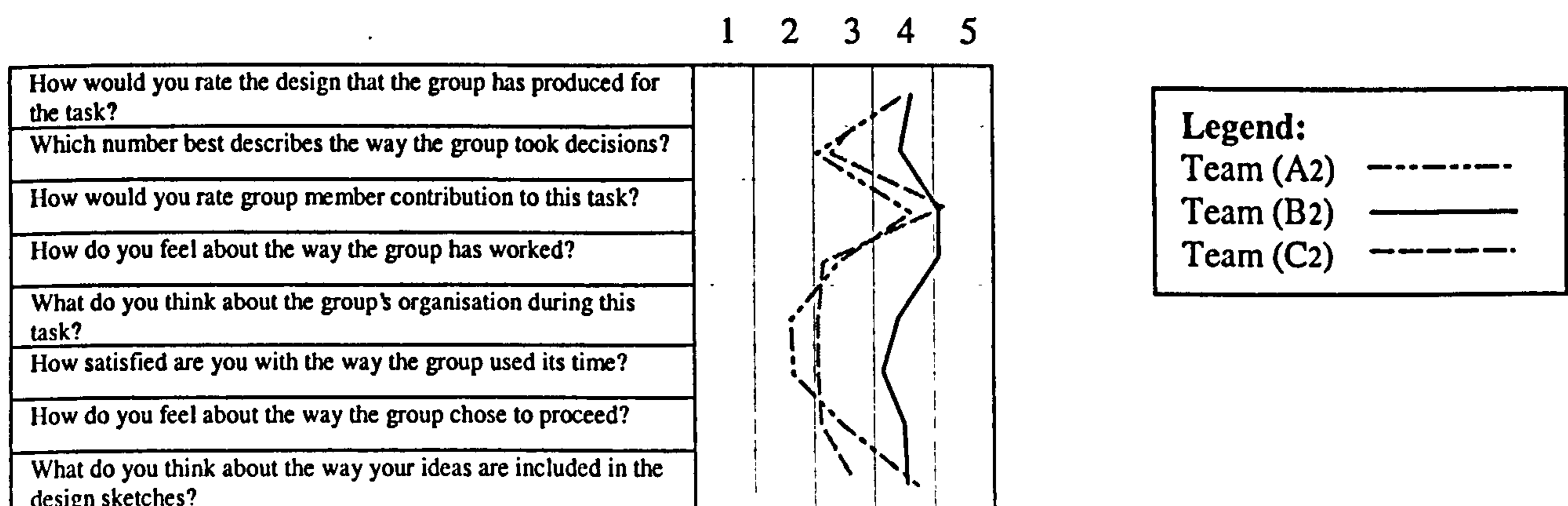


Figure 6.8 Team performance questionnaire responses by team

On average team B2 scored their performance higher than teams A2 and C2 and in all cases positively. Teams C2 and A2 rated themselves similarly to team B2 for their group member contribution and for the way their individual ideas had been included in the design sketches respectively.

The latter rating undoubtedly owes much to the fact that team A2 generated a kit-of-parts solution, which included the ideas of all its members, rather than deciding to develop a single concept.

Only team A2 responded negatively to any of the questions - these related to group organisation and individual's satisfaction with the way the team used its time.

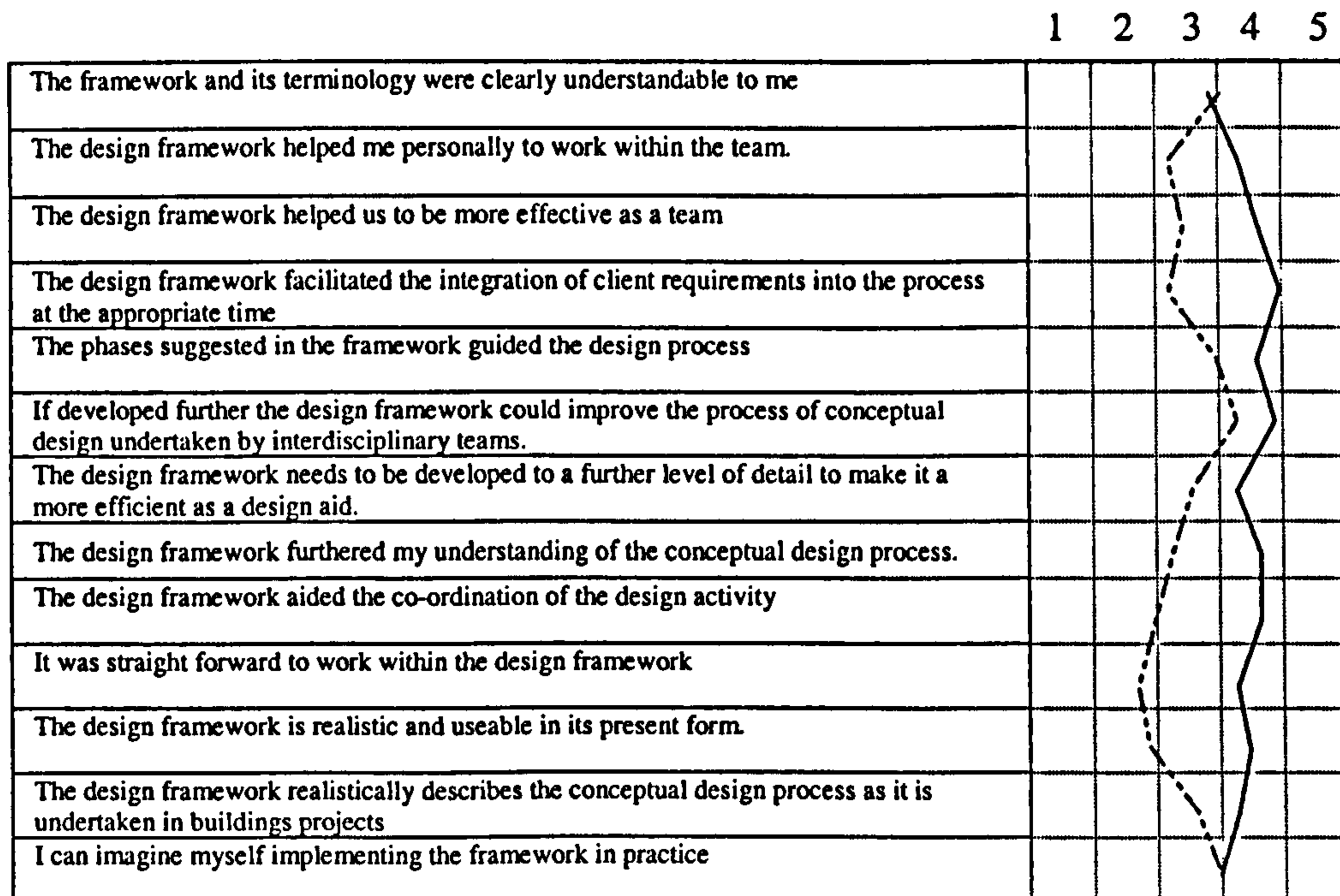


Figure 6.9 Design framework questionnaire responses by team

Teams A2 and B2 found the framework and its terminology to be equally understandable. However, the responses of team A2 averaged between 0.5 and 1.5 points lower than those of team B2; a differential which was also apparent in the responses to the team performance questionnaire. This finding appears to suggest that there is a connection between the manner in which the framework is utilised and individual perception of team performance.

6.5 Analysis of data

6.5.1 Comparisons and contrasts across the workshops

It is noticeable that three of the four teams without a framework to utilise (A₁, B₁ and C₂) progressed by taking a number of iterative steps. This is particularly noticeable in team A₁'s progression, with two iterations being undertaken to establish requirements, followed by a second two to develop the proposal. Team B₁ iterated twice to develop the proposal, once the requirements had been initially established, whereas team C₂ progressed through all activities very quickly, before undertaking a second loop from activity 5 onward. Team C₁ is the anomaly to this pattern. However, this may owe much to the fact that team C₁'s members spent a long period

of time, approximately 35 minutes, near the outset of the exercise discussing, and subsequently generating, a design procedure to follow.

These iterative bursts are conspicuous by their absence in the design progression of the teams that were provided with the conceptual design framework, i.e. teams A₂ and B₂. However, there is noticeable difference in the fashion in which these two teams progressed. This difference can be accounted for by the ways the team's used the framework.

Team A₂ used it as a guide to the design phases to be addressed over the course of the exercise and not as a systematic procedure. As such, although the team hopped between the framework activities opportunistically, there was still linearity within the pattern of progression, albeit fairly loose, without the iterative loops portrayed by the teams without the framework.

Conversely team B₂, after some initial hesitancy, followed the framework activities sequentially in an almost linear fashion without iteration being performed.

An additional observation made concerned the nature of the final proposals generated by teams C₁ and A₂, which both produced 'Kit-of-parts' proposals. This is in contrast to the proposals generated by the other teams, which were integrated solutions. This is interesting owing to the fact that teams C₁ and A₂ were the only two teams of the six monitored where there was noticeable adversarial and confrontational atmosphere between certain members. In this sense, this finding suggests that there is a clear link between the social interaction of the team and the product generated.

6.5.2 Activity and phase duration

Activity duration

Table 6.5 provides a breakdown of the percentage of time spent by the teams in each of the framework activities. A graphical representation of table 6.5 is provided in figure 6.10.

Activity		% of time spent undertaking activities						
		Workshop1			Workshop2			
		A1	B1	C1	C2	B2	A2	
Developing need into a design strategy	1	Specify the need	10	8	9	9	7	6
	2	Assess functional requirements	5	4	3	6	11	7
	3	Identify essential problems	3	4	2	6	4	8
	4	Develop functional requirements	8	4	2	2	8	11
	5	Set key requirements	5	4	3	6	2	8
	6	Determine project characteristics	11	1	2	2	4	2
Developing design strategy into concept proposal	7	Search for solution principles	11	24	7	20	18	22
	8	Transform and combine solution principles	29	10	24	14	14	3
	9	Select suitable combinations	5	6	2	2	18	2
	10	Firm up into concept variants	3	29	24	16	4	10
	11	Evaluation and choice of alternatives	Not included in comparison					
	12	Improve details	Not included in comparison					
Time unclassified by framework activities			10	6	22	17	10	21
Total spent undertaking activities 1-6			42	25	21	31	36	42
Total spent undertaking activities 7-12			48	69	57	52	54	37

Table 6.5 Comparison of time spent undertaking the respective design activities

Initially the data suggests that there is a link between the amount of time that was unclassifiable and the teams in which confrontational attitudes were apparent, but this is not the case. As has been stated previously, team C₁ spent the majority of this time discussing and defining their design process, whereas team A₂ used the time to introduce and understand one another's team and professional roles initially. Thus, it is apparent that each team spent the unclassifiable activity in quite different ways.

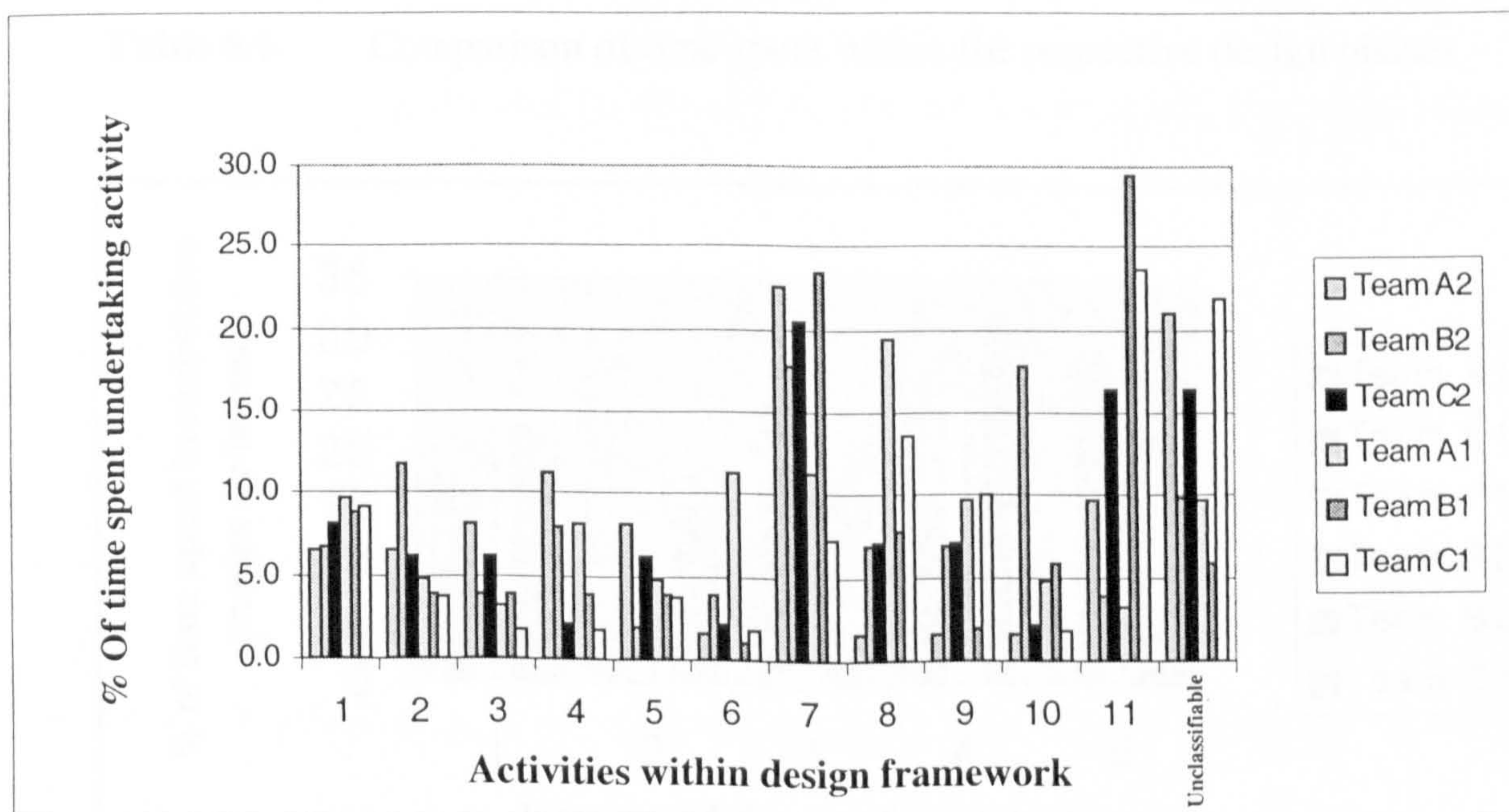


Figure 6.10 Comparison of time spent undertaking the respective design activities

However, the remainder of this unclassifiable time was spent in a similar manner by both teams, in discussions attempting to resolve disputes and implement some form of team maintenance. The differences and commonalities between the teams over both workshops are identified in section 6.5.3 (table 6.8).

Phase duration

Table 6.6 provides a breakdown of the percentage of time spent by the teams in each of the framework phases (a graphical representation of which is provided in figure 6.11).

Phase			% of time spent undertaking activities					
			Workshop1			Workshop2		
			A1	B1	C1	C2	B2	A2
Developing design strategy into concept proposal	1	Interpretation	18	16	14	21	22	21
	2	Development	24	9	7	10	14	21
	3	Divergence	11	24	7	20	18	22
	4	Transformation	34	16	26	16	32	5
	5	Convergence	3	29	24	16	4	10
Time unclassified by framework phases			10	6	22	17	10	21
Total spent in phases 1-2			42	25	21	31	36	42
Total spent in phases 3-5			48	69	57	52	54	37

Table 6.6 Comparison of time spent within the respective design phases

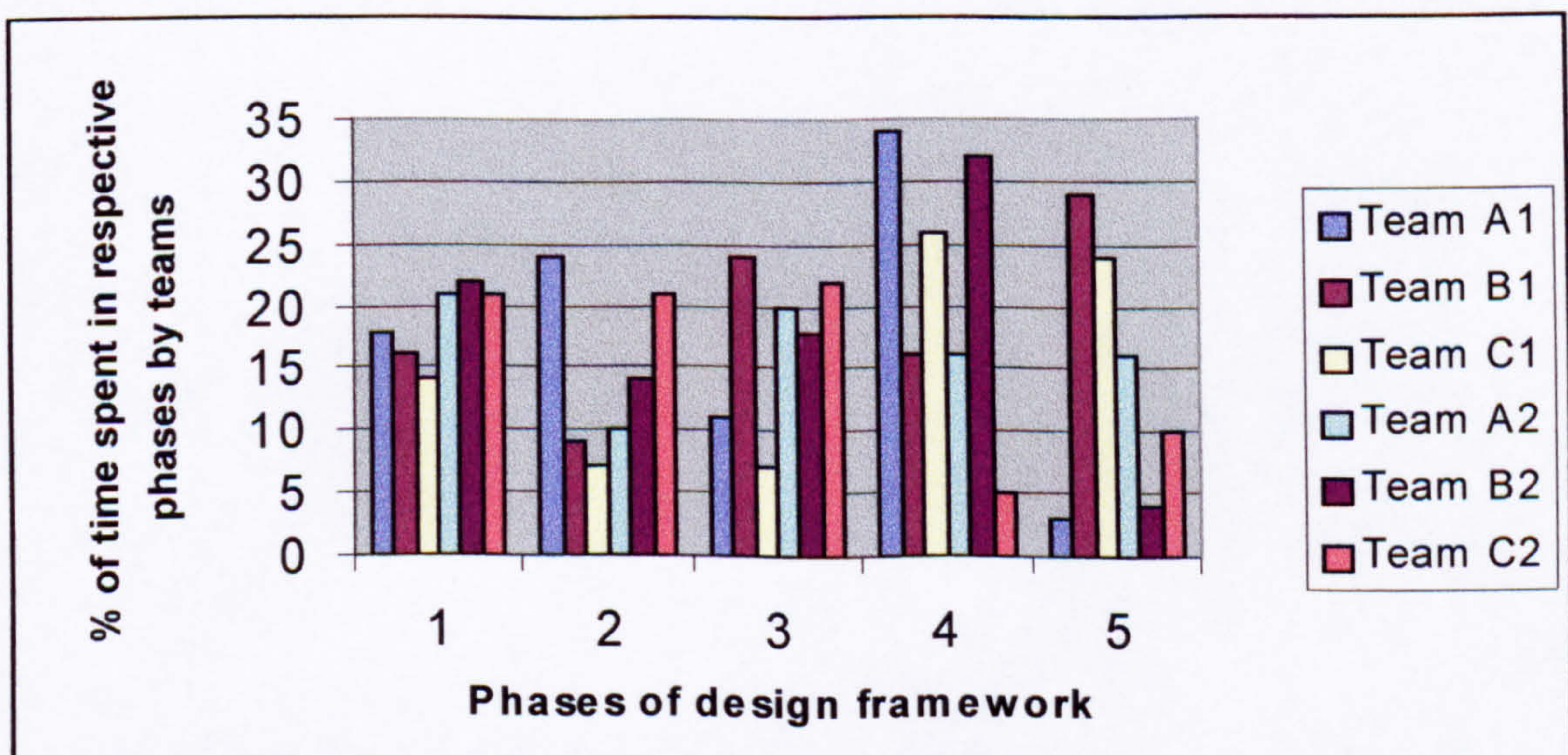


Figure 6.11 Average time spent in phases of design

Detailed comparison

Across the teams in workshop 1 there was little consistency in the time spent on each of the activities or each of the phases, with the average co-efficient of variation for both = 42%).

Across the teams in workshop 2 the average co-efficient of variation for time spent on each of the activities was again = 42%. However, there was considerably less variability in the time spent on each phase (average co-efficient of variation = 30%), particularly during phase 1 (Interpret: 2%) and phase 3 (divergence: 8%).

Upon analysing separately those teams who had worked with the framework and those teams who worked without the framework (table 6.7) it was apparent that the former group portrayed less variability in the time spent on both the activities and the phases of the framework.

	Nature of grouping			
	Teams in Workshop 1	Teams in Workshop 2	Teams without the framework	Teams with the framework
Activities	42%	42%	45%	37%
Phases	42%	30%	40%	29%

Table 6.7 Comparison of co-efficient of variations within and across workshop teams

Although the data suggests that those teams which utilised the framework have lower variability in time spent in both the phases and activities of the framework, it is unclear whether this correlation is a result of the team having a framework against which to plan their activity (even at a subconscious level). In this respect, although this is an interesting finding, it is unclear whether this has any significance in improving understanding of the affect of the framework on group conceptual design activity.

6.5.3 Unclassifiable design activity

Disregarding the unclassified activities of teams C₁ and A₂ discussed previously, which were the result of attempts to maintain the team, it was noticeable that in general the teams involved in workshop 1 spent part of their non-design time in a different manner to the teams in workshop 2. Table 6.8 makes a comparison between the two workshops in terms of these unclassified activities that averaged 14% of the time (see figure 6.10).

Activities undertaken which were unclassifiable within the existing phases of the framework	Teams in workshop1			Teams in workshop2		
	A1	B1	C1	A2	B2	C2
Planning & generating a design process to follow	✓		✓			✓
Allocation of elements of design for each team member to undertake	✓	✓	✓	✓	✓	✓
Allocation of time periods for producing deliverables	✓	✓	✓	✓	✓	✓
Discussions held in a bid to maintain performance or redirect the team			✓	✓		
Introductions and outlining of roles by team members				✓	✓	✓
Pooling of team knowledge in a briefing period	✓			✓	✓	
Connectedness of elements of both problem & solution made explicit						✓

Table 6.8 Comparison of unclassifiable activities between workshops

All teams planned their activity in terms of allocation of resources and time, irrespective of being provided with the framework or not. It is apparent that, of those teams not given the framework, only team B₁ did not attempt to agree a design process. This is the result of the team's decision to progress in an *ad hoc* fashion, owing to their performance during the preliminary exercise. The reasoning behind this decision was given as; '*If it's not broken why fix it?*'

Teams C₁ and A₂ were the only teams that needed to address explicitly the social interaction aspects of the team (team maintenance). This owed much to the fact that there was a confrontational atmosphere apparent between members in these teams, whereas in general the other teams negotiated common understanding and agreed on direction to progress.

All teams in workshop 2 (but none in workshop 1) undertook an introduction of team members and the outlining of their team roles. This would suggest that this procedure is a necessity for newly formed teams. Owing to the fact that the delegates of workshop 1 knew one another professionally, as well as socially in the majority of cases, this phase was not necessary.

The pooling of team knowledge was undertaken by some teams and not by others. This appeared to be undertaken only when one team member suggested it to their counterparts. Finally, the identification of the connectedness of certain aspects of the design was only undertaken explicitly by team C₂. This is not to suggest that the other teams did not attempt to do this as it may have been undertaken by each designer before forwarding concepts. However, the panel of judges stated that only the proposal of team C₂ reflected that this activity had been undertaken.

Upon further analysis of this final point it became apparent that discussions were generally based on five specific issues:

- Working as a team (initial introductions, roles, responsibilities, i.e. defining teamwork)
- Maintaining interaction between members
- Lack of communication
- Team dynamics (attempts to maintain collaboration between team members)
- Redirecting the team to maintain efficiency

To this end, it was recognised that one of the main elements missing from the paper-based version of the conceptual design framework was the need to recognise and manage team maintenance. This needs to be addressed and accounted for in a realistic model of conceptual design activity.

6.6 Dependency across framework structure

6.6.1 Introduction

The maps of actual design progression of the teams (figures 6.12 – 6.17) could be the result of one of two things: i) there is some form of dependency between those

activities; or ii) the team picked the next activity to be addressed at random, simply because they recognised that it had to be visited at some point during the process. However, if the latter eventually proves to be true then present attempts to understand conceptual design are doomed to fail.

Thus, for the purposes of this research it has been assumed that design progression has an underlying rationale, and it is this that the author seeks to discover and, ultimately, support. A technique developed in the 1980's (Steward 1981) known as the dependency structure matrix (DSM), which has been applied previously in design research (McCord and Eppinger-1993, Rogers and Padula-1989, Huovila, Koskela, Lautanala and Tanhuanpaa-1995, Austin, Baldwin, Li and Waskett-1998) to portray the dependencies between sets of activities, can be utilised to analyse design progression. In the context of this investigation, the DSM is produced by assuming that, as the various patterns of progression depict the actual design activity of the teams, progression from one activity to another must be the result of some dependency between those activities. The DSM works on the premise that the activities are undertaken in the order suggested by the rows (and columns; which are always in the same order). The dependence of one activity (e.g 2) on another (e.g 4) is indicated by placing a mark in row 2, column 4 of the matrix. A mark placed above the diagonal indicates feedback (i.e dependence on a future activity) and hence, iteration.

A DSM is usually evolved from a previously defined process model of activities and dependencies. The optimum order of activities (minimising iteration) can be found by applying a 'partitioning' algorithm. In this instance the process has been reversed: the sequence in the pattern of progression has been used to infer the activity dependencies and hence, construct the matrix.

Once the DSM has been produced it can be used to identify 'loops' of activities based on the boundary of those marks which appear above the leading diagonal (the shaded areas), where iteration occurred between several activities. DSMs representing each team's design progression are shown in figures 6.12 to 6.17.

6.6.2 Workshop 1: Dependencies across framework components

Team A₁

The DSM of team A₁ (figure 6.12-a) depicts a large interdependency block that envelopes all of the framework's design activities except 'Improving details' (activity 12). From this DSM it could be assumed that activities 1-11 were wholly dependent on one another. However, as has been noted previously, team A₁ progressed in a number of iterative bursts, rather than in a random and non-linear fashion.

This becomes apparent when a differentiation is made between the nature of dependencies within the large iterative block of activities.

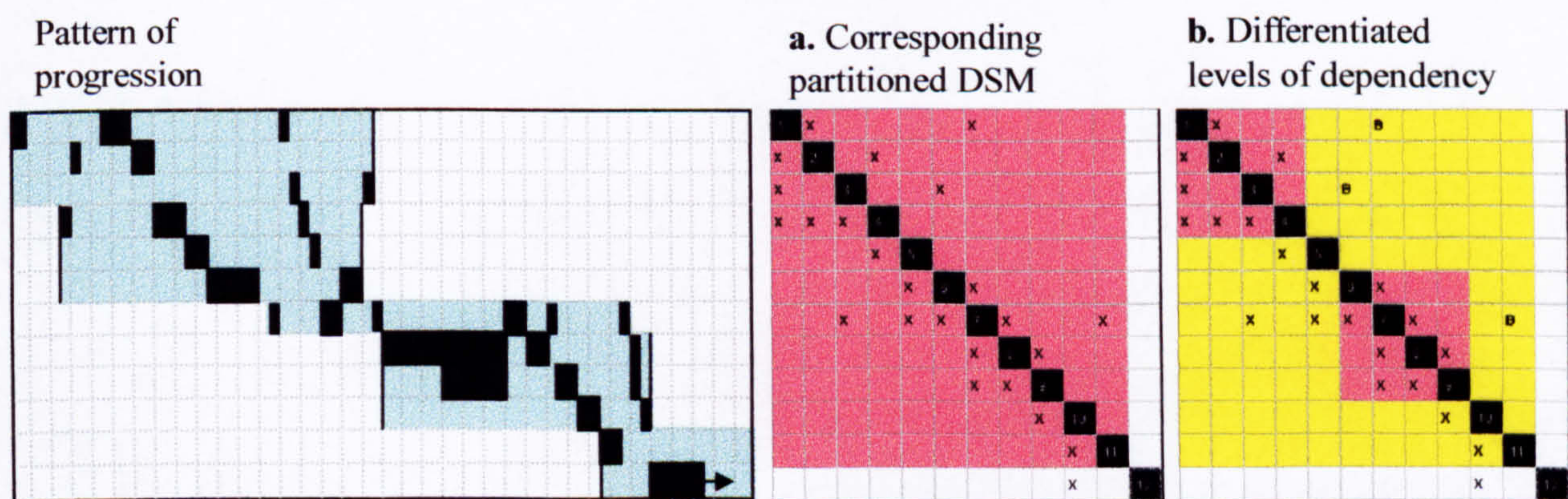


Figure 6.12 DSMs representing design progression of team A₁

If those marks furthest from the leading diagonal are designated as having a different level of dependency (marked B) to those representing a lesser backward step (i.e. those falling closer to the leading diagonal) it is apparent that iterations within certain clusters of activities fall inside the higher level of iteration represented by the large dependency block.

Team B₁

As with Team A₁, the DSM produced from team B₁'s pattern of design progression (figure 6.13-a) describes a large block of interdependency which encapsulates activities 1 to 11. However, the differentiated DSM of team B₁ (figure 6.13-b), although also describing two blocks of interdependent activities, differs significantly from that of team A₁. This difference lies in the interdependency between activities; with figure 6.13-b showing interdependencies between activities 4 – 7 and 8 – 9

respectively, while figure 6.12-b shows one interdependency block comprising activities 1 – 4 and a second comprising activities 6 – 9.

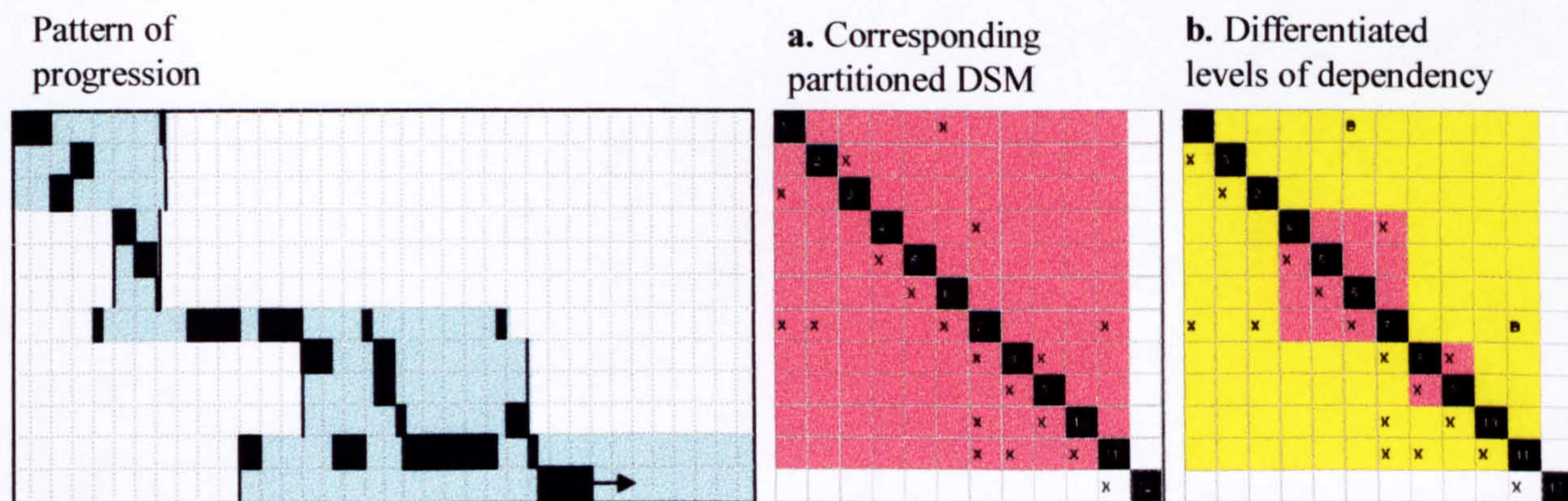


Figure 6.13 DSMs representing design progression of team B1

Team C1

The DSM developed from team C1 (figure 6.14-a) provides a very different picture of interdependency between the design activities, with activities 1 – 4 being undertaken independently of one another in a linear fashion, before activities 5 – 11 were undertaken in an iterative manner. This difference was the direct result of a confrontational situation within the team (detailed in section 6.3.4) which saw members begin to clash with regard to the optimum manner in which to progress. This led to a lack of harmony within the unit and resulted in the remainder of the design time being spent jumping between activities in a fairly *ad hoc* fashion.

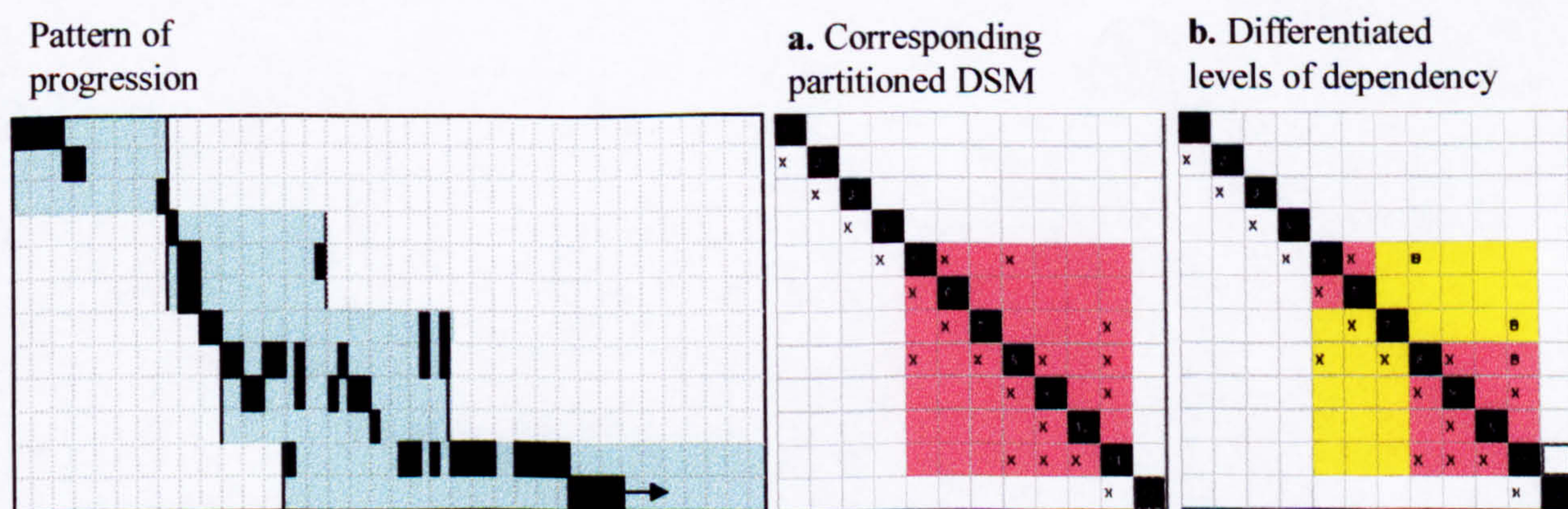


Figure 6.14 DSMs representing design progression of team C1

However, upon differentiating between levels of interdependency in team C1's design progression (figure 6.14-b) a similar pattern of iteration-within-iteration to that shown

by teams A₁ and B₁ become apparent; although the interdependency blocks are miscellaneous.

6.6.3 Workshop 2: Dependencies across framework components

Team A₂

The DSM of team A₂ (figure 6.15-a) again portrays a large single interdependency block. However, the interdependency lies within and between activities 1-9. During this period, rather than completing one activity entirely before progressing to the next, the team jumped between them. Once they had selected suitable combinations of concepts (activity 9) they progressed sequentially through the remainder of the design activity.

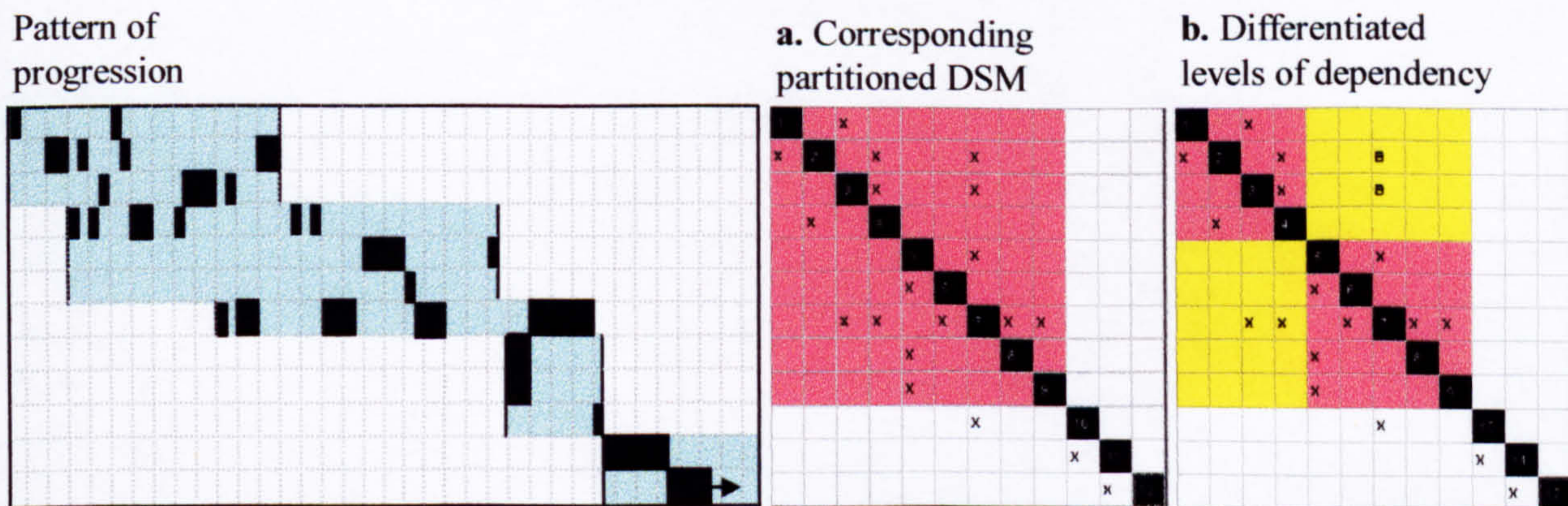


Figure 6.15 DSMs representing design progression of team A₂

Again, it is apparent that iterations within certain clusters of activities fall inside the higher level of iteration represented by the large dependency block. This revised DSM (figure 6.15–b) moves closer to the DSM describing team B₂'s design activity (figure 6.16).

Team B₂

The design progression of team B₂ is very similar to that of the previous teams (figures 6.12 - 6.15), with each describing two blocks of interdependence. However, they differ in the fact that the blocks of iteration described in figure 6.16 are independent of one another and are not contained within a larger iterative loop.

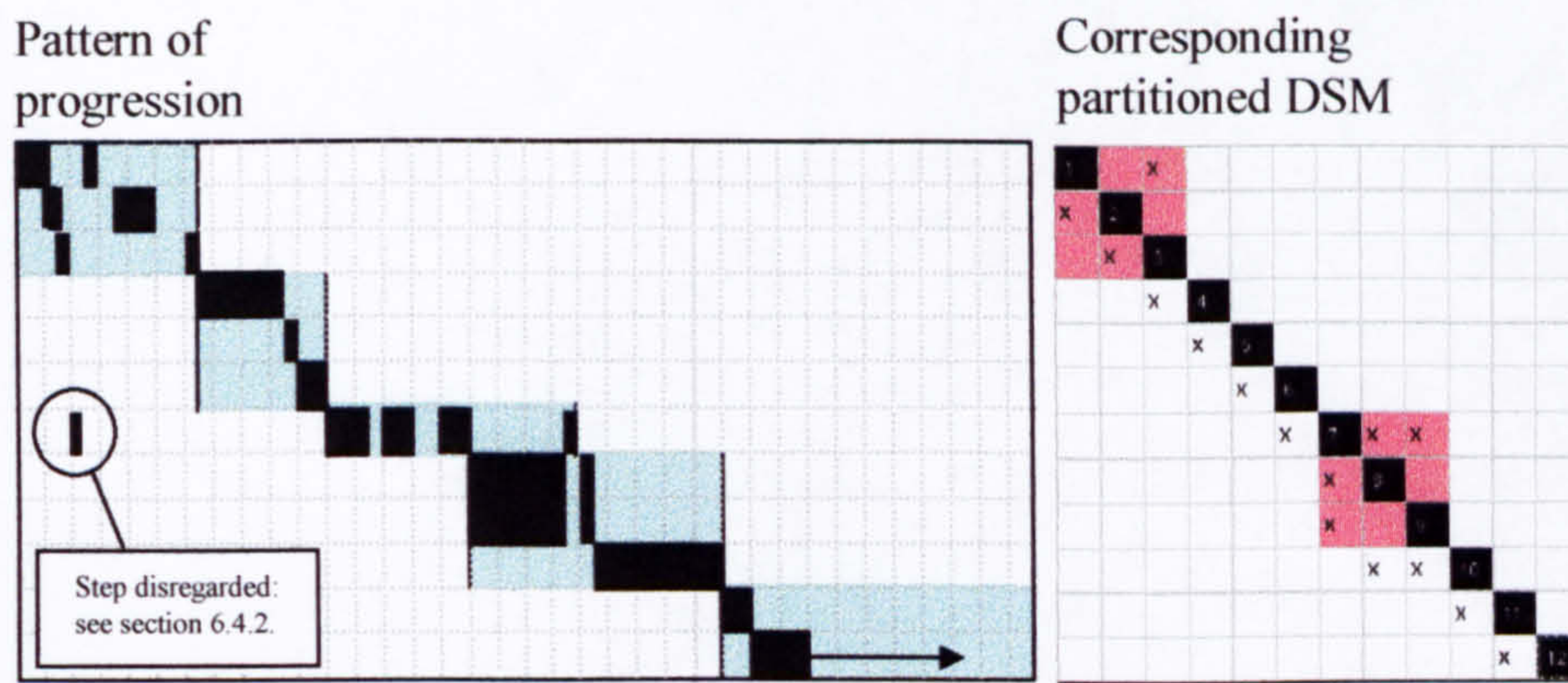


Figure 6.16 DSM representing design progression of team B2

Activities 1-3 are interdependent, after which there is a sequential progression up to the determination of project characteristics (activity 6). Upon completion of this activity, the following three activities- 7) searching for solution principles; 8) transforming and combining these, and 9) selecting suitable combinations, were undertaken in an iterative manner. Again, once this 'loop' was complete the remaining design activity was undertaken sequentially.

Team C₂

Like team A (figure 6.15-a) in this workshop and all the teams from workshop 1, the DSM developed from team C₂'s pattern of progression (figure 6.17-a) portrays a single large block of interdependency. However, the interdependency lies within and across activities 3-12. The team progressed sequentially through the first two-activities before entering this large iterative loop. If, again, marks furthest from the leading diagonal are represented differently to those near to it, two independent clusters of interdependent activities lay within the larger iterative block.

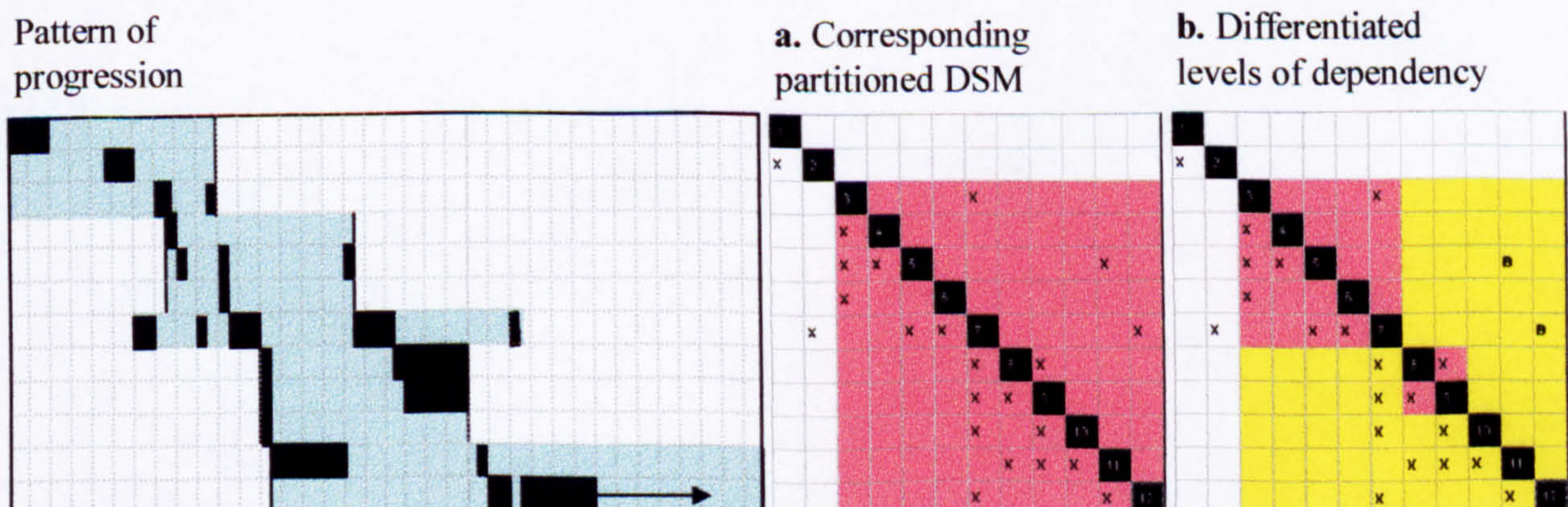


Figure 6.17 DSMs representing design progression of team C₂

However, it is important to note that, once the team had identified the essential problems (at activity 3), they undertook what appear to be two similar processes to complete the exercise. Upon further examination it is apparent that, if the two similar processes are considered separately, the design progression, and the resulting DSMs, are very similar to those exhibited by team B2.

6.6.4 Duration and nature of phase interdependency

The DSMs in figures 6.12 to 6.17 describe the varying degrees of interdependency between the 12 activities as undertaken by the workshop teams. However, considering the manner in which the five second-level phases were undertaken provides further insights into the nature of conceptual design activity (table 6.9).

	Team	Addressing a single phase only	No. of phases addressed in parallel			Total design time up to activity 12 final step
			2	3	4	
% of total time	A1	10%	71%	19%	N/A	310 min
	B1	31%	21%	48%	N/A	255 min
	C1	55%	4%	33%	8%	260 min
	A2	20%	57%	23%	N/A	305 min
	B2	84%	16%	N/A	N/A	250 min
	C2	24%	39%	20%	16%	245 min

Table 6.9 Nature of design activity by phase interdependency and duration

Team B2 spent the majority of their design time working through the phases in series, first completing one phase before commencing the next, and only a small proportion (approximately 16%) in parallel. This iterative behaviour represented divergent search for concepts and their ensuing transformation. This sequential progression is the direct result of following the experimental procedure.

The more important observation relates to the manner in which teams A2, C2 and all teams in workshop 1 progressed with respect to addressing phases in parallel (table

6.9). Team A₂, which had a copy of the framework to utilise as a guiding principle, addressed two phases in parallel for the majority of the time (57%), followed by three phases for 23%, and a single phase for only 20%. At no point during the exercise did they attempt to address four phases in parallel. This is also the case with teams A₁ (71% - two phases, 19% - three phases) and B₁ (21% - two phases, 48% - three phases). Teams C₂ and C₁ however, neither of which had a copy of the framework, spent approximately 16% and 8% respectively of their design time considering four phases simultaneously.

Team C₂ spent much longer than team A₂ 'Interpreting the need' in isolation of the other phases, before attempting to address other issues simultaneously. After this point team A₂ addressed only 3, or less, phases in parallel for the remainder of the exercise. Team C₂ however, mid-way through their design activity, spent 40 minutes (approximately 16% of their overall design time) addressing 4 phases in parallel.

It must be remembered that team C₂'s progression through the activities, once activity four had been completed, represented two discrete iterations (figure 6.7). Table 6.10 considers these two progression patterns individually, based on the premise that phase one is common to both iterations.

	Iteration	Addressing a single phase only	No. of phases addressed in parallel			Total design time up to activity 12 final step
			2	3	4	
% of total time	First	64%	19%	16%	N/A	160 min
	Second	66%	34%	N/A	N/A	160 min

Table 6.10 Analysis of two individual iterations performed by team C₂

This data suggests that a larger proportion of time, approximately 65%, was spent undertaking phases in isolation of one another. Additionally, rather than considering 4 phases in unison for periods during the design activity, team C₂ actually considered 3 phases in parallel during the first iteration and then only two during the second.

This implies that team C2, who were considered to have developed the solution which could be subsequently developed to meet the brief most effectively, considered phases in isolation, and two and three phases in parallel to generate the holistic concept. After which, the team, having settled on the high level concept, developed the final proposal by undertaking phases singularly, or by considering no more than two phases in parallel. This suggests that team C2 considered multiple phases to form the concept, which then allowed them to reduce the number of phases being performed in unison to crystallise the proposal.

6.6.5 Observations and comparison

Considering figures 6.12 to 6.17 in addition to the analysis undertaken in section 6.6.4, it is apparent that iterations across the activities and phases of the recorded design processes fit within a higher level of iteration representing the entire conceptual design phase. In light of these findings the preliminary design framework was developed into a more realistic representation of the conceptual design phase (figure 6.18).

In the DSMs that were produced from the team design activity (figures 6.12 - 6.17), interdependencies between the majority of activities within the framework were common. However, by designating different levels of dependency within these iterative blocks, it has been shown that there are also dependencies within specific clusters of activities (activities clustered by phase within figure 6.18). The arrows designate these connections, with the frequency of occurrence being indicated by line thickness.

Within the models of design progression (figures 6.2 to 6.7) it was apparent that a large proportion of each teams design process involved short bursts of sequential progression through activities and phases, followed by steps backward over a number of activities to recommence design activity within an earlier phase.

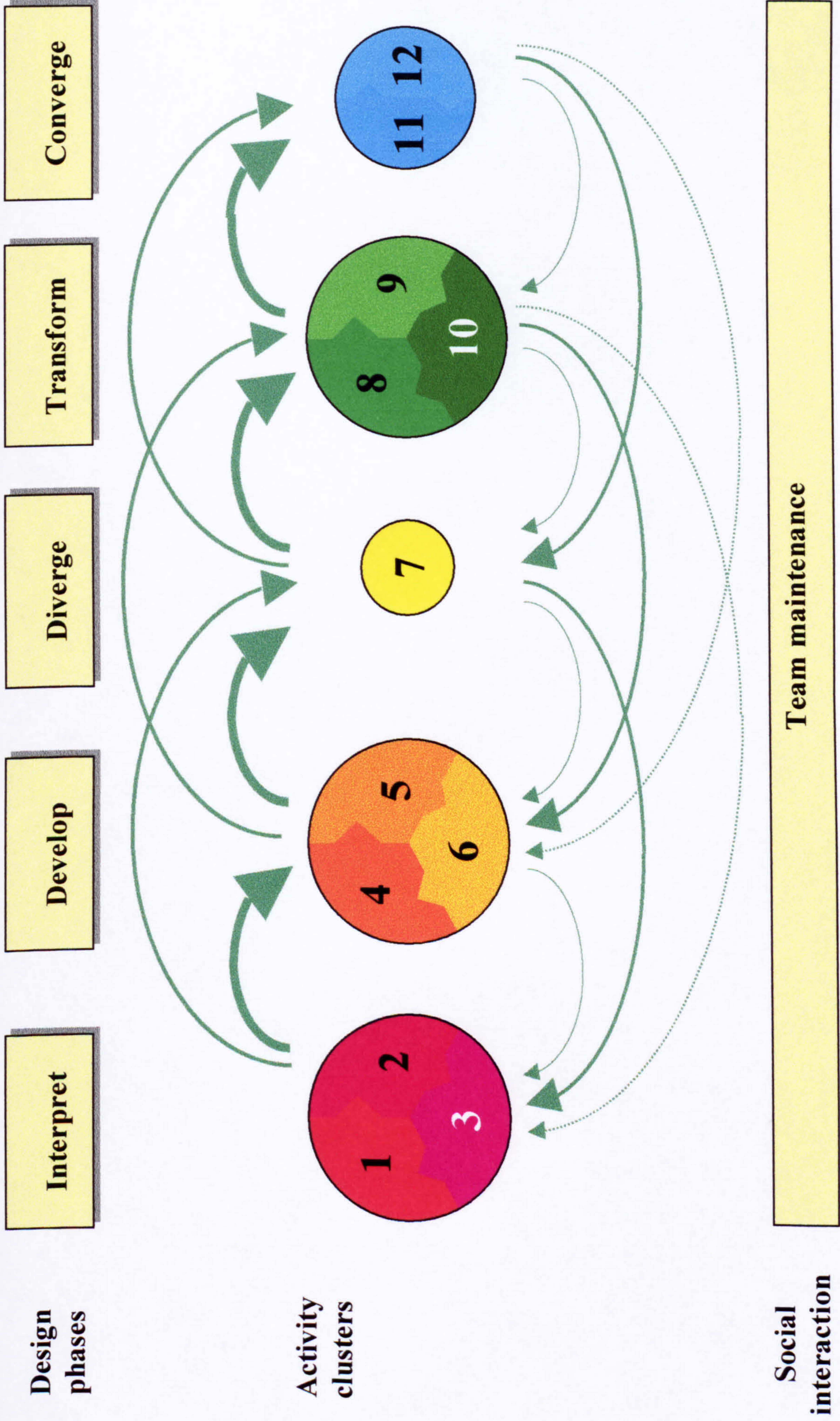


Figure 6.18 Reinterpreted conceptual design framework model

Although this cyclic progression led to confrontation within some teams (with a number of individuals criticising their fellow members for ‘going round in circles’) design is a learning activity and it is often only by moving ahead to improve knowledge, before taking a step back to re-address a problem with improved understanding, that the design process can proceed. Ultimately, it was this iterative behaviour that enabled raw concepts to evolve and blossom into workable solutions.

This concept of iteration-within-iteration has been proposed previously by Hickling (1982), who represented the whirling process of decision making in design in a similar manner (figure 3.2, in chapter 3). Owing to the fact that ‘no foolproof experiment was available with which to demonstrate these connections’ (Hickling 1982), Hickling suggested, rather than asserted, their existence. However, upon comparing the iterative nature of the design activity of the workshop teams with the cyclic whirling process prescribed by Hickling, the notion that differing levels of dependency exist within and across activities appears to be substantiated.

6.7 Feedback on design techniques

6.7.1 Introduction

As was stated in chapter 3, although the design technique literature is vast, few of the texts describe the testing of the techniques in practice. As such, there is little evidence to support claims that the various methods and procedures described are effective in aiding group design activity. This is very surprising given that a vast proportion of the techniques were developed primarily to assist in team working environments. Thus, as has been stated at the outset of this chapter, a number of design tools were tested during the workshop sessions. The techniques that were tested varied in nature; some coming direct from the design science literature, while others were hybrids of several existing tools. For the purposes of this session these various techniques were deemed ‘Team Thinking Tools’ (these have been outlined in tables 6.2 and 6.4). The following sections describe team member feedback on the use of the tools.

6.7.2 Workshop 1 – Responses to design techniques

Table 6.11 summarises the extent to which the design teams used design techniques during the workshop, and their comments.

Comments on design techniques used during exercise				
Team	Brainstorming	Mind-mapping	Pros & cons w/ weighting	Additional comments regarding techniques
A	Not followed as described by author. Continual criticism of proposals. Excellent as an idea generator (even when used in this manner).	Used to help formulate links between issues and concepts. Not followed as described by author but proved very useful to team.	Used w/out weighting to evaluate proposals. They generated pros & cons of options then simply used opinion to make final choice.	Only these techniques were used because team knew how having used them in practice. They felt uncomfortable attempting to use a 'technique' that they had not come across before. A technique must be practised or it's use facilitated for a team to apply it in practice. They suggested they would have only utilised a 'new technique' if forced to.
B	Used extensively but not followed as described by author w/ criticism of proposals throughout. This did not adversely affect team effectiveness. Assisted greatly when generating concepts.	Not used	Used w/out weighting (just opinion) to choose criteria (value requirements). Stated that it would be used for evaluating final concepts but again used w/ opinion & not weighting.	Only used these techniques because they were commonly known. Member stated that techniques must be simple and quick to be useful and accepted.
C	Used but proposals were criticised throughout. Concepts were immediately discussed & criticised (defend & criticise scenario ensued).	Not used	Weighting used in isolation to prioritise key aspects in terms of value to brief. Pros & cons used w/out weighting (opinion used) for evaluation.	Techniques utilised were made redundant owing to conflict between team members. When confrontation arose the techniques were ineffectual.

Table 6.11 Team comments regarding team thinking tools

Only three of the six design techniques that were introduced to the delegates were used during the workshop. Delegates were willing to use only techniques that they knew or had used previously, and they said that techniques must be quick and simple to apply if designers are going to take them seriously in practice. Additionally, the whole team must agree to participate in using them.

6.7.3 Workshop 2 – Responses to design techniques

This workshop saw four of the six 'Team Thinking Tools' being employed by the design teams.

A questionnaire was introduced into this workshop to allow quantitative, as well as qualitative, response data to be gathered. The weighting scale was such that a 5 represented strong agreement with the statement and a 1 represented a strong disagreement. A score of 3 was classified as neither agree nor disagree. The Team Thinking Tools (T-3) questionnaire can be referenced in Appendix II.

	Lotus Blossom/ Mind map	Ranking and weighting	Forced analogies	Six Thinking Hats	Comments on T-3s in general
Team A	No comment made	Helped to emphasise divisions within the team.	No comment made	Tended to take this approach naturally without consciously thinking about it.	Would have proven more useful given an extended period to exploit their use
	The team did not find this helpful	Helped us prioritise issues and requirements	Did not find useful personally	Did not use in formal manner but members did naturally wear different hats at different times	Creative tools did not produce ideas already generated. Evaluative tools were more useful.
	Did not implement effectively & did not lead us anywhere	No comment made	No comment made	No comment made	Could have been used more effectively if we understood them further. They have great potential & I will use some of these in the future
	Our map did not make things clearer as our choice of major issues was poor.	This can detract from major issues and focus on 'middle' elements if team is not careful.	No comment made	Did not use particular hats, just noted that comments/actions fitted 'a hat' type.	Everybody needs to understand tools fully to make them useful. Different opinions led to conflict and thus, techniques could not be used effectively.
	Dabbled with it but it did not help us.	Useful if it is used at the appropriate times in the design process.	No comment made	Not used as suggested but helped us to understand one another's approaches.	Needed to spend time learning how to use them. Team could then have used them more effectively
Team B	Lack of team understanding of tool meant it was abandoned part way through.	No comment made	No comment made	Aided team member involvement. Stopped one member dominating.	No comment made
	Was over simple and did not fulfil it's potential	A familiar tool; useful in assessment of requirements and solutions.	Often used as a matter of course by designers. Depends on the individual.	Improved contribution of introverts and stopped dominance of others.	All quite formal & not required when team works well anyway. Tools look most helpful for teams that are not working together.
	Lotus blossom looked too complicated. Mind map could be useful if took time to learn it.	No comment made	Helped me look at things from a different perspective.	Useful tool.	I now have some new methods to use for problem solving.
	Used a simple mind map to review requirements. Lotus blossom seemed too complex to learn given time available.	No comment made	I believe designers use this constantly	Only really used the blue hat. It was a way of stopping the team and taking a step back to review and choose the best way forward	Creative (structuring) tools used to establish problem, client needs and requirements.
	Simple mind map was used and was effective. Lotus blossom appeared too complicated.	No comment made	No comment made	Used to focus team and assess direction to progress	Difficult to use with newly formed team. Must be simple and quick. Simple tools will be remembered.
Team C	Allows all options to be stated and recorded no matter how radical or impractical. Mind is not closed off. All can be considered for development.	Useful when team members cannot come to a shared agreement.			I know these two tools and find them useful in practice.
	Used to reinforce links between aspects but did not help us progress.	All concepts scored equally; were proposals to similar or was criteria ranking in correct?			I believe tools are used intuitively. Designers must have detailed knowledge of them to use them.
	Team did not use this effectively to make decisions.	No comment made			No comment made
	No comment made	No comment made			I feel the tools could be helpful to some designers. In our case however, no real benefit was gained from their use.
	No comment made	Just a formalised version of a natural decision making process which we had already undertaken.			They seemed helpful as a measure of progress and to focus on attitudes of the team's members.

Table 6.12 Delegate comments regarding T-3s

Upon analysing the questionnaire data it became apparent that there was a wide variation in the spread of individual member responses to each of the questions regarding each technique. This suggests that, even when the entire team used a technique, the opinions of individual members regarding its usefulness varied greatly. This finding is reiterated in the qualitative data responses (table 6.12). However, the combination of this information did allow a number of conclusions to be drawn regarding the nature and use of design techniques (see section 6.8.1 for details).

6.8 Conclusions

6.8.1 Summary of conclusions

This experimental period of the research involved six interdisciplinary design teams comprising design professionals from several different organisations. The investigations did not take into account the abilities, expertise or knowledge base of the individual designers and as such, no comment can be passed on the influence that these issues can have on the design process. It is clear that each of the factors must have an impact on the way that the team will function. However, it was not within the remit of this work to investigate the effect of these factors in practice. This is, of course, an obvious limitation of the work. However, such factors and their existence within teams should be reflected in the relevant benefits gained from the application of the framework. For example, experienced, expert designers, who are familiar with working as part of large interdisciplinary teams on specific project types, may gain little benefit from the application of the framework. Conversely, graduate designers, only recently introduced to the rigours of the project environment, may profit considerably from its application. Given the focus of this research investigation, and the limitations of the experimental environment, it is recognised that these factors are worthy of far greater interdisciplinary study (through collaboration with psychologists and sociologists) though this falls outside of the scope of this particular enquiry.

In statistical terms the number of participants in the workshop is very few and it would be premature to draw general inferences from this limited evidence. However, within these limitations, the following conclusions were drawn:

The design framework model

- i. Each of the teams undertook the same design activities and phases over the course of the exercise. However, the sequence and duration of these varied greatly between teams.
- ii. the majority of design activity undertaken by the teams (between 79 and 90%) could be classified within the activities of the conceptual design framework;
- iii. social interaction and team maintenance account for a portion (between 10 and 21%) of design time but neither issue is classified within the conceptual framework model;
- iv. The two teams that were provided with the design framework progressed fairly linearly without obvious iteration. This is apparent despite of the fact that one team followed it stringently while the other used it purely as a guiding principle.
- v. Conversely, those teams that were not provided with the design framework tended to progress in a number of iterative bursts. These iterations occurred irrespective of whether the teams had pre-defined a design process for themselves or not. However...
- vi. When teams agreed a process in advance it appeared to help the members to adhere to a programme and work in accordance with it.
- vii. Although the teams were constrained in terms of time and the differences were not great, those teams that utilised the framework in this workshop did take less time to complete the project.
- viii. However, there is no substantial evidence to suggest that following a design process, be it in an iterative or systematic manner, will help the team to generate a better design concept or reduce the time period spent reaching that concept.
- ix. The teams in which members worked well together produced integrated solutions. The two teams in which conflict was apparent between members, produced kit-of-parts design solutions. In this sense there was a clear link between the process and the product.
- x. The teams of individuals from the single organisation began the exercise less formally and were more relaxed with one another on a social level, whereas the multi-organisational teams commenced formally and attempted to decrease formality with initial introductions. These differences did not stop confrontation in either workshop.

- xi. the evidence suggests that designers perceive they have performed better as a team when they agree on, and subsequently follow, a design process;
- xii. the evidence suggests that a team must be led throughout the design activity. However, the team must agree on who should lead it and how it should be led if it is to work effectively as a unit and avoid confrontation; and
- xiii. if the team does not agree on a design process to follow, individual team members tend to make opportunistic forays into particular areas of the problem in an ad hoc manner. If other team members do not agree on the direction of that foray then this can lead to a lack of synchronisation in the team effort and a lack of input from one or a number of its members.

The team thinking tools

- i. Designers prefer to utilise design techniques that they are familiar with.
- ii. When designers do use design techniques, they may do so in a manner that works for them, even if this is not exactly how the creators of the techniques originally envisaged them being used.
- iii. When teams were working well as a unit there was no need to introduce the tools. Design tools should only be introduced to assist the team in getting over a sticking point.
- iv. All team members need to 'buy into' the use of tools if their application is to assist the design activity. If some members are reluctant to use a particular tool then their input will be lost.
- v. The use of a facilitator skilled in the application of a team thinking tool can increase the willingness of the team to try it out. The facilitator can be either a team member with a working knowledge of the tool or another individual who is conversant with its application.
- vi. The teams considered tools to be more helpful and relevant when their application was facilitated.
- vii. Design tools must be simple to learn and quick to use if they are to appeal to practising designers. Simple tools, such as brainstorming, are remembered easily by designers and then used intuitively owing to their simplicity and ease of application.
- viii. Designers will dismiss tools that appear over complex without attempting to apply them.

ix. The evidence appears to suggest that design tools prove helpful for some individuals and not for others; it is a matter of personal preference on the part of the individual designer. There is no evidence to suggest that any one of the tools tested assisted all of the designers or all of the design teams to produce a solution.

6.8.2 Defining a medium for delivery of the model

The design framework developed to describe the sub-phases and activities of the conceptual phase was supported by the findings of the workshops. Additionally, the investigations outlined herein confirm that no single design process is generic to the conceptual design phase of building projects as the sub-phases and activities do not simply follow sequentially, but are instead highly iterative and unique to a particular design environment.

Although the model illustrated in figure 6.18 is both robust and representative of the manner in which interdisciplinary conceptual design activity is undertaken. It also accounts for a major factor of successful design team working that was absent from the original design framework, namely self-management / maintenance by the design team. Thus, in addition to addressing the activities of design the model of the conceptual design phase should address the associated social interaction, collaboration and communication issues. Additionally, though no conclusive evidence has been obtained regarding the effectiveness of 'Team Thinking Tools' in practice, any model of the conceptual design phase should incorporate design techniques that the team can apply should they be required.

It must be concluded that for any model of the conceptual design phase to be realistic and usable in practice it must be flexible, to allow it to be adapted to the needs of the team and the project environment in which it is being used, while still allowing the design activity to be structured around a basic framework. Additionally, it must account for the social, as well as the process and technical, aspects of early stage design, and provide advice and procedures detailing how different activities can be achieved.

For these reasons it was decided that the paper-based conceptual design model should be developed into a more appropriate and favourable form. With low cost computing now readily available and the majority of the construction industry now reliant on the use of IT, it was decided that the optimum means of delivering the model would be in the form of an interactive computer-based system.

In recent years there has been an increasing deployment of computer-aided tools to support the design process. Recently, this has been stimulated by a desire to establish computer-based design support (Mazijoglou, Scrivener, Clark 1996). Unfortunately, the rigidity of the majority of the existing electronic tools does not support the informal nature of conceptual design work (Gardiner and Theobald 1999) with the majority the tools being useable only in the latter stages of design while even then they provide only limited support (Baya and Leifer 1996). Currently, no commercial computer based design tool exists for, or has been developed with the sole intention of, supporting the conceptual design phase (Jensen 1999).

As such, the following chapters of this thesis outline the preliminary specification of a computer-based version of the conceptual design model (chapter 7), its subsequent development into a prototype Web-based system which allows the user to follow various alternative pathways through it depending on the needs of a particular project and its design team (chapter 8), and its preliminary trialling on a live design project in industry (chapter 9).

As will be discussed in chapter 9, the trialling of the system in practice was not undertaken with the aim of fully validating the computer-based version of the framework, although it did enable a preliminary assessment of the suitability of the internet as the medium for delivery of the framework to be achieved. The primary aim of this component of the research was to allow further validation of the underlying framework structure by applying it in a live project and, ultimately, to gain further insights into interdisciplinary conceptual design in practice.

Chapter Seven

**Preliminary specification of a computer-based version
of the conceptual design model**

7 Preliminary specification of a computer-based version of the conceptual design model

7.1 Introduction

The preceding chapters have described the need for an interdisciplinary conceptual design framework, the subsequent development of such a framework, albeit a preliminary version, and lastly, in chapter 6, the testing and validation of this preliminary framework in real-time experimental workshops. This has enabled a generic model of the conceptual design process to be proposed (figure 6.18).

The focus of this chapter rests on defining a specification for a computer-based version of the design model. In order to test the applicability of the model and its underlying framework structure it was necessary to develop it into a format that was familiar to the intended users and could be readily accessed. The computer was chosen as the medium for delivery for the conceptual design model owing to its frequency of use in practice and its ease of accessibility in the design office. As has been stated in the preceding chapter, the transformation of the model into a computer-based form was as much about constructing and preliminarily verifying a prototype design support system by applying it in a live-design scenario, as it was about investigating further: i) the applicability of the conceptual design model in practice; and ii) the veracity of the underlying framework structure; to provide further insights into the manner in which interdisciplinary teams work together during conceptual design activity.

The chapter begins with a definition of requirements and functions of the computer-based system. This involves a discussion of the options for operation and outlines the appropriate system characteristics. These system characteristics are assessed in two ways: i) by reviewing the findings made in the preceding chapters of this thesis; and ii) by undertaking a review of existing surveys into computer-based support tools as a means of verifying, and building upon, those findings. The discussion concludes with a choice of application type and organisational structure for the system.

7.2 System Requirements

7.2.1 Nature of operation

The data gathered during both the case study investigations and the designing together workshops supported the early literature search finding that team conceptual design activity is generally approached, and subsequently undertaken, in an *ad hoc* fashion. There has been little, if any, emphasis placed on the development of a harmonised understanding of the design process, let alone the shared application of available design techniques. This characteristic can lead to discontentment, and more importantly a confrontational environment, within the design team; both of which are factors that can lead to sub-optimum team performance. This thesis to date has highlighted several attributes that must be present in any mechanism developed to support interdisciplinary design activity:

- It must represent the phases through which conceptual design activity progresses at varying levels of detail.
- It must not prescribe a fixed systematic procedure, but instead be flexible and adaptable to allow the team to define their own path through it.
- It should however, allow systematic progression should the team require it.
- It should contain both a framework of design techniques and provide advice on how to apply them. Additionally, advice should be provided regarding the optimum point of application of the tools.
- It should assist in a major factor in effective design team working; namely self-management and maintenance by the design team.

The computer tool, which was to be based on the preliminary conceptual design framework model (figure 6.18), had to be developed to allow flexibility in approach while still providing a framework with which to structure and support interdisciplinary conceptual design activity.

7.2.2 System characteristics

The overriding aim of the computer-based system was to support the interdisciplinary team while undertaking design activity during the conceptual phase of building projects. It was based upon the preliminary conceptual design framework, the

development and testing of which have been described previously in chapters 5 and 6 respectively, and had to include some form of team maintenance facility with which the team could manage the social dynamics of collaborative working.

7.2.3 Surveys of computer-based design tools

Several surveys have been undertaken (Peng 1993, 1999, Jensen 1999) with the purpose of identifying and classifying state-of-the-art research and development in computer-based design support tools. Peng (1993, 1999) investigated the tools available to support collaborative drawing and design, and characterised these concisely into four categories: i) Supporting graphical conversations (e.g. *TeamWorkStation*, *ROCOCCO Station*); ii) supporting team room activities (e.g. *TIVOLI*, *WeMet*); iii) supporting rationale, or legacy, management (e.g. *Xnetwork*); and iv) implementing document or workflow management models (e.g. *MicroStation Teammate96*, *ArchiCAD for Teamwork*). Fundamentally, these collaborative design tools focus on the development of shared workspaces and document, or workflow, management within conventional CAD systems (Peng 1999). In fact, an earlier survey described by Brakke and de Vries (1991) discovered that 95% of all commercially available design support tools are limited to CAD support and numerical simulation systems (Blessing 1996).

However, although CAD systems provide support during the later stages of design, they are seldom, if ever, used during conceptual design activity and as such, it is questionable whether these systems can support the design team during the conceptual phase or, for that matter, divulge details of requirements upon which to base this system. A more recent survey (Jensen 1999), which considers in excess of seventy computer-based design tools from across all applications, classified computer-support systems into ten categories:

- Design language systems
- Modelling systems
- Feature based systems
- Object-oriented systems
- Constraint based systems

- Bond-graphs based systems
- Knowledge based systems
- Solution libraries
- Case based systems
- Design history systems

Of those systems examined only Prosus (**Process based support system**) (Blessing 1993, 1994), which is classified by Jensen as a case based system, was developed with the sole aim of providing process-based support to the designer or design team. According to Blessing, Prosus does not describe how designers design, nor does it prescribe how they should design, it merely suggests how designers could design around a given activity structure. Given the size and extent of this survey it is reasonable to suggest that this area of computer-based design support was in need of further development.

7.2.4 A blue-print of system requirements

The requirements specification of Prosus suggests that a realistic and useful computer based system developed to support the individual or the team during any phase of design activity should possess five basic characteristics. It must be i) co-operative; ii) subordinate; iii) flexible; iv) guiding; and v) structuring (Blessing 1994). These characteristics, which are representative of the system attributes outlined in section 7.2.1, are described below.

Co-operative

The co-operative system should direct design activity in close association with the design team. The design team should provide input to direct the progression through the phases and activities, while the system should interact with the design team by either proposing direction of progression or alternatively, allowing the users to take the initiative and direct themselves. In essence the system should co-operate with the user to reach a common goal.

Subordinate

The system, which should interact with the team throughout the design activity, should always work under the control of the team. This appears to be a direct contradiction of the co-operative system. However it is not. Both the team and the system should be capable of directing progression through the activities and phases, but the system must always be subservient to the team; with the users always being able to overrule the system irrespective of its suggestions. In this respect, the team must have the option to utilise the system purely as a contingency mechanism.

Flexible

A flexible system should provide the team with support throughout conceptual design activity irrespective of the manner in which it is approached. The system should propose a direction for progression, however it must not force the design team to follow it should the team members decide that an alternative approach is preferable. This can be facilitated by offering the team a question or prompt to act as a trigger to initiate the process. Design activity demands flexibility of approach owing to the variability of the design situation, and because of the lack of knowledge available at present regarding the relationship between approach and design situation (Blessing 1994).

Guiding

The co-operative and flexible nature of the system should support the design team's need to define its own procedure while still providing structure. Thus, the system as a guide should offer the team direction (present a next step). It should also assist the design team in accomplishing its objective(s), not only by directing progression should it be needed, but also by offering appropriate prompts, knowledge, tools and procedures at the appropriate points within the process. However, as has been stated previously, the team should always have the choice to follow or reject the proposal.

Structuring

The support system should structure conceptual design activity. This is not to say that the structure should impose system, it should instead provide a framework within which the relevant assisting attributes can be stored. Chapter 6 has shown that the structuring of the design activity helps synchronise the team and enhances team

member interaction, ultimately improving teamwork. A defined structure also provides a categorical system within which project-specific data and knowledge can be stored. This will enhance knowledge capture, storage and retrieval and as a result, will support the design team in both the current and future projects.

In addition to these factors, the testing of the preliminary conceptual design framework (chapter 6) identified that it had neglected to account for an important characteristic of conceptual design activity; team maintenance. Thus, an additional characteristic has been introduced:

Maintaining

The system should support not only the technical aspects of design but also the social aspects. As such, the system should facilitate team member interaction and collaboration. This mechanism should allow team members to interrupt the process at any time if they are discontent. The system should provide support relating to those social interaction issues unearthed in chapter 6:

- i) Working as a team
- ii) Maintaining interaction between members
- iii) Lack of communication
- iv) Team dynamics
- v) Redirecting the team to maintain efficiency

7.2.5 Context of the design environment

To enable a realistic and genuinely useful computer support system to be developed it was necessary to define the context within which it was intended to function.

The context described here, which is divided into a list of key areas for consideration, emerged from various sources within a state-of-the-art survey of existing tools and from details described in the previous chapters. However, a similar list generated by Barrett and Stanley (1999) indicates five key improvement areas for better construction briefing. These key improvement areas, which were based on an analysis of sixteen construction projects, are defined as: i) empowering the client; ii) managing the project dynamics; iii) appropriate user involvement; iv) appropriate visualisation

techniques; and iv) appropriate team building. The interrelationships between these five issues are depicted in figure 7.1.

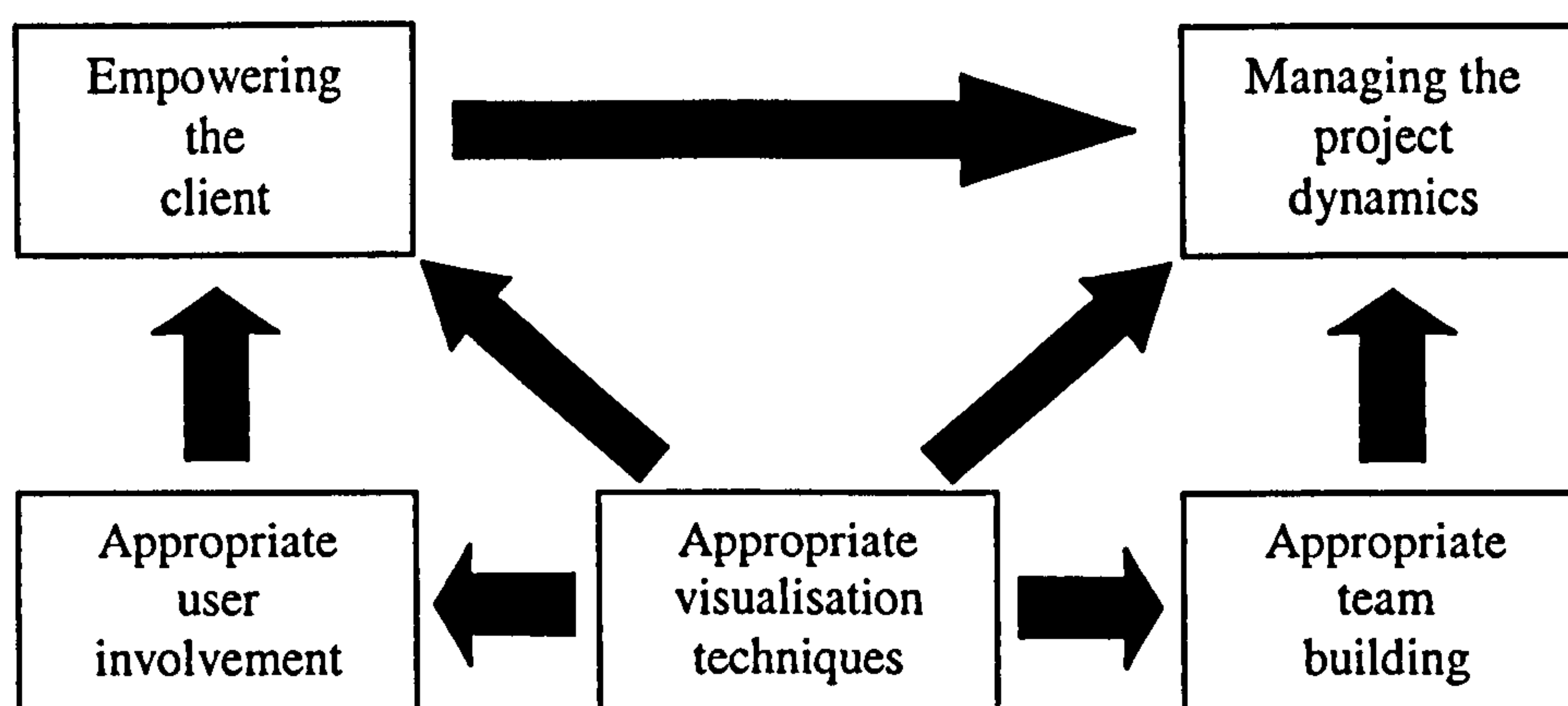


Figure 7.1 Five key areas for improved construction briefing (after Barrett and Stanley 1999)

Although this model was developed to identify areas for improvement in construction briefing, both the terminology used to describe the key improvement areas, and the interconnectedness of these various issues, represented the context in which the computer-based support system was intended to function.

Thus, figure 7.1 and its terminology were used as the basis of definition for the conceptual design environment. Although the definitions differ slightly from those used by Barrett and Stanley (1999), the classification system still represents the key issues that the support system had to address.

Appropriate team building - Team formation

The increasing complexity of projects within the built environment necessitates the introduction of teams of designers representing each of the relevant disciplines. These interdisciplinary design teams can represent a single organisation or, as is more often the case, comprise individuals from a number of organisations. It is likely that each organisation has its own design procedure, developed internally, which the others neither use nor have access to. Moreover, it is unlikely that team members know one another or have any concept of how each other work individually. Thus, the macro-organisation (the design team) requires alignment and synchronisation.

Empowering the client - Client involvement

These newly formed teams are provided with a statement of the client's need, which can take many forms depending on the nature of the client. Some clients provide very detailed documents of their requirements, while others have only a vague and fuzzy idea of their business need. Resultantly, client (or stakeholder) input throughout the conceptual design period can vary greatly between projects. Some clients will want to be an integral component of the team, while others will want to have minimal input during the design activity. As such, the system had to be applicable to both scenarios.

Appropriate user involvement - Users of the system

The design team is made up of a number of individuals who have varying levels of skill, experience and expertise. Depending on these factors, individuals may have little, if any, understanding of the terminology utilised by their fellow disciplines and the probability that the individuals share a common understanding of a conceptual design procedure is remote. Most designers are also unfamiliar with the approaches, methods, and tools that are available to assist the design team. Additionally, other knowledge such as rules of thumb, intuition, knowledge of the type of project at hand, and knowledge of other domains are all relevant inputs. It was imperative that the system both recognised and supported these variations in user type.

Managing the project dynamics - The team dynamic

The group dynamic must be maintained throughout conceptual design activity if the team is to have any chance of functioning optimally. The members of the design team must find ways of working together that allow different, complimentary, perspectives to be combined during design activity (Palmer, Busseri, Macmillan 1998). Effective teamwork does not occur automatically (Cooley 1994) so it is imperative that the dynamics of social interaction are maintained. Thus, the system had to provide support for the social, as well as the technical, element of the conceptual design process.

Appropriate visualisation techniques – Visualisation of process steps

Barrett refers to the use of visualisation techniques as a means of increasing potential for shared understanding within the team (which includes the client). Visualisation is

a very effective tool for allowing an intangible concept to be externalised and shared. This theory does not have to be confined to the product of design activity e.g. the building; it is equally applicable to the processes of design. Chapter 6 described the benefits of maintaining shared understanding of the steps within the design process across the interdisciplinary team. As such, the support system should provide a visual representation of the phase and activity that the team are performing in relation to the entire process, and provide an appropriate visualisation of the manner in which the team are progressing. To aid in maintaining shared understanding of concept proposals, the system should allow sketches, drawings, models, and so on, to be accessed and viewed throughout the design activity to allow all team members to appreciate the conceptual proposal of a team mate.

7.2.6 The nature of the product

In addition to the five key components of the conceptual design environment discussed in section 7.2.5, it was also important to address the nature of the product of conceptual design activity. This was achieved by defining the output of the conceptual design phase from various perspectives:

Royal Institute of British Architects (RIBA) – Stage C

To determine general approach to layout, design, and construction, in order to obtain authoritative approval of the client on the outline proposals and accompanying report. This report is to comprise: i) the brief as far as it has been developed; ii) an explanation of the major design decisions; and iii) firm cost estimates with outline cost plan.

Generic Design Construction Process Protocol (PP) – Phases 3-4

To develop (iteratively) and choose solutions before translating the chosen option into an outline design solution according to the project brief. A number of potential design solutions are identified and presented for selection. Some of the major design elements should be identified. The deliverables should include: i) Revised project brief and business case, ii) outline conceptual design with execution plan, iii) initial cost plan and procurement plans.

In chapter 3 an extensive survey of the existing design literature, which included the above models, allowed a high level definition of the product of conceptual design to be developed (see appendix III). In this definition the product of conceptual design represents a conceptual design proposal that has been developed to such an extent that the team and the client are confident that, with further development, it will sufficiently, if not optimally, satisfy the need. This definition remains generic to all projects and all clients. As such, the support system had to be specified to recognise that subsequent design progression is dependent upon stakeholder confidence in the product resulting from the process undertaken to that point. This confidence encapsulates product, process, team competence and cost certainty.

7.2.7 Process Drivers

The structure of the computer-based system had to mirror that portrayed by the preliminary design framework, in that it had to represent a multileveled structure comprising phases and activities. However, no means of driving progression through the activities of the system was designated within the framework. This co-operative attribute, which becomes applicable when the users do not wish to take the initiative in defining the process, was required to transfer control of progression to the system.

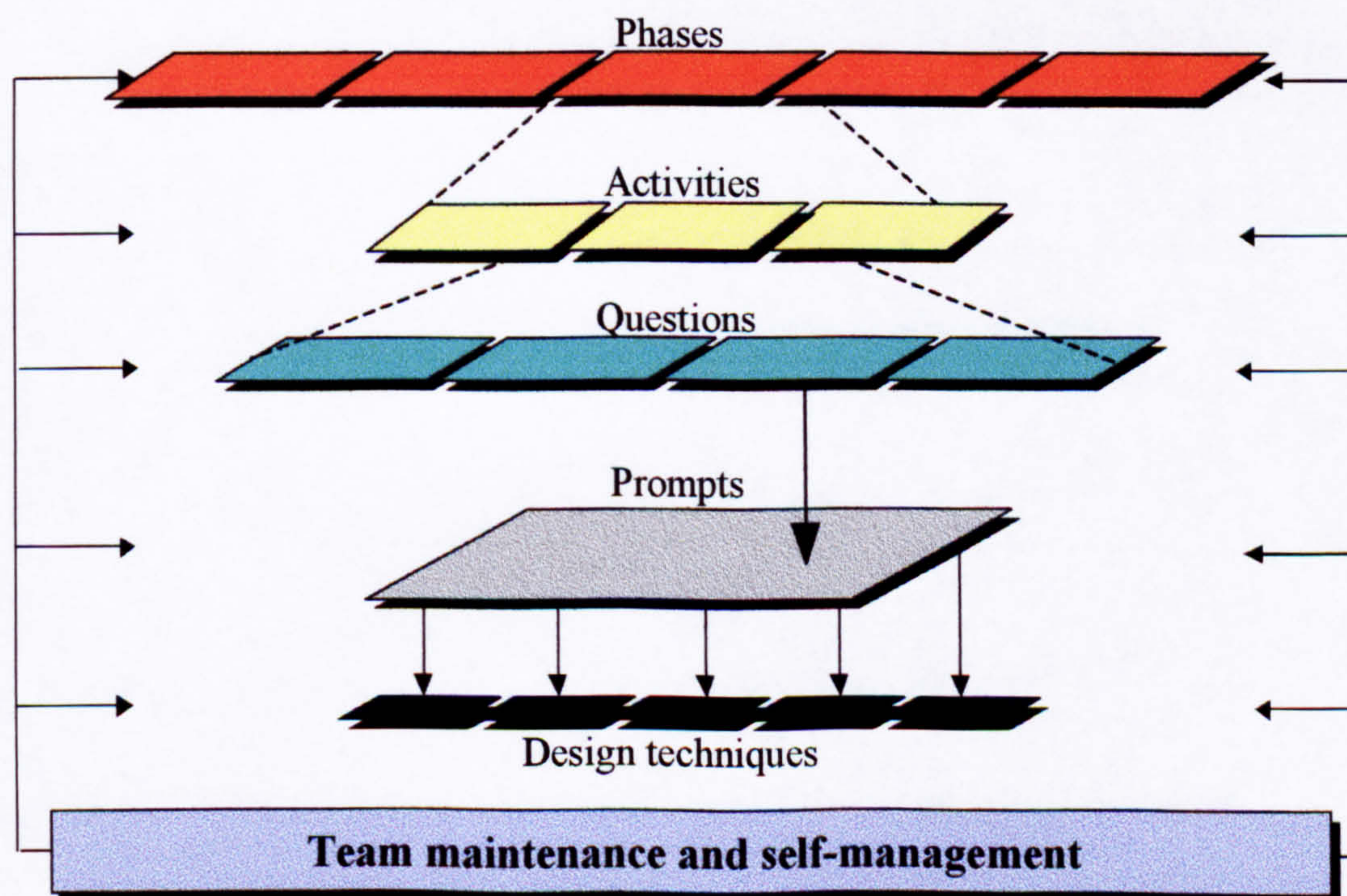


Figure 7.2 Proposed layout of computer support system

This progression was facilitated within the system by offering the team questions or prompts to act as triggers to initiate the process (thus providing the flexibility of the system). This type of driver was indicative of the manner in which design activity was forwarded during the experimental designing together workshops and as such, provided an appropriate basis to drive progression through the support system.

Chapter 3 described how conceptual design was driven via negotiations between the client and the designers. Thus, it was apparent that the system had to instigate negotiations by offering the users suitable questions, around which discussions can be held, concerning the progression made to that point. In this manner, positive answers to questions should drive the progression forward instantaneously, while negative answers should induce either a step back to re-address an earlier agreement or the introduction of a prompt. These prompts should offer various types of information, knowledge, or advice on undertaking a particular activity. Additionally, depending on the nature of the activity in which the team are involved, the system should provide a number of appropriate design tools with which to address the situation.

The knowledge, information and design tools should be stored within the framework structure to ensure that they can be easily retrieved during the course of the design process. The conceptual arrangement of the support system is illustrated in figure 7.2.

7.3 System basis: Web-based HTML

7.3.1 Introduction

In the contemporary design environment the design of buildings can be improved by developing systems which use the Internet as a repository for information (Bartlett School of Architecture 1999). A web-based system can be built around the HyperText Mark-up Language (HTML). This is an internet-based system that functions in parallel with HyperText transfer protocol (HTTP) and is most commonly associated with the WWW.

7.3.2 Background to HTML

Having being developed over the last 25 years, Internet usage has only risen dramatically during the last decade. This increase in popularity is primarily due to the influence of the WWW - proposed in 1989 - which is now making the internet accessible to an ever-increasing proportion of the population (Ando *et al.*, 1989). However, it also owes much to Tim Berner-Lee's development of an Internet based draft of HyperText Mark-up Language (HTML).

HTML is a language that web browsers, such as Internet Explorer and Netscape Navigator, use to display web pages on the Internet. It was derived from a meta-language (a language used to describe languages in general) known as Standard Generalised Mark-up Language (SGML), which was adopted and approved by the International Standards Organisation (ISO) in 1986, and behaves much like any standard programming language (Tittel *et al.*, 1995).

The Internet was originally conceived as a means of transferring and accessing large amounts of data quickly and easily. However, more recently both industry and academia are increasingly demonstrating the benefits of internet-based collaborative work for design and development purposes (Ando *et al.*, 1998, Nidamarthi *et al.*, 1999).

7.3.3 Benefits of a Web-based framework

Cowperthwaite (1999) describes a number of benefits that the internet offers to the interdisciplinary design team:

- i. It allows low cost computing and is currently utilised by the majority of organisations working within the design and construction industry, thus avoiding the need for introduction of additional technology.
- ii. It is interactive and allows access to masses of images and information that stimulate and inform.
- iii. It allows simple navigation around information held in many remote locations.
- iv. It allows this information to be downloaded, manipulated and published easily.

Additionally, owing to the fact that designers are already familiar with the mechanics of the internet, staff being introduced to a Web-based system should not require additional training regarding the software environment.

Moreover, HTML, being the dominant internet language, has several attributes that made it ideal as a mechanism for developing a Web-based version of the conceptual design model:

- i. It allows individual components of a structure to be held in an isolated environment. Thus, details can be stored regarding discrete components of the framework without being sensitive to the process involved in reaching that point.
- ii. Elements of a model can be related to one another in a number of ways. As such, both systematic and team designated progression can be facilitated within the single system. The fragments are related using the appropriate types of connection.
- iii. The users (viewers) are able to view specific elements of the model in isolation. Thus, information specific to a particular phase or activity can be made available only when it is required.
- iv. Endless supplies of information can be accessed via the WWW. As such, connection to the appropriate information can be facilitated via specific HTML pages.

Additionally, as both the internet and the globalisation of economics spreads, the nature of team design activity is changing drastically, with an increasing amount of projects requiring the collaboration of geographically distributed individuals (Ando *et al.*, 1998). As such, a Web-based system could facilitate a collaborative design process over the internet, and provide opportunity for immediate access to geographically distributed resources (Nidamarthi *et al.*, 1999). Considering the many benefits offered by the internet it was decided that the Web-based version of the conceptual design framework should be developed using HTML.

7.4 Development of the organisational structure

7.4.1 Introduction

HTML allows relationships between elements of a model to be developed in several ways. Appropriate connections between various text documents and additional compatible software interfaces needed to be introduced to allow the users to navigate efficiently through the system and make optimum use of the facility. For example, studies have shown that providing a viewer with too many direction choices in a single page can be confusing, while too few choices may indicate that there are needless layers within the fabric of a system. Additionally, various organisational structures exist, each being appropriate to a particular application. As such, in the following sections a number of organisational structures are discussed and evaluated as appropriate for developing a Web-based version of the conceptual design framework.

7.4.2 Review of available organisational structures

The differences between HTML organisational structures owes much to the fact that hypertext is non-spatial, non-physical, possibly dynamic, and often non-linear. Good HTML structure must embrace these differences, while preserving navigability (Graham 1998), as without this the users can become frustrated and deem the system redundant as a useful design aid. These differences needed to be recognised and understood in order to identify the most applicable organisational structure (alternatives shown in table 7.1) for the system.

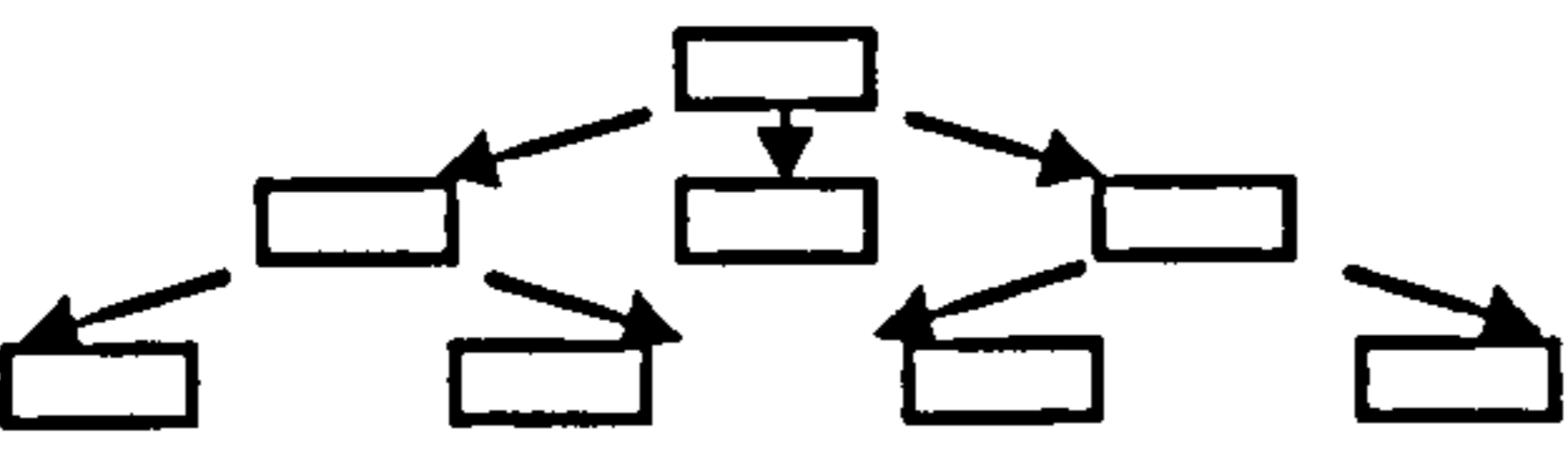
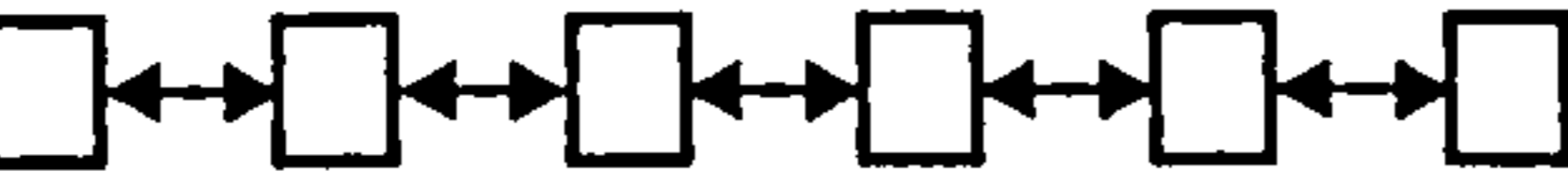
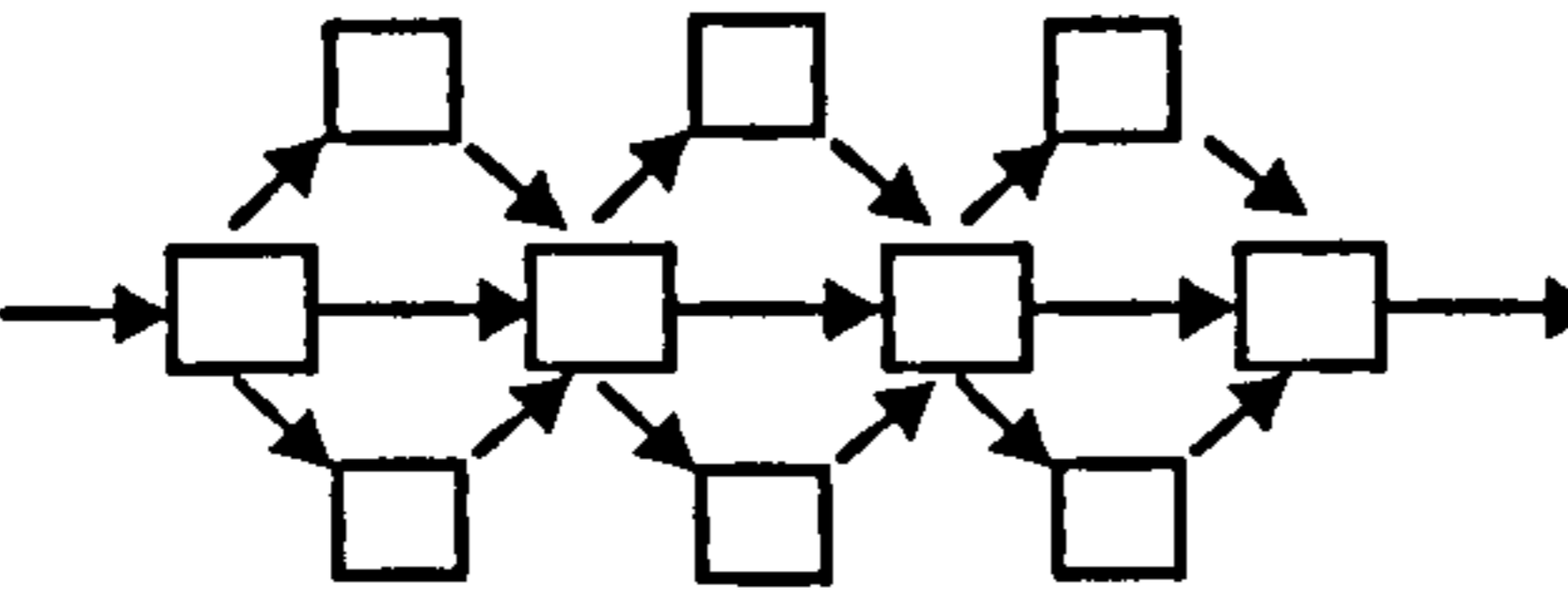
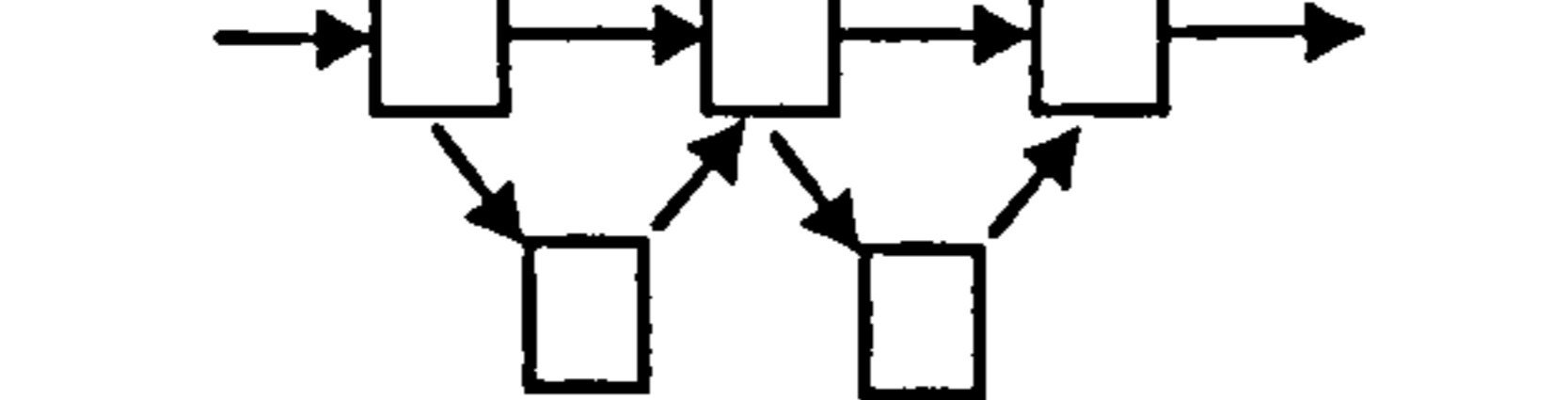
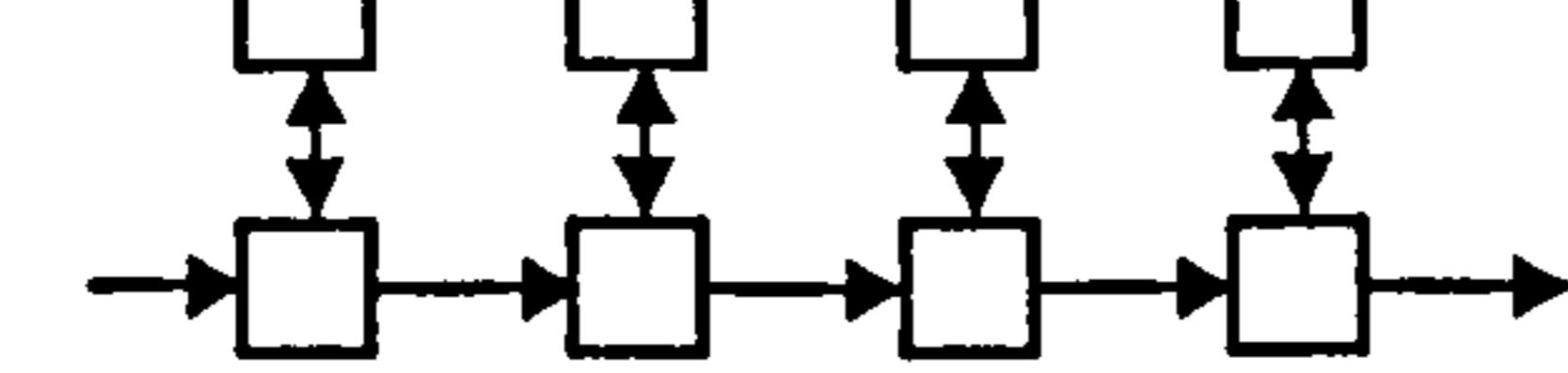
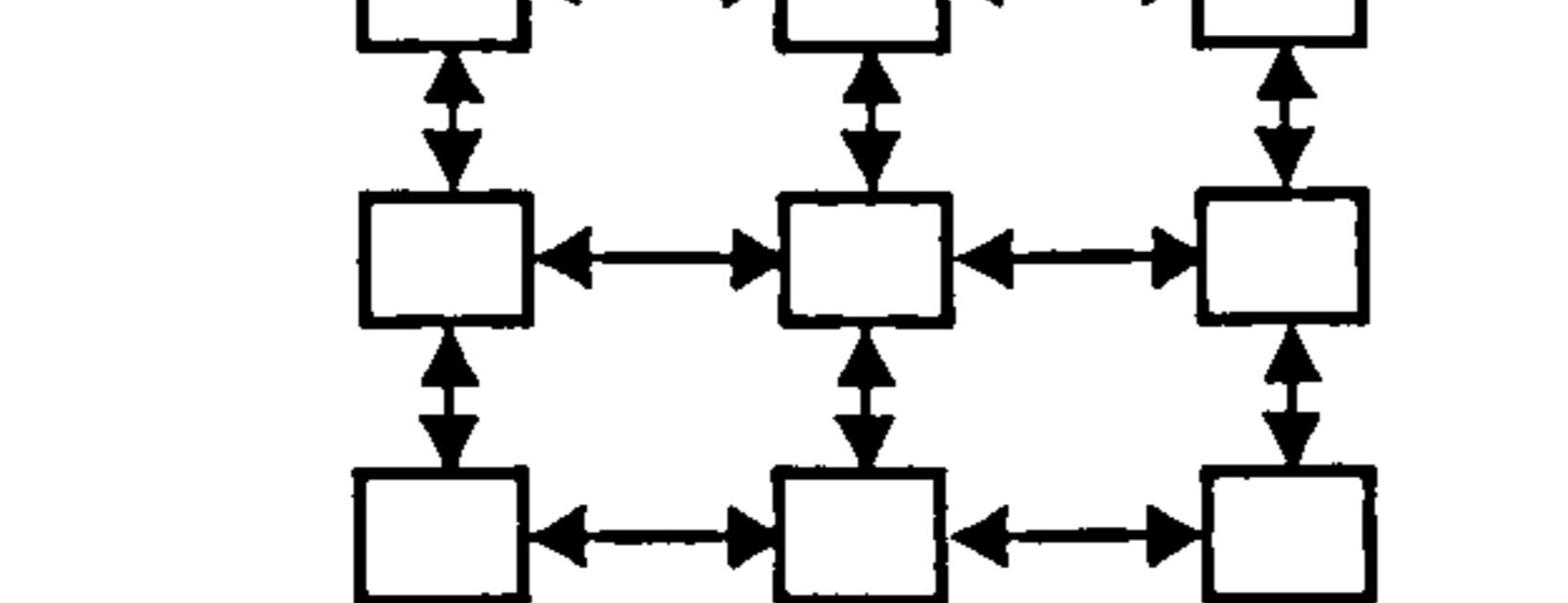
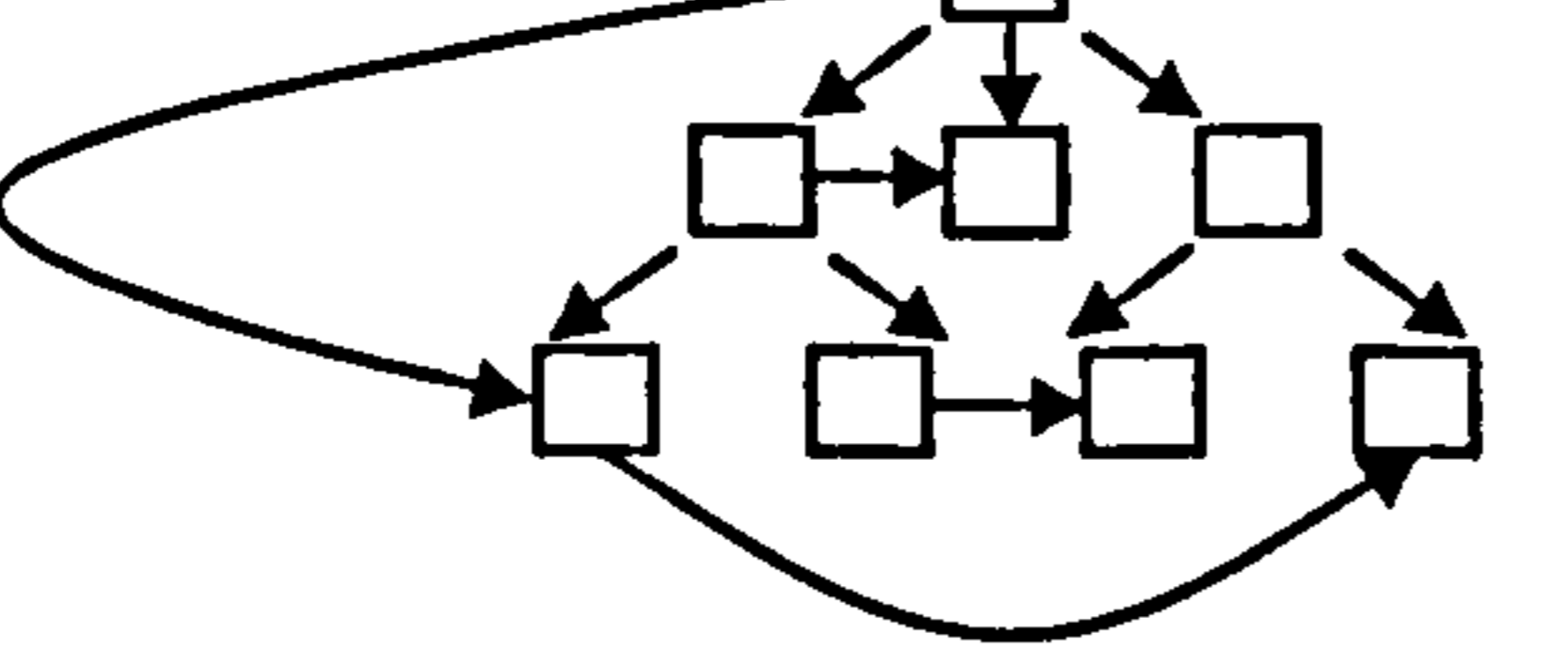
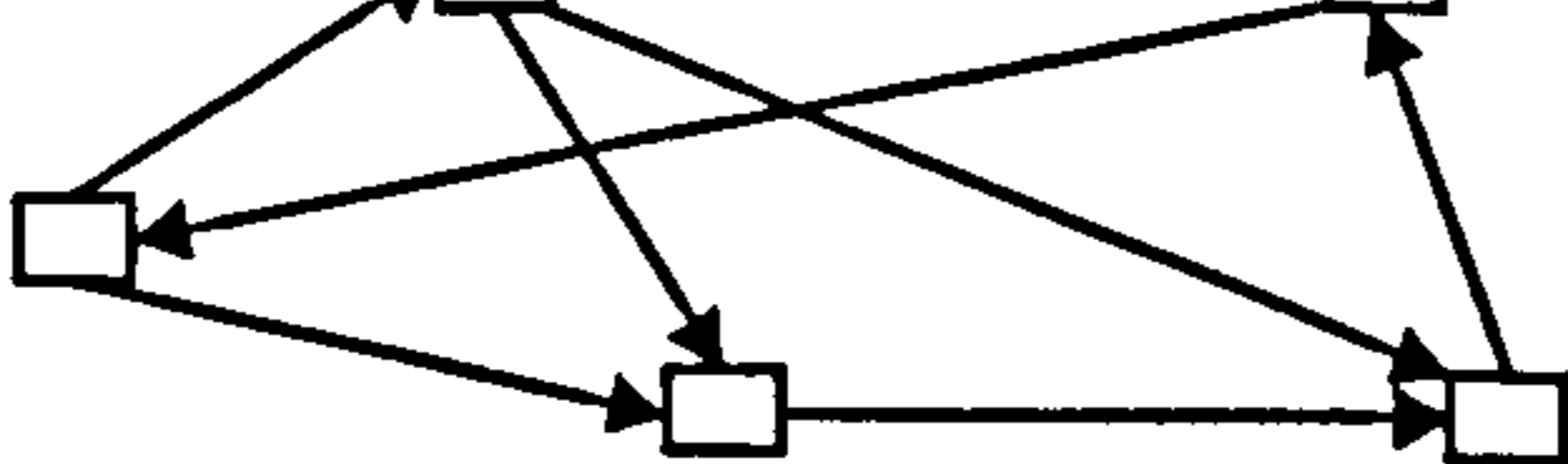
Organisational structure	Graphical representation	Description
Tree (hierarchy)		<p>This structure groups similar items within a hierarchical format. The tree structure can be either narrow or wide. A narrow structure provides few choices for the user, but requires many links to get to the destination. Conversely, the wider structure offers more choices and thus requires fewer link to get to the destination. However, it is more reliant upon the users making the correct decision immediately. Both arrangements provide acceptable spatial organisation for the framework.</p>
Purely linear		<p>This provides a fixed linear structure, which is static and fixed, such as that represented by a book. The back button facility within the web browser means that a purely linear structure is actually bi-directional. This layout is applicable to sequential progression through a system.</p>
Linear with alternatives		<p>This structure is used with a series of questions with yes and no answer. The next in the sequence question being dependent on a positive or negative response to the latter. An effective application of this structure would allow progression to be made using yes and no responses, but the answers would eventually lead the user to the next stage regardless of choice. This gives the users a false sense of interactivity, which is more engaging than a purely linear progression.</p>
Linear with options		<p>This structure is good for sets of information that are sometimes optimal. This structural organisation allows the users to skip over irrelevant questions while preserving the general path of information. Thus it can facilitate size and direction of step depending on user input.</p>
Linear with side-trips		<p>This is most applicable to bodies of information that may have useful supplementary information sets. This organisational structure provides diversion while preserving direction.</p>
Grid		<p>This system is ideal for developing structures of related items. It has a high degree of spatial organisation but it provides fundamentally a linear form. This type of arrangement allows blocks to be networked in relation to the directly connected elements.</p>
Mixed hierarchy		<p>The problems described with the broad versus narrow tree structures mentioned previously can be balanced by implementing a mixed hierarchy structure. This system amalgamates step progression and the skip-ahead option with the hierarchy provided by the tree structure. The organisational hierarchy provides simple spatial arrangement while still allowing connection based on directive response to questions.</p>
Pure web		<p>This structure has little, if any, spatial organisation and lacks any rational structure. This system is simply a set of fragmented elements with most, or all, fragments providing links to one another. This type of structure tends to be the direct of poor planning prior to the development of the system.</p>

Table 7.1 HTML organisational structures (developed from Graham 1998)

7.4.3 Evaluation and choice of organisational structure

Upon consideration of the many available structures, it is apparent that the mixed hierarchy (table 7.1) is most applicable to the manner in which the conceptual design

phase is addressed in practice. It provides flexibility in approach, allowing the users to either take control or use a designated system structure, depending on the problem under consideration and the nature of the team. The only significant downfall of the mixed hierarchy is that it can quickly degrade into the pure-web form that is nothing more than tangled messes of links with no clear organisation (Powell 1998). When developing an organisational structure using this strategy it is critical that transition into pure-web format is avoided.

7.5 Functional specification for the system

7.5.1 Introduction

The system requirements that have been designated in the preceding sections of this chapter have allowed a fairly robust overview of the proposed system to be described. However, in order to combine and develop these intangible concepts into a tangible working prototype system it was important to produce a concise account of the issues in the form of a functional specification. The remainder of this section defines the system specification from which the prototype system was developed.

7.5.2 System specification

The following list summarises the provisional functional specification for the proposed process-oriented Web-based system based upon the characteristics and requirements identified previously and those designated by Blessing (1994, 1996). It should be recognised that this was used as merely a provisional specification, as it is commonly recognised that additional requirements can be exposed during actual system development (as will be elaborated in chapter 8). This is particularly pertinent when an action research methodology is the planned means of developing a system or product (see chapter 2, section 2.7).

The system should represent a design framework that:

- defines the phases of conceptual design
- describes the activities comprising each phase
- can be populated with project specific tasks and details
- can be interfaced with other computer-based applications
- supports, but is sub-ordinate to, the user(s)

- can be navigated with ease

The system should provide context-sensitive guidance and assistance when required by:

- suggesting suitable process steps
- suggesting suitable prompts
- enabling the use of appropriate methods and tools at the appropriate point within the process
- providing appropriate knowledge

The system should enable different process approaches to be taken, i.e. it should allow:

- steps to be executed in different sequences
- steps to be disregarded
- users to designate the next process step, i.e. overrule the guidance mechanism
- new requirements to be introduced throughout the process

The system must contain, or enable access to, appropriate knowledge stores such as:

- Rules and guidelines
- Checklists
- Standard forms
- Catalogues
- Standard equations

The system should contain descriptions and advise on the use of design methods and tools. These should include:

- Aim
- Procedure
- Typical application
- Any additional information
- Source of origin

The system should also allow any electronic versions of the tools to be stored or accessed as and when they are developed. Additionally, the methods must be simple to retrieve.

The system must support the team in managing itself and maintaining social interaction by:

- providing a team maintenance facility
- allowing the facility to be accessed at any time during the design process
- defining problematic areas of social interaction
- suggesting means of overcoming team problems

Additional Extraneous requirements:

The system:

- must focus on supporting the interdisciplinary design team as a single entity during the conceptual design phase and not isolate individuals within the group
- should function as the core from which other applications (manual or computerised) can be accessed and activated
- should enable the users (individual organisations or strategic alliances) to integrate and link their own systems, methods, and tools into it

7.5.3 Summary of system functions

Based on this preliminary system specification, the main functions of the design support system are:

- To structure the iterative progression through the design phases and activities
- To be co-operative with the interdisciplinary design team
- To be subordinate to that team
- To allow storage and retrieval of knowledge, methods and tools
- To be flexible, i.e. allow the team to define its own process path. Yet...
- To provide guidance and assistance in progressing as required
- To maintain and support the social interaction of the design team

The subsequent development of a prototype process-oriented Web-based conceptual design system, based upon this preliminary functional specification, is described in the following chapter.

7.6 Conclusions

This chapter has: i) defined the nature of the system and its key requirements; ii) identified the most applicable mechanism with which to generate the computer-based version of the conceptual design framework; iii) distinguished the optimum organisational structure to apply to a model of this nature; and iv) outlined a preliminary functional specification for the prototype design tool.

Observations made within chapter 6 suggested that the most important element of interdisciplinary conceptual design activity was the thriving interaction and collaboration between the members of the team. As such, the requirements outlined herein have focused on the interaction between the users and the system in order to facilitate improved collaboration between members of the team. Chapter 8 describes the generation and development of a process-oriented Web-based conceptual design system based on the details outlined within this chapter. The web-based system, as it will now be described, serves to reinforce and convey the important difference among iterations between clusters of activities and across the entire phase of the conceptual design process.

Chapter Eight

Development of a prototype Web-based system

8 Development of a prototype Web-based system

8.1 Introduction

Chapter 5, section 5.3.4, described how the categorical, or tool-kit, approach was considered to represent the most suitable basis for the development of a model of the conceptual design phase of building projects. Consequently, this approach was utilised to develop the preliminary design framework that was tested, and subsequently validated, in the experimental workshops. Thus, this same approach was adopted as the essence of the Web-based version.

The categorical approach was utilised for several reasons, one of which was the fact that it enables project specific knowledge, data and information to be stored rationally within a generic system structure. This characteristic makes it indispensable as a means of developing a Web-based version of the framework as it allows the framework to integrate the system's generic knowledge of the conceptual design process, i.e. possible steps, their relationships (based on contents rather than their sequence of execution), with suitable means to support and perform those steps (Blessing 1994). This system support not only includes advice on how and why parts of the process are performed, it also provides a tool-kit of the most appropriate design techniques with which to address problems arising within specific phases of the process.

This chapter discusses the development of the system based on the computer support system layout proposed in chapter 7 (figure 7.1). It discusses the generation of the system's guiding attribute, the development of the related prompts and the designation of the design tools within the categorical system structure (the assisting attributes). The development of an appropriate visual layout for the system and its importance to the acceptance and effectiveness of the system in practice is also elaborated. Additionally, the utilisation of an action research approach to system development is discussed.

8.2 Development of guiding attribute

8.2.1 Introduction

For a model of the conceptual design phase to be realistic and acceptable in practice it must be flexible and adaptable to take account of the dynamic nature of design activity (Bessant and McMahon 1979). However, a support system which embodies such a model must also include a guiding principal, i.e. suggesting suitable steps through the system structure, should the team decide against controlling their own progression. Within the case study investigations and the 'Designing Together' workshop sessions it was apparent that design progression was triggered by team member negotiations emerging from the raising and addressing of questions regarding the process and the nature of the design activity to that point. Thus, the guiding component of the Web-based framework utilises the same mechanism for driving progression through the system. As a guide the system suggests the next step(s) in the process.

8.2.2 Research workshop

In order to develop the questions with which to direct the system users, a half-day workshop was held involving the author and three researchers from within the built environment domain. The three researchers (an architect, a building services engineer, and a structural engineer respectively) had, in addition to their research experience, substantial professional experience within the design industry. This disciplinary mix was chosen specifically to ensure that a full compliment of the relevant building design disciplines was involved in the creation of the system's guiding attribute.

The research group was provided with a copy of the conceptual design framework and asked to develop, through discussion and debate, appropriate points of negotiation that would propel a designer or design team through the framework's conceptual design activities. The fact that the conceptual phase is largely concerned with making decisions and reaching agreement, rather than about locating information and providing deliverables, is a factor that is reflected in this designation of questions (or decision points) as the mechanism for guiding design activity. The discussions, which were facilitated by the author, resulted in the development of a number of questions

that could be used to guide the team through the respective framework activities in a rational manner (figure 8.1)

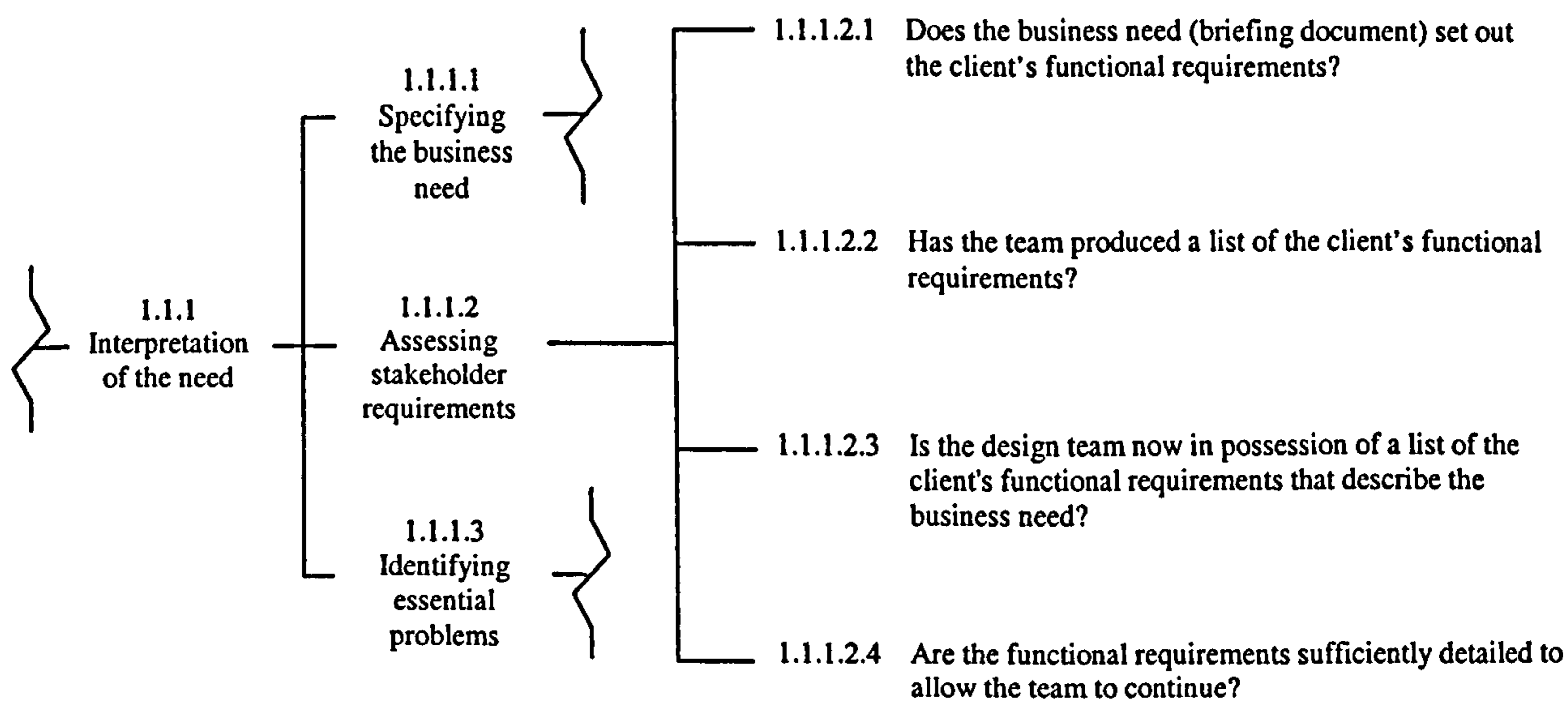


Figure 8.1 Section of the guiding attribute (question structure)

8.2.3 Nature of progression within guiding attribute

The designing together workshop findings suggested that the framework activities, although representative of the conceptual design phase, are not followed sequentially, but instead are fragmented with many loops and iterations. This characteristic must be present in any realistic design support system. However, interdependencies between activities within particular phases of the design activity are apparent, and these too must be evident within the system structure. As such, the questions representing the driving mechanism for progression through the system had to allow jumps between respective activities depending on the answer provided.

The manner of progression through the process was classified in one of three ways, depending on the nature of the response to a specific question:

- i) sequential step forward into next activity (within same phase or into next phase);
- ii) leap forward over a number of activities (from one phase to the next); or
- iii) Step backward to re-visit an earlier activity (iteration within phase or across phases).

However, in answering a question the team members do not progress directly, instead they are first given a suggestion (or prompt). This prompt assists the team by suggesting a course of action for addressing the situation at hand.

8.3 Development of assisting attribute

8.3.1 Introduction

As an assistant the system had to support and help the design team with the execution of the process steps by suggesting relevant prompts. The assisting prompts had to represent various types of knowledge, methods and tools relating to the current process step (Blessing 1994). The existing design literature was utilised primarily to develop the assisting attribute within the Web-based system. However, the author introduced the elements that were not addressed in the literature by referring to both the case study investigation data and the observations recorded during the 'Designing Together' workshops.

8.3.2 Existing literature applied

The existing design literature was examined, with relevant prescriptions for executing activities within the conceptual design process being extracted and introduced into the appropriate point within the system structure. There are numerous texts available, the majority of which have been discussed in chapter 3, which introduce methods and procedures for tackling design problems.

These writings describe operations for addressing such issues as conception, visualisation, calculation, transformation, and so on. As such, these components were introduced into the support system to offer advice and assistance on the execution of the various design activities.

8.3.3 Development of prescriptive elements from observation periods

For those components that could not be satisfied sufficiently by the existing literature, the author introduced methods and procedures which had been utilised during the case study investigations and the 'Designing Together' workshops (chapters 5 and 6 respectively).

The author developed these assisting attributes in a context-insensitive manner to allow them to be accessed without having to reflect the process in which they had been reached.

8.3.4 Designation of design techniques

The proposed use of design techniques was aimed at harnessing the expertise of the entire team rather than simply that of a few of its members. However, it was concluded in chapter 6 that there is no standard aggregation of design techniques that is suitable, or acceptable, to all designers in a similar scenario (a conclusion which has been proposed elsewhere - Rickards 1981, Cross 1989, Jones 1992). As such, the choice of which technique to apply in a particular situation is a matter of personal preference on the part of the designers involved in the activity.

Thus, it was recognised that the optimum means of assisting the team was to suggest the most appropriate techniques with which to address a certain type of problem. Of course, selection would be influenced by a number of factors; such as the nature of the problem, the degree of training in the use of the techniques, and the nature and personal preference of the team members involved. However, by offering the team a selection of suitable techniques from which to choose their preferred option, rather than forcing them to use a single 'best-fit' technique, system flexibility would be provided.

The design techniques literature has evolved over the last forty years and as a result, there are many techniques available for use by design teams. As such, the many writings were explored and the most promising design techniques were extracted and introduced into the framework structure. Additionally, in order to test design techniques within the experimental portion of the research (chapter 6) new design techniques were developed which represented the amalgamation of two of the existing methods, e.g. Isolated Option Testing (combination of 'Boundary searching' and 'Pro's and con's analysis'). These techniques were also included within the framework structure.

8.3.5 Appointment within system structure

Owing to the fact that many of the design techniques can be applied within several of the framework phases, the individual techniques were appointed as single fragments within the Web-based system's structure. Thus, rather than offering direct access to a specific type of technique by relating it to the phase or activity at hand, the system was developed to offer a link to a number of the most appropriate techniques with a common purpose. These groups were designated as tools to assist with: i) assessment; ii) prioritisation; iii) conception; and iv) evaluation. In this way only the links that were designated in a context-sensitive manner, while the techniques themselves were introduced as individual entities with which to assist in undertaking an activity irrespective of what the activity itself involves.

This system attribute allows selective retrieval of techniques by the user from within the system hierarchy. Additionally, owing to the nature of the internet-based medium (HTML) the technique base can be extended gradually as new developments in design research emerge.

8.4 Introduction of maintaining attribute

The observations made during the 'Designing Together' workshops suggested that in order to align the working practices of the team, its individual members had to focus consciously on integrating the tasks, responsibilities and roles involved in the social, as well as the technical, aspects of collaborative design. To this end, it was recognised that any realistic conceptual design support system had to include an element of self-management and team maintenance.

Both the case study investigations and the 'Designing Together' workshops highlighted several key components of team-maintenance. However, these observations alone were insufficient to utilise as the basis of the maintaining attribute of the system. It was wholly unrealistic to attempt to undertake a detailed and extensive investigation of teamwork within building design projects during the course of this particular research project. Additionally, whether any substantive data could be obtained or derived from a study that did not concentrate solely on social interaction during collaborative design is questionable. As such, the details contained within the

maintaining attribute of the system, although structured around the five key issues which were highlighted in the experimental workshops, were adapted from the findings of a recent research project into team work entitled, 'Building Teams: working together in construction design' (Palmer, Busseri, Macmillan 1998). This project, entitled 'Achieving Quality in Teamwork', was funded by the EPSRC and represents an intensive 12-month investigation into design team working in practice.

8.5 Visual layout of system components

8.5.1 Introduction

The nature of this type of system was such that it required a multi-levelled structure within which to store the various process components outlined in the preceding sections. It was recognised that this could, potentially, confuse the user owing to the fact that it could be fairly easy to become buried within the fabric of the model. As such, it was considered very important to develop an appropriate visual layout that ensured the users did not become disorientated or lost within the many layers of the system structure.

As has been described in section 7.4, the mixed hierarchy proved to be the most applicable of the available HTML organisational structures with which to develop the Web-based system. This structure allowed the definition of the intrinsic structure of the system to be derived but it did not designate an appropriate visual layout for the model on screen. This characteristic may appear to be purely cosmetic, however, the ease of which a multi-layered structure is navigated can contribute significantly to its acceptance in practice and as such, it must be deemed an important consideration when developing such a system.

The various components of the visual layout of the system are described in the following sections. The layout of the actual prototype system is shown in figures 8.2 and 8.3.

8.5.2 Components requiring continuous availability

Within the Web-based system it was apparent that navigation required certain elements of the structure to be displayed throughout the design activity irrespective of

which point the design team had reached, or were undertaking, within the overall process. Additionally, owing to the need for the system to support the social, as well as the technical, aspects of interdisciplinary design working, the team maintenance component of the mechanism also had to be made available continuously.

Process components

Upon consideration of the four basic levels of the framework structure (table 5.4) it was apparent that, holistically speaking, the proposed system in its entirety represented level one (undertaking conceptual design). Thus, including this level as a component of the visual layout served no purpose in aiding system navigation. Likewise, the two discrete stages delineated by level two ('development of the business need into a design strategy' and 'development of the design strategy into a concept proposal') only really served to enhance the dendroid hierarchy of the original framework. Moreover, inclusion of this level within the visual layout of the Web-based system would narrow the system structure significantly and force the user to navigate more links to reach the desired destination.

As such, it was apparent that the optimum position at which the user should be introduced to the framework structure was at the five-phase level (level three in table 5.4). Essentially, in addition to the arguments presented above, three comments made by design professionals during the verification of the preliminary framework (section 5.4.2) drove this decision:

- All interviewees agreed that the design activity undertaken during the conceptual phase could be classified and grouped into the proposed activity and phase structure.
- The phase description (level 3 in table 5.4) was deemed most appropriate as a means of guiding design progression in practice, with this sequence of progression being more akin to the way the design actually advances during conceptual design activity.
- The phases outlined in the framework were described as being 'understood intuitively by professional/expert designers', thus making them more acceptable to users of the system *a priori*.

Team maintenance components

In addition to addressing formal issues such as identification of design phases, the system had to also address social interaction, collaboration and communication. The social element of teamwork proved to be a major contributor to successful collaboration within the experimental sessions described in chapter 6. As such, it was imperative that the visual layout of the system allowed access to the self-management attributes at any point within the process should problems arise. The team-maintenance issues were separated into five discrete areas:

- Working as a team
- Maintaining interaction between members
- Lack of communication
- Team dynamics
- Redirecting the team to maintain efficiency

This division represents the basis of the team maintenance attribute of the system.

8.5.3 Navigation within phases and team maintenance issues

Upon selecting an appropriate phase or team maintenance issue (figure 8.2 - frames 1 and 4 respectively) the users are presented with navigation bars that identify the sub-components of that particular entity (in frame 2), while access to the low-level issues remains preserved. In the case of the phases, the users are introduced to the appropriate level four activities representing that particular phase. Within the team maintenance components, the users gain access to the sub-issues relating to each specific problem area.

This was facilitated within the system by introducing a single additional navigation bar that displays the sub-components of the phase or team maintenance issues as they are selected. As such, the content of this navigation bar represents the last generic level of the framework structure and provides the arrangement within which the design process drivers, prompts, techniques and information are held.

8.5.4 Introduction of design drivers

Once an activity is chosen, a generic definition of the objective of the activity is provided, while still leaving the activity navigation bar displayed. However, this does not assist the team directly in undertaking a particular activity within the system. As such, the user is introduced to an assisting attribute or design driver (in frame 3, figure 8.2), in the form of a question regarding a particular component of the designated activity.

Offering the team a question triggers progression. This type of driver is indicative of the manner in which design activity was forwarded both within the case study investigations and during the experimental designing together workshops and as such, provides an appropriate basis to drive progression through the Web-based system. The question represents a pivot for discussions concerning both the activity and the progression made to that point. A simple 'yes' or 'no' response induces step progression forwards or backwards, depending on the nature of the question, within the framework or alternatively, the introduction of a prompt.

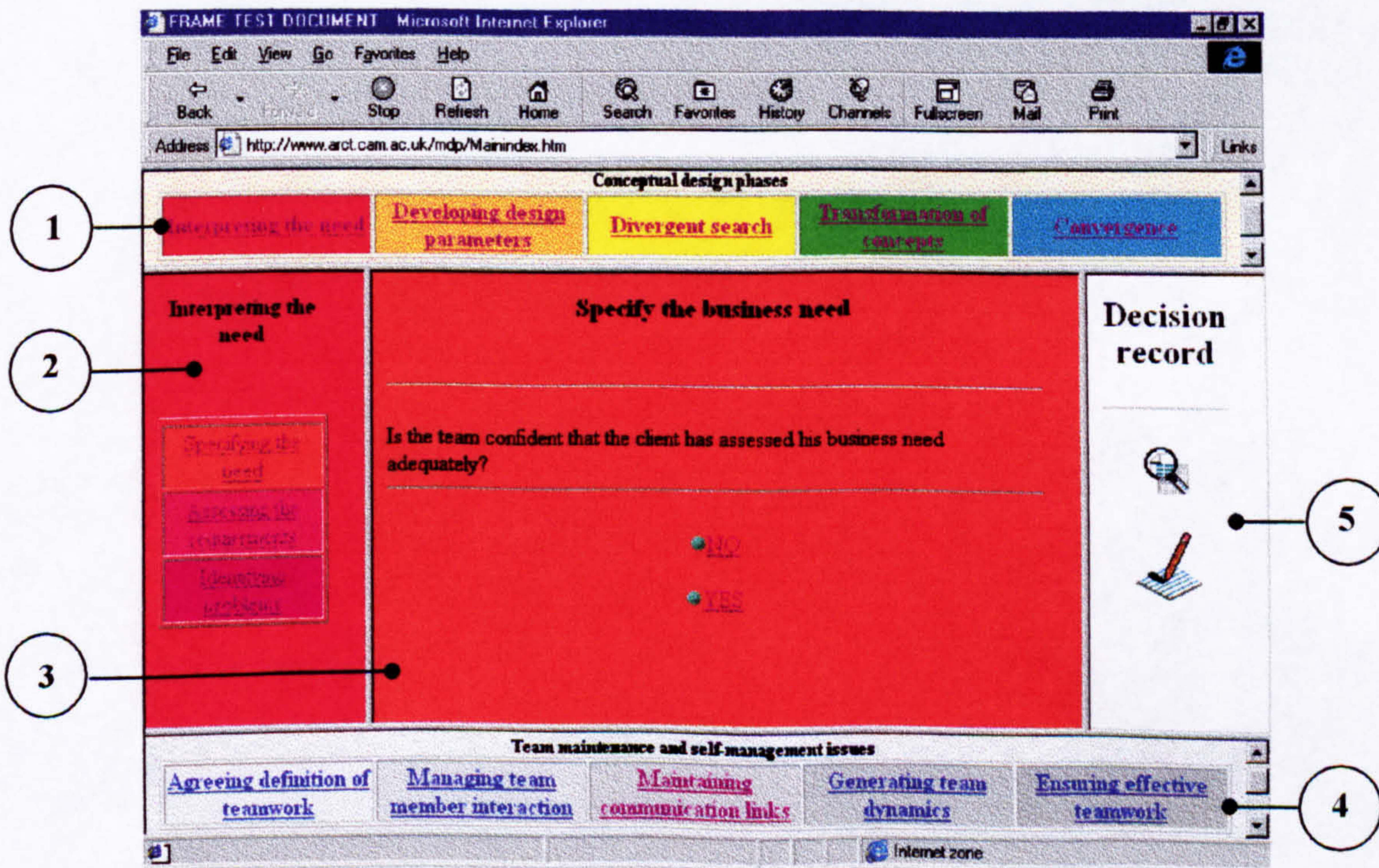


Figure 8.2 Visual layout of Web-based conceptual design support system

8.5.5 Prompts and design techniques

The designated prompt is displayed, along with the question that promoted its introduction, in frame 3 (figure 8.2). The prompts themselves offer various types of information or advice on undertaking a particular activity. Also, depending on the activity in which the team members are involved, the system can provide a number of appropriate design tools with which to address the situation. These are linked to the prompt window and are displayed within the same area of the screen.

8.5.6 Information stores and the application of design techniques

Links to the various stores of knowledge, information and design tools are held within, and accessed via, the prompts; however, the stores themselves are not. The links provide access to internet-based sites where the relevant details can be accessed. In this manner, the users can view and assemble vast amounts of material quickly and easily without the support system itself having to hold the data.

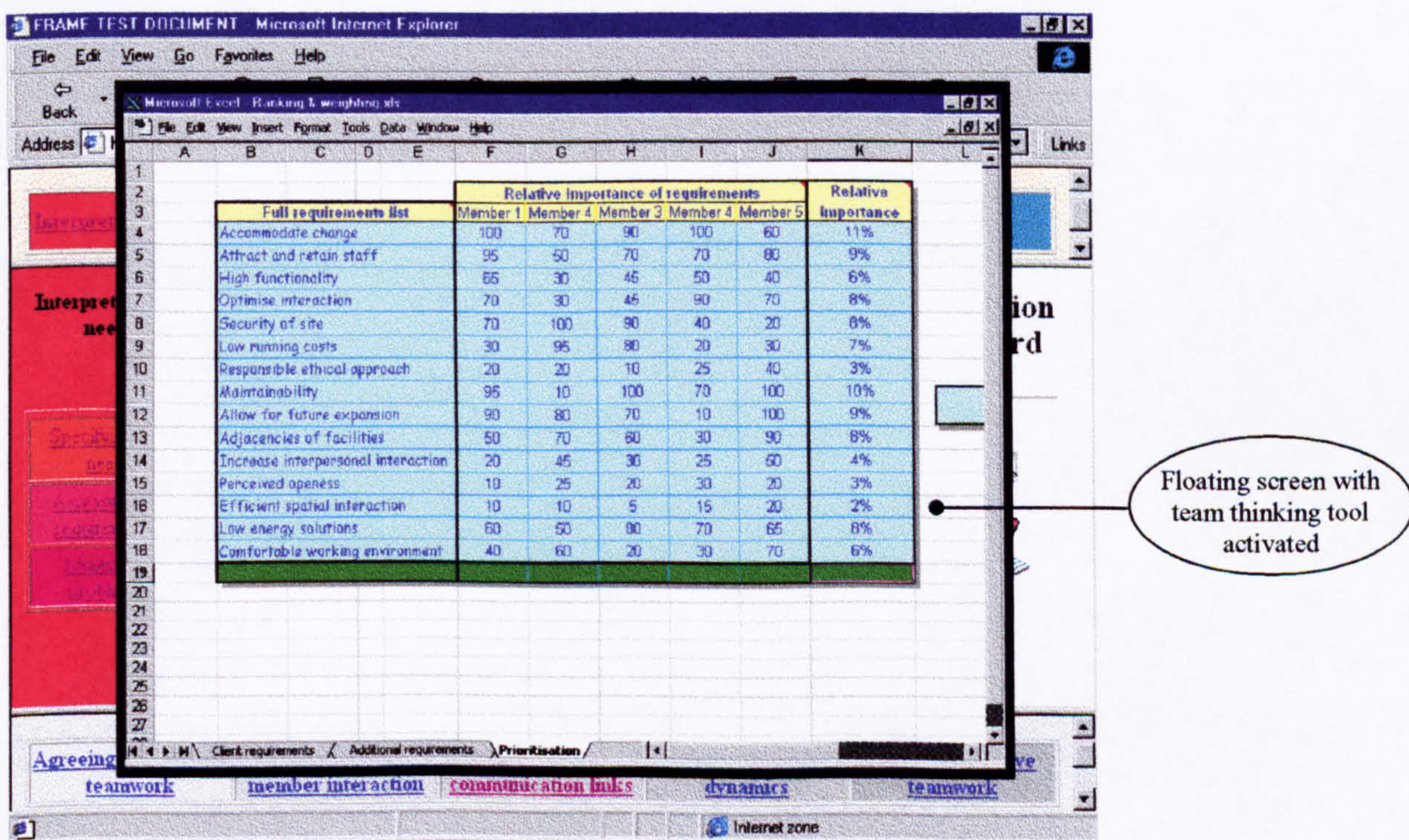


Figure 8.3 Visual layout with floating screen in use

The viewing of information and implementation of electronic design tools is accommodated in a floating screen that opens over the system structure (figure 8.3). This ensures that navigation through the external site is undertaken independently of

the design framework, thus keeping the multi-layered structure in tact throughout this outlying investigation.

8.6 Concurrent system demonstration and development

8.6.1 Introduction

In order to develop the Web-based system, which was derived from the preliminary framework that had been both verified and validated within the professional design community, an evolving prototype version was taken to each of the organisations that had been involved in its development, and an extensive demonstration was provided. These demonstrations, which were held intermittently over a six-week period, provided a platform from which the system could be improved and enhanced incrementally.

The utilisation of this form of methodology, which is known as Action research (described in section 2.8), allows the development and modification of research ideas via the direct input of the end users. However, several additional benefits are gained from taking this approach: i) it develops the stakeholders knowledge and willingness to implement any change arising from the research; and ii) it improves general practice within the participating organisation (Oja and Smulyan 1989).

In utilising this approach the system was developed from both an internal and external perspective, with the designers moulding the system attributes and the author facilitating the systems evolution concurrently.

8.6.2 Demonstration sessions

The concurrent demonstration and development cycle for the Web-based framework (figure 8.4) involved taking the preliminary system to those organisations that were involved directly in its preliminary generation and demonstrating its various attributes. The actual action research process that was applied during this period was adapted from that described by Ebbutt (1985) – see section 2.8.2, figure 2.2.

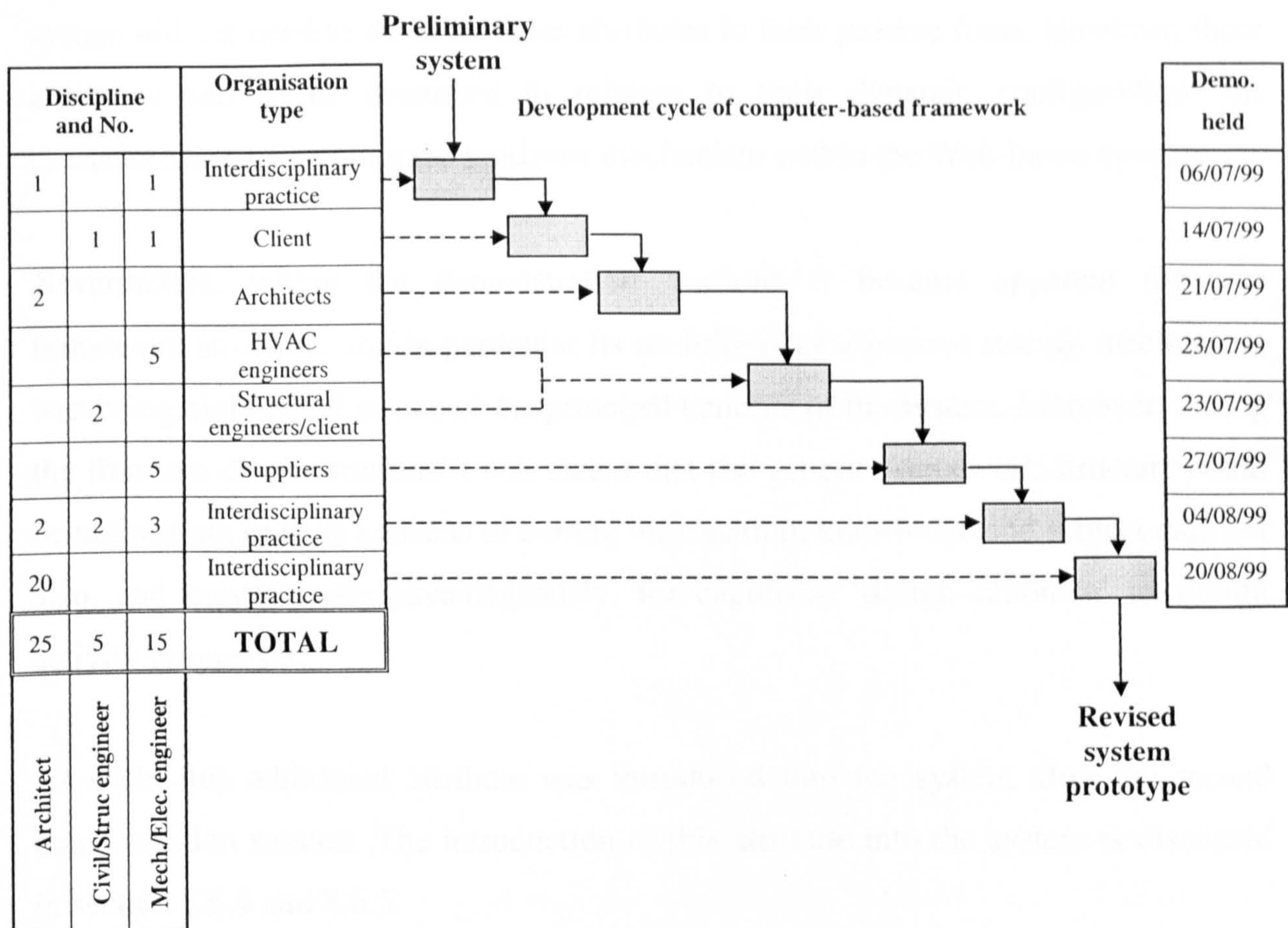


Figure 8.4 Verification/development cycle of Web-based system

Each demonstration session followed a similar format. First; a short presentation regarding the development of the preliminary design framework was provided. This was followed by a detailed demonstration of the system. This demonstration introduced each of the system attributes and related them to the envisaged system characteristics (described in chapter 7, section 7.2.2). Finally, the designers participated in a round table discussion of the systems validity. These discussions, which took the form of an open forum for debate, were fairly informal and as a result, those involved were relaxed and more willing to contribute to the debate in an open and unrestricted manner. According to Oja and Smulyan (1989), this degree of interaction and collaboration between the investigator and the practitioners can have far reaching effects on the success of both the action research approach and the development of the research ideas.

8.6.3 Systematic development and improvement

Owing to the fact that the core of the system, the phases and activities representing the system structure, had been validated and verified previously, the demonstration of the

system did not need to consider these attributes in their passive form. However, these attributes had to be discussed in relation to their dynamic configuration; the characteristic representing the guidance mechanism within the Web-based system.

Nevertheless, within the demonstration sessions it became apparent that the framework structure, and in particular its usefulness as a passive storage mechanism, was being highlighted as one of the principal benefits of the system. Moreover, during the first two demonstrations it was stated that the generic framework structure could be utilised not only as a means of storing information, knowledge and project data but also, and maybe more advantageously, for capturing 'design rationale' as design activity progresses.

As such, this additional attribute was introduced into the system after the second demonstration session. The introduction of this attribute into the system is discussed in section 8.6.4 and 8.6.5.

8.6.4 Demonstration feedback

Throughout the six-week demonstration and development period there was a cyclic progression through the 'demonstration-idea-action' process. This resulted in a systematic crystallisation of the support system into the prototype version shown in figures 8.2 and 8.3, and allowed the benefits of the proposed tool to be disseminated within those organisations in which it was to be verified and validated. Very early within this period it was suggested that the system structure could provide an additional facility that would be of prime benefit during conceptual design activity; it could provide a basis for recording and storing the decisions made during a project, i.e. facilitate the capturing of design rationale.

8.6.5 Design rationale

Design rationale, a term used synonymously with design history, and design intent, is the concept that information regarding the design process is as, if not more, important than information regarding the product resulting from it.

Moran and Carroll (1996) suggest a number of dictionary-style definitions for the term *design rationale*:

1. An expression of the relationships between a designed artefact, its purpose, the designers conceptualisation, and the contextual constraints on realising the purpose.
2. The logical reasoning to justify a designed artefact.
3. A notation for the logical reasons for a designed artefact.
4. A method for designing an artefact whereby the reasons for it are made explicit.
5. Documentation of: i) the reasons for the design of an artefact; ii) the stages or steps of the design process; iii) the history of the design and its context.
6. An explanation of why a designed artefact (or some features of an artefact) is the way it is.

Bearing these definitions in mind, the decision recording attribute (Frame 5, figure 8.2) enables, at the user's option, a record to be made of who took a decision, who else contributed, and other associated explanatory material, thus allowing the justification or reasoning behind the decision to be recorded. When used, this facility makes a list of key decisions, who it was that took them, when and why, available to the team. In providing this facility the system not only helps the users to avoid making unnecessary decision loops during the design activity, but capture, storage and retrieval of decisions during the process also provides 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.

8.7 Conclusions: Towards system verification and validation

The Web-based system supports the design team in designing as opposed to prescribing how they should design. It not only provides a conceptual design process, in the form of a number of inter-linked phases and activities, but it also outlines a decision sequence based around those phases and activities. This mixture, according to Markus (1969) and subsequently Maver (1970), is required to provide a complete picture of design method (Lawson 1980). Additionally, the proposed support system allows the user to follow various alternative pathways through it. This enables it to be utilised as a contingency model, while ensuring that it is flexible and adaptable to the needs of a particular project and its design team.

As has been discussed in chapter 5 (section 5.4.1), there is a substantial difference between verification and validation within the research domain; with verification involving an internal check of both system integrity and logic, and validation being an external check of correlation between the system and reality. The action research approach to the system development allowed the end users to drive its evolution. This activity allowed the system to be verified off-line (without actual implementation in practice) to some extent. Yet this did not provide a means of evaluating the system outside of the environment in which it was developed. As such, the following chapter describes the manner in which the system was tested and verified provisionally through a trialling of the system on a live design project. As has been stated previously (chapter 6) the main focus of the system trial was not to fully validate the Web-based version of the framework, although it did enable a preliminary assessment of the suitability of the internet as the medium for delivery of the framework to be achieved.

The primary aim of the final component of the research, as will be discussed in chapter 9, was to further validate the underlying framework structure and, ultimately, to gain further insights into interdisciplinary conceptual design in practice.

Chapter Nine

Preliminary evaluation of the Web-based system and further validation of the conceptual design framework

9 Preliminary evaluation of the Web-based system and further validation of the conceptual design framework

9.1 Introduction

The application of the action research methodology enabled the web-based tool, and underlying framework, to be developed and verified concurrently. The system now needed further testing to initiate validation and allow a preliminary evaluation of the prototype tool. It is appreciated that further validation is required before such an approach could be used by industry, but this stage of development is beyond the scope of this research.

Additionally, the conceptual design framework (phase and activity model) had only been applied in an experimental environment based around a simulated design problem. It was therefore also appropriate to test the framework underlying the Web-based system through application on a live design project.

This chapter describes the validation mechanisms, the application of the system on a live design project and the subsequent feedback from the project team on the potential of a web-based version of the framework. New insights into conceptual design practice were gained from this live application and a mechanism is proposed to improve the efficiency, and management of, interdisciplinary conceptual design.

9.2 Overview of the project workshop

9.2.1 Introduction to the project

This project workshop, which involved the design of a £100m-plus airport terminal building, marked the interface between the feasibility study and conceptual design phases (using the BAA Project Process (1995) phase description) of this project. Owing to its magnitude, the project was sub-divided into a number of packages. The trial focused on one of the sub-project elements: a flight pier.

The feasibility study, which was used as the basis for the conceptual design workshop, contained several assumptions owing to the fact that only the major stakeholders had been involved for knowledge gathering purposes to that point. This

was the direct result of the confidential nature of the project. Thus, the assumptions, which had been verified internally as being realistic and appropriate for progressing feasibility, were to be reviewed, amended if necessary and, ultimately, validated through consultation with the operational level stakeholders throughout the definition (conceptual design) phase of the project.

Additionally, it was made apparent that a number of decisions on which the project was proceeding were still to be finalised at high level within the business. Thus, the design team members were fully aware of the possible problems associated with proceeding on the basis of the incomplete data.

A number of high level concepts had been produced previously based on the site layout. However, upon detailed investigation in relation to the existing buildings on site, it was apparent that many were unworkable and thus, fairly radical changes were required. These concept sketches focused on the terminal as a single entity. The sub-components of the facility were, at that point in the design process, unexplored. This first workshop was aimed at developing an initial concept for the pier component of the project.

9.2.2 Workshop format

In the one-day workshop the client organisations were not represented in person. This role was taken by the senior project manager, who, being employed by one of the client organisations, had been party to the stakeholder meetings to that point and as a result, had an in-depth knowledge of the business need driving the project. The design team itself comprised five designers and two project managers from five organisations. Each organisation had been employed to perform a specialist role within the project: architectural, civil, structural, mechanical and electrical services, and project management.

Each team member was provided with: i) a paper copy of the conceptual design framework (figure 5.5); ii) a list of definitions of the design activities of which it comprises (table 5.5); and iii) a paper copy of the reinterpreted conceptual design framework model (figure 6.18). They were then tutored on the framework's terminology and structure. This was followed by a 30-minute presentation which

described the genesis of the framework (chapter 5), its trialling in the design workshops (chapter 6), and its subsequent development into a Web-based system. The system was then demonstrated. This allowed the designers to improve their knowledge of the system attributes and structure, and relate this back to the paper version of the framework. The designers had a fairly robust understanding of the system as they had been asked to visit the system web-site and 'play' with the system on-line prior to the event. As such, this demonstration enabled the designers to further improve their understanding of the system.

Once the design activity was complete the design team participated in a round table discussion of the system, the framework, and the manner in which the team had collaborated and interacted. This post-design discussion was recorded in note-form, and, like the design activity itself, supplemented by audio-taping to ensure that important response data was not lost.

9.2.3 Compensating for the incompleteness of the prototype system

Computer system prototypes are useful for conducting early stage development tests because they allow system concepts to be portrayed in a physical, and thus tangible, form. At its most primitive level, a prototype may be static, or non-runnable, in which case it can only be used to demonstrate a concept with no user input. Conversely, a dynamic, or runnable, prototype might be advanced enough to allow human-computer interaction (HCI), with the only inactive component being a connection to a live database (Lingaard 1994). The conceptual design support system, although runnable, was too incomplete to allow HCI at this stage of its development. However, the usability of the decision recording mechanism and the benefits to be gained from mapping, and reflecting upon, an evolving pattern of design progression needed to be evaluated. Owing to the fact that neither the design rationale capture mechanism nor the progression tracking and mapping mechanism were fully operational at time of trial, these elements of the system had to be simulated with pen and paper to compensate for the incompleteness of the prototype.

The use of pen and paper simulation is often overlooked as a means of testing incomplete systems. However, it provided a methodologically sound means (Lingaard 1994) of describing and testing the concepts that were not fully operational within the

prototype system. As testing the suitability of the internet as the medium through which to present the design framework was only a subsidiary aim of this part of the research it was deemed more appropriate for the author to facilitate the use of the system during the trial. Thus, the author operated the step-wise progression through the system structure, as designated by the design team, and mapped the team's design progression on a white-board (in full-view of all participants throughout the exercise), while the team members used paper versions of the on-screen decision recording mechanism to record decisions as they were taken.

9.2.4 Team design activity based on the pattern of design progression

The design progression of the team is shown in figure 9.1 below. The vertical axis represents the sequence of activities (in black) and phases (in grey) outlined by the conceptual design framework and the support system, and the horizontal axis represents time spent over the course of the day.

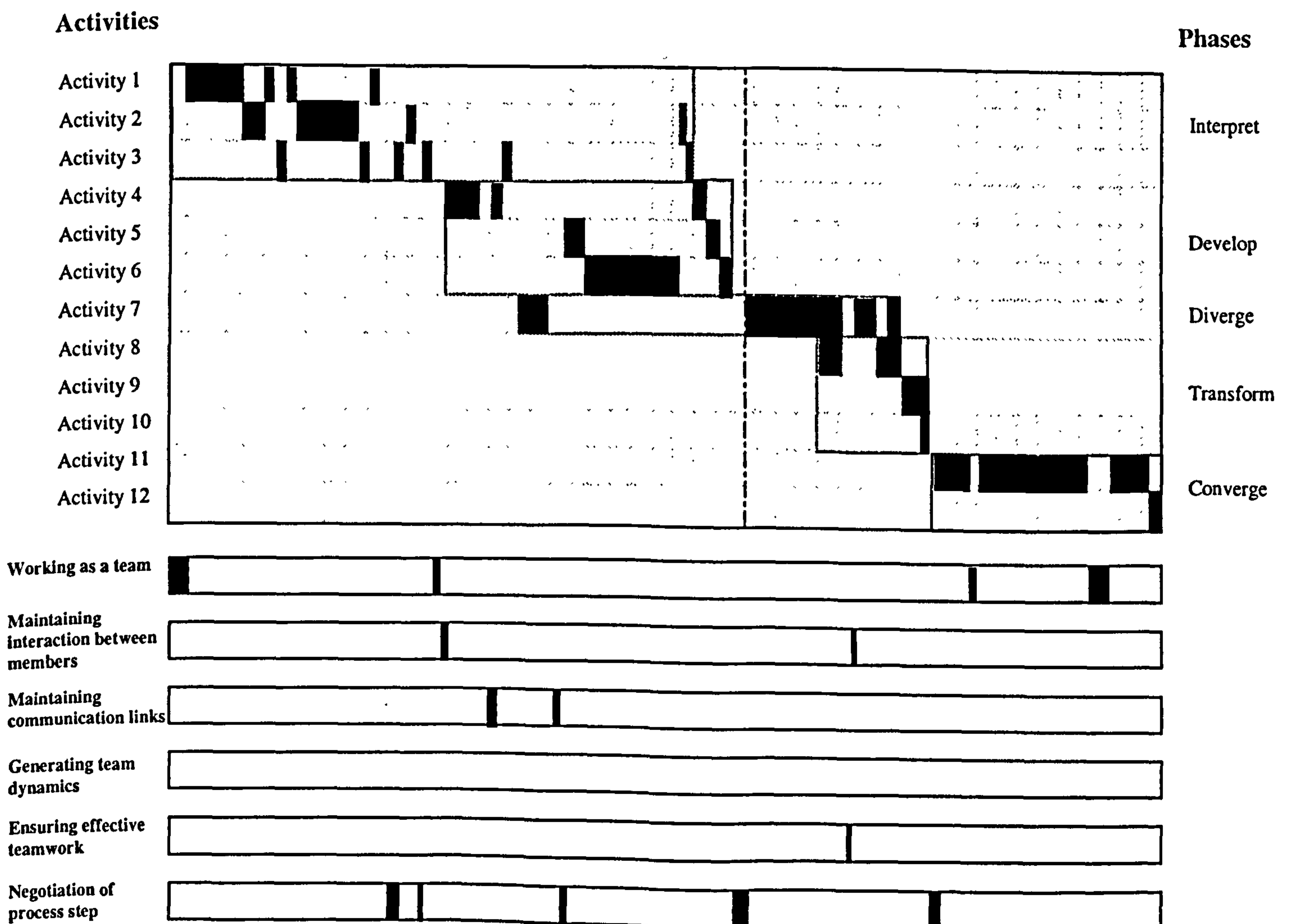


Figure 9.1 Pattern of design progression of live-project team

The additional rows at the bottom of the figure represent the point in the process, and the time spent, undertaking activities relating to social interaction and self-management. Each row represents one of these additional activities.

The design team spent approximately 240 minutes designing during the course of the day. Approximately 86% of this time was spent undertaking the phases and activities outlined by the system. A breakdown of the design time is provided in table 9.1. The remaining 14% of design time was spent undertaking activities relating to team maintenance and self-management (these are described by the six rows beneath the pattern of progression in figure 9.1).

Phase	Activity		% of design time spent in section of the framework	
Interpret	1	Specify the need	9	25
	2	Assess functional requirements	10	
	3	Identify essential problems	6	
Develop	4	Develop functional requirements	5	21
	5	Set key requirements	4	
	6	Determine project characteristics	12	
Diverge	7	Search for solution principles	16	16
Transform	8	Transform and combine solution principles	5	9
	9	Select suitable combinations	3	
	10	Firm up into concept variants	1	
Converge	11	Evaluation and choice of alternatives	15	15
	12	Improve details	Not included in comparison	
Time unclassified by phases of model			14	
Total spent in phases 1-6			46	
Total spent in phases 7-12			40	

Table 9.1 A comparison of time spent in the respective framework phases and activities

9.2.5 Observations from the pattern of design progression

Initially the team addressed a number of activities in parallel. It is apparent that this early stage of the process focused on achieving the phase objective of interpreting the clients need. This was followed by a brief exploratory step to generate concepts before stepping back to resume a fairly linear and, as described by one designer, 'smooth', progression. The only deviation from this 'smooth' pattern of progression was an 'iterative spike' mid way through the design activity. This was a needless iteration that occurred as a result of the team neglecting to introduce a requirement for

consideration, even though it had been recorded during the development of requirements. The reason for this was, in fact, an oversight on the part of an individual. Thus, this period of iteration, although relatively short in terms of total design time, could well have been avoided.

The design team comprised individuals that worked together regularly on projects of this type for the same client organisations. Consequently, the team knew one another well on both a social and professional level, and there was a good team dynamic from the outset, with no confrontation between individuals.

9.2.6 Analysis of design progression using DSM

If DSM is used to analyse the team's pattern of design progression it is apparent that, like the workshop teams (chapter 6), there is a single large block of interdependency between activities 1 to 8. The remainder of the activities are then addressed independently of one another.

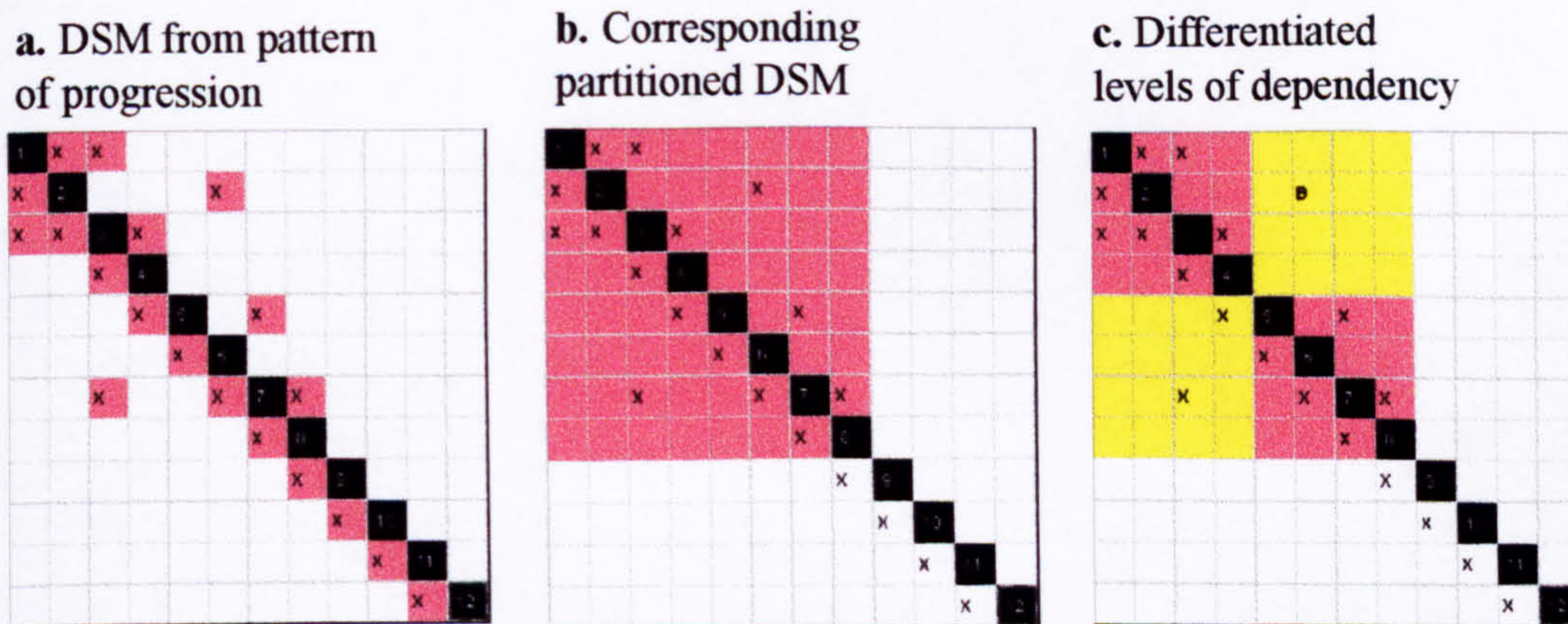


Figure 9.2 DSM analysis of pattern of design progression

Again, if the mark furthest from the leading diagonal is designated as having a different level of dependency (marked B) than those marks lying closer, the large block can be divided into two discrete blocks of interdependent activities. This finding further reinforces the integrity of the reinterpreted conceptual design framework model (chapter 6, figure 6.18) and suggests that it is representative of holistic, as well as of sub-elements of, design projects.

9.3 Questionnaire data

9.3.1 Team performance questionnaire

The design team members completed two questionnaires at the end of the workshop. The first of these, which captured details of perceived team performance, had been utilised previously during the Designing Together workshops. The second, which was a paper version of the on-line questionnaire utilised to gather data on the preliminary evaluation of the system over the internet, elicited details of the team member's thoughts regarding the framework and its potential for application in the web-based form (each of these questionnaires is provided in Appendix II). Table 9.2 provides details of the average team performance questionnaire responses.

	1	2	3	4	5
How would you rate the design that the group has produced for the task?					
Which number best describes the way the group took decisions?					
How would you rate group member contribution to this task?					
How do you feel about the way the group has worked?					
What do you think about the group's organisation during this task?					
How satisfied are you with the way the group used its time?					
How do you feel about the way the group chose to proceed?					
What do you think about the way your ideas are included in the design sketches?					

Table 9.2 Average of team performance questionnaire responses

No team member responded negatively to any question. Moreover, over 85% of all responses registered a score of 4 or above, with over 20% of all responses registering a score of 5. This must be considered to be a result of the team members being accustomed with one another's ways of working, rather than a consequence of the application of the framework. However, in a post-workshop discussion it was stated that having the framework structure enabled the team to negotiate process progression around a shared model. It was suggested that this helped the design team '*work together*' during the design activity.

9.3.2 The framework/system questionnaire

As the team members did not utilise the team thinking tools during the workshop, these issues were not addressed in the questionnaire. However, two team members had explored these over the internet. These individuals agreed that; i) the design tools

could be accessed easily; ii) there was enough instruction to apply them; and iii) they would use the tools in the given form. However, the question of whether they believed that other members of the design team would use the tools in the given form was undecided (a neutral response was given).

Typically, the team members agreed with all of the questionnaire statements, with the responses to approximately 60% of the questions averaging a 4-rating (marking agreement with the statement). However, there were a number of exceptions. These are outlined below:

Questions with which, on average, the team strongly agreed:

4. The framework will support teams while undertaking conceptual design.

This question relates to the usefulness of the system as a design support mechanism. In the post-design discussion the designers stated that, potentially, conceptual design would benefit greatly from a system which would provide process-oriented guidance and assistance in conjunction with decision rationale capture. Additionally, it was stated, that if the system were married with a document management facility the team would be able to search for, and retrieve, appropriate design information very efficiently

13. The phases and activities are a good representation of the conceptual design process.

This response reinforces the prior validation of the framework phase and activity structure. It was apparent that all members of the design team, irrespective of discipline or background, could associate with the framework components. The level at which the designers addressed the framework was not discussed. However, more important was the finding that the system hierarchy was acceptable to practising design professionals.

20. Recording decisions in a structured manner during the design process is beneficial.

The design team members were very confident with the design options that were generated during the session. This was not only on a functional basis i.e. the fact that the proposals were feasible, but also because the team could justify and defend the

proposals with rationale. The designers stated that the discipline imposed by having to record decisions formally (although this was at the option of the team members) ensured that the rationale was in place. This was perceived as being vitally important to a conceptual design proposal. However, several issues and, subsequently, concerns were raised about the type of mechanisms with which designers in practice could record decisions efficiently without invasion of design time. These are discussed in section 9.4.3.

30. All designers should be given equal opportunity to contribute throughout the conceptual design process

This finding reflects the manner in which the team worked during the workshop. No single individual controlled the discussions. Instead, each person was allowed to input ideas and suggestions throughout.

34. It would be beneficial for me to think about the process as well as the product during design activity; and...

35. It would be beneficial for me to think about the process as well as the product during design activity.

This suggests that the team members are aware of the benefits to be gained from both discussing, and reflecting upon, the processes of design as well as the product.

Questions with which, on average, the team disagreed:

7. I think the team could use the framework without facilitation.

This was a fairly predictable response given that i) the system was facilitated during the trial; and ii) although designers believe it would be beneficial to think about the process during design activity (see responses to questions 34 and 35), they, typically, want to '*just get on and design*'. It has been shown previously (chapter 6) that designers tend to become very focused on the product during design activity and as a result, spend little time contemplating the process. In the post-design discussion the designers stated that it would be far more acceptable for a team to be guided by the system if they did not have to focus on it continually, but instead were only given process advice when it was actually required, i.e. with the system being used as a contingency mechanism. It was suggested that the project/design manager could take the role of facilitator.

29. The framework's structure inhibits creativity.

It was pleasing that the designers felt that the system did not inhibit creativity, particularly as several of the existing multi-phase/activity process models have been criticised for constraining creative thinking.

Neutral (neither agree nor disagree):

6. The team maintenance issues are relevant; and...

9. The framework could reduce confrontation within the design team.

Owing to the design team having worked together previously there was a very good team dynamic. As such, the self-management mechanism was never brought into play. This is not to say that the team did not maintain itself for periods of design time (see figure 9.1). However, when this did take place the team members did not require external assistance, preferring instead to address situations from within the group.

16. It is simple to navigate through the framework.

This reflects the fact that the use of the system was facilitated during the trail session. However, those team members who had visited the system on-line suggested that having a 'map' (image) of the framework on-screen continuously would ease navigation.

22. I can envisage using the framework individually.

Although the average designer response to this question was neutral (neither agree nor disagree) two of the respondents stated that they would use the system on their own - particularly if the proposed links to organisational procedures and documentation were embedded. It was stated that the system, in addition to supporting design activity, has the potential to be developed into a training package to teach graduates about the conceptual design process.

9.4 Feedback and thoughts on the Web-based system

9.4.1 Introduction

The post-design discussion enabled the design team members to discuss their thoughts and perceptions with regard to the application of the web-based design support system. The feedback, which is described in the following sections, provided insights

into the manner in which the system would be applied and, more importantly, accepted, by practising teams of designers.

9.4.2 The use of the web as the medium for delivery of the framework

Although this concept was addressed in the questionnaire, during the post-design discussion it was stated that conceptual design activity would be enhanced and could be undertaken more efficiently if this type of guidance-system, incorporating appropriate links to web-based design information, were used in practice. Particularly, as has been described above, if it were used in conjunction with a document management system based around a project, or organisational, database; Thus, ensuring that decisions made at the early stages of the design process could be based on as much available data as possible.

9.4.3 Decision recording mechanism

The design team members stated that this attribute of the system would be highly beneficial if applied in practice. It was suggested that the decision recording mechanism would be a key design tool even without the framework structure in place. However, in the discussion that ensued as a result of this conjecture the design team acknowledged that it would be very difficult, and possibly impractical, to record decisions without relating them to the design process. It was suggested that in the later stages of design, decisions could be recorded against drawing revisions and design changes (a concept that is being investigated by the University of Sheffield in the Advanced Decision Support (ADS) research project). However, as there are, typically, very few, if any, formal drawings produced during the conceptual design period, it would only be possible to record decisions based around either: i) evolving design sketches; ii) the progression through the activities in the conceptual design process (as is the case with the design support system); or iii) a combination of both i) and ii).

In referring to the definitions of design rationale outlined by Moran and Carroll (1996) - presented in section 8.6.5 of this thesis – the most applicable in this instance, in light of the system trial, would appear to be:

Documentation of: i) the reasons for the design of an artefact; ii) the stages or steps of the design process; iii) the history of the design and its context.

However, in the context of the support system, the decision rationale capture, being based around the actual design progression of the team, could be utilised as a form of process-facilitation tool (Moran and Carroll 1996) for prompting and guiding the design team to carefully consider the reasons for certain choices or steps in the design process. This is a concept that is discussed further in section 9.8.3.

A major point of contention with regard to the capturing of design decisions was the fact that completing a formal document every time a decision was made was both labour-intensive and time consuming. During the course of the workshop only ten decisions were recorded formally, when in actuality a far greater number of decisions were made. Eight of those decisions were taken and recorded within 40 minutes of the start of the exercise and the remaining two were recorded soon after. When questioned as to why this was the case, the architect, who had assumed responsibility for recording decisions, stated that although it was felt to be a worthwhile activity, while completing the form he was isolated from the teams discussions of the project. The architect stated that he was trying to listen to what was being said, and contribute to the discussion, while writing. This was described as being a major problem associated with attempting to record decisions while designing; the fact that '*you [the designer recording the decisions] have to stop designing to do it*'. Thus, as design activity progressed the decision recording was neglected in favour of focusing on design product.

The problem is that the activity invades design time. Decision capture, design rationale, is recognised as being vitally important as it allows a design team/designer to defend a concept, option, or project once complete, and explain why they did what they did. However, how to develop a mechanism for doing this during design activity in a non-invasive manner should be the real question. It was suggested that if the decisions and rationale can be captured quickly and simply (without expending design time and effort) then designers will accept it. Whereas, if recording a decision takes too long and requires lots of extra work, then designers will not do it.

It was suggested that the decision capture mechanism should be based around a number of pull-down menus, thus minimising the amount of typing involved.

Additionally, at early stage design decisions are not absolute, they represent merely a snapshot of an evolving understanding of the problem and solution at any moment during that period of the design process. Thus, if, as the design process progresses, an earlier decision needs to be superseded, it is insufficient to simply amend an earlier decision record, as this will not reflect the true evolution of the design. Thus, it is apparent that decisions must be recorded chronologically over the life of the design process in order for the rationale behind the design progression to be understood.

This introduces a further problem. Owing to the iterative nature of design it is common for an issue to be raised time and time again. As a result, decisions, which may need to be based on assumptions, need to be updated constantly. This can very quickly lead to masses of documentation being produced, much of which refers to similar issues, that is organised around the manner in which that team progressed through the design process. However, hypertext can provide the links that connect these decision amendments without having to re-shuffle the chronological, and thus linear, decision order; an activity that would destroy the rationale. The problem here is handling the increasing amount of documentation as the design progresses and storing it in a rational manner, i.e. producing a taxonomy for classifying the decisions to allow simple storage and thus ease retrieval for future re-use.

Thus, to conclude, the designers agreed that the support system has the potential to allow the design team to leave a process trail that incorporates the capture of a great deal of knowledge. However, it is apparent that for a design rationale, or decision recording, mechanism to be accepted in practice it must be both non-invasive and simple to apply. In this respect it appears that any tool which deals with the capture of design rationale must be integrated into the everyday practices of design. The recognised strategy for achieving this is to embody rationale capture in tools that are of immediate utility to designers (Fischer 1996). It is this that has been attempted in developing the decision-recording attribute within the Web-based system.

9.4.4 Evolving pattern of design progression

The design team thought that the pattern of design progression that was produced as the team advanced was an extremely useful means of understanding the design process. It was stated that design teams are not, generally, inclined to stop designing

in order to pause and reflect upon their design process. The concept of reflection-in-action (Schon 1983) is not recognised, typically, among practising designers. However, within the workshop the design team referred regularly to the evolving pattern of design progression as a means of contemplating their design activity, highlighting sticking points in progression, and deciding upon the next activity to be undertaken.

Additionally, when the team overlooked a requirement during activity 6 – determining project characteristics (see figure 9.1) – the ‘iterative spike’ that this caused in the pattern of progression allowed the team to assimilate the implications that this oversight had on their design activity. In fact, it was the suggestion that this iteration was ‘uncharacteristic’ of the rest of the design progression that prompted the concept of identifying ‘iteration bandwidth’ – a concept that is introduced in section 9.6.6.

9.4.5 Facilitation of the system

Within the workshop it was the opinion of the design team that the system would have to be facilitated during use in practice. This was not only because the designers involved did not have a full working knowledge of the system, but also because they wanted to focus on designing. The author’s role as facilitator involved mapping the design progression of the team and raising the issues within the framework at the appropriate point in the process. This action focused the design team and made them reflect on their design activity. Making the team aware of the process assisted them in negotiating the next step to be taken.

Within the workshop the team’s use of the system was focused around the evolving pattern of design progression. In the post-design discussion it was suggested that, in practice, the design manager could facilitate the use the system. If the design manager monitored the design progression of the team using the system it would only be necessary to offer system advice when it was actually required (it could be used as a real contingency model) rather than continuously throughout the design process irrespective of whether the team are functioning inefficiently or not.

9.4.6 The issues as the basis of step progression through the activity structure

Even though the use of the system was facilitated during the workshop, it was apparent that the designers were driving their own progression through the activities. It was only when the team assessed their design activity when there was unrest within the team and one or more of the members became frustrated, that the activity structure of the framework was addressed, e.g. *'Have we finished activity 3; can we move on from activity 3 to activity 4 now, or is there more to consider?'*

In this respect the questions comprising the guiding attribute of the system accounted for only a fraction of the issues that the team actually addressed during the workshop. There were far more questions/issues that were raised and addressed within each activity before the final (transition driving) issue was raised. This suggests that the issues in the system mark, or promote, step-progression from one activity to the next and neglect to account for the issues which need to be considered within each activity individually.

Additionally, the team suggested that the issues in the support system appear too stringent in terms of the expectation for response, e.g. *'Has the team produced a list of the client's functional requirements? YES or NO'*. If the team responds *'NO'*, advice is offered on assessing requirements – along with tools to support this activity. However, when the team *'CONTINUE'* they are met with *'Are the functional requirements sufficiently detailed to allow the team to continue? Yes or No'*. If the team members answer yes then they step out of *'Assessing functional requirements'* and into *'Identify essential problems'*.

This reflects the fact that the issues (questions) within the system were developed to mark/promote this type of step progression from one activity to the next. However, this is not always the manner in which conceptual design activity actually progresses. The raising of the issues which exist at present merely promote a step into the next activity within the sequence; they do not necessarily mean that the team will stop performing the latter activity, i.e. in answering positively to an issue, the team merely bring another activity into consideration in parallel with any number of the prior activities (this, and the consequences of it, are discussed in section 9.6.6). Thus, the system was validated in terms of its ability to drive *'stage gate'* progression through

activities, but this type of issue represents only a fraction of the issues that need to be addressed in practice. However, to develop a system which could assist a design team at this level of detail would require it to contain project specific issues. The design team suggested that the existing system could act as the generic skeleton of such a system, from which a number of project specific versions could be developed. The fractal structure of the framework, which has been verified over the course of this empirical investigation in that the framework was equally applicable to the design of an entire building (a flight pier) as it was to the design of a sub-system (a window cladding system) of a building, would enable this concept to be applied.

9.4.7 Embedded design techniques

The tools within the system were not utilised during the workshop. However, the team developed a ranking and weighting system, which consumed approximately 20 minutes of design time, in order to evaluate alternative designs. The team members were directed to the Team Thinking Tools section of the relevant activity (activity 11) but were too engrossed in the design activity to sit down, read and learn the procedure provided. One team member stated an electronic tool would be invaluable at this point in the process (a point with which the other team members agreed). However, it was stated that had the team members been taught a suitable evaluation method prior to the event they could have applied it and, thus, saved a lot of time and effort.

9.4.8 Conclusions regarding the Web-based version of the framework

In general, the designers were very positive about the potential of the framework as a web-based system. All team members agreed that Web-based design was going to be a major component of design collaboration in the very near future. As such, they felt that, with further development, the Web-based version of the framework would offer the optimum means of applying it in practice. However, it was stated that the on-line layout of the system would have to be improved and simplified substantially for it to be accepted within the industry.

9.5 Comparing the patterns of design progression

9.5.1 Introduction

This workshop witnessed the first application of the design framework, and the development of an evolving pattern of design progression, in a project other than the

window cladding exercise (in the Designing Together workshops). Thus, until this point, it could have been argued that any trends in the patterns of design progression may well have been representative of the 'windows' design problem and/or the experimental environment within which it was undertaken and not common to conceptual design activity in general. Thus, the following sections, commencing with the pattern of progression of the live-workshop team, outline: i) trends and commonalities in the seven patterns of design progression that have been produced during the course of this research project (reflecting upon the patterns of design progression illustrated and discussed in chapter 6); and ii) a fresh means of monitoring and managing the conceptual design process based on the characteristics of design progression.

9.5.2 Live Workshop team

Initially the team addressed a number of activities in parallel.

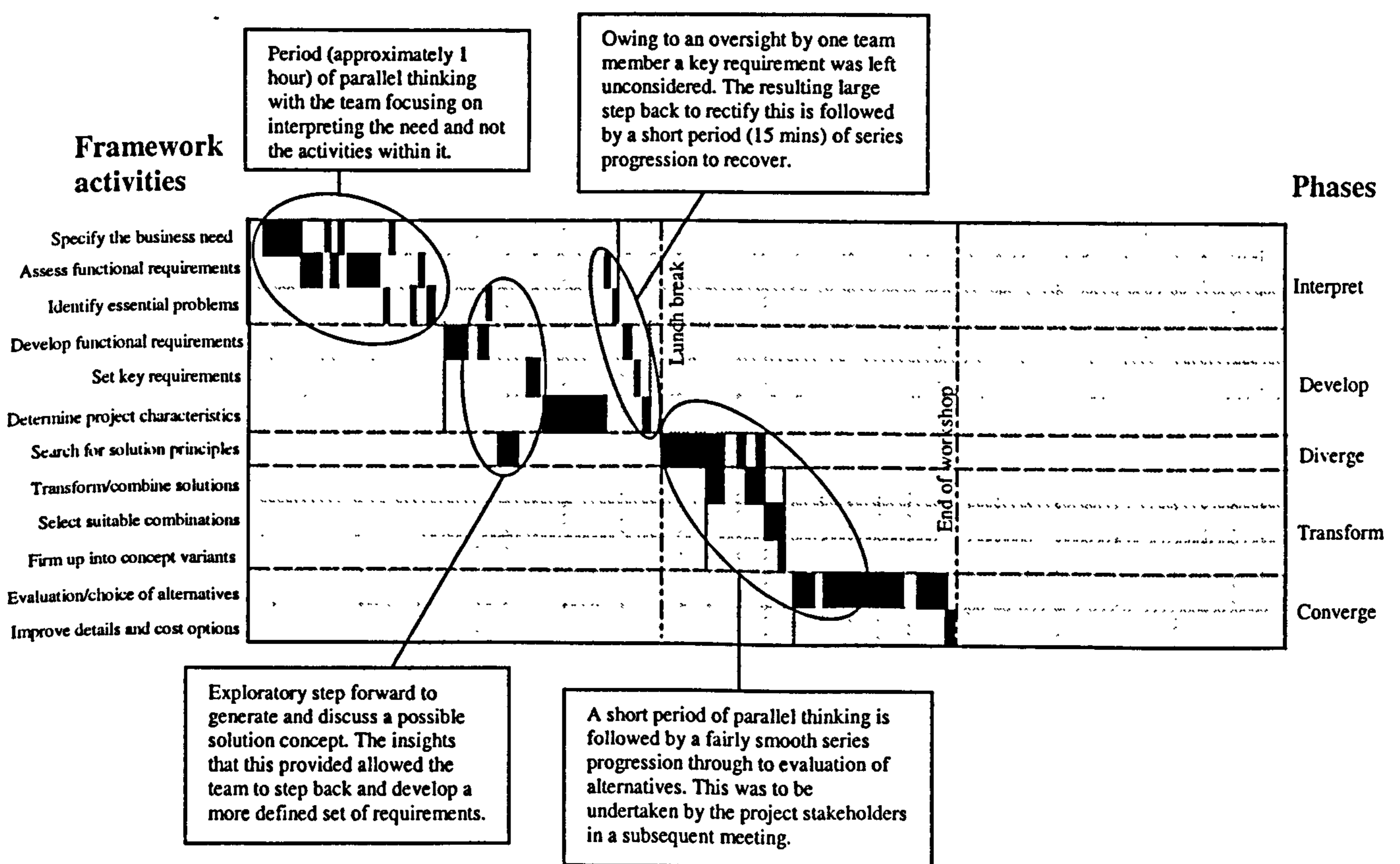


Figure 9.3 Annotated pattern of progression of live workshop team

It is apparent that this early stage of the process focused on achieving the phase objective of interpreting the clients need. This is followed by a brief exploratory step to generate concepts before stepping back to resume a fairly linear progression.

The pattern of progression portrays an iterative spike mid way through the design activity. This was a needless iteration that occurred as a result of the team neglecting to introduce a requirement for consideration, even though it had been introduced earlier in the workshop. Thus, the design time spent performing this iteration could well have been avoided.

9.5.3 Workshop 1: Team A₁

Although a linear sequence of phases was pre-defined by team A₁ it is apparent that the design actually progressed linearly but in a number of iterative bursts.

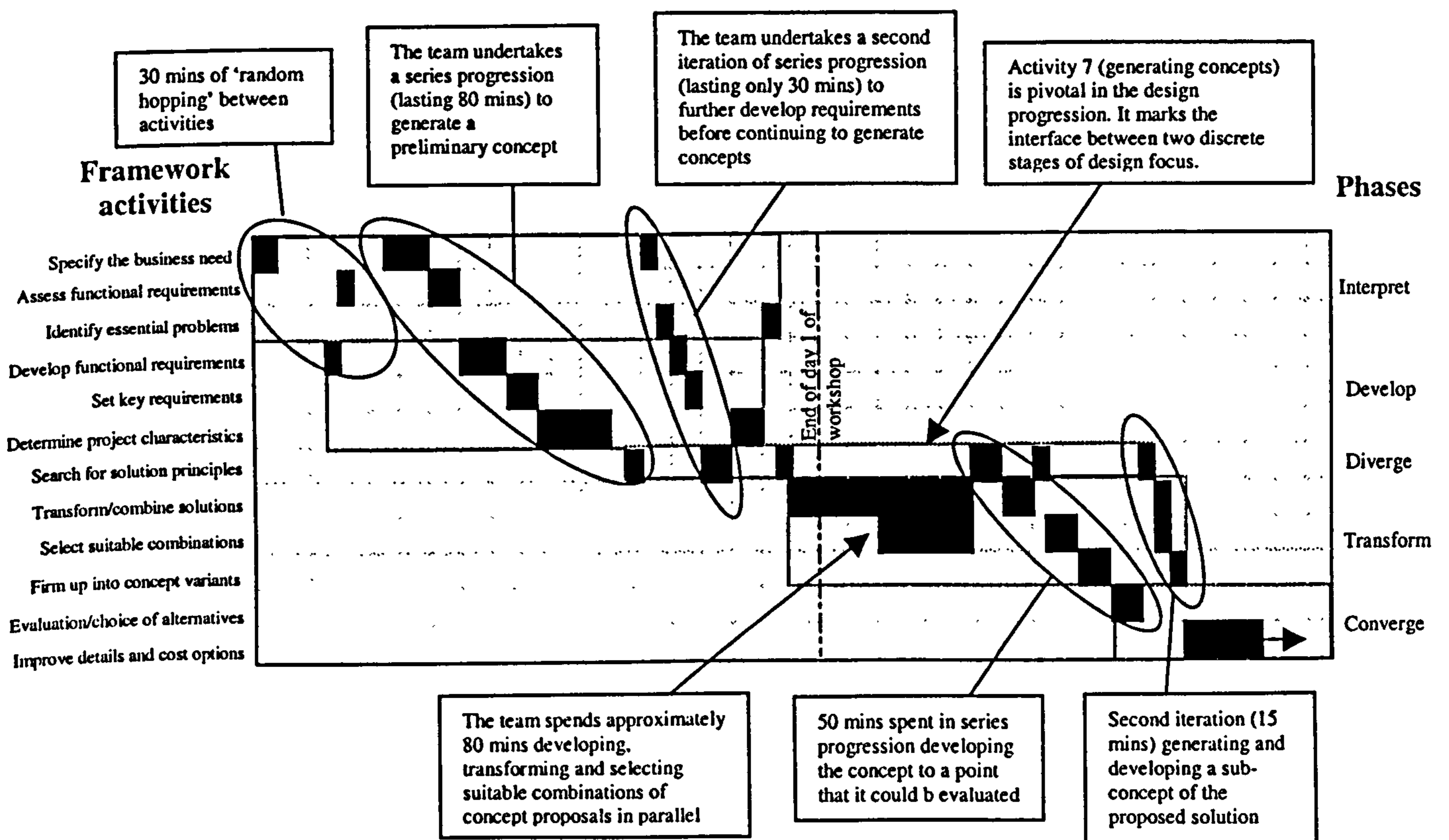


Figure 9.4 Annotated pattern of progression of team A₁ (workshop 1)

Two iterations were performed to establish requirements while developing a design strategy, after which a period of concept generation and transformation took place.

Two further iterations were undertaken to arrive at the final proposal - one to generate and choose the primary concept and another, to conceive and crystallise sub-elements of the proposal. The team members collaborated successfully throughout the exercise with little, if any, confrontation between members.

9.5.4 Workshop 1: Team B₁

This pattern of progression is the result of the team deciding to agree on the direction of progression as and when they saw fit, rather than pre-defining a design process. This decision manifests itself in the sporadic appearance of the team's progression through activities.

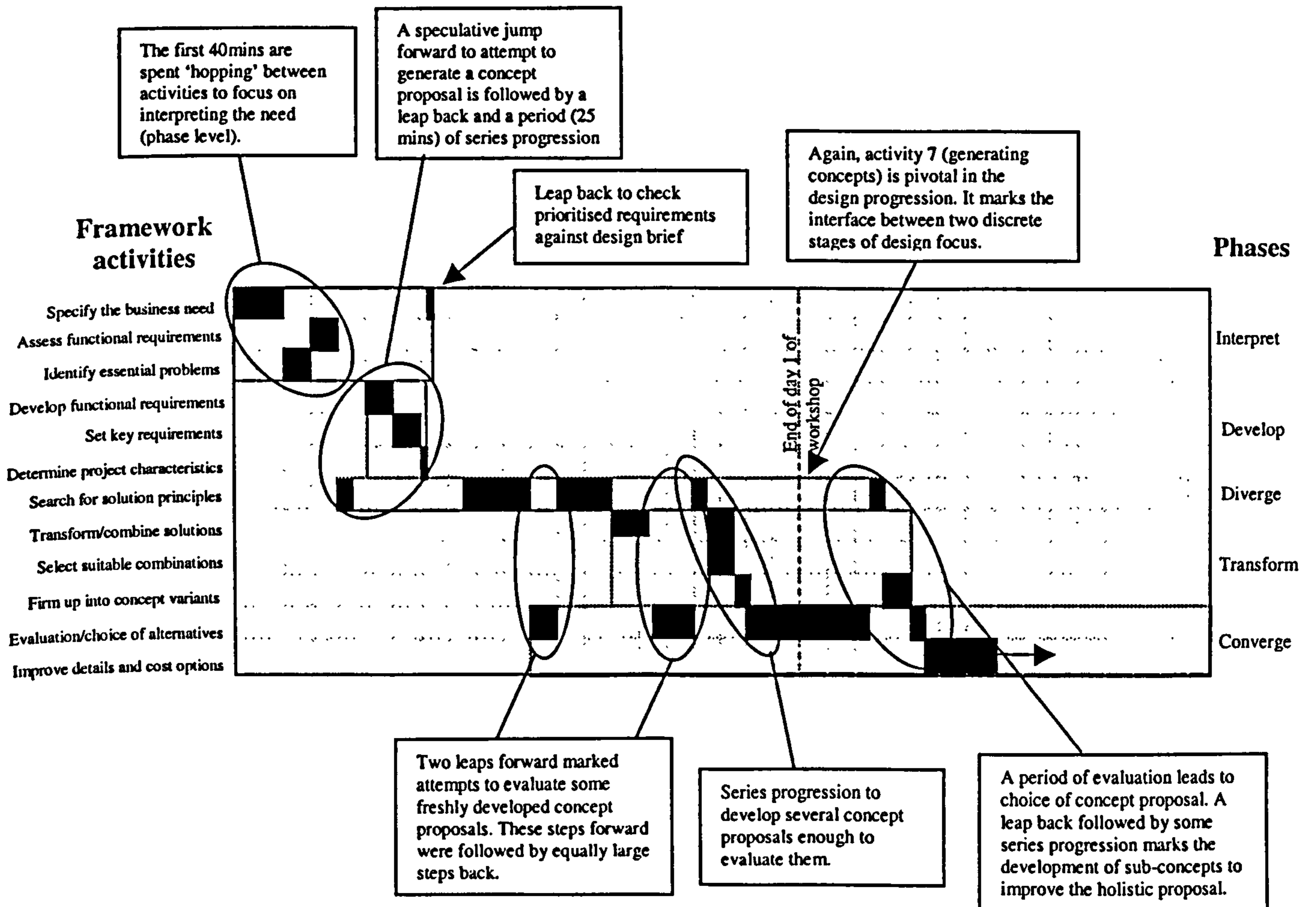


Figure 9.5 Annotated pattern of progression of team B₁ (workshop 1)

The team members appeared to be compatible and as a result, collaborated well throughout the course of the exercise.

9.5.5 Workshop 1: Team C₁

This team progressed linearly through the design process in the early stages of the exercise. This was the result of spending time at the outset to define, and agree upon, a design process. Consequently, the team progressed quickly, efficiently and without

incident. However, the team faltered when faced with the task of evaluating their proposals.

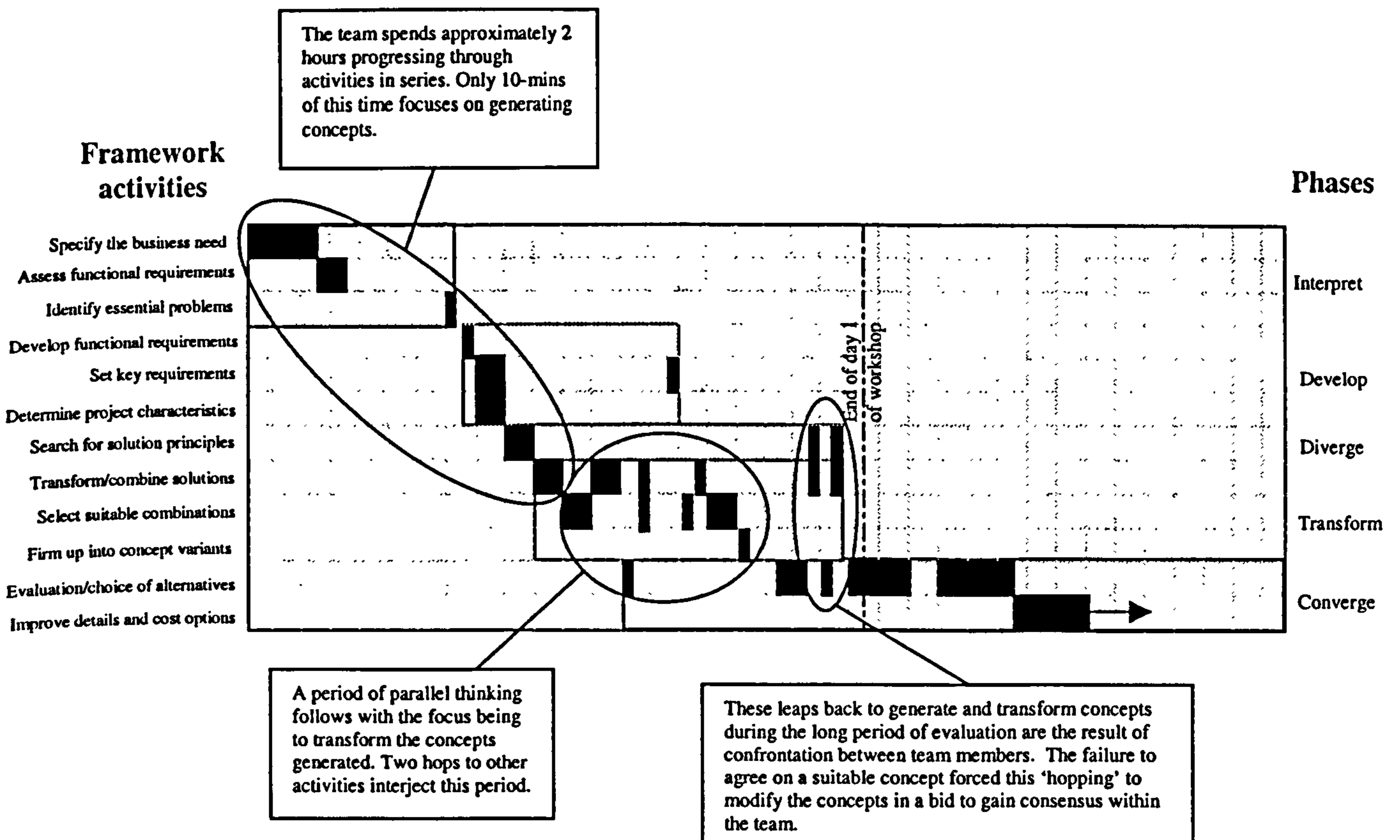


Figure 9.6 Annotated pattern of progression of team C₁ (workshop 1)

Confrontation between two team members resulted in a lot of material being produced in an attempt to reach consensus without any final evaluation or choice of single options ever being undertaken.

9.5.6 Workshop 2: Team A₂

The team tended to 'hop' between activities. However, although the iteration appears miscellaneous in manner, a noticeable sequential pattern is apparent.

There was a clash of personalities within the team that led to discontentment and resulted in a confrontational atmosphere and general lack of cohesion between individuals. The early jumping between activities did not improve matters, making the team members frustrated. Several team members agreed that concerns were not aired at an early enough time in the process to enable the team to make changes and remedy the situation.

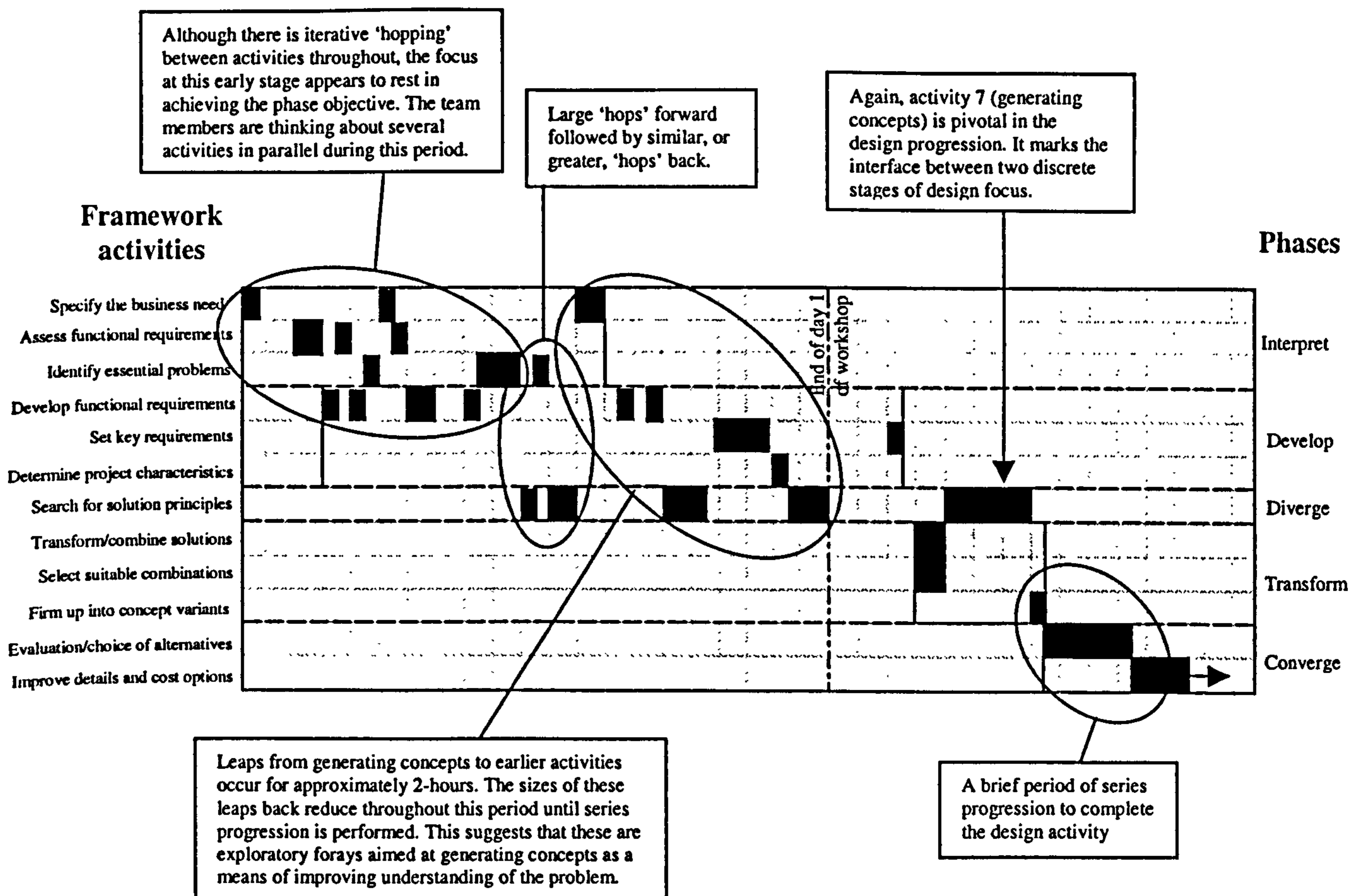


Figure 9.7 Annotated pattern of progression of team A₂ (workshop 2)

9.5.7 Workshop 2: Team B₂

The team progressed fairly sequentially through the activities for the majority of the design period. A short interval of parallel thinking interrupts the series thinking midway through the process. This represents a period of transformation and selection of concept proposals.

Generally, a high level of cohesion was apparent within the group throughout the exercise and the individuals involved were flexible in their approach to forwarding ideas across the boundaries of the disciplines. In fact, one individual stated that *'the group worked together very well right from the start, but became even more organised as time went on'*.

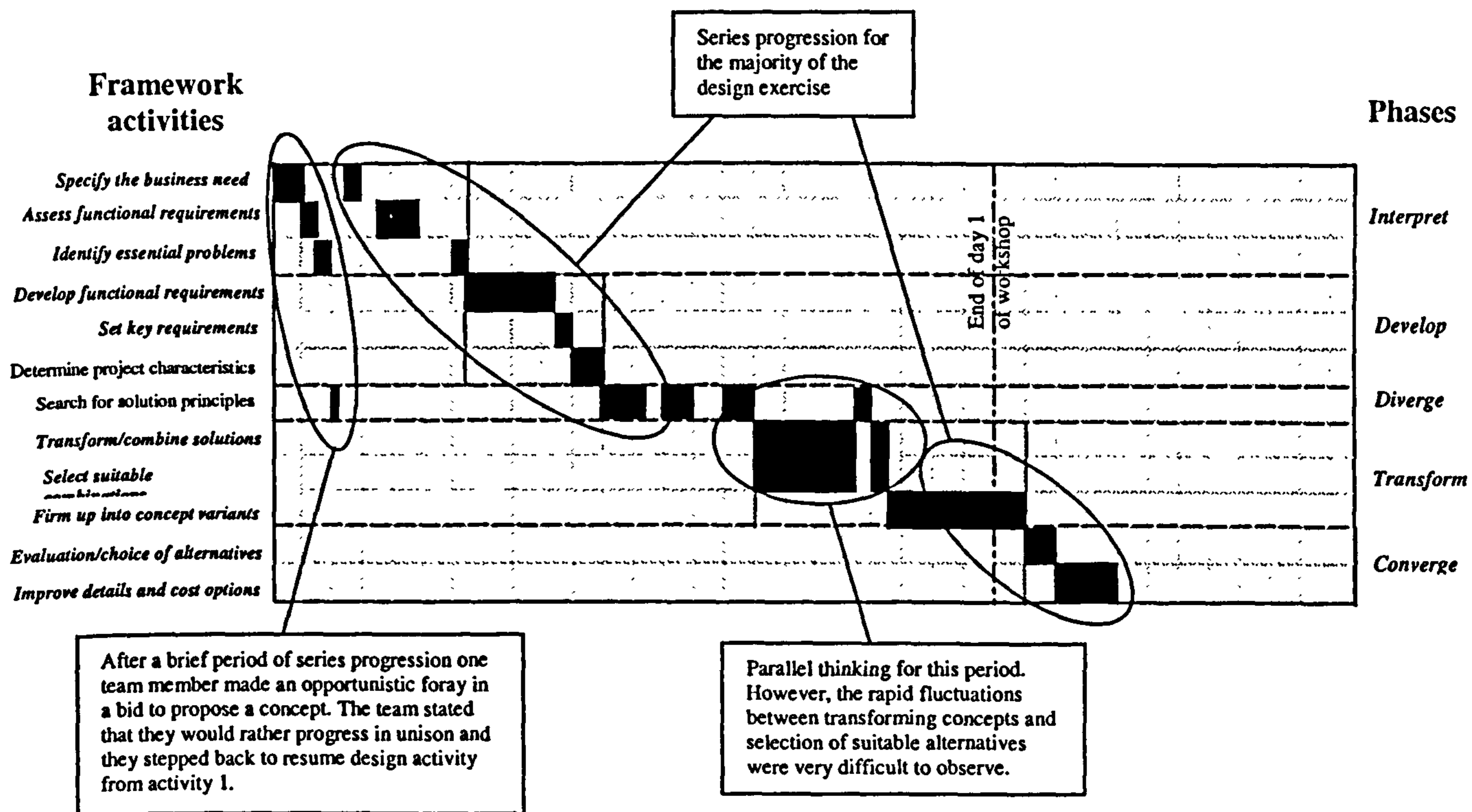


Figure 9.8 Annotated pattern of progression of team B₂ (workshop 2)

9.5.8 Workshop 2: Team C₂

This team moved through the activities very quickly in a fairly rigid fashion to the point at which a number of alternatives needed to be evaluated. In attempting to evaluate these alternatives it became apparent that none was felt to satisfy fully the requirements of the brief and in consequence, the team came to an abrupt halt. After leaping back to an earlier activity the team progressed through the activities fairly linearly.

The team worked well together but became frustrated at times. They attributed this to not having been given, nor having defined for themselves, a process to follow prior to commencing the design activity.

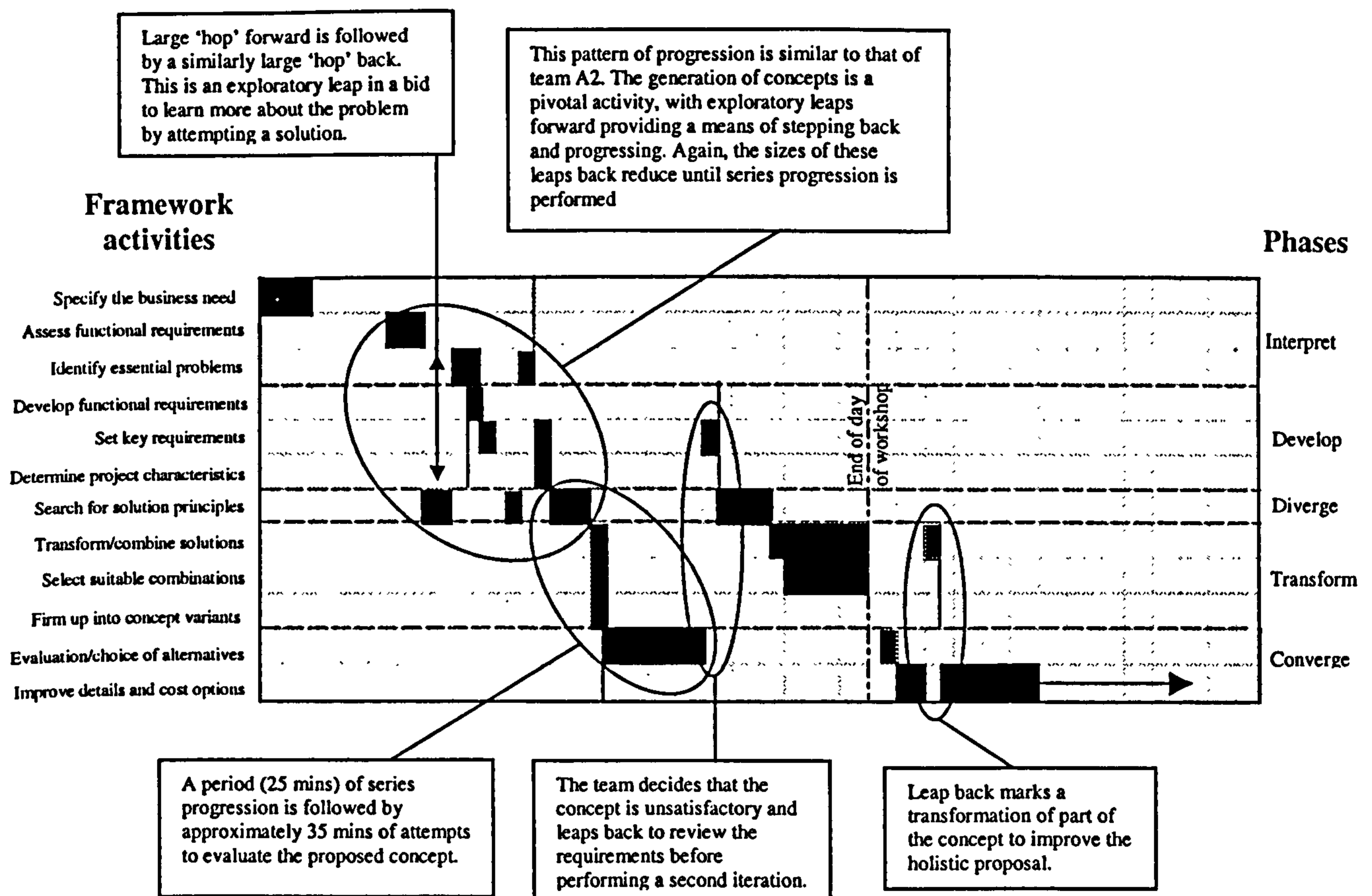


Figure 9.9 Annotated pattern of progression of team C₂ (workshop 2)

9.6 Trends within the patterns of progression

9.6.1 Introduction

Each of the patterns of design progression, described and illustrated in the previous section, is unique in that the same holistic pattern is never repeated. However, in analysing sections of design progression it is apparent that there are certain generic sub-patterns of design activity. These are discussed in the following sections.

9.6.2 Series and parallel thinking and progression

In analysing figures 9.3 to 9.9 it appears as if steps between activities mean exactly that - that each of the activities are considered in isolation of the others for a given period of design time. It may be more beneficial for the design team to think of activities as objectives that it must strive to reach (ways of thinking to reach an objective), rather than as steps that can be made in sequence if certain tasks are performed at each step. Of course, if this idea is applied, exactly what each team member cogitates individually becomes irrelevant as long as the focus of their individual thinking aims at achieving the activity objective - their thought processes

will be very different but their objective in thinking is synchronised. Thus, it is the suggestion of the author that, depending on the manner in which the steps were taken (two types are identified in figure 9.10 based on the design progression of the live workshop team (figure 9.3)), the team are focusing on a different level of objective, i.e. they are working toward the phase objective rather than the activity objective. In effect, different periods of design time are spent focusing on different levels of the framework.

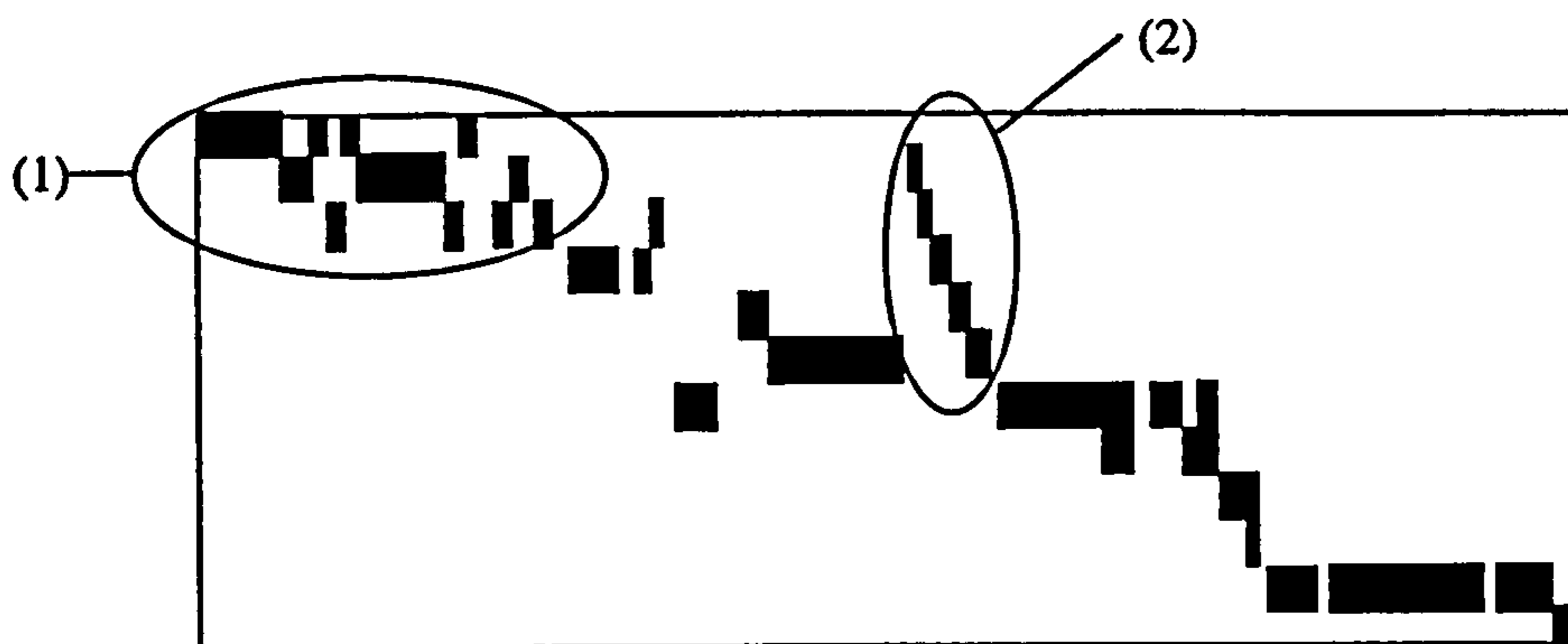


Figure 9.10 Differentiating between parallel and series focus

Figure 9.10 illustrates two very different types of progression. Instead of regarding all steps between activities in the same manner it may be valuable to differentiate between these periods in terms of parallel thinking (1) and series thinking (2) periods. Assuming this is the case then figure 9.10 could be reinterpreted as figure 9.11 below.

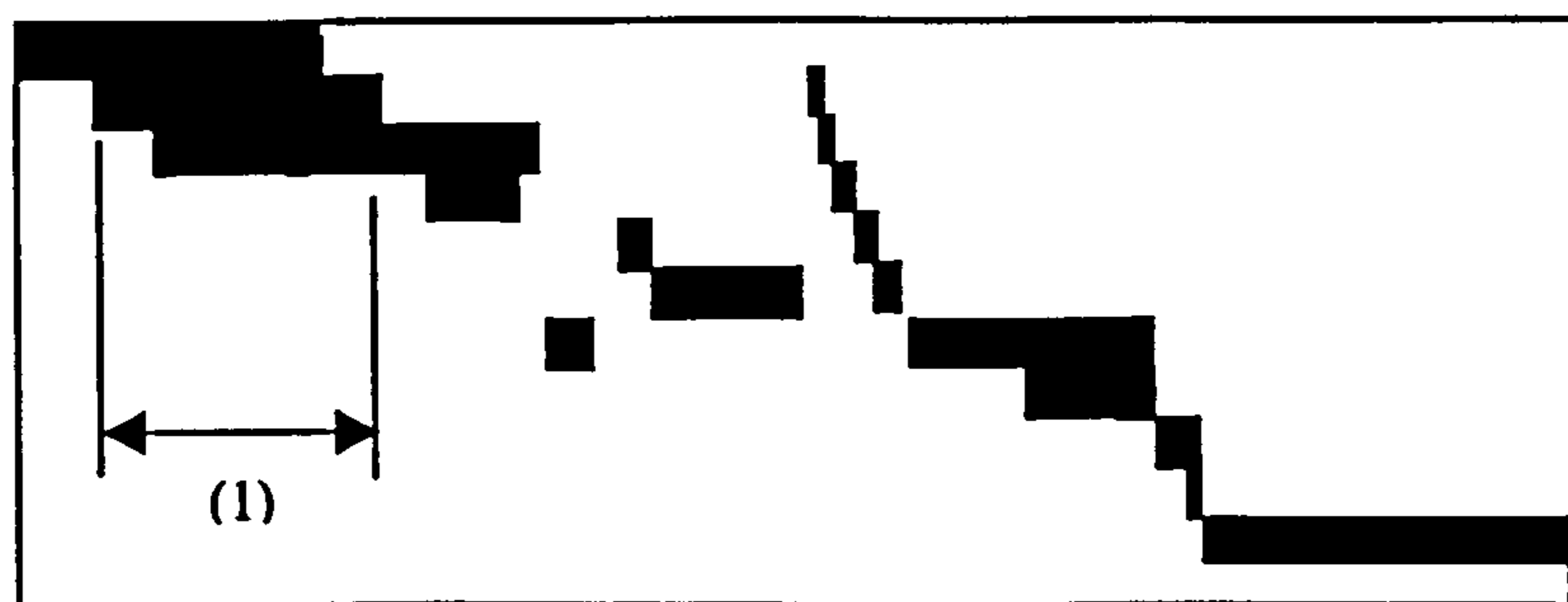


Figure 9.11 Reinterpretation of figure 9.10 given differences in periods of design progression

The patterns of design progression can be misinterpreted if it is assumed that taking a step forward automatically means that the last activity has been completed and is no longer being considered. Although this does occur during series progression it is not

of having designers who do not understand fully the high level design phases and activities.

9.6.4 Iterative steps

When progression has been made either using series thinking, or parallel thinking a large backward step over a number of activities is typically followed by some further series or parallel thinking/progression. It was common to observe this pattern of iteration repeat until an appropriate design was generated (figure 9.13 illustrates this in the pattern of progression of team A₁ (figure 9.4)).

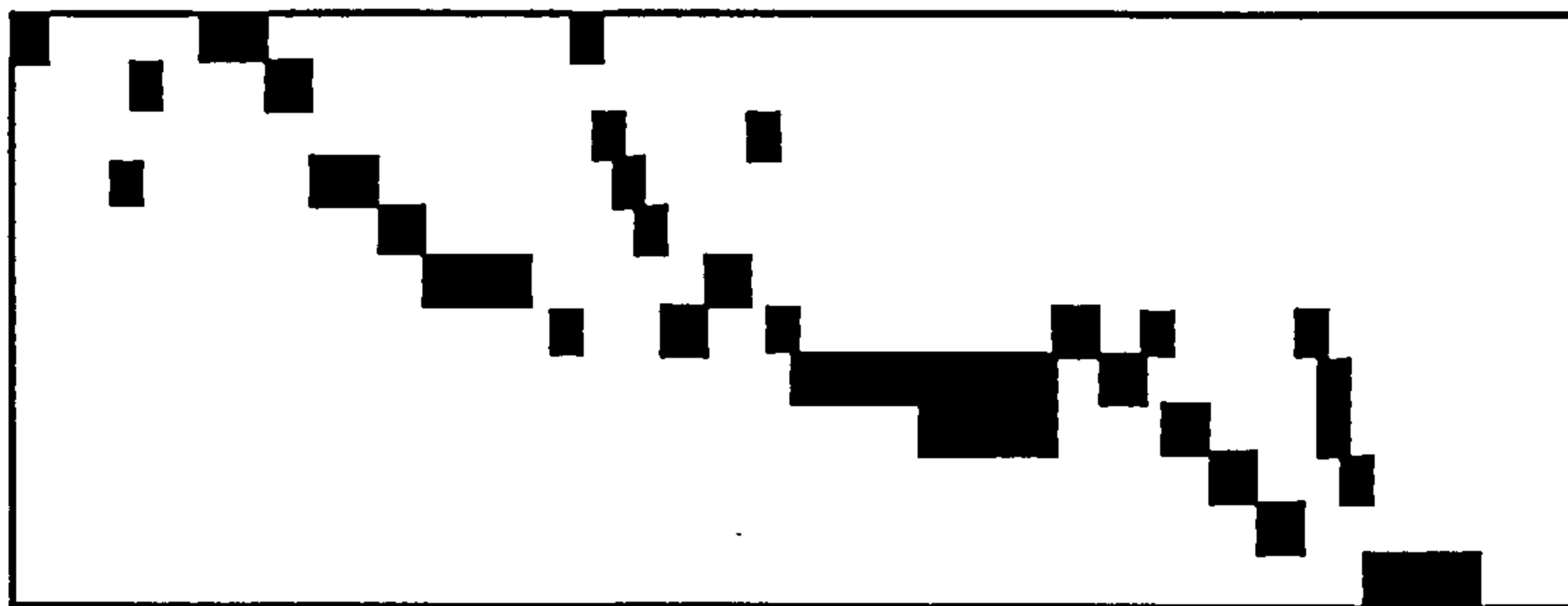


Figure 9.13 Iteration as a driver of design progression

When iterative design progression occurs (within the relatively small sample available for analysis) it is apparent that, in all cases, the gradients of the iteration are different to the gradients of the first occurrence of design progression. Although it may be expected that the iteration would always be steeper than the first occurrence of design progression (since some learning has taken place), in those design teams observed this was not the case.

When a team has progressed very quickly through a series of activities, any iteration tends to take longer to perform than the first occurrence, i.e. a reduced gradient is apparent (figure 9.14). The first rapid progression appears to be the result of the team rushing ahead in design terms out of either i) naivety, a lack of knowledge of the design process and its constituent elements; or ii) necessity, a project deadline is looming. Either way, this type of progression, be it series or parallel activity focused, can lead to a lack of certainty in proposals and increase the possibility of oversights.

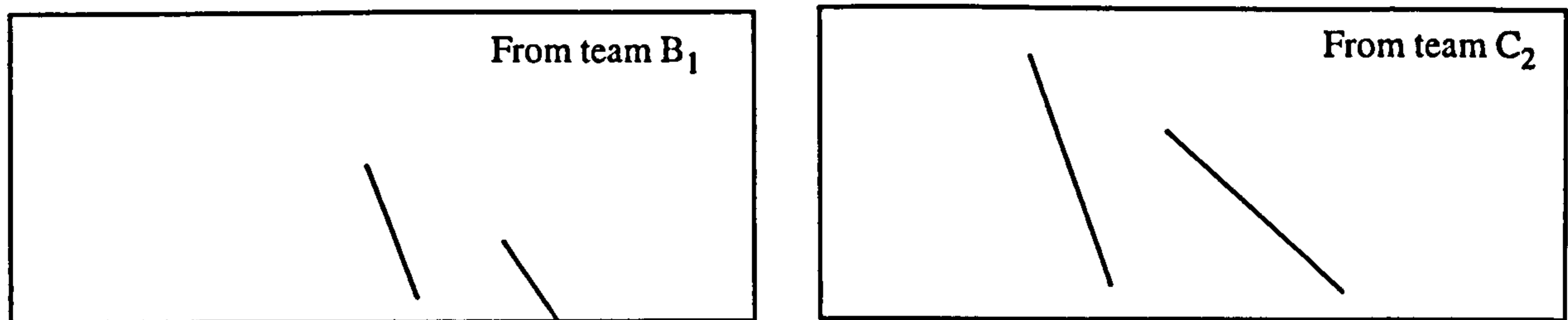


Figure 9.14 Illustration of reduced gradient of iteration

Conversely, when teams progressed slowly through a number of activities, any iteration through those activities was completed more quickly, i.e. an increased gradient is apparent (figure 9.15). When this has occurred the reasons were many, for example – an oversight on the part of a team member, recognition that an early decision was incorrect, or simply the reworking of a solution to improve its definition. The important thing to recognise is that the team members return very quickly to the point they were at in the process irrespective of the cause of the iteration.

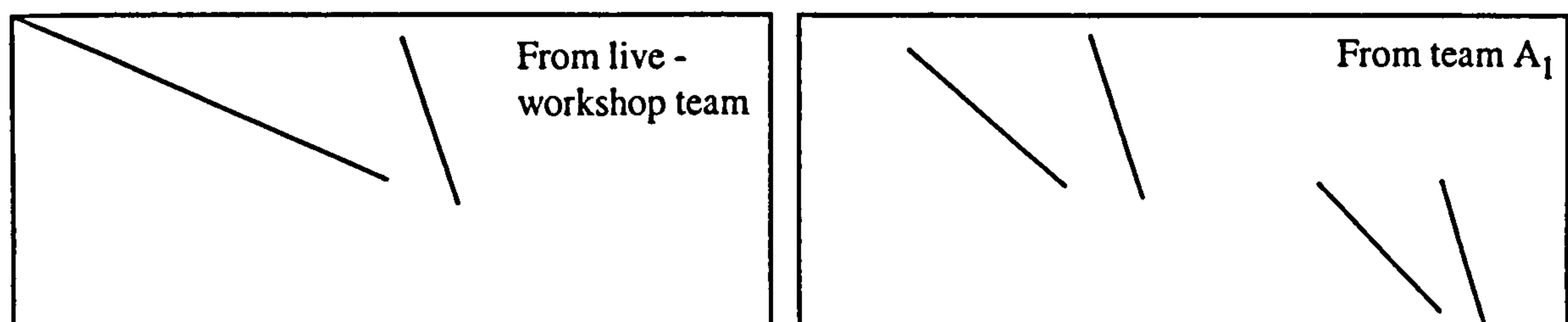


Figure 9.15 Illustration of increased gradient of iteration

In outlining the differences between the types of iteration it must be noted that no data has been gathered to suggest that one is more beneficial than the other. Moreover, excluding the case of parallel lines, it is impossible for the gradient of iteration to be anything but flatter or steeper than the first progression. However, this latter type of iteration could be deemed more beneficial for the team members as it provides short periods of reflection on design activity thus improving their understanding of the problem and solution as they progress (the reader is referred to Schon (1983) for details of this concept of 'reflection-in-action').

It is important to recognise that the nature of the problem or project being addressed will influence greatly the manner in which the team progresses through the design

activity. However, it is questionable (for the reason stated above) whether this observation of iteration gradient is meaningful in improving understanding of conceptual design activity. It would be interesting to investigate this further in future research should the phase and activity framework be applied to monitor and subsequently map more design teams in practice (as will be discussed in chapter 10, section 10.4).

9.6.5 Effects of problem definition on patterns of design progression

Problems can be categorised in terms of their level of definition or degree of complexity. Rittel and Webber (1973) have described this as the wickedness of the problem. Ill-defined, or wicked, problems require, typically, exploratory (speculative) design progression and large amounts of iteration in order to be solved. Conversely, well-defined problems, typically, require far less iteration (although it is still a very necessary component of the design activity) and speculation in order for a suitable proposal to be developed. The difference between the types of iteration that are performed to solve these types of problem rests in the size of the 'leaps' between activities (this is discussed further in section 9.6.6)

Typically, the term wicked is used to describe a highly complex problem in terms of its integration of components and sub-elements. However, the wickedness of a problem is not only a symptom of the technical aspects of the project; as the environment in which the problem is being solved must also contribute to its wickedness (Rittel and Webber 1973). A team designing for a set of stakeholders should, over time, evolve to understand those stakeholders more fully. The team will begin to develop solutions with the idiosyncrasies of that stakeholder group in mind and as a result, the proposals generated should fit their needs more fully. In today's construction environment, where long term partnerships are being forged, it is likely that teams will see design projects reduce in wickedness over time. This is the result of having a continually improving understanding of the stakeholders and their needs, rather than the project itself reducing in complexity.

9.6.6 Iteration bandwidth

The previous sections have identified differing types of design progression that characterise periods of conceptual design activity. It has been suggested that, at times,

step progression from one activity to the next does not necessarily mean that the team will stop performing the latter activity, it may mean the team merely brings another activity into consideration in parallel with any number of the prior activities.

If the activities being performed in parallel over a period of time are recognised as such (figure 9.16) a band can be drawn across the conceptual design phase which describes the activities that are under consideration over any given period of time. This can be termed the iteration bandwidth. Depending on the manner in which a team progresses and, more importantly, iterates the width of this band may not remain constant but instead narrow and widen as the design activity progresses. If the analogy of a concertina is used, expanding and contracting over a period of time, it may be simpler to envisage the evolving band enveloping more or fewer activities as the team progresses.

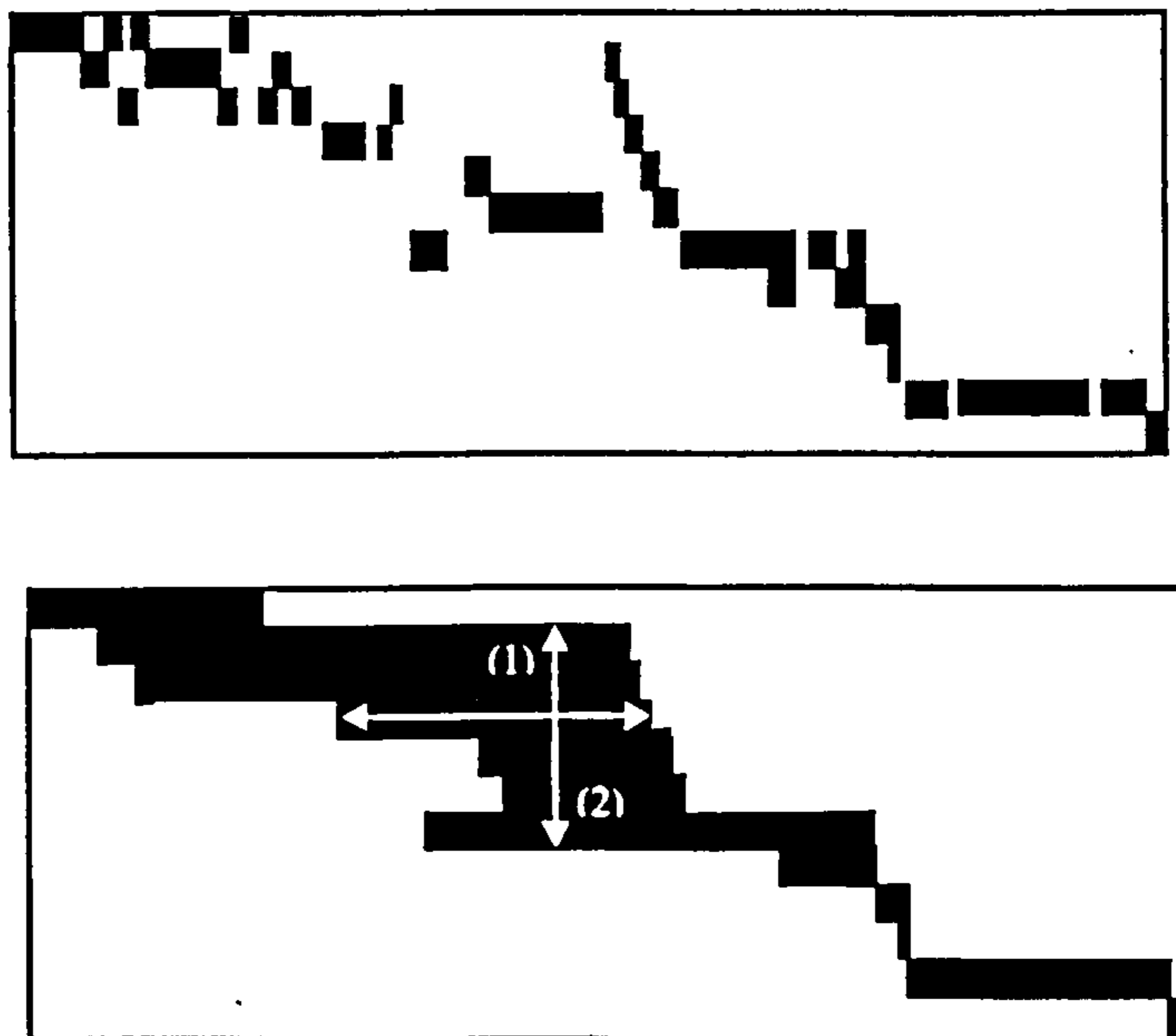


Figure 9.16 The concept of the evolving bandwidth – based on the design activity of the live workshop team

If this is related to the previous discussions on reasons for iteration it is apparent that the narrower the bandwidth becomes the fewer the number of activities that are enveloped, and thus addressed or considered, in parallel (this is shown as the vertical dimension (1) in figure 9.16) over a given period of time. Additionally, the horizontal dimension (dimension (2) in figure 9.16) at any point on the pattern of progression relates to the period of time over which a single activity or phase is considered during

the design period. This can infer either constant focus or sporadic revisiting of the activity or phase over the duration represented by the band. It is important to recognise that both the vertical and horizontal dimensions of the bandwidth are highly relevant as, in practice, the interdependency of activities must be related to the duration of the design period to allow the design activity to be managed and planned.

As has been discussed in the previous section, given a working environment where a team has worked together previously on a similar project, and will do so again, it is fair to assume that knowledge of the problem will evolve; thus reducing its perceived complexity or wickedness. The members of the live project team verified this notion during the post-design discussion when, referring to the ‘smoothness’ of their progression through the process, it was stated that; *“This is an airport and we are all airport people and we kinda know where we are going...this is why the map [pattern of progression] is so smooth”*.

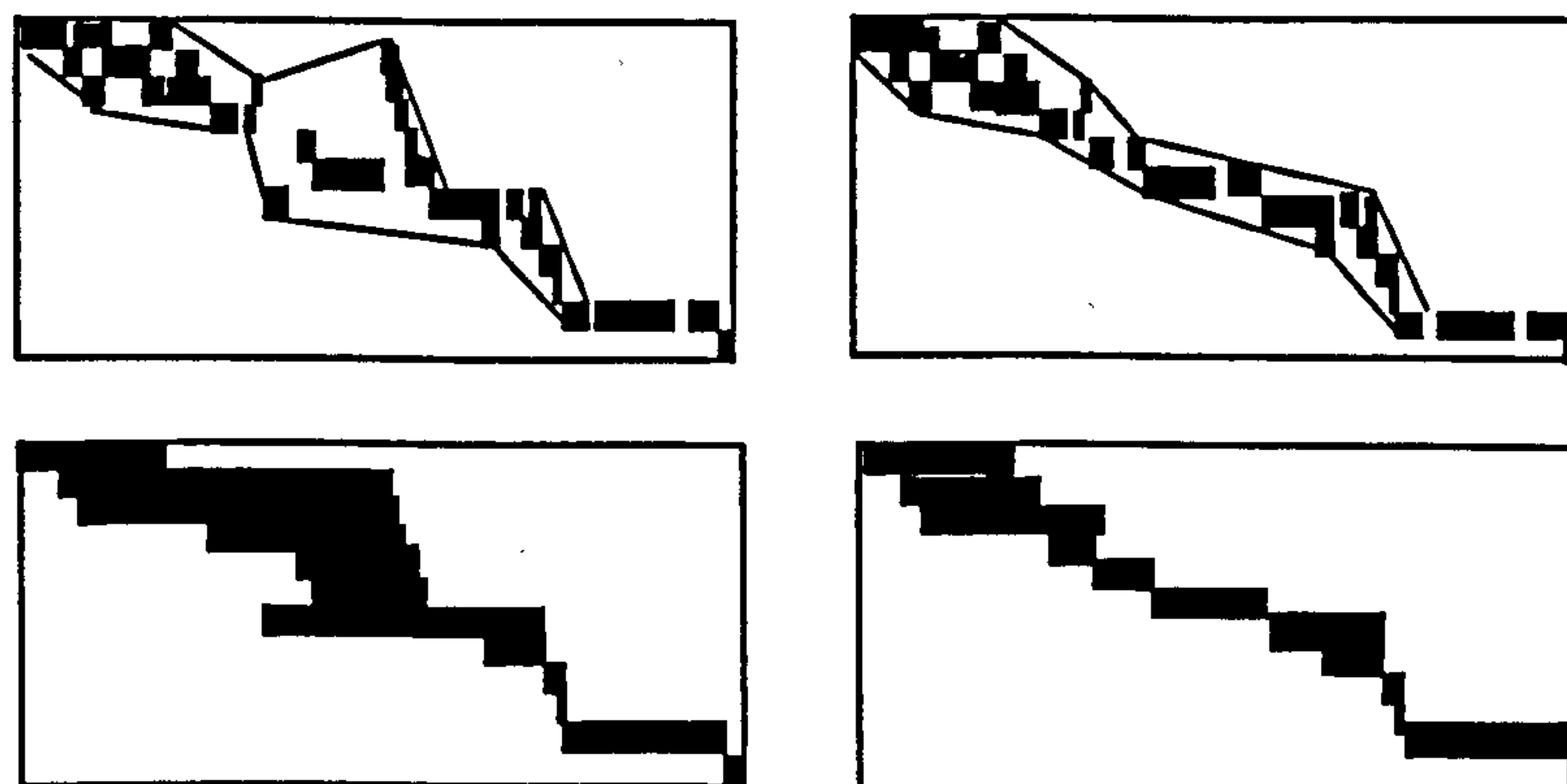


Figure 9.17 A reducing bandwidth (notional) resulting from improving understanding of the problem type – moving towards being well-defined

Thus, it is not unreasonable to suggest that teams that have worked together previously on a certain type of project for a certain stakeholder group could fine-tune their design progression around characteristic iterations. This, in theory, could allow the bandwidth to be reduced over the course of a number of projects (figure 9.17), thus removing any wasteful iteration from future design activity. This concept of bandwidth and its possible implications on both the practice, and management of, design are discussed in the following section.

9.7 Applying the bandwidth concept as a design management tool

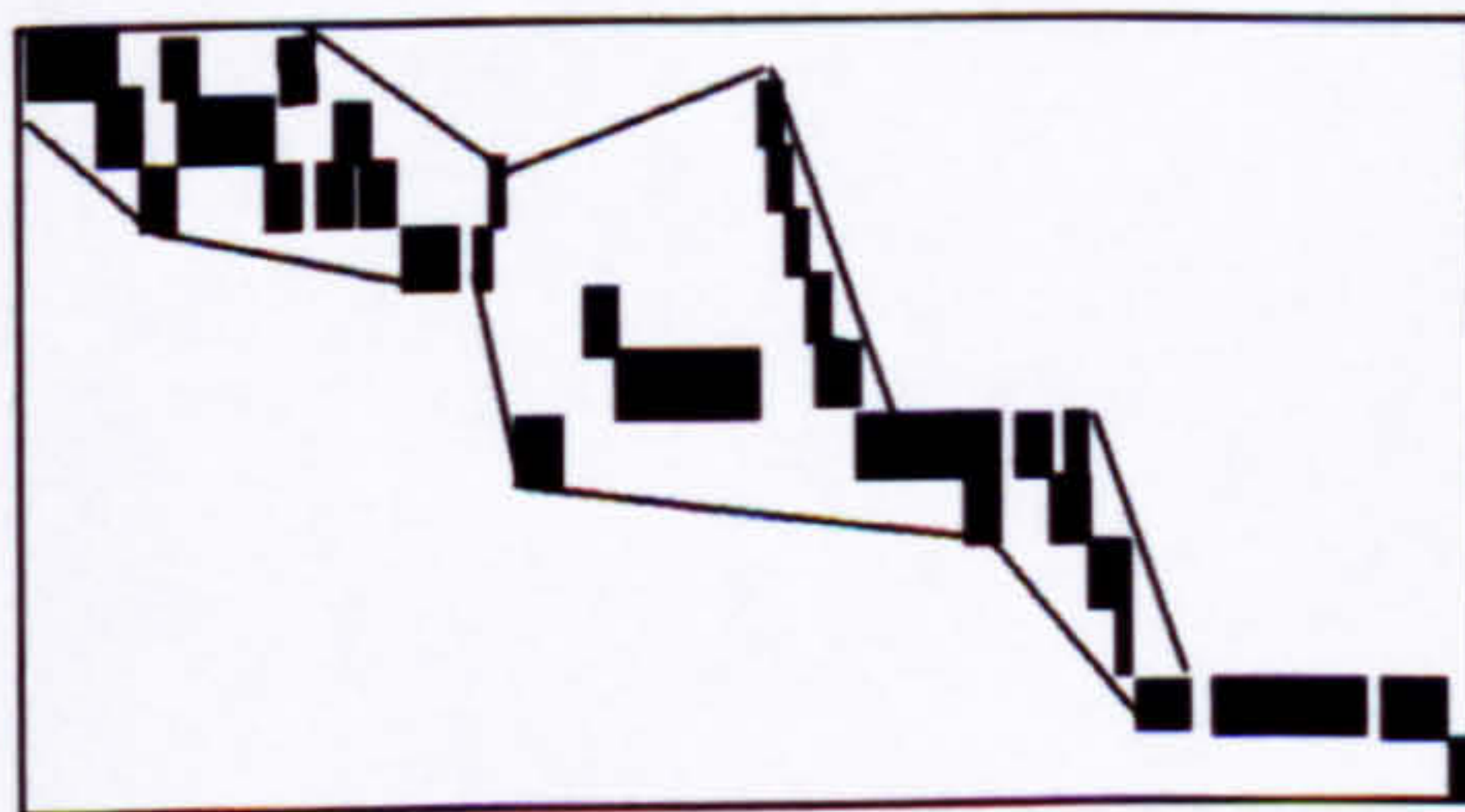
9.7.1 Introduction

This chapter to date has focused on the observations of design teams and the description of their processes. However, it may be possible to apply the findings more prescriptively to help designers become more reflective on their design progression and, potentially, to work more effectively. It is to be expected that teams addressing ill-defined problems would need to progress far more speculatively (section 9.6.3), with large amounts of iteration (wide horizontal bandwidth dimension), addressing larger numbers of activities in parallel (wide vertical bandwidth dimension), while those addressing fairly well-defined problems would expect to exhibit a narrower vertical bandwidth dimension, though not necessarily a narrower horizontal dimension. This concept is discussed and developed in the following sections.

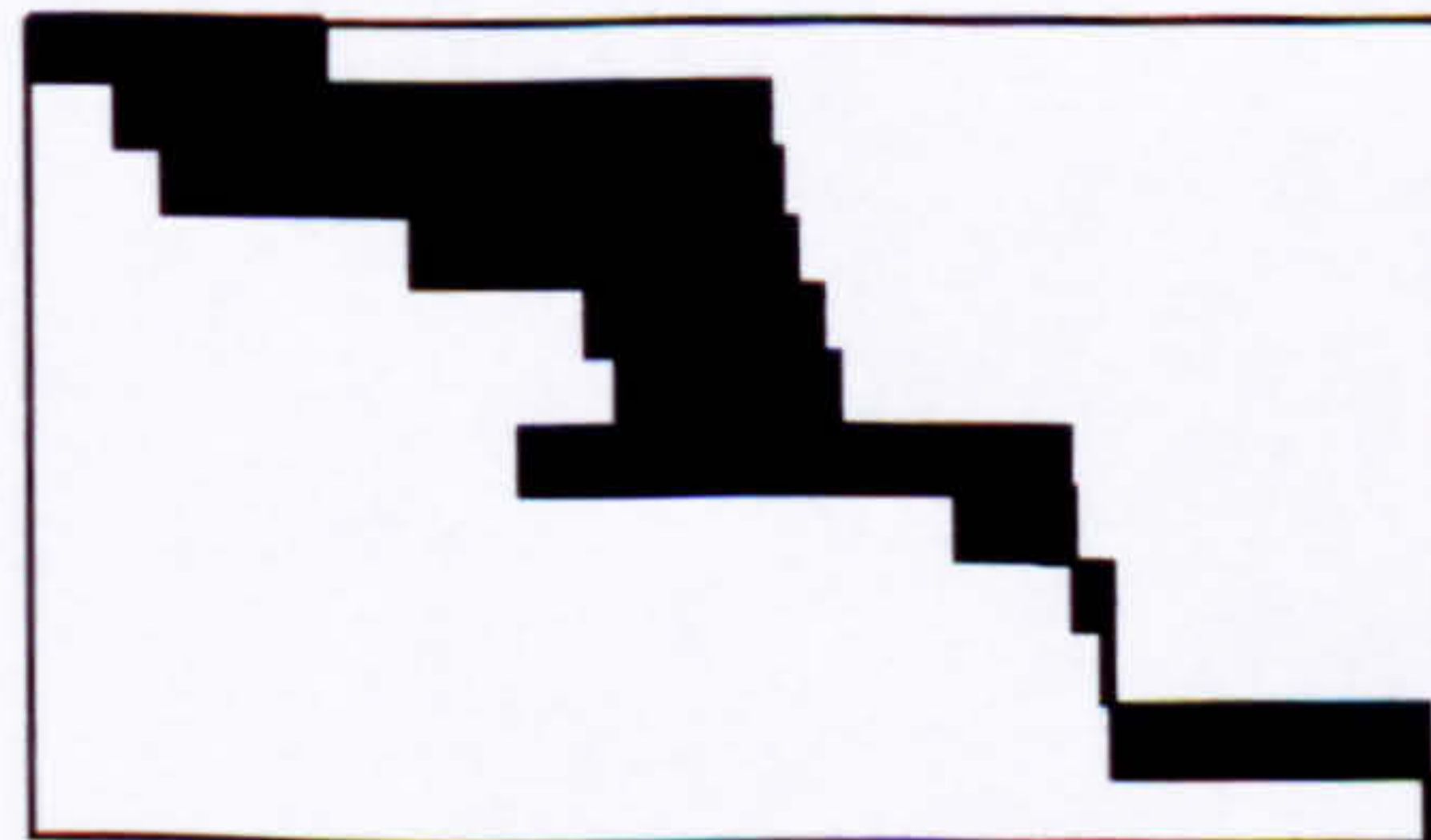
9.7.2 Establishing expected bandwidth

As has been suggested previously, it may be possible to look at a design team, their experience on a particular project type, in a particular working environment and set expected (characteristic) iteration bandwidth dimensions. This could be achieved by applying the Dependency Structure Matrix, the technique used previously to analyse the patterns of design progression, to define the vertical bandwidth dimension based around blocks of characteristically interdependent tasks (figure 9.18).

(a) Pattern of design progression for new team, unfamiliar project, ill-defined problem



(b) Concertina bandwidth in place showing activity interdependencies and duration.



(c) DSM of teams pattern of progression; representing team's activity interdependency - the vertical bandwidth.

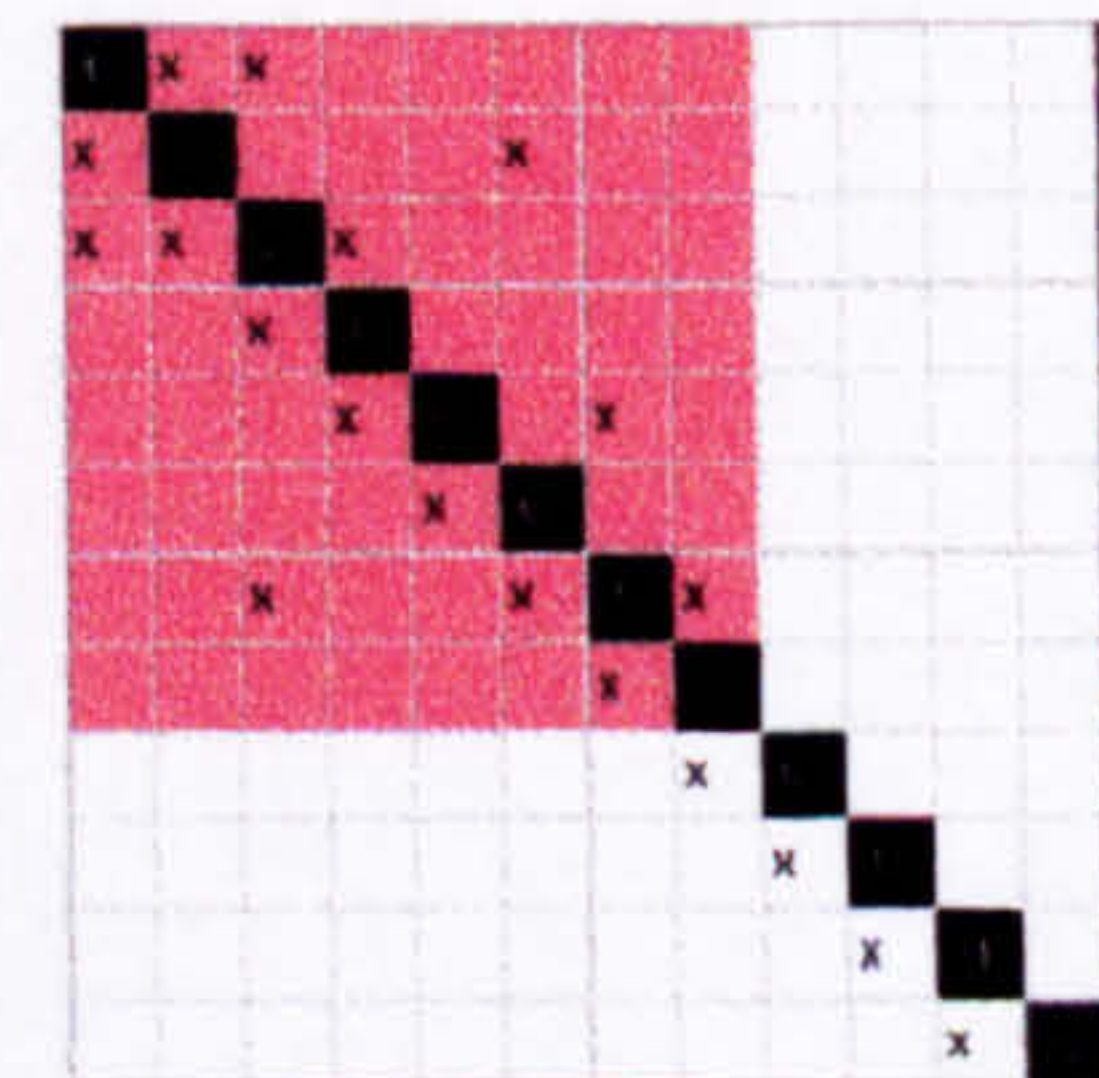


Figure 9.18 Producing DSM based around bandwidth

As has been demonstrated in section 9.5, it is fairly simple to capture the reasoning behind the progression of the team and rationalise the reasons underlying the patterns of design progression based on this data. Thus, once an initial DSM has been

produced it would be possible for a team to reflect upon their pattern of progression and differentiate between differing levels of dependency based on the reasoning behind the pattern, thus allowing the matrix to be partitioned accordingly. This has been illustrated in figure 9.19, based upon the pattern of progression of the live workshop team.

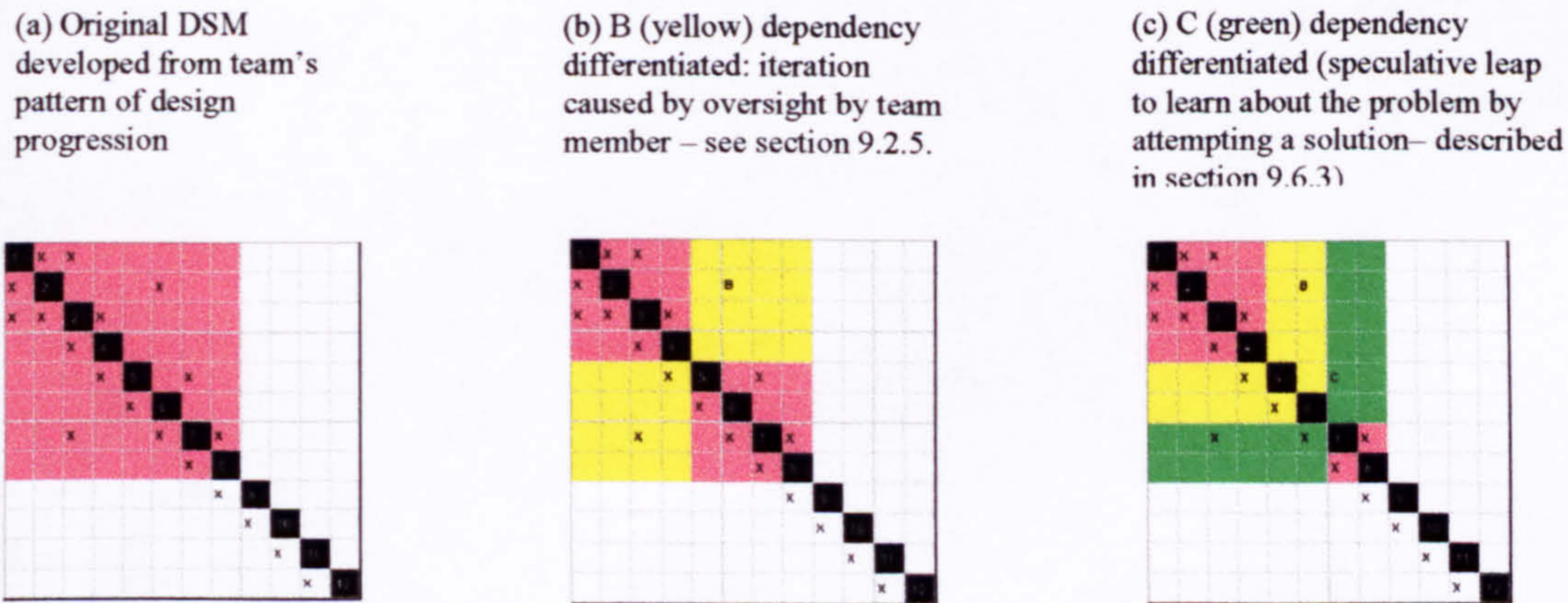


Figure 9.19 Partitioning the DSM based on rationale underlying interdependency

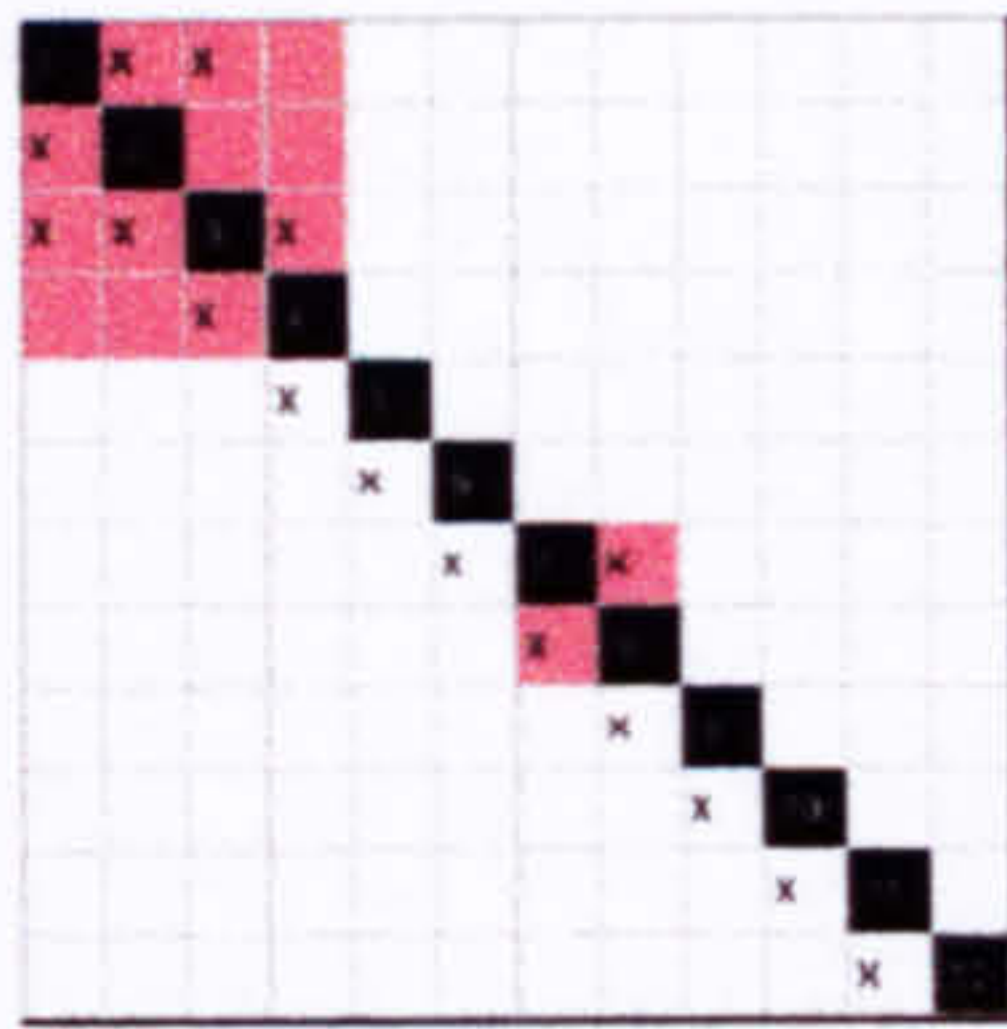
In effect, the team would use post-design reflection as a means of understanding their design activity based on the manner in which they actually progressed. Assuming that the team members have learnt about the problem, the stakeholders and the manner in which the team functions as a result of the design activity, the knowledge could be fed forward into the next project process of that type, thus highlighting necessary interdependency between activities and designating the associated vertical dimension of bandwidth (figure 9.20a).

This same feed-forward approach could be applied to the period of time over which a single activity or phase is conducted during the design period. If, like the analyses performed earlier within this thesis, the activity and phase duration was recorded as a percentage of the total time spent in the conceptual design phase of the project, it would be possible to calculate a datum duration for any phase and activity as a percentage of the pre-set conceptual design phase duration.

Having done this the design team, or project manager, would have enough information to pre-define the vertical and horizontal dimensions of a characteristic

bandwidth, and produce a guidance programme for future use (figure 9.20b) based on previous work of this nature.

(a) DSM representing necessary interdependency based on previous projects of this type



(b) Programme for use as a guidance mechanism based on previous design activity of this type

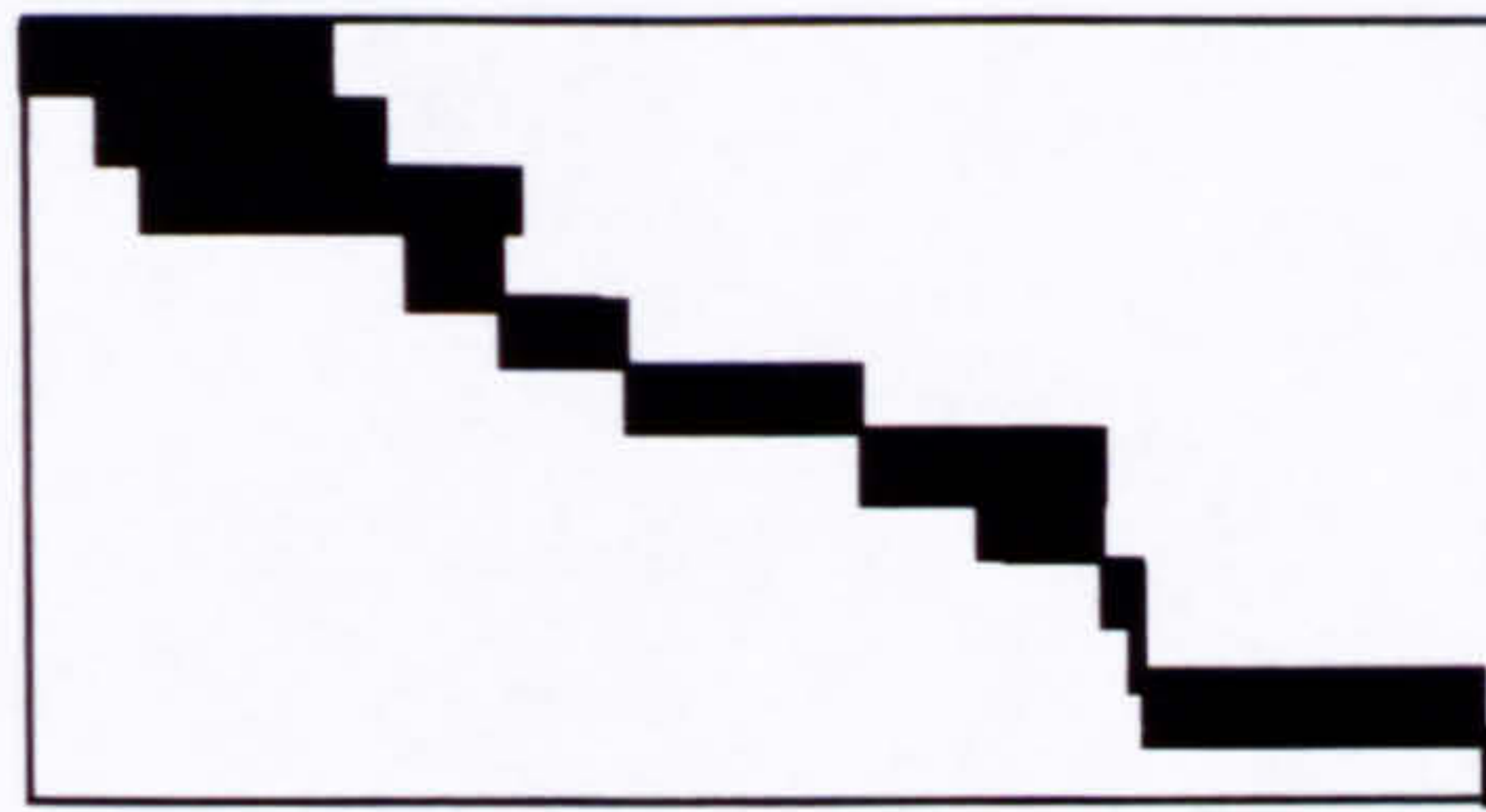
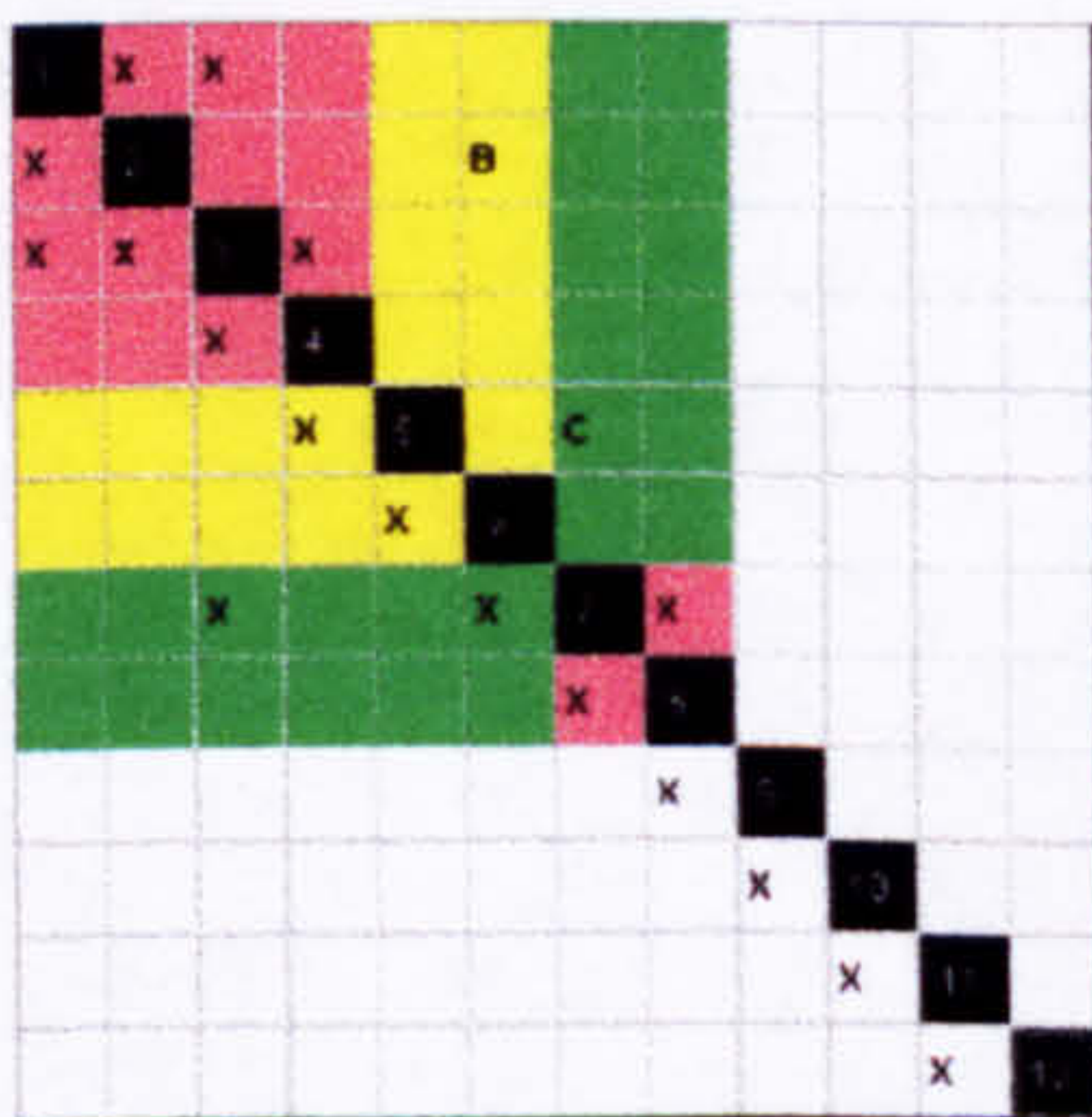


Figure 9.20 Producing a guidance programme

This programming could be developed to give the team further insights into the conceptual design phase by illustrating within the programme the differing levels of interdependency that have been witnessed previously (figure 9.21). This could be useful to the team, as it could allow previous explorations into the solution domain to be made explicit, and the underlying rationale behind them to be elaborated, within the revised guidance programme.

(a) DSM based on differing levels of interdependency between activities



(b) Conceptual design programme illustrating levels of interdependency based on previous activity duration and the differing levels of interdependency witnessed previously

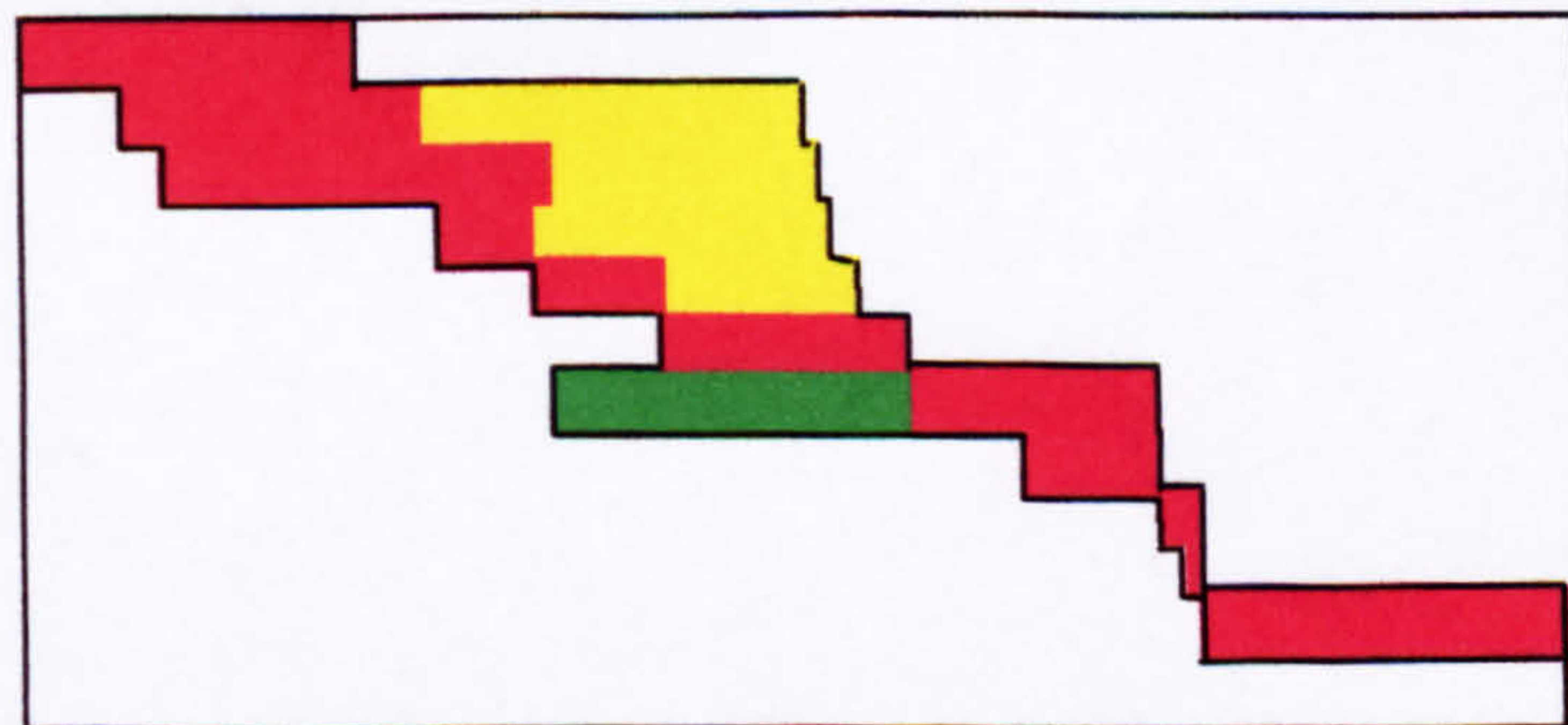


Figure 9.21 Design guidance programme including details and reasoning behind previous activity interdependencies.

If a design manager were to monitor the design team based on this characteristic bandwidth it would be possible to identify when the team step outside of it. Reasoning for the uncharacteristic step could be sought and then fed forward into the next project process of that type.

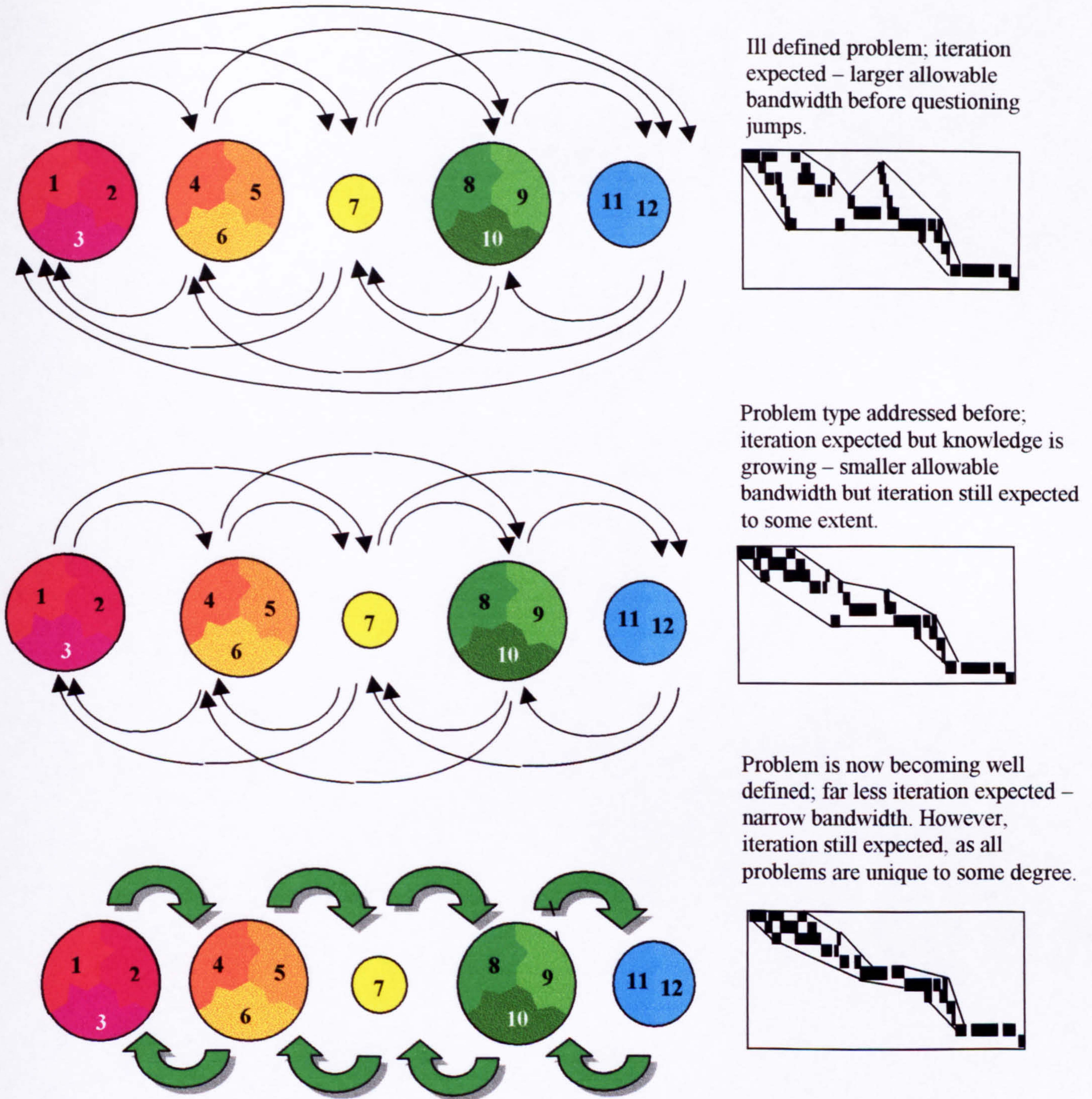


Figure 9.22 Iterative loops as the designator for bandwidth

This concept is based around attempts to manage conceptual design by encouraging iteration within prescribed boundaries based on descriptions of previous design activity.

In effect, bandwidth could be a mechanism that allows the iterative loops to be revised and reviewed over a number of projects. The iterative loops designate the appropriate expected bandwidth (figure 9.22) based around the model of conceptual design (figure 6.18) developed from previous descriptions of design progression.

Of course, the programmes developed using this principle would only represent guidance models based on previous patterns of progression, and would not provide a stringent programme around which to control the team. However, they would allow the team to visualise the progression during previous design activity and, if used in conjunction with the framework model (be it in the form of the paper or web-based version), it would provide a model programme on which to ruminate during design activity.

9.7.3 Application in the Web-based system

To enable the Web-based system to function using the bandwidth concept as a design management mechanism, it needs to maintain the driving (guidance attribute) issues that are already embedded – to drive the team to step forward (these were confirmed as ‘stage gate’ questions within the live-project workshop system trial). However, in stepping forward it appears to be very important to recognise across which activities the vertical dimension of the bandwidth rests, as this describes the number, and therefore nature, of activities that are being contemplated during a period of time. This idea relies on the system/facilitator differentiating between series thinking and parallel thinking; although this is fairly simple to do once a basic understanding is gained of how to analyse patterns as they evolve. It may be that as the users answer ‘YES’ to the issue driving step progression into the next activity, the system highlights the fact that X number of other issues are still being addressed as well. This will make the users aware of the fact that they are about to bring another activity into parallel contemplation and, given the bandwidth, it may be wiser to either i) step out of the earliest activity enveloped by the bandwidth – thus isolating it from this next period of parallel thinking; ii) delay progression at this time and focus on completing the parallel thinking around the several activities already at hand; or iii) decide that increasing the bandwidth is acceptable and revise the bandwidth accordingly for the next project of this type. These alternatives are discussed in further detail below.

Stepping ahead

In taking this position the team is not forcing early closure on addressing the earliest design activity: during this parallel thinking period they are simply moving the focus of their thinking for the next period of design time. This is most likely to occur when

teams are either a) addressing ill-defined problems, as they are more prone to cyclic speculative forward jumps to learn before stepping back; or b) stumbling forward (as discussed in section 9.6.3). In either case, the bandwidth would be set to expect, and allow for, a revisiting of the earlier activity at some point in the future. However, the horizontal bandwidth setting will suggest an acceptable time limit within which this revisit can take place without having to justify the step. There will be no problem if the step is taken later than the bandwidth suggests. However, if this occurs the team will be asked to explain why. This information can then be analysed and, depending on the reason provided, action can be taken to either include, or avoid, it in a future project of this type (i.e. Reason: Forgotten to address an issue – Action: Raise awareness that this issue needs to be addressed in an earlier activity within the Web-based system (on the next project of this type)).

Delaying progression

In taking this position, which would generally be the case when the problem is well-defined, the team would be encouraged to spend more time contemplating the activities at hand rather than bringing another into consideration in parallel. In doing this the team would be avoiding the problems associated with considering large numbers of activities in parallel. However, the associated difficulty is that the team may feel that there is no more to be gained from prolonging the focus of their present thinking, as the problem needs further exploration.

Within the Web-based system this would be the ideal point at which to promote the use of a design technique (Team Thinking Tool) to help the team change the focus of their thinking. The project manager could highlight this need based on the pattern of design progression and the period over which the team have considered activities concurrently. Alternatively, the Web-based system could offer a link to a number of Team Thinking Tools when a pre-set time period has elapsed (again based on the characteristic bandwidth for the project type and team).

Accepting an increase in bandwidth

In taking this position the key would be for the system to ensure that the team members realise that this step will take them outside of the designated characteristic bandwidth. Again, this is not a problem as long as it can be justified with reasoning. It

may well be the case that a particular component of a project is substantially different from anything that has been developed previously and as a result, this requires some further insight to be gained. In this case, it may be more appropriate to isolate this component of the building from the present design discussion and contemplate it in isolation for a period. This would not be a problem as long as it was reasoned and registered on the map of design progression. Thus, out of the well-defined problem, an ill-defined component would have to be developed. As such the bandwidth for the external investigation would be expected to be much wider. However, this would not affect the bandwidth of the existing design, as the issue has been raised and the team is aware of it.

Given the above discussions the Web-based system would have to be adaptable to allow for a variety of problem types, teams, experience, and so on. However, given the idea of that a problem can evolve from being ill-defined to well-defined over a number of projects in a steady environment this should be possible by looking at the various team members and their experience of a particular type of problem. Of course, an additional factor that must be taken into account is whether the team members have worked together before, and if so, whether there is an existing team dynamic. This is supported in the Web-based system by the team maintenance facility.

9.7.4 Issues within activities

During the course of the system trial it was apparent that, as has been discussed in section 9.4.6, the existing internal system issues were only appropriate as a means of driving progression out of one activity and into another. This is not the way things work in reality, as a significant amount of design time is spent in 'parallel thinking' mode - considering a number of activities simultaneously (see chapter 6, tables 6.9 and 6.10). During these periods the design teams hop from one activity to another, with their objective not being to complete one activity completely, but rather to address the problem at a higher (phase as opposed to activity) level of thinking. This rapid interchange can be disaggregated into individual activities, however while addressing each activity each team member may be performing very different tasks at a cognitive level (the simplest difference to envisage would be the different disciplinary foci). It is commonly recognised that some design tasks can be performed independently of one another (by a single individual or discipline), while others need

to be addressed simultaneously (the tasks are interdependent), with several tasks being wholly dependent on one another. The observations of conceptual design practice that have been described previously in both chapter 6 and this chapter (section 9.5) would suggest that within the conceptual design phase the high level issues that need to be addressed are, typically, interdependent; with the majority of issues relating to the holistic entity being designed. However, previous researchers (Kunz and Rittel 1970, McCall 1989, 1991) have suggested that these high-level issues for deliberation typically comprise hierarchies of sub-issues – possibly, for example, in the form of, or in relation to, a designated task (this is illustrated in figure 9.23). It is, of course, the prerogative of the designer to identify that task owing to the fact that the same task may be undertaken during several activities, however, the objective of performing the task would be very different.

Issue:

- *What should be the design for vehicular and pedestrian transportation from the town centre to the proposed supermarket?*

Subissues:

- *What are the problems with the current transportation from the town centre to the proposed supermarket?*
- *What are the desirable characteristics of the current transportation from the town centre to the proposed supermarket?*
- *How could the current transportation from the town centre to the proposed supermarket be improved?*

Subissues:

- *What could be done to improve parking?*
- *What could be done to improve automobile traffic*
- *What could be done to improve bicycle transportation?*
- *What could be done to improve pedestrian traffic?*

Figure 9.23 Example of issue, sub-issue hierarchies (adapted from McCall 1991)

In this way it would seem more appropriate to populate the activities within the Web-based with the interdependent issues for group consideration/deliberation. These would have to be developed around particular project types, e.g. Airport pier, pharmaceutical laboratory (or modular bay), process plant. It may then be possible to introduce sub-issues for consideration from a particular disciplinary perspective, thus

providing prompts for the designers within the team. These sub-issues could be either independent or interdependent depending on the project. The important thing would be to notify the design team of the various connections between issues. In effect, this would provide a checklist of issues for consideration, and would raise awareness of the issues at an early enough stage in the process to ensure that their consideration is not neglected during the downstream development of the design.

Within the Web-based system this would not have to be systematic as this would be inflexible, i.e. the system must not promote the idea that issues should be addressed sequentially as this would, indirectly, suggest that activities should be addressed in sequence. The system must simply highlight that in addressing certain issues, a number of interdependent issues must be considered in parallel. Given that the system is based around hypermedia, and thus supports the creation and exploration of complex non-linear information bases (Conklin 1987), this type of approach would be fairly simple to introduce.

9.8 Proposals for an improved design support system

9.8.1 Introduction

The previous discussions have introduced a number of concepts relating to the patterns of design progression and the manner in which they are manifested within the existing Web-based system. It has been made apparent that some of the mechanisms within the existing system could be modified to enable the design team to be supported more effectively. This section proposes some changes to the system, based on the previous discussions within this chapter, that are intended to improve its effectiveness as both a design management system and a design support tool.

9.8.2 Change of system focus

The focus of the system could change away from the phases and activities being the driver, toward the evolving pattern of design progression, which is generated by an individual (a team member, the design manager, the project manager) as the team progress, being the mechanism which raises the teams awareness of issues to be addressed.

Designers could be trained to design and think around the phase and activity framework structure. The system allows the project manager to generate a pattern of design progression (for example: by positioning the cursor on the activity being addressed at any time). In this way an evolving pattern of design progression could be generated as the team proceeds. When a new activity is being brought into consideration the team would be informed of the issues which need to be addressed. If parallel thinking were taking place the team would be informed of the combination of issues requiring consideration. If the team were addressing more activities than the bandwidth designated, which is dependent on the nature of the problem (discussed in section 9.6.6), for a given period of time they could be warned (made aware) of this (as discussed in section 9.7.3).

The next step in developing the type of system outlined above is to understand the manner in which interdisciplinary conceptual design is undertaken in the 'real world', i.e. outside of the workshop environment, possibly with team members working in geographically dispersed locations, over a period of several weeks. In this scenario the project management (facilitation) role will be of critical importance as that individual will be responsible for driving the pattern of progression based on updates of the design process from the various members of the design team.

In this scenario it may be possible for the entire team to work from a standard database based around an extranet (for research purposes this could be an in-house team working on an intranet). Thus, as the project manager updates the main file at the end of each day, for example, the issues addressed by each individual designer/discipline can be logged. When interdependent issues have been addressed, the other design disciplines are informed of the interconnectedness of the issue, and the people involved are asked to discuss the matter and negotiate a common understanding. If the conceptual design period involves a number of review workshops at agreed intervals the design team can be aligned and updated as they progress. Should an interdependent issue be addressed by one discipline before another is ready to address it, then the second discipline should be informed that the issue has been addressed and be asked to assist in making the assumption on which it will be based (if no firm data is available). Once the second discipline has addressed the issue, based on the first disciplines work, he can update the assumption

accordingly by either confirming it or offering improved advice in light of his own work.

9.8.3 Design rationale as the basis of design guidance

Within the exploratory design process forced by wicked problems, where any set of decisions is inherently unstable, designers may be reluctant to record decisions formally because, after subsequent investigation, the source of inaccurate or incorrect decisions would be chronicled (Conklin and Yakemovic 1996). However, the designer must become accustomed to the fact that only by making considered decisions could the exploration have progressed, hence enabling the decision to be recognised as being in need of review. Thus, in effect, this was a critical part of the design process.

This concept highlights the benefit of capturing design rationale as an evolving design history, rather than as simply a reviewing mechanism with which to amend earlier decisions. In reflecting upon the proposed means of establishing bandwidth (section 9.7.2), it is apparent that this design rationale could be used to reduce an inherently ill-defined problem to one that is reasonably well-defined over the course of a number of similar projects. The design rationale would allow the designers to learn from the previous projects and pre-empt similar problems while designing similar projects in the future (it is this which represents the underlying concept of the Analytical Design Planning tool (ADePT) (Austin *et al.* 1999) that has been received with much interest and enthusiasm within the design management field). Understanding the rationale behind the design process is the only means of narrowing the bandwidth and for that matter, understanding needless iteration (if, in fact, any of the iteration was needless!).

A team being introduced to a complex project for the first time may perceive it as being ill-defined. In this case they would expect to approach the design in an exploratory fashion, with lots of iteration. Decisions will be made that are constantly being updated in light of the direction they drive the design. Only when a problem with the design resulting from that decision becomes apparent, can the designers recognise that the decision was either wrong or in need of refinement, and take a step back. Thus, in this type of ill-defined design problem, it is the author's suggestion that all iteration is necessary as it leads either directly or indirectly, through a process of conjecture and refutation (Popper 1970), to the final design proposal. Thus, all that

can be stated with absolute certainty is that the iterations which took place influenced the final design proposal in some way.

However, a team involved with a particular client type over a number of projects will start to see the problem in a different light as they begin to better understand the variables. Thus, over a number of projects the problem may become clearer and more defined, i.e. it will evolve, for that team, into a well defined (better defined at least) problem. In this scenario it would be possible, by capturing the reasoning (rationale) behind why the iterations occurred in the earlier processes, to identify which iterations were necessary and which were needless (having being investigated previously). Moreover, it would be possible to identify the root-cause of each iteration - the sub-issue that was not considered during deliberation of the key issue; the outcome of which was the decision on which the design was progressed until it was refuted - and smooth out the design process over a number of projects.

Of course, this assumes that the reason for the iteration was that a sub-issue was not considered. It could equally be that the issue was raised but the option that resulted from it was not applicable or, simply, not very good. However, this introduces another possible reason for the iteration: the fact that a forceful member of the design team argued the case for an inferior option more convincingly than another member who had suggested a better option. Additionally, it could be simply that the options introduced to address the issue were not particularly good. However, if the design rationale were recorded in great enough detail (how acute a level of detail, and whether it could be captured cost effectively without invading design time needs much consideration) it would be possible to reason iterative behaviour.

Only when a store of reasoning behind iterations is available for review would it be possible to classify an iteration as needless, and this would only be possible on a particular project type, with a particular set of people, in a particular environment.

9.9 Concluding remarks

This chapter has discussed the application of the Web-based design support system in a live, design project. Although the system was not fully functional, the incomplete mechanisms were simulated to ensure that a methodologically sound evaluation could

be achieved. The feedback from this practical application was, on the whole, positive. Additionally, it raised several issues regarding both the suitability of the internet as a medium for delivery of the framework and the possibility of using the patterns of design progression as a means of gaining insights into, and, potentially, improving the practice and management of, interdisciplinary conceptual design activity.

The seven patterns of design progression that have been produced during the research have been analysed and compared. This comparison has highlighted a number of generic sub-patterns of progression which are apparent across each of the unique full phase patterns. Additionally, a new means of defining iteration within these patterns, the iteration bandwidth, has been developed and discussed. A potential mechanism for applying this to the management of conceptual design in practice has also been proposed.

Finally, these ideas have been discussed in relation to the Web-based system and the basis of an improved support system has been suggested. These assertions have not been embodied within the existing system but offer the potential for integration in a future version. If the system is to be accepted as a practical guidance and management system it is important that these suggestions are incorporated.

The following chapter reflects on the above findings and the research project in its entirety. Additionally, recommendations are made for potential future research in relation to the application of the ideas outlined within this research. These fall into three complementary categories: practice, research and education.

Chapter Ten

Conclusions and recommendations for future work

10 Conclusions and recommendations for future work

10.1 Introduction

This last chapter reviews the research investigation by: i) providing a synopsis of the investigation; ii) drawing together conclusions from each of the previous chapters; and iii) comparing the outcome of the investigation with respect to the aim of the project:

To generate, and assess the viability of, a flexible and adaptable design model aimed at improving the effectiveness of interdisciplinary interaction and collaborative design activity during the conceptual phase of building projects and apply the model in practice as a means of developing a further understanding of the design activity of interdisciplinary teams.

The 26 conclusions drawn in the following sections (and numbered sequentially) indicate that the aim and associated objectives, which were stated at the outset of this thesis (chapter 1), have been accomplished.

These conclusions act as a precursor to the author's reflections on elements of the research investigation and recommendations for further work. The latter concerns both the refinement and further validation of the computer-based process-oriented conceptual design support tool, and the identification of areas of inquiry which may lead to an improved understanding of the conceptual design of buildings in general.

10.2 Summary of thesis and conclusions

10.2.1 Introduction

During the period of this research investigation, in addition to the development of the conceptual design framework and its subsequent transformation into the Web-based system, a number of germane conclusions were reached regarding the conceptual phase of the building design process. These conclusions are described below within a brief summary of the research investigation.

10.2.2 Literature review

Initially a comprehensive literature search, encompassing upward of 200 texts, was carried out. This data gathering exercise did not aim to concentrate solely on design within the building and construction industry or for that matter on the particular phase of conceptual design. Its aim was to inform the research of the ways in which the field of design had been explored previously. The findings of the literature search stressed the existing gaps in knowledge that the research project aimed to address. These findings enabled a detailed insight into the existing design knowledge to be gained and reinforced the direction of the research. It was concluded that the existing models of the full design process from the building design domain tended to:

1. Describe a sequence of phases showing progression from broad outline to elaboration of detail which, typically, imply starting with an analysis of requirements before the generation of possible solutions (even though much design work involves the modification of existing solutions, not the invention of new ones) and iteration within phases but not between one phase and another.

Typically, although there were exceptions, the models:

2. Set out only what should be undertaken, not why, how or by whom it should be done.
3. Limit their concerns to the problem requirements and their solution. They do not address the social aspects surrounding team-working, such as the selection and involvement of team members at various stages, the exchange of information, or the promotion of effective collaboration.

Within the existing models of the conceptual design process, although there was some consistency in terminology, there was a lack of synchronisation across the various sub-phases identified. Additionally:

4. Engineering models subdivide the concept phase into a number of sub-phases to be undertaken sequentially; in contrast, building design models do not have the sub-phases mapped.

5. Few of the models explicitly encourage the generation of alternative concepts for evaluation and not one describes how to generate concepts - none of the models makes explicit reference to techniques for stimulating a wider solution space, or to formal measurement, evaluation or assessment methods - nor succeeds in capturing ways to help a new design team deal with the potentially confrontational environment that can result from teamworking.
6. The literature review concluded that for any model of the conceptual design process to be realistic and acceptable in practice it had to be a flexible and adaptable framework for the content of the work that generally expands the accepted notions of what is being worked on in a group design practice and includes a collection of practices, and techniques, that designers can use in getting the social and technical work of design accomplished.

10.2.3 Primary data gathering

Several meetings of a design project were monitored by the author to gather data to develop models of the conceptual design process using a number of structured analysis and design techniques. Structured note taking was utilised to record the team design activity. This was supported by audio-taping. The direct observations were complimented by data gathered during post-meeting interviews with the design team members.

Additionally, an historic case study approach was utilised, in conjunction with some archival analysis where appropriate, as a means of developing a generic model of the conceptual design phase.

Several designers and design team leaders from a number of design and construction organisations were interviewed about the processes that were followed during the conceptual phase of previous projects in which they had been involved. Again, these interviews were audio-taped to ensure that as many details were gathered as possible.

The historic case study phase of the research served two main purposes: First, to reinforce the findings of the literature search by gathering the views of a number of practising design professionals on various aspects of design practice; and second, to gather further information on how conceptual design activity was actually undertaken

by interdisciplinary design teams on live projects, in order to allow a preliminary phase model to be generated for testing in laboratory experiments. The following characteristics were found to be representative of the conceptual design phase of building projects:

7. The generation of design solutions, the starting points for which appear to be experiences and pre-conceptions, by the individual disciplines tend to be compromises rather than designs to ensure optimisation of the overall design strategy. These are then challenged and transformed to suit the problem at hand. In general, the architects appear to drive the initial designs.
8. Designers appear to neither follow any rigid sequence of design decision-making procedure at the conceptual design phase nor to record formally the progression of their design decisions in detail, preferring instead to trust memory to stop them taking the same decision-loops time and time again. This can lead to frustration within a team.
9. The flow of information between designers appears to be unstructured, if not chaotic during conceptual design. Ideas, thoughts and assumptions are externalised rapidly, resulting in mass information flow, and doubtless loss of important concepts. In this respect it is impossible to track the flow of verbal and informal information transfer at the conceptual design stage.

10.2.4 Modelling techniques

A number of existing modelling techniques were investigated to assess their suitability for generating descriptions of design processes. The decision regarding which of the modelling techniques was most applicable to the conceptual design phase involved several inquiries. These investigations involved: evaluating existing modelling techniques; then taking the most promising of these and applying them, to construct models of design activity; and finally, making a decision regarding the optimum means of delivery of the design model. This part of the research concluded that:

10. Modelling the information flows within a process can improve the understanding of that process. However, none of the existing structured analysis and design

techniques are suitable as a means of developing realistic and flexible generic models of the conceptual design phase.

11. The optimum means of delivering the preliminary conceptual design process framework was found to be the categorical (or toolkit) model. Models of this nature allow teams to define their own pattern of progression; thus making them adaptable and flexible, allowing sub-models developed using the structured modelling techniques to be integrated into the framework structure and their interfaces to be aligned. Additionally, they can describe the elements of design activity that will be undertaken by the design team without constraining the manner in which they are undertaken or over systematising the details of the actual design activity involved.

10.2.5 Experimental workshops

Two experimental workshops, each involving 15 design professionals, were held to investigate the manner in which design teams work in practice. The first of these involved designers from a single construction industry organisation. The data gathered assisted in the development of the preliminary conceptual design framework.

The second workshop, which involved designers from six construction industry organisations, allowed this model to be tested. This second workshop saw two teams applying the framework and a number of team thinking tools that had been gathered during the literature study. A third group worked without being given the preliminary model – they were designated as a control group. The teams were monitored by detailed note-taking, self-monitoring, and completion of questionnaires.

The details gathered during this period of the investigation allowed patterns of design progression – graphical representations of the manner in which the teams progressed through the phases and activities of the model – to be mapped. In statistical terms the number of participants in the workshops was very few. However, within these limitations, the following conclusions were drawn:

The design framework model

12. Each of the teams undertook the same design activities and phases over the course of the exercise. However, the sequence and duration of these varied greatly between teams.
13. The majority of design activity undertaken by the teams (between 79 and 90%) could be classified within the activities of the conceptual design framework, the remaining period (between 10 and 21%) of design time was spent on social interaction and team maintenance - neither of which was accounted for by the conceptual design framework.
14. The two teams that were provided with the design framework progressed fairly linearly without obvious iteration. This is apparent despite of the fact that one team followed it stringently while the other used it purely as a guiding principle. Conversely, those teams that were not provided with the design framework tended to progress in a number of iterative bursts. These iterations occurred irrespective of whether the teams had pre-defined a design process for themselves or not. However...
15. When teams agreed a process in advance it appeared to help the members to adhere to a programme and work in accordance with it. If the team does not agree on a design process to follow, individual team members tend to make opportunistic forays into particular areas of the problem in an ad hoc manner. If other team members do not agree on the direction of that foray then this can lead to a lack of synchronisation in the team effort and a lack of input from one or a number of its members.
16. Although the teams were constrained in terms of time and the differences were not great, those teams that utilised the framework in this workshop did take less time to complete the project. However, there was no substantial evidence to suggest that following a design process, be it in an iterative or systematic manner, helped the teams to generate better design concepts or reduce the time period spent reaching those concept.
17. The teams of individuals from the single organisation began the exercise less formally and were more relaxed with one another on a social level, whereas the multi-organisational teams commenced formally and attempted to decrease formality with initial introductions. These differences did not stop confrontation in either workshop.

The Team Thinking Tools

18. When teams were working well together there was no need to introduce the tools. Design tools should only be introduced to assist the team in getting over a sticking point. When designers do use design techniques, they may do so in a manner that works for them, even if this is not exactly how the creators of the techniques originally envisaged them being used.
19. The use of a facilitator skilled in the application of a team thinking tool can increase the willingness of the team to try it out. The facilitator can be either a team member with a working knowledge of the tool or another individual who is conversant with its application. The teams considered tools to be more helpful and relevant when their application was facilitated.
20. Design tools must be simple to learn and quick to use if they are to appeal to practising designers; overly complex tools will be dismissed before attempts are made to apply them. Simple tools, such as brainstorming, are remembered easily by designers and then used intuitively owing to their simplicity and ease of application.
21. All team members need to 'buy into' the use of tools if their application is to assist the design activity. If some members are reluctant to use a particular tool then their input will be lost. However, it can be concluded from the evidence that design tools prove helpful for some individuals and not for others: it is a matter of personal preference on the part of the individual designer. There is no evidence to suggest that any one of the tools tested assisted all of the designers or all of the design teams to produce a solution.

10.2.6 The Web-based system

In order for the conceptual design model to be accepted and, ultimately, utilised in practice it had to be developed into a more suitable format. The optimum means of delivering the model was found to be in the form of an interactive computer-based system. The reason for this was that:

21. Presently, although low cost computing is readily available and the majority of the construction industry are now reliant on the use of IT, no commercial computer-based design tool exists for, or has been developed with the sole intention of, supporting the interdisciplinary design team during the conceptual phase of the design process.

It was concluded that Web-based HTML, being the dominant internet language, had several attributes that made it ideal as a mechanism for developing a computer-based version of the conceptual design model:

22. It allows individual components of a structure to be held in an isolated environment. Thus, details can be stored regarding discrete components of the framework without being sensitive to the process involved in reaching that point and the elements of a model can be related to one another in a number of ways. As such, both prescribed and team designated progression can be facilitated within the single system as the fragments are related using the appropriate types of connection. However, the users (viewers) are able to view specific elements of the model in isolation. Thus, information specific to a particular phase or activity can be made available when, and only when, it is required.
23. Endless supplies of information can be accessed via the WWW. As such, connection to the appropriate information can be facilitated via specific HTML pages. Additionally, a Web-based system could facilitate a collaborative design process over the internet, and provide opportunity for immediate access to geographically distributed resources.

10.2.7 System trial

The preliminary framework model was converted into web-based format and a half-day workshop was held to develop a number of key issues aimed at driving the users through the framework activities. Once the Web-based structure was developed, the system was populated with prompts, key information, and a number of the Team Thinking Tools that had been trialled in the experimental workshops. This preliminary system was then demonstrated at the offices of six construction industry organisations, the feedback from which enabled the system to be refined in line with the wishes of the intended end users. At the end of this process a prototype system was available for trialling in a live-design project. This system was made active on the internet and members of the live-project team were given access to it on-line. To gather further information an on-line questionnaire was made available for completion after the system had been visited.

The trialling of the system on a live-design project enabled a number of conclusions to be drawn with regard to the applicability of the Web-based version of the model. It was suggested that:

24. Conceptual design activity would be enhanced and could be undertaken more efficiently if this type of guidance-system, incorporating appropriate links to Web-based design information, were used in practice. However, the system would have to be facilitated during use in practice to allow designers to focus on designing. It was suggested that, in practice, the design manager could facilitate the use of the system.
25. The decision recording attribute of the system would be highly beneficial in practice. However, if the decisions and rationale could not be captured more quickly and simply (without expending design time and effort) in a less invasive manner designers would not utilise that attribute of the system.
26. Additionally, all team members agreed that Web-based design was going to be a major component of design collaboration in the very near future. As such, they felt that, with further development, a Web-based version of the framework would offer the optimum means of applying it in practice.

The trialling also allowed a further validation of the underlying phase and activity structure of the framework to be achieved and a further insight into the interdisciplinary conceptual design process to be gained. These insights lead to a number of proposals being made for the potential application of the research findings in practice.

10.3 Reflections

This research has provided an opportunity to monitor the design activities followed by interdisciplinary teams during the conceptual phase of building projects. A simple graphical means of recording and displaying the pattern of progression through the team's design activity has been devised. This has been used to study and analyse these patterns in terms of the gradients and bandwidths of iterative working, the output of which has enabled a clarification of conceptual design practice to be achieved.

It seems highly appropriate that graphical methods have been used to study design, since design is often a graphically-based process. And indeed, the designers who have participated in the project do seem interested in these patterns, which they can readily assimilate. These ideas about iteration, bandwidth and gradient may encourage designers to reflect on their own processes, and help design teams manage their own teamwork processes more effectively.

The notions of phases and activities of conceptual design have been embodied in a prototype web-based interactive system that can be run over the internet. This was tested in a live-project environment. This support tool for conceptual design focuses on the gates between the various activities, and provides a database for recording design decisions taken during each of the phases. It also contains 'Team Thinking Tools', should designers need help to broaden the solution space by generating more concepts, set priorities, or choose between competing alternatives. One of the industrial organisations that has been involved in this research investigation is proposing to develop it further as part of their in-house management of design.

10.4 Recommendations for future work

10.4.1 Introduction

The numbers of design teams that it has been possible to monitor during the course of the study is only seven. In every case, the monitoring has been undertaken in workshops. Six teams were working on artificially defined problems in a training workshop. In the seventh case, the team worked on a live project, but again during a short workshop. Bearing this in mind, the obvious question to ask is; *can the approach be scaled-up to account for conceptual design practice over a period of weeks rather than hours?* Although means of achieving this have been suggested in chapter 9, it is apparent that far more research will have to be undertaken in this domain before any truly robust method of application can be developed. Given this, it is the author's recommendation that future work into the conceptual design activity of interdisciplinary teams should fall into three complimentary categories: practice, research and education.

10.4.2 Practice

As has been stated above, the workshop environment within which the framework, in both its paper and Web-based forms, was applied and verified is not sufficient to allow general conclusions to be drawn regarding its applicability to the conceptual design of a full-scale project undertaken over a period of weeks. Thus, it is recommended that:

1. The paper framework is applied to real design projects in practice over a number of weeks to allow patterns of design progression to be mapped. These patterns are then compared with the patterns of design progression outlined within this thesis (chapters 6 and 9) allowing conclusions to be drawn regarding any correlation in trends.
2. The Web-based system is made fully dynamic (runnable) to allow it to be applied by designers in a live project over a number of weeks. This will allow: i) the human-computer interaction to be assessed; and ii) provide details of how the decision recording mechanism can be refined and made less invasive. Additionally, the system needs to be married with a document management system and trialled using a live database connection to an organisational intranet. This will assist in achieving recommendation (1) as the system, if developed in line with the specification provided in chapter 8, will record patterns of design progression as the conceptual design activity proceeds.
3. The iteration bandwidth concept is applied in a live design project. This will require recommendation (1) to be fulfilled, allowing a collection of patterns of progression to be compiled and stored. Moreover, it will require a team working within a fairly static environment to be tracked over a number of similar projects (see recommendation (4) below). However, having accomplished this it should be possible to assess the suitability of the bandwidth idea, when used in conjunction with the paper or Web-based framework, as a design management and guidance mechanism.

10.4.3 Research

There are many avenues to be explored in relation to the conceptual design activity of interdisciplinary teams. It has been made clear within this thesis that, in statistical terms, the number of teams monitored is fairly small. Thus, the major recommendation for further work would have to be that:

4. The framework and the mapping methodology are applied in both live and empirical investigations of interdisciplinary conceptual design. This would allow the trends within patterns of progression (proposed in section 9.6) to be verified and further developed.

Additionally, it is recommended that:

5. The concepts proposed for an improved Web-based design support system are investigated. This applies to:
 - The focus of the system moving away from the phases and activities driving design progression, toward the evolving pattern of design progression being the mechanism which raises the team's awareness of the issues, activities and phases being addressed.
 - The design decision recording mechanism being investigated as a means of refining the conceptual design process, rather than as simply a recorder of design rationale. It may be possible to develop models of decision making and analyse these using DSMs. If these decision matrices were developed in conjunction with a set of issues for deliberation (see recommendation (6) below) it may be possible to map them onto one another and propose decision sequences. This would not dictate a stringent process but would allow a team to start anywhere they want; it would simply allow the team members to understand and prepare for the implications of making concrete decisions to early, or late, within the process, thus allowing them to make more considered decisions.
6. Databases of issues for deliberation pertaining to particular types of project are constructed and married with the existing Web-based system stage-gate issues/questions, thus allowing the generic 'skeleton' system to be made project specific.
7. The social dynamics of collaborative working are investigated further in terms of the changing roles of the design team members over the life of the project and the effects that this evolution has on the design activity and proposals. Although this thesis has developed a framework which recognises and accounts for the social component of the design process, interdisciplinary research, involving psychologists, social scientists and design researchers, needs to be executed to

enable a deeper understanding to be gained of the implications of social interaction on both design practice and design products.

8. Further empirical testing of design techniques is undertaken to allow conclusive recommendations to be made regarding the effectiveness of certain methods in specific working environments.

10.4.4 Education

The building design industry comprises a number of disciplinary specialists that are trained, typically, in isolation of the other disciplines to perform a single role within a specific design domain. As a result of this design team members tend to function on different levels of cognition based upon their disciplinary background. This does not enhance the synchronisation of the teams thinking, as the members tend not to apply a common design process. As such, it is recommended that:

9. The paper version of the conceptual design framework is introduced to designers as a training mechanism to allow them to assimilate that individuals can function on different levels of thinking, while still retaining a common objective. In using a common framework within which their different types of thinking can be aligned the activity of the team can be synchronised and focused without forcing individuals to cogitate in a manner which contradicts their formal training.
10. The Web-based system is developed into a training tool to allow designers in practice to understand not only what activities are performed during conceptual design, but also why, and how (see recommendation (11) below).
11. Designers are trained in the application of design techniques. Even if they are used infrequently, having a working knowledge of tools to assist in widening the solution space, setting priorities, evaluating options, and so on will ensure that, should they be required, the team have the understanding required to apply them without taking time out of design activity to learn them.

10.5 Concluding remarks

To conclude, although the author, along with those designers who have either been introduced to or used the design framework in its various forms, believe that the patterns that have been identified are of considerable interest, insufficient data has

been gathered to allow irrefutable conclusions to be drawn as to its applicability outside of the workshop environment. However, within the limitations of the research environment it is believed that the investigation has lead to some robust and generally applicable findings being made. It would be pleasing to think that the ideas and methods outlined within this thesis might be the basis for further data gathering and analysis by others, adding flesh to the skeleton that has been conceptualised and constructed.

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Appendix I

Publications arising from the research project

PUBLICATIONS LIST

Refereed conferences

Parker AD, Steele JL (1998). 'Improving the effectiveness of the conceptual design process by learning from other industries'. *Proceedings of Chartered Institute of Building Services Engineers National Conference 1989*. Bournemouth, UK. Pgs. 69-83.

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. Pgs. 38-49.

Macmillan S, Steele J, Austin S, Kirby P, Spence R (1999). 'Mapping the early stages of the design process - A comparison between engineering and construction'. *Proceedings of the 12th International Conference on Engineering Design 1999*. Munich, Germany. Pgs. 1175-1178.

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. Pgs. 297-305.

Steele J, Austin S, Macmillan S, Kirby P, Spence R (2000). 'An internet-based system to support interdisciplinary and inter-organisational collaborative conceptual design'. *Proceedings of Chartered Institute of Building Services Engineers (CIBSE) National Conference*. Dublin, September 2000.

Steele J, Murray M (2000). 'Interdisciplinary working within a multi-cultural design team'. *Proceedings of Chartered Institute of Building Services Engineers (CIBSE) National Conference*. Dublin, September 2000.

Refereed Journals

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

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

Working papers

Steele J, Austin S, Macmillan S, Kirby P, Spence R (2000). 'One step forward and three steps back: a study of the patterns of interdisciplinary conceptual design'. *Proceedings of the Design Research Conference*. Coventry, September 2000.

Macmillan S, Steele J, Austin S, Kirby P, Spence R (2000). 'The conceptual design of buildings'. *Proceedings of the International conference on design management in the architectural and engineering office*. Atlanta, Georgia, USA. May 20-22, 2000.

Appendix II

Questionnaires:

Preliminary design and construction industry survey

Team performance questionnaire

Design framework questionnaire

Team Thinking Tools questionnaire

Web-based system (framework) questionnaire

Title of Organisation: _____

**Name and role
of respondent:** _____

**The Interdisciplinary Conceptual Design of Buildings:
A preliminary design and construction industry survey**

*Please take a few moments to complete the relevant questions. If there is a lack of space for
comments please attach additional sheets as required.*

1. Does your organisation follow a formal work plan and/or process map for managing construction projects?

Published work plan

Unpublished work plan

None

2. If you follow one or more published work plans and/or process maps please list their title, author and publisher.

3. If you follow one or more unpublished work plans and/or process maps, were those developed in-house or by another organisation?

In house

Another organisation

4. If you follow one or more work plans and/or process maps developed by other organisations, please list their title and the name of the organisation.

This questionnaire is continued overleaf

5. If you follow an in-house developed work plan and/or process map, please describe how this was developed (if known).

6. If you follow a work plan and/or process map in practice, is it applied to the conceptual phase of design? Yes No Don't Know

7. On approximately what proportion or percentage of your projects are the work plan and/or process map followed? %

8. Who is responsible for the application of the work plan and/or process map in practice?

9. If your company utilises any form of quality management procedure, is it linked to the work plan and/or process map? Yes No Don't Know

10. Does the work plan and/or process map include the application of techniques such as value management, value engineering, cost benefit analysis, formal evaluation of alternatives, brainstorming, or others? Yes No Don't Know

11. If yes, please list the techniques included in the work plan and/or process map.

12. Do you actually use the techniques included in the work plan and/or process map in practice? Yes
 No
 Not applicable

Thank you for your time and assistance.

Team Performance Questionnaire

Name:
Organisation:
Discipline:
Team:

1. Please tick the relevant boxes to indicate your response to the following questions:

	Very poor 1	2	Average 3	4	Excellent 5
1. How would you rate the design that the group has produced for the task?					

	Very ineffective 1	2	neutral 3	4	Very effective 5
2. Which number best describes the way the group took decisions?					

	No one contributed ideas 1	2	Half the group contributed ideas 3	4	Everyone contributed ideas 5
3. How would you rate group member contribution to this task?					

	Very displeased 1	2	Neutral 3	4	Very pleased 5
4. How do you feel about the way the group has worked?					

	Very disorganised 1	2	Neutral 3	4	Very organised 5
5. What do you think about the group's organisation during this task?					

	Very dissatisfied 1	2	Neutral 3	4	Very satisfied 5
6. How satisfied are you with the way the group used its time?					

	Very displeased 1	2	Neutral 3	4	Very pleased 5
7. How do you feel about the way the group chose to proceed?					

This questionnaire is continued overleaf

	Very displeased 1	2	Neutral 3	4	Very pleased 5
8. What do you think about the way your ideas are included in the design sketches?					

9. Please use the box to elaborate on any of your answers, or make other comments:

Thank you for your participation.

Design framework Questionnaire

Name:
Organisation:
Discipline:
Team:

1. Please tick the relevant boxes to describe how you feel about the following statements:

	Agree strongly	Agree	Neither agree nor disagree	Disagree	Disagree strongly
The framework and its terminology were clearly understandable to me					
The design framework helped me personally to work within the team.					
The design framework helped us to be more effective as a team					
The design framework facilitated the integration of client requirements into the process at the appropriate time					
The phases suggested in the framework guided the design process					
If developed further the design framework could improve the process of conceptual design undertaken by interdisciplinary teams.					
The design framework needs to be developed to a further level of detail to make it a more efficient as a design aid.					
The design framework furthered my understanding of the conceptual design process.					
The design framework aided the co-ordination of the design activity					
It was straight forward to work within the design framework					
The design framework is realistic and useable in its present form.					
The design framework realistically describes the conceptual design process as it is undertaken in buildings projects					
I can imagine myself implementing the framework in practice					

Please comment on any improvements that you feel could be made to the design framework to make it more realistic and usable for interdisciplinary design teams in practice:

This questionnaire is continued overleaf

Please summarise any other views you may have about your team design activity:

Thank you for your participation.

Team Thinking Tools Questionnaire

Name:
Organisation:
Discipline:
Team:

1. How much time did you spend looking at the T-3 document you were handed:
- 1 minute or less
 - 2-10 minutes
 - 10-30 minutes
 - >30 minutes

2. Did your team use any of the T-3 techniques?
- Yes
 - No

3. If your team did not use any of them, was this because they were:
- a) Too complex to understand quickly
 - b) too time consuming to use in the context of the design exercise
 - c) unlikely to help us deliver a better design
 - d) unusable in their present form
 - e) other (please describe briefly below)

-
-
-
-
-

4. If you team did use techniques, which ones did it use (please tick):
- a) Forced analogies
 - b) Six thinking hats
 - c) Lotus Blossom/Mind Map
 - d) Isolated option testing
 - e) Ranking and weighting
 - f) Analysis of interconnected decision areas

This questionnaire is continued overleaf

Assessment of Creative Techniques

5. If your team used Forced Analogies please tick the relevant boxes to describe how you feel about the following statements:

	Agree strongly	Agree	Neither agree nor disagree	Disagree	Disagree strongly
Forced analogies helped our team to see the design problem more clearly					
Forced analogies helped us to generate a wide range of options					
Forced analogies helped us to be more innovative in our proposals					
Forced analogies helped us to be more effective as a team					
Forced analogies was irrelevant to us given the nature of the problem we were set					
Forced analogies was irrelevant to this type of design exercise					
Forced analogies as a method is irrelevant to the design of buildings					

Please summarise any other views you may have about Forced Analogies:

6. If your team used '6 Thinking Hats' please tick the relevant boxes to describe how you feel about the following statements:

	Agree strongly	Agree	Neither agree nor disagree	Disagree	Disagree strongly
Thinking hats helped our team to see the design problem more clearly					
Thinking hats helped us to generate a wide range of options					
Thinking hats helped us to be more innovative in our proposals					
Thinking hats helped us to be more effective as a team					
Thinking hats was irrelevant to us given the nature of the problem we were set					
Thinking hats was irrelevant to this type of design exercise					
Thinking hats as a method is irrelevant to the design of buildings					

Please summarise any other views you may have about '6 Thinking Hats':

7. If your team used 'Lotus blossom/mind map' please tick the relevant boxes to describe how you feel about the following statements:

	Agree strongly	Agree	Neither agree nor disagree	Disagree	Disagree strongly
Lotus blossom/mind map helped our team to see the design problem more clearly					
Lotus blossom/mind map helped us to generate a wide range of options					
Lotus blossom/mind map helped us to be more innovative in our proposals					
Lotus blossom/mind map helped us to be more effective as a team					
Lotus blossom/mind map was irrelevant to us given the nature of the problem we were set					
Lotus blossom/mind map was irrelevant to this type of design exercise					
Lotus blossom/mind map as a method is irrelevant to the design of buildings					

Please summarise any other views you may have about 'Lotus blossom/mind map':

This questionnaire is continued overleaf

Assessment of Evaluative Techniques

8. If your team used 'Isolated option testing' (IOT) please tick the relevant boxes to describe how you feel about the following statements:

	Agree strongly	Agree	Neither agree nor disagree	Disagree	Disagree strongly
IOT helped our team to see the design problem more clearly					
IOT raised our awareness of critical elements of the design problem					
IOT helped us to evaluate our concepts in a more rational manner					
IOT helped us to be more effective as a team					
IOT was irrelevant to us given the nature of the problem we were set					
IOT was irrelevant to this type of design exercise					
IOT as a method is irrelevant to the design of buildings					

Please summarise any other views you may have about 'Isolated option testing' (IOT):

9. If your team used 'Ranking and weighting' please tick the relevant boxes to describe how you feel about the following statements:

	Agree strongly	Agree	Neither agree nor disagree	Disagree	Disagree strongly
Ranking & weighting helped our team to see the design problem more clearly					
Ranking & weighting raised our awareness of critical elements of the design problem					
Ranking & weighting helped us to evaluate our concepts in a more rational & systematic manner					
Ranking & weighting helped us to be more effective as a team					
Ranking & weighting was irrelevant to us given the nature of the problem we were set					
Ranking & weighting was irrelevant to this type of design exercise					
Ranking & weighting as a method is irrelevant to the design of buildings					

Please summarise any other views you may have about Ranking and weighting:

10. If your team used 'Analysis of Interconnected Decision Areas' (AIDA) please tick the relevant boxes to describe how you feel about the following statements:

	Agree strongly	Agree	Neither agree nor disagree	Disagree	Disagree strongly
AIDA helped our team to see the design problem more clearly					
AIDA raised our awareness of critical elements of the design problem					
AIDA helped us to evaluate our concepts in a more rational & systematic manner					
AIDA helped us to be more effective as a team					
AIDA was irrelevant to us given the nature of the problem we were set					
AIDA was irrelevant to this type of design exercise					
AIDA as a method is irrelevant to the design of buildings					

Please summarise any other views you may have about Analysis of Interconnected Decision Areas (AIDA):

This questionnaire is continued overleaf






11. Have you any other comments you wish to make about the introduction of creative and/or evaluative techniques for use by design teams?






Thank you for your participation.

Web-based system (framework) questionnaire

The Web-based system (framework) is comprised of a number of phases and activities which are generic to the conceptual design phase of building projects. The purpose of this questionnaire is to allow you to rate how well the prototype version of the system works for you. The questionnaire proposes a number of statements followed by a standard rating scale. Please indicate the strength of agreement or disagreement with each statement (1-36) by clicking on the appropriate box. A text box is provided at the end of each section for you to include any additional comments regarding the framework.

The final section of the questionnaire (37-41) focuses on issues relating to design experience, discipline, and so on to help with the analysis of the data

Supporting the team					
1. The framework will assist the team in undertaking conceptual design activity.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2. The framework will assist me in working as part of a team.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3. I would want to use the framework as part of a team.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4. The framework will support teams while undertaking conceptual design.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5. I believe my colleagues would be willing to use the framework.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6. The team maintenance issues are relevant.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7. I think the team could use the framework without external facilitation.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8. The framework could help synchronise the teams design activity.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9. The framework could help reduce confrontation within the design team.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10. The framework will encourage consideration of the design process during design activity.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<div style="border: 1px solid black; height: 30px; width: 100%;"></div>					

Design phases and their navigation					
11. The issues suggested in the framework usefully describe the design process.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
12. The prompts are helpful in guiding design activity.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
13. The phases and activities are a good representation of the conceptual design process.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
14. The language is understandable to me.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
15. The questions are appropriate.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
16. It is simple to navigate through the framework.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
17. The framework allows designers to define their own path through it.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
18. The framework does not constrain design activity.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
19. The framework is both flexible and adaptable.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
20. Recording decisions in a structured manner during the process is beneficial.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
21. Being able to link design documents to appropriate framework activities would be beneficial.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<div style="border: 1px solid black; height: 30px; width: 100%;"></div>					

As an aid to improving understanding of conceptual design...



- 22. I can envisage using the framework individually.
- 23. The framework improved my own understanding of conceptual design activity.
- 24. The tool could develop designers understanding and knowledge of conceptual design.

Team Thinking Tools (T-3s)



- 25. The design tools described are easily accessed within the framework.
- 26. There is enough instruction provided to apply the design tools.
- 27. I would use the tools in this form.
- 28. I believe that other members of my design team will use the tools in this form.

General



- 29. The framework's structure inhibits creativity.
- 30. All designers should be given equal opportunity to contribute throughout the design process.
- 31. I would feel comfortable using a computer during design activity.
- 32. My colleagues would be comfortable using a computer during design activity.
- 33. I would use an internet-based system to access design information.
- 34. It could be beneficial for me to think about the process as well as the product during design activity.
- 35. It could be beneficial for the team to think about the process as well as the product during design activity.

36. I use the Internet...

Personal details

37. Organisation/company:

38. Discipline:

39. Occupation/Role within organisation:

40. Years of design experience:

41. Age:

Thankyou for your time.

Submit Questionnaire

Appendix III

Definitions of conceptual design

Definitions of conceptual design

The following definitions of conceptual design were gathered from a literature survey, which encapsulated upwards of 200 academic papers and book publications.

Andersson P (1996). 'A Semi-analytical Approach to Robust Design in the Conceptual Design Phase'. *Research in Engineering Design* - Vol. 8(229-239)

'Conceptual design starts with the functional decomposition of the need situation that clarifies the system boundary, and the functions required to fulfil the systems overall task, through the generation of concept variants (usually presented in the form of sketches) that show the solution principles and the spatial relationship between parts'.

Blessing LTM (1994). 'A process based approach to computer aided design'.

Pg.108:

'The conceptual design stage is defined as the stage in which the principle solutions for the product and its main elements are generated based on the functions the product has to fulfil'.

BS 7000 (1989):

'Conceptual design is the design process in which concepts are generated with a view to fulfilling the objective'.

BS 7000 pt: 4 (1996):

'Conceptual design is the stage of a design process at which ideas and outline proposals are conceived. Such ideas need only contain those details necessary to define the essential characteristics and features. The primary aim should be to provide a client with an appraisal and recommendation on the development of the project so that decisions can be made on the functional, technical and financial aspects'.

Chakrabarti A, Bligh T.P (1994). 'An Approach to Functional Synthesis of Solutions in Mechanical Conceptual Design. Part 1: Introduction and Knowledge Representation.' *Research in Engineering Design - Vol. 6/Pgs: 127-141*):

.Conceptual Design is considered the activity of transforming the functional requirements of a design problem into a solution concept or concepts for fulfilling the requirements. There can be more than one solution to a problem, and therefore scope exists for better, if not optimum, designs if a larger space of solutions can be explored'.

French M.J (1971). Engineering Design: The Conceptual Stage. Heinemann Educational Books:

'Conceptual design takes the statement of the problem and generates broad solutions to it in the form of schemes; It is the phase that makes the greatest demands on the designer, and where there is the most scope for striking improvements; and where engineering science, practical knowledge, production methods and commercial aspects need to be brought together, and where the most important decisions are taken'.

Hales C (1992). 'An Analysis of the Engineering Design Process in an Industrial Context'. Pgs: 54-57:

'Conceptual design should provide the concept which most fully satisfies the requirements of the design specification. Only those candidate concepts that satisfy every 'demand' in the specification should pass from the selection step to the final evaluation step. The most appropriate concept is then determined from an evaluation of how well each candidate meets the stated wishes or preferences'.

Hill P.H (1970). 'The Science of Engineering Design'. Holt, Rinehart & Winston:

'Conceptual design involves the generation of alternative solutions to a stated goal in the form of concepts. The research phase must be considered and the task specification must be continually reviewed as the designer engages in ingenious, innovative and creative activity focused on the end product. Alternative solutions will be recorded and tested against selected criteria to determine which has the best chance of success'.

Olson F (1976). 'Systematic Engineering Design'. Lund Doctoral Thesis, Dept. of Machine Design, Lund Institute of Technology, Lund University:

'Conceptual design is the assessment of mode of action, structure arrangement and preliminary form of the product'.

Pahl & Beitz (1988). 'Engineering Design: A Systematic Approach'. The Design Council-Springer/Verlag:

'Conceptual design is that part of the design process in which, by the identification of the essential problems through abstraction, by the establishment of function structures and by the search for appropriate solution principles and their combination, the basic solution path is laid down through the elaboration of a solution concept'.

Parmee I.C (1996). 'Towards an Optimal Engineering Design Process Using Appropriate Adaptive Search Strategies'. *Journal of Engineering Design* – Vol.7/No.4/1996:

'Conceptual design consists of a search across an ill-defined space of possible solutions using fuzzy objective functions and vague concepts of the structure of the final solution. The problems in attempting integration include the appropriate representation of the design concepts and components which must allow the generation of alternative designs and the formulation of an appropriate evaluation function in order to assess, in a meaningful manner, the relative fitness of these solutions'.

Proceedings of S.E.E.D (1985) Working Party (Curriculum for Design Engineering Undergraduate Courses):

'The Conceptual design phase is concerned with 'synthesis' and is the phase in which outline schemes are generated and evaluated in relation to the specification criteria. This sequence may be repeated several times, involving a progressive development of the best alternatives, before final conceptual choice is made for detail design'.

Spillers & Newsome (1988). 'Design Theory '88'. Springer-Verlag:

'Conceptual design is that portion of the design process that requires complex cognitive information processing, including knowledge and information acquired outside of the particular design project at hand; It will most likely involve elements of creativity (unique ideas) and consequently represent the most difficult portion of the design process to automate'.

The BAA Project Handbook (1995):

'The concept stage develops the single, costed business solution in terms of architecture, interior design, engineering and execution. Options for the major physical and engineering systems are studied and selected through a process of value engineering. The outline specifications are defined in conjunction with phasing and buildability strategy. Change logging is initiated during concept design'.

Ullman D.G (1997). 'The Mechanical Design Process (Second Edition)'. McGraw-Hill:

'Conceptual design is the phase at which an idea is conceived; a concept; that is sufficiently developed to evaluate the physical principles that govern its behaviour. At this stage it must be confirmed that the proposal will operate as anticipated and, with reasonable further development, will meet the set targets. The proposal must also be refined enough to evaluate the technologies needed to realise it, its basic architectural form, and its manufacturability (to some limited degree)'.

From the numerous definitions shown above, a generic version of the term 'conceptual design' has been compiled. It is felt that this version not only incorporates all the fundamental aspects of the definitions generated through the literature search, but also extends the definition slightly further, bringing into play another fundamental factor, designer confidence. It is suggested that, for the purposes of the research Project, the following definition be utilised:

"The conceptual phase of the design process takes and develops the statement of the problem and generates broad solutions which the designers are confident can subsequently be developed to meet the requirements."

Appendix IV

Examples of design techniques from existing literature:

Creative design techniques

Rational design techniques

Creative design techniques

Technique	Aim
Value analysis 'blasting'	To increase the rate at which designing and manufacturing organisations learn to reduce the cost of a product
Strategy switching	To permit spontaneous thinking to influence planned thinking, and vice versa
Searching for visual inconsistencies	To find directions in which to search for design improvements
Brainstorming	To stimulate a group of people to produce many ideas quickly
Synectics (forced analogies)	To direct the spontaneous activity of the brain and the nervous system towards the exploration and transformation of design problems
Removing mental blocks	To find new directions of search when the apparent search space has yielded no wholly acceptable solution
Mind mapping/ Lotus blossom	To represent visually a designer's or design team's thinking and ideas in a structured form
Six thinking hats	To provide a structure for productive discussion, promote fuller input from more people, and separate ego from performance
Challenge	To challenge why we do things the way we do or why things are the way they are
Alternatives	To search for alternatives even where there are no deficiencies in the current options
Provocation and movement	To generate new and original ideas as a means of producing fresh solutions
Filament technique	To develop a fresh idea from an existing one by reviewing it's filament (component) elements
Documenting output from creative thinking	To formally document the output from periods of creative thinking so that key concepts are not lost

Rational design techniques

Technique	Aim
Systematic search (the decision theory approach)	To solve design problems with logical certainty
Systems engineering	To achieve internal compatibility between the components of a system and external compatibility between a system and its environment
Man-machine system designing	To achieve internal compatibility between the human and machine components of a system and external compatibility between the system and the environment in which it operates
Boundary searching	To find limits within which acceptable solutions lie
Page's cumulative strategy	To increase the amount of design effort that is spent on analysis and evaluation, both of which are cumulative and convergent, and to reduce the amount of non-cumulative effort spent on the synthesis of solutions that may turn out to be duds, i.e. to make it unnecessary to develop bad designs in order to learn how to develop good ones
CASA (Collaborative Strategy for Adaptable Architecture)	To enable everyone concerned with the design of a building to influence decisions that affect the adaptability of the building and the compatibility of its components
Matchett's Fundamental design method (FDM)	To enable a designer to perceive and control the pattern of his thoughts and to relate this pattern more closely to all aspects of a design situation
Stating objectives	To identify external conditions with which the design must be compatible
Literature searching	To find favourable information that can favourably influence the designer's output and that can be obtained without unacceptable cost and delay
Interviewing users	To elicit information that is known only users of the product or system in question
Questionnaires	To collect usable information from the members of a large population
Investigating user behaviour	To explore the behaviour patterns, and to predict the performance limits, of potential users of a new design
Systemic testing	To identify actions that are capable of bringing about desired changes in situations that are too complicated to understand
Selecting scales of measurement	To relate measurements and calculations to the uncertainties of observation, to the costs of data collecting, and to the objectives of the design project

Data logging and data reduction	To infer, and to make visible, patterns of behaviour upon which critical design decisions depend
Morphological charts	To widen the area of search for solutions to a design problem
Interaction matrix	To permit a systematic search for connections between elements within a problem
Interaction net	To display the pattern of connections between elements within a design problem
AIDA (Analysis of Interconnected Decision Areas)	To identify and to evaluate all the compatible sets of sub-solutions to a design problem
System transformation	To find ways of transforming an unsatisfactory system so as to remove its inherent faults
Innovation by boundary shifting	To shift the boundaries of an unsolved design problem so that outside resources can be used to solve it
Alexander's method of determining components	To find the right physical components of a physical structure such that each component can be altered independently to suit future changes in the environment
Classification of design information	To split a design problem into manageable parts
Checklists	To enable designers to use knowledge of requirements that have been found to be relevant in similar situations
Selecting criteria	To decide how an acceptable design is to be recognised
Ranking and Weighting	To compare a set of alternative designs using a common scale of measurement
Specification writing	To describe an acceptable outcome for designing that has yet to be done
Quirks reliability index	To enable inexperienced designers to identify unreliable components without testing

Appendix V

Designing Together workshop project brief

CONTENTS

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APPENDIX C	Graph Paper Blank

DESIGNING TOGETHER

WINDOWS PROJECT BRIEF

ORIGINAL					
REV	COMMENT	PREPARED BY	DATE	CHECKED BY	DATE
		DOCUMENT NUMBER:			

1.0 INTRODUCTION

1.1 CONTEXT

Windows represent the meeting of technology, functionality and aesthetic perception. Providing a tool for environmental control, windows also have cultural, symbolic and aesthetic properties.

The importance of the windows use for the regulation of indoor climate as well as to admit natural light has been heightened by the trend towards the exploitation of natural processes of environmental control. The design of a window system therefore demands the integration of skills across the disciplines. For further reading see extract from "How Designers Think".

1.2 WORKSHOP FORMAT

The course members will work in 3 separate teams of 5. Each team will be multi-disciplined. The teams will work in a studio environment over the two-day period as indicated on the workshop programme.

Following the studio work design activities, each team will be pin up and present their system design proposals and design methodology.

2.0 THE TASK

2.1 OUTLINE

You are being asked to propose a modular "window" system which may be used to re-clad existing buildings. The building type would most likely be a slab type office building typical of the 1960s or early 70s, a typical example of which is ADAM, Stratford (see accompanying drawing), and would be in need of improved environmental performance. The system would be a manufactured product available virtually from stock.

There are two parts to the assignment, one is the design itself, the other is the design methodology. You therefore need to communicate the result of your efforts and the way in which your team achieved that result.

2.2 DESIGN REQUIREMENTS

2.2.1 Cladding System Requirements

The system, which would comprise the entire building envelope, should be flexible and adaptable to a range of different buildings.

The building plate comprise both cellular offices, 3m wide by 4.5m deep, and deep plan open office environments. The height from floor to floor, will vary but is likely to be around 3.5 m.

The building structural grid is nominally 6m. The overall width of the building is nominally 18m and of variably length.

The office may be of any orientation.

The office building will be occupied 8 hours a day, and each cellular office will occupy a maximum of 1 person. The open plan office area is 1 person per 8m². A single personal computer will be shared between 2 people.

The refurbishment of the building will include the addition of a raised floor.

The ceiling could be exposed concrete.

The building will not be located in a city but in a sub-urban location, such as that found at ADAM Stratford.

The system shall take into account the potential differences created by office floors being at a variety of heights above ground level.

2.4 Environmental Design Parameters

Because internal construction and finishes may vary, the effects of thermal storage may not be relied upon.

In summer the air temperature in the room should not exceed the external air temperature by more than 3 degrees C.

The design should seek to minimise the use of artificial lighting, and we suggest an average daylight factor of 5%. The window solutions should not be overtly dependant upon technology/or expensive to maintain.

2.3 DELIVERABLES

2.3.1 The Proposed System Design

It is unlikely that in the short time available that polished designs will emerge. This is not the intention. Rather, the teams should be in a position to present sketches of the proposal which illustrate how the design requirements could be met.

The following information should be provided:

Elevation and section of a typical module

Elevation illustrating a facade area of modules grouped together to provide an overall aesthetic. This could be in the form of a perspective view.

Model of a window module

Sketches of typical details where appropriate

Statement of unresolved issues and possible solutions.

Statement on the commercial aspects of the scheme.

Environmental Performance Calculations - daylighting, ventilators.

You may find it useful to graph various results for quick "what if" comparisons.

2.3.2 The Design Process

Present an insight into and a commentary on the following:-

The rationale behind the team structure

Team roles and responsibilities.

The design team's design processes and techniques used

An analysis of the factors for success compared with factors that were against success of the team.

Where issues remain unresolved these should be identified and should carry with them an assessment of necessary further investigations and a range of possible solutions.

Drawings need only be sufficiently detailed to convey the design principles.

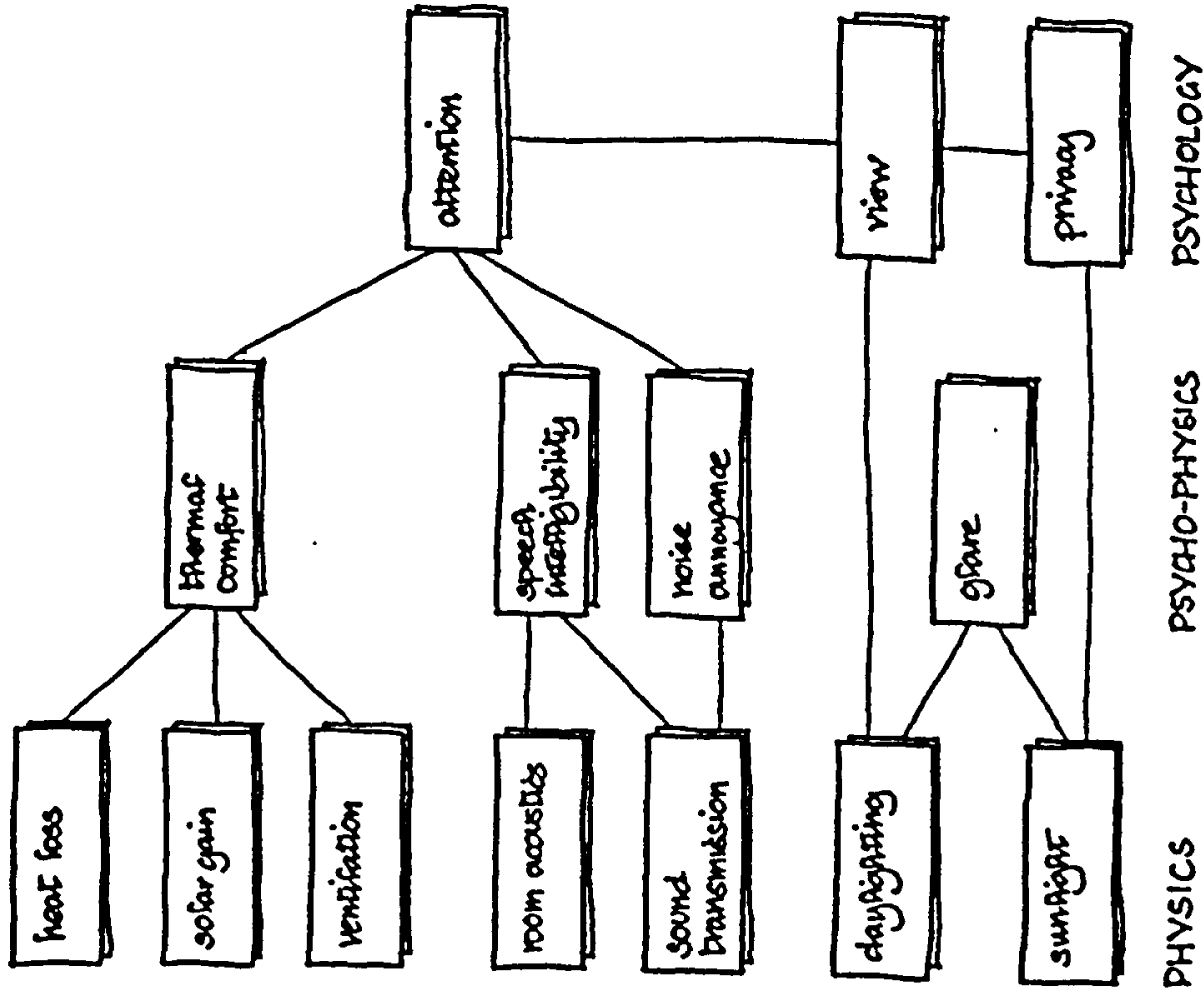
APPENDIX A

Extract from "How Designers Think"

The Design Process Demystified.

2nd Edition Brian Lawson

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4.2 Some of the complex array of issues involved in designing a window

stacked and be sympathetic to the designer's visual intentions for the chair as a whole. The designer of such a chair is unlikely to succeed by thinking separately about the problems of stability, support, stacking and visual line since all must be satisfied by the same element of the solution. In fact, the designer must also be aware of other more general problems such as cost and manufacturing limitations, the availability of materials and the durability of finishes and joints.

In design it is frequently necessary to devise an integrated solution to a whole cluster of requirements. We saw in Chapter 2 how George Sturt's dished cartwheel provided such an

The multi-dimensional design problem
 Design problems are often both multi-dimensional and highly interactive. Very rarely does any part of a designed thing serve only one purpose. The American architect Philip Johnson is reported to have observed that some people find chairs beautiful to look at because they are comfortable to sit in, while others find chairs comfortable to sit in because they are beautiful to look at. Certainly no one can deny the importance of both the aesthetic and economic aspects of chair design. The legs of a stack-

well as letting in daylight and allowing for natural ventilation, the window is also usually required to provide a view while retaining privacy. As an interruption in the external wall the window poses problems of structural stability, heat loss and noise transmission, and is thus arguably one of the most complex of building elements. Modern science can be used to study each of the many problems of window design with branches of physics, psycho-physics and psychology all being relevant. This is indeed a complex array of concepts to lay before an architect. Most courses in architecture attempt to teach most of this scientific material. However, the methods of science are perhaps surprisingly unhelpful to the designer. Modern building science techniques have generally only provided methods of predicting how well a design solution will work. They are simply tools of evaluation and give no help at all with synthesis. Daylight protractions, heat loss or solar gain calculations do not tell the architect how to design the window but simply how to assess the performance of an already designed window.

Sub-optimising

Chris Jones (1970) summarises how John Page, a professor of building science, proposes that designers should adopt what he calls a cumulative strategy for design in such a situation. This would involve setting carefully defined objectives and criteria of success for the performance of the window on all the dimensions we have identified. Page's strategy then calls for the designer to collect a variety of what he calls sub-solutions for each criterion and then discard the solutions which fail to satisfy all the criteria. Thus the window designer would produce a succession of designs, some intended to achieve a good view, others to avoid solar gain or good daylighting and so on. We are told that this strategy is intended to increase the amount of time spent on analysis and synthesis and reduce the time spent on the synthesis of bad solutions.

It is interesting that this strategy, suggested by a scientist, resembles the behaviour of the science students in the experiment described in the last chapter. Such an approach, however, does not seem born of a clear understanding of the true nature of design problems. Because design problems are so multi-dimen-

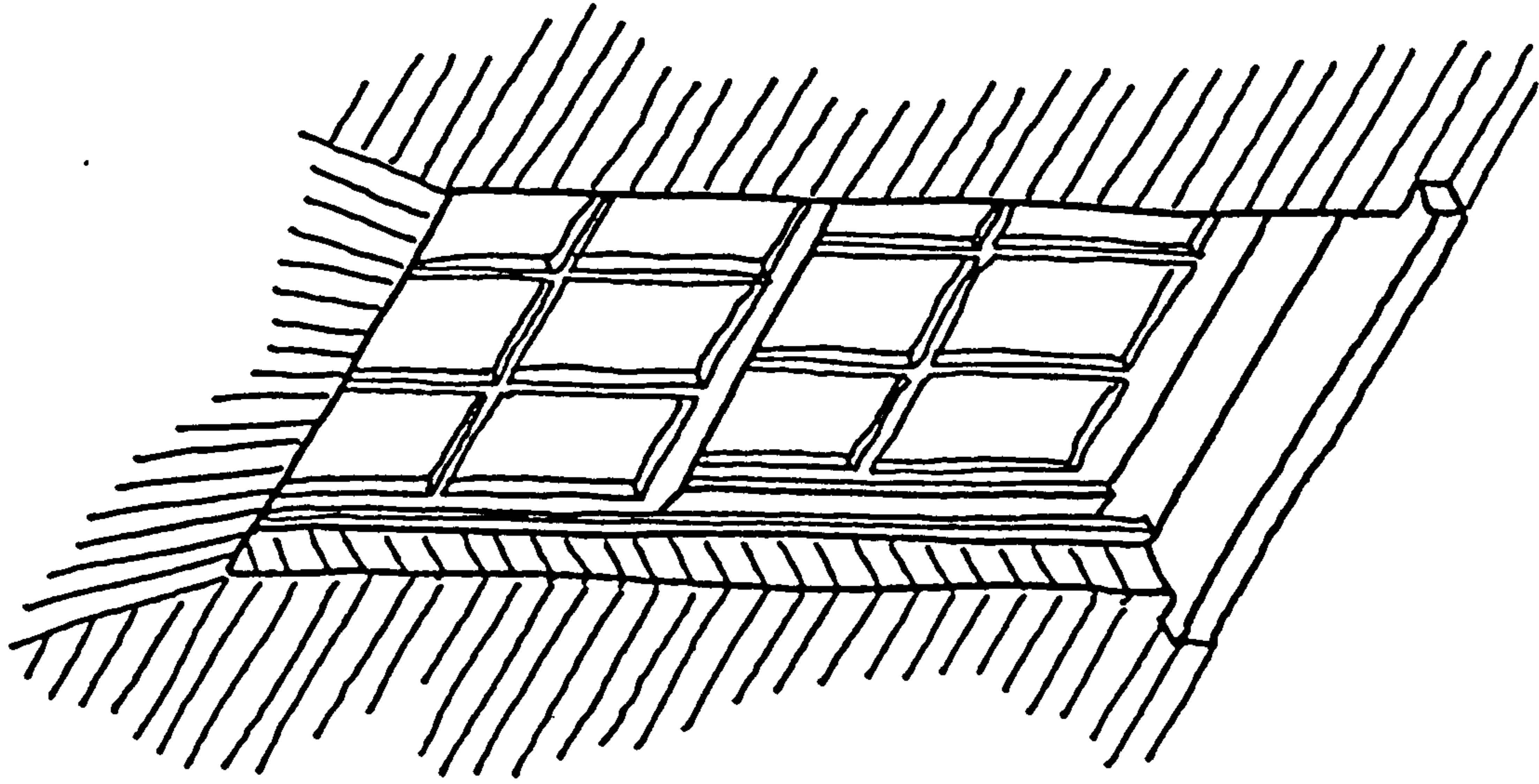
result in more heat loss and may create greater problems of privacy. It is the very interconnectedness of all these factors which is the essence of design problems, rather than the isolated factors themselves. In this respect designing is like devising a crossword. Change the letters of one word and several other words will need altering necessitating even further changes. Modify the dish of George Sturt's cartwheel and it may fail to support its load and the lateral thrusts unless the angle of toe-in and axle mounting are also changed. After this the cart may not fit the rutted roads unless the length of the axle and shape of the body are changed. As we have seen, the cartwheel was the result of many years of experience rather than theoretical analysis.

The integrated solution

Until the advent of modern building science this is just how windows were designed. Perhaps the finest period for window design in England was the eighteenth century. The vertical proportions of Georgian windows positioned near the outer edge of the wall and with splayed or stepped reveals gave excellent daylight penetration and distribution (Fig. 4.3). The vertical sliding sash was reasonably weatherproof and gave much more flexible ventilation configurations than the hinged casement which was to replace it. The proportions of solid wall and window, so fundamental to the late renaissance, worked well structurally, gave an even light and offered privacy for those behind. Above all, of course, the Georgian window was integrated into a superb architectural language. So it seems unlikely that the eighteenth-century architect would have been distressed by a lack of expertise in building science.

Thus it is the case that good design is usually an integrated response to a whole series of issues. If there was one single characteristic which could be used to identify good designers it is the ability to integrate and combine. A piece of good design is rather like a hologram; the whole picture is in each fragment. It is often not possible to say which bit of the problem is solved by which bit of the solution. They simply do not map on to each other that way.

However if modern designers are going to abandon traditional or vernacular solutions, they cannot afford to remain so ignorant



4.3 The Georgian window offers a beautifully integrated solution

Too many designers miss the fact that the new issues which legitimately demand new forms are there, if the pattern of the problems could only be seen as it is and not as the bromide image (of a previous solution) conveniently at hand in the catalogue or magazine around the corner.

This 'pattern of the problem' is comprised of all the interactions between one requirement and another which constrain what the designer may do. Chermayeff and Alexander (1963) again:

We can observe some general rules about the nature of this pattern of constraints in design and we discuss these in a later chapter. First, however, we need to look more carefully at the way the performance of designs can be measured against criteria of success.

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APPENDIX B

BRE Information Paper

"Average daylight factor a simple basis for daylight design"

CIBSE Guide A4 : Air Infiltration and Natural Ventilation

Average daylight factor: a simple basis for daylight design

P J Littlefair, MA, PhD

Good design of windows should include planning for daylight at the early design stage. Average daylight factor is especially suitable for this purpose as it can be used in the direct calculation of target glazing areas. This paper describes the use of formulae developed at BRE to enable average daylight factor to be calculated quickly and accurately. It will be of interest to architects and engineers involved in window design.

DAYLIGHT — A PASSIVE SOLAR OPTION

A recent BRE Report¹ describes the results of a study of the energy potential of daylight. According to the report, daylighting can be viewed as an option in passive solar design, aiding building energy efficiency as well as providing an attractive environment. By the year 2020 this improvement in exploitation of daylight to displace electric light could be worth between 0.66 and 1.31 million tonnes of coal equivalent per year in the UK. Buildings like the BRE low-energy office² have shown that, even with fairly conventional design, annual lighting use as low as 5 kWh/m² is possible.

Moreover, new technology has been developed which can promote the efficient use of daylight. A breakthrough here has been the availability of new forms of lighting control, such as daylight-linked photoelectric switching, time switching and localised manual control³. Studies by BRE⁴ have shown that a typical system in an open-plan office which combines all three of these operations can result in 40% saving in lighting energy use, compared with traditional manual switching — provided that the windows are large enough to admit reasonable amounts of daylight.

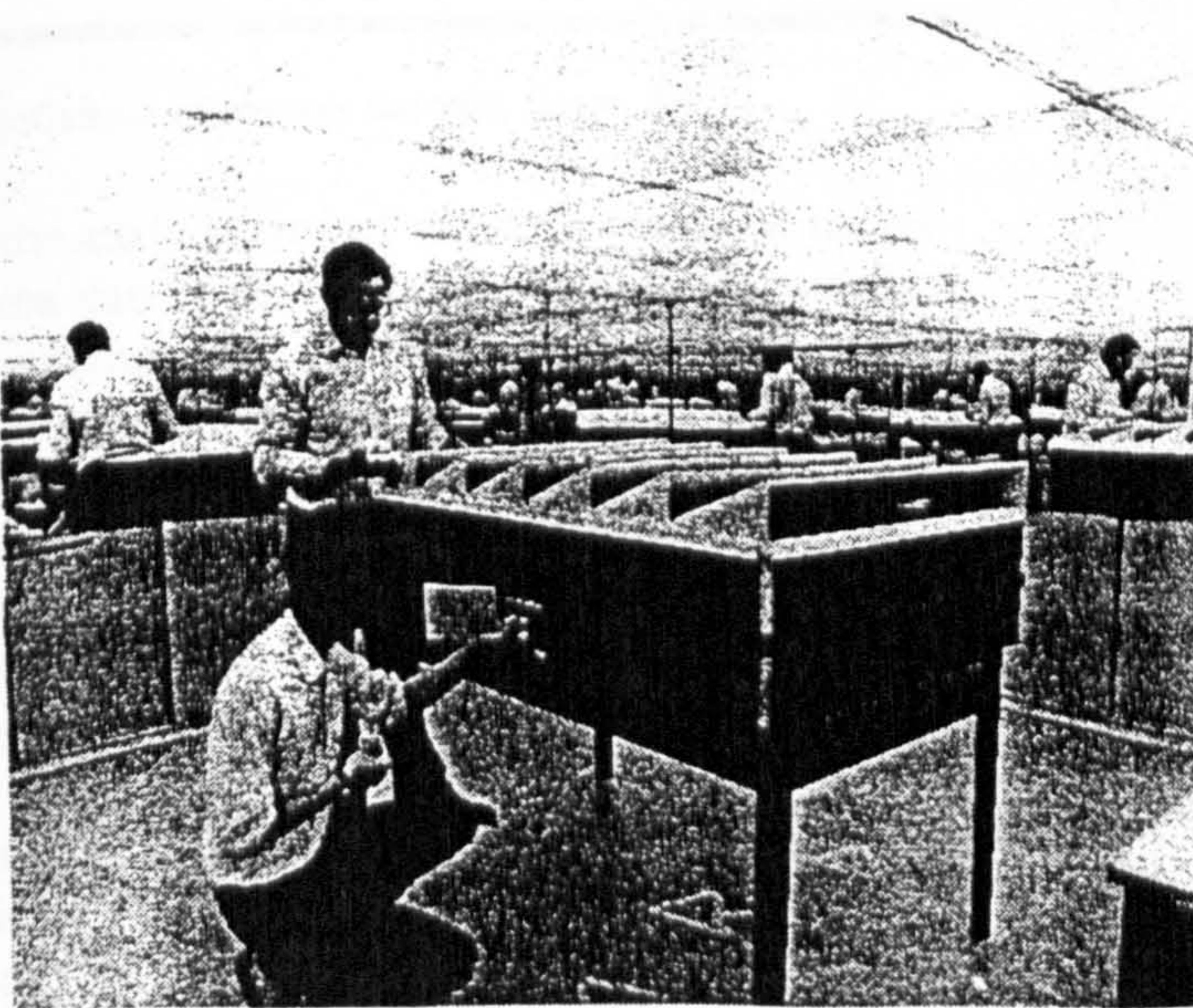


Figure 1 The model room, fitted with one of the roof profiles (sawtooth with vertical glazing), in the BRE artificial sky laboratory

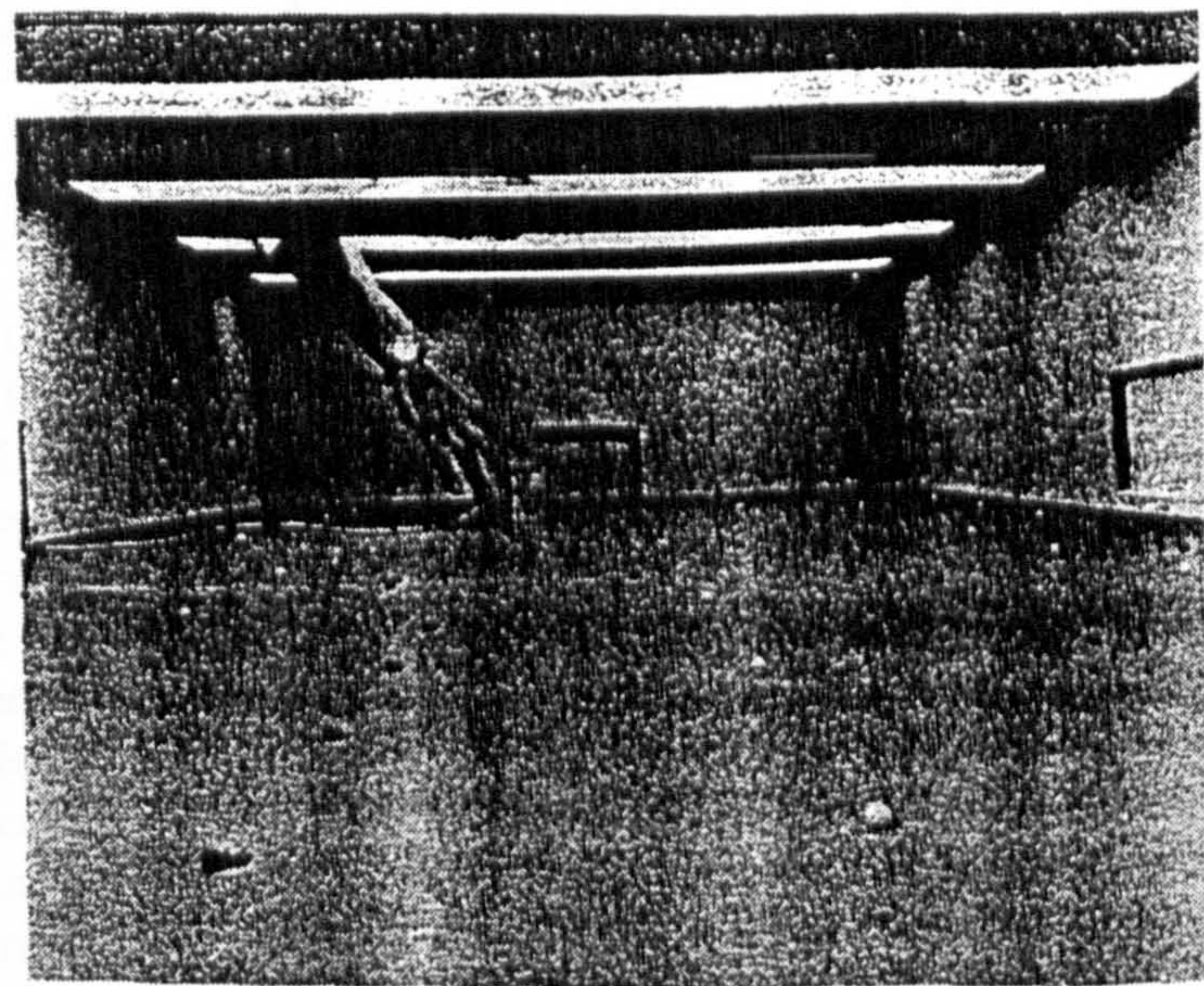


Figure 2 Inside the model room where daylight factor was measured

AVERAGE DAYLIGHT FACTOR AND WINDOW DESIGN

Conventional methods of daylight design use the daylight factor⁵, evaluated at a point (usually the minimum) or points inside the room. The daylight factor is the ratio (usually a percentage) of interior illuminance to external global horizontal illuminance, under standard overcast sky conditions. One of the drawbacks of this conventional approach is that it can only be used once the window size, shape and position have already been fixed; by this late stage in design it may be too late to alter glazing areas. In any case this 'trial and error' approach to window design can be time consuming.

Average daylight factor, \overline{DF} , is defined in a similar way: as the ratio of average interior illuminance (a spatial average over the working plane) to external global horizontal illuminance, again under standard overcast sky conditions (Figure 3). However, the advantage of \overline{DF} is that it can be simply related to glazing area. Compared with point daylight factors, average daylight factor is considerably less dependent on window shape or position.

Under standard overcast conditions:

$$\text{Average daylight factor } \overline{DF} = \frac{\bar{E}_{in}}{E_{out}} \times 100\%$$

Unobstructed illuminance E_{out}

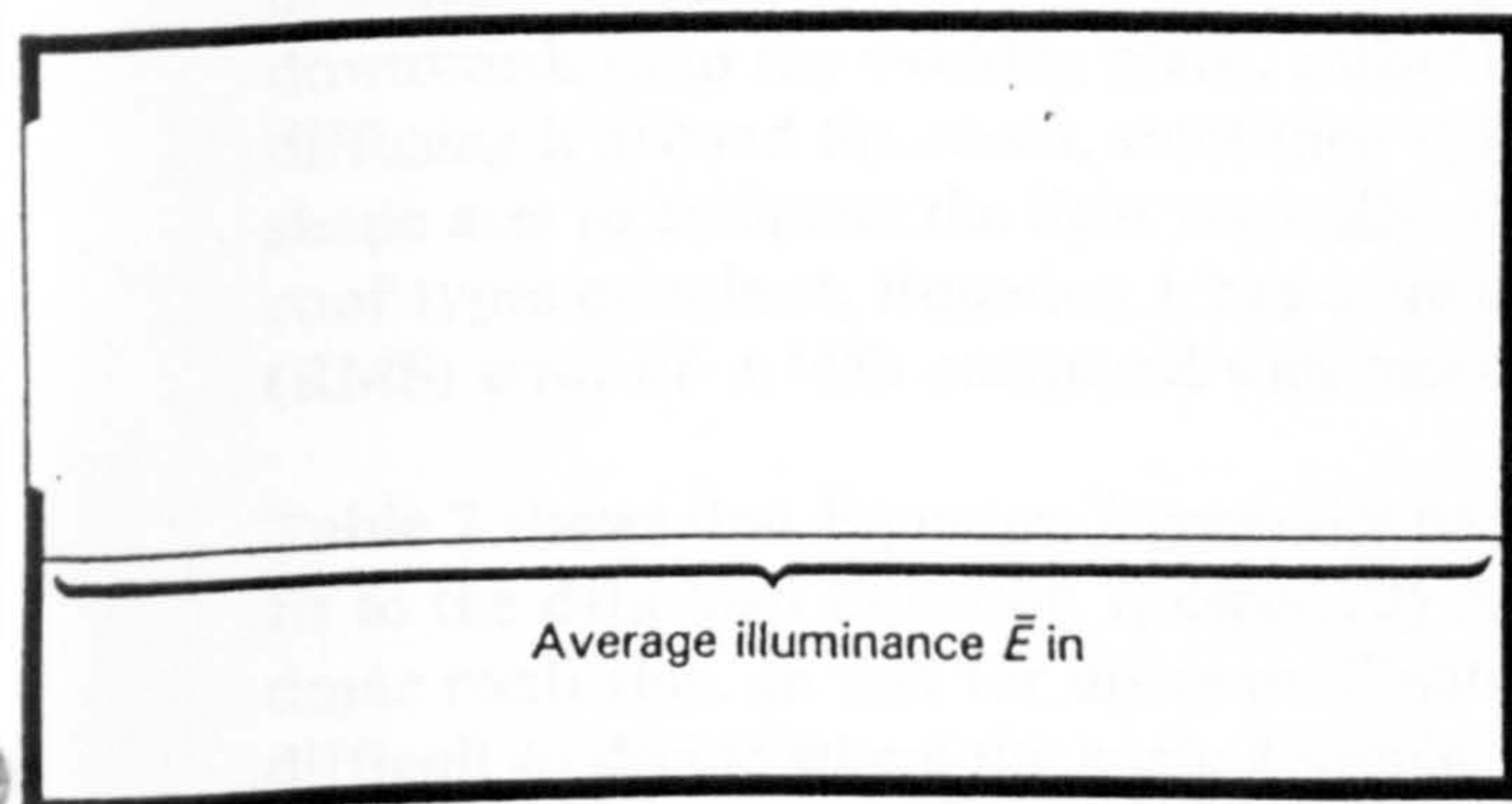


Figure 3 Definition of average daylight factor, \overline{DF}

Thus, at the early stages of window design, a target glazing area can be directly calculated from criterion values of average daylight factor. The CIBSE manual for window design⁶ gives recommended values for \overline{DF} in a number of types of interior; typically 5% for full daylighting, and 2% where supplementary artificial lighting is intended to be used. The resulting glazing areas can then be used as a starting point in design and in heat loss and solar gain calculations. Later on the exact shape and position of windows can be decided and, where necessary, the detailed daylight distribution checked, possibly using models. Then appropriate lighting controls can be chosen to maximise the energy effectiveness of the daylight³.

AVERAGE DAYLIGHT FACTOR IN SIDELIT ROOMS

Crisp and Littlefair⁷ derived the following formula, based on earlier work by Lynes⁸, for average daylight factor in rooms with side windows:

$$\overline{DF} = \frac{M W \theta T}{A (1 - R^2)} \%$$

where W is the total glazed area of windows

A is the total area of all the room surfaces (ceiling, floor, walls and windows)

R is the area-weighted average reflectance of the room surfaces

M is a correction factor for dirt and glazing bars⁹

T is the glass transmission factor

θ is the angle of visible sky (Figure 4).

When the predictions of this formula were compared⁷ against existing daylight factor data measured in model rooms, the formula gave good results, with a standard error of $\pm 10\%$ of the measured values.

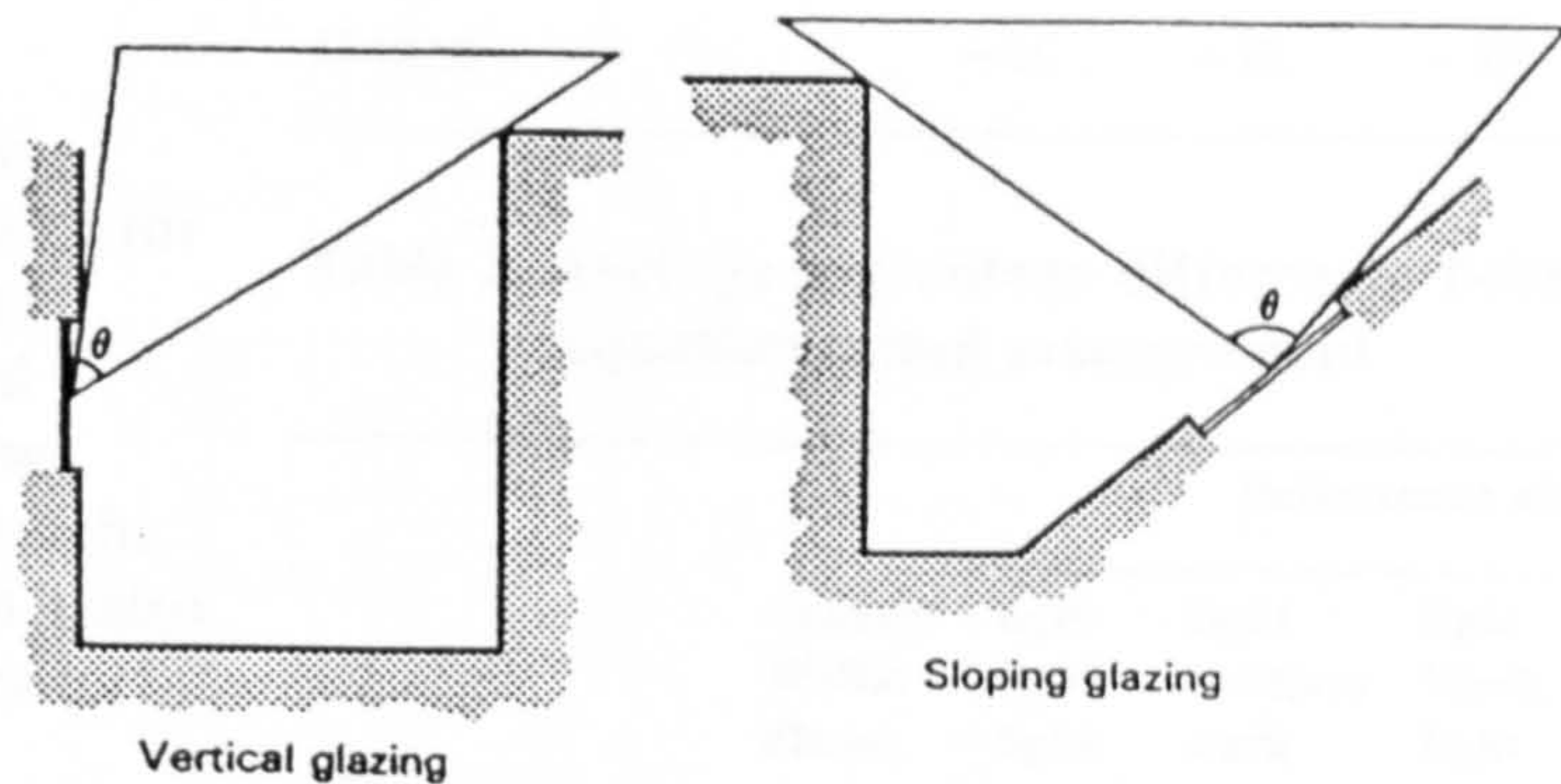


Figure 4 Definition of θ : the angle subtended, in the vertical plane normal to the window, by sky visible from the centre of the window

AVERAGE DAYLIGHT FACTOR UNDER ROOFLIGHTS

Recent work at BRE¹⁰ has been aimed at extending this simple formula-based approach to rooflit spaces. The two most widely applicable formulae for average daylight factor are:

$$\overline{DF} = \frac{2 M K W}{A (1 - R^2)} \% \quad \dots(1)$$

$$\overline{DF} = \frac{M W \theta T}{A (1 - R^2)} \% \quad \dots(2)$$

Note that Equation 2 is exactly the same as the formula for side windows, but angle θ will usually have a different value, as Figure 4 indicates. The difference between the two equations is that the first uses an obstruction coefficient, K , for the type of rooflight under consideration. Values of K have been calculated for a range of rooflight slopes and obstruction angles, and are tabulated in *BRE Digest 310*⁹. K can be as much as 88 for an unobstructed horizontal rooflight with single clear glazing, falling to 50 if tinted glass of 50% transmission factor is used. For an unobstructed vertical rooflight (single diffusing glass) K would be 37, falling to 19 with a 45° obstruction facing the rooflight⁹.

Figures 1 and 2 illustrate an experiment to check the accuracy of these two equations against measured data. Daylight factor measurements were made using a model placed in the artificial sky laboratory at BRE. A specially designed grid of points on the working

plane was used for measurements, then the mean value taken to find \overline{DF} . Any of six different roof profiles could be fitted on the model, and a removable internal partition and removable upper half of the walls enabled six different room shapes to be analysed. Thus the results would be applicable to smaller rooflit spaces as well as to large factories, or even to tall spaces like atria. The reflectances of the model could also be altered; both extreme values and typical values were chosen. Full experimental details are given in reference 10.

Tables 1 and 2 contain a summary of the results, presented as average percentage differences between calculated and measured average daylight factors for each roof type. These can reveal any systematic variations between the two, over the range of room shapes. A negative difference means that the measured values were greater.

Table 1 compares Equation 1 with the measured values. Generally the agreement is good, especially for flat and shed rooflights. For sawtooth rooflights Equation 1 usually underestimated the measured values, probably because the external roof of the model room was light coloured, reflecting extra light into the room. Under dome rooflights Equation 1 also tended to underestimate average daylight factors on the working plane. This is probably because, compared with other rooflight types, domes are unusually effective at directing the incoming light downwards onto the working plane, rather than diffusing it around the room, since their cylindrical shape acts to collimate the light vertically. Over all the roof types examined, Equation 1 had a standard (RMS) error of $\pm 14\%$ compared with measured data.

Table 2 shows that Equation 2 generally had a worse fit to the data than Equation 1, especially for the dome rooflights. In fact for dome rooflights it is difficult to decide where the angle θ should be taken from, and the reflected light from the dome skirt cannot be allowed for. For the other five roof types, however, Equation 2 had a standard (RMS) error of $\pm 19\%$ compared with the measurements. Nevertheless Equation 2 is very easy to use, and at the early stages of design this lack of precision may not be a handicap. It is worth remembering that the target values of average daylight factor (5% for a well daylighted space and at least 2% for areas with a mix of daylight and supplementary artificial light) are only approximate rules of thumb based on experience.

PRACTICAL USE

The CIBSE manual for window design⁶ describes how to use this method to determine window or rooflight sizes at the initial stages of design. First a target value of \overline{DF} is set, say 5% for a well daylighted room. Then glazing areas can be calculated directly using one of the two equations. Rearranging Equation 2, for example, we obtain:

$$\text{Glazing area } W = \frac{A(1 - R^2)\overline{DF}}{M\theta T}$$

Table 1 Average percentage differences between Equation 1 and measurement

Roof types	Reflectance set				
	Ceiling:	light	light	light	
	Walls:	light	medium	black	
Floor:	light	dark	light	black	
Flat		0	-6	-1	-3
Northlight (sloping glazing)		3	-4	10	25
Shed		-1	-5	0	2
Sawtooth (vertical glazing)		-20	-23	-12	36
Monitor		4	10	16	22
Domes		-16	-22	-23	-22

Table 2 Average percentage differences between Equation 2 and measurement

Roof types	Reflectance set				
	Ceiling:	light	light	light	
	Walls:	light	medium	black	
Floor:	light	dark	light	black	
Flat		-9	-15	-11	-12
Northlight (sloping glazing)		-24	-30	-20	-8
Shed		-17	-21	-16	-14
Sawtooth (vertical glazing)		-19	-23	-12	36
Monitor		6	13	18	25
Domes		-33	-38	-39	-39

With typical values of reflectance $R = 0.4$, glass transmission $T = 0.8$, maintenance correction $M = 0.7$ and $\overline{DF} = 5$, this reduces to:

$$\text{Glazing area } W = \frac{7.5A}{\theta}$$

Angle θ can be readily measured from preliminary drawings (Figure 4) as can room surface area A . This equation can give an initial glazing area which can then be used as a starting point in design.

CONCLUSIONS

The average daylight factor approach has considerable advantages over other daylight prediction methods which can only be used as a check once final window shape and position have been fixed; by this late stage in design it may be too late to alter glazing areas. Use of the formulae given in this paper ensures that adequate glazing areas are chosen from the start, and that daylighting is exploited positively and explicitly at critical stages in the design process.

ACKNOWLEDGEMENT

I would like to thank Mr G M Phillips who performed the measurements in rooflit model rooms while on secondment to BRE from North East Surrey College of Technology.

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SECTION A4 AIR INFILTRATION AND NATURAL VENTILATION

INTRODUCTION

Infiltration is the fortuitous leakage of air through a building due to imperfections in the structure—mainly as cracks round doors, windows or infill panels or between cladding sheets and such other joints or perforations as may exist in the structure. It is closely dependent on the construction, materials, workmanship and condition of a building, factors normally outside the control of the building services engineer.

Natural ventilation is the air flow resulting from the designed provision of specified apertures such as openable windows, ventilators, shafts, etc. and can usually be controlled to some extent by the occupant. Infiltration, on the other hand, cannot be so controlled.

Both infiltration and natural ventilation are at the mercy of natural forces, and cannot be relied upon to provide a constant rate of air interchange under all conditions. In particular, infiltration may sometimes be far in excess of fresh air requirements whilst in other circumstances it may be grossly inadequate. Therefore, the designer must always check to determine whether infiltration alone will provide sufficient fresh air or if additional means of supply, either natural or mechanical, will be required.

In the interests of economy of design of the heating installation and of fuel conservation, the building designer should endeavour to reduce infiltration by making the structure as airtight as possible when all doors and windows are closed. Where air change rates are suggested in this Section, these apply to the average case and the designer's judgement will determine whether deviation from the given value is warranted.

The rate of air flow through a building depends upon the areas and resistances of the various apertures (both intentionally provided and fortuitous) and the pressure difference across the building. The pressure differential may be caused either by wind, in which case air will enter through cracks and openings in the leeward side, or by differences in density of the air due to the indoor/outdoor temperature differences (commonly referred to as the 'stack effect'). In the latter case, air will move from low level inlets to high level outlets in a heated building or in the opposite direction if the air in the building is cooler than outside. Other factors which may influence the pressure distribution are the presence of atria, stairwells, lift shafts, flue shafts, ventilators and mechanical ventilation and exhaust systems.

NOTATION

A	= area of opening	m^2	N	= air change rate	h^{-1}
A_B	= equivalent area for ventilation by stack effect only	m^2	Q	= flow rate through opening ..	m^3/s
A_W	= equivalent area for ventilation by wind only	m^2	Q_B	= volume flow rate due to stack effect only	m^3/s
A_{rep}	= representative area	m^2	Q_T	= total volume flow rate	m^3/s
C_d	= discharge coefficient		Q_W	= volume flow rate due to wind only	m^3/s
C_i	= window infiltration coefficient	litre/s m	Q_r	= room infiltration rate	litre/s
C_p	= pressure coefficient		Q_i	= total infiltration rate	litre/s
F	= factor relating flow rate to applied pressure difference		Q_v	= volume flow rate	litre/s
$J(\phi)$	= function of angle of window opening		Q'_b	= basic infiltration rate per unit length of window opening joint	litre/s m
K_s	= parameter relating wind speed to nature of terrain		Q'_u	= uncorrected infiltration rate per unit length of window opening joint	litre/s m
L	= length of opening window joint (crack length)	m	a	= exponent relating wind speed to height above ground	
L_r	= crack length per unit area of glazed facade	m/m^2	a, b	= plan dimensions of building (glazed facades)	m

c	= specific heat capacity of air ..	J/kg K	t_1, t_2	= temperature of air column 1, 2 etc.	°C
f_1	= correction factor for geographical location		t_i	= mean inside air temperature ..	°C
f_2	= correction factor for internal resistance		t_o	= outside ambient temperature ..	°C
g	= gravitational constant (= 9.81) ..	m/s ²	\bar{t}	= mean of temperature t_i and t_o ..	°C
h	= height of building	m	u	= mean wind speed	m/s
h_a	= height of air column	m	u_m	= mean wind speed at 10m height in open country	m/s
h_o	= height of opening	m	u_r	= mean wind speed at height equal to the building height ..	m/s
h_r	= height of room above ground level	m	x	= increase in infiltration rate above average	%
n	= exponent relating volume flow rate to applied pressure difference		z	= height above ground	m
p	= mean pressure at any point on the surface of a building ..	Pa	ΔC_p	= difference in pressure coefficient	
p_o	= static pressure in undisturbed wind	Pa	Δp	= applied pressure difference ..	Pa
q_v	= ventilation allowance per unit volume of room	W/K m ³	Δt	= difference between t_i and t_o ..	°C
			ϵ	= ratio of areas of openings	
			ρ	= density of air	kg/m ³
			ϕ	= angle of window opening ..	degree

CALCULATION OF INFILTRATION AND NATURAL VENTILATION

Flow through Openings

The magnitude of the flow through an opening due to an applied pressure difference depends upon the dimensions and shape of the opening and on the Reynolds Number for the flow. In general terms this relationship may be written¹ as:

$$Q = A F \left(\frac{2\Delta p}{\rho} \right)^{0.5} \dots \dots \dots \text{A4.1}$$

where:

Q	= flow rate through opening	m ³ /s
A	= area of opening	m ²
Δp	= applied pressure difference ..	Pa
ρ	= density of air	kg/m ³
F	= factor relating flow rate to applied pressure difference	

The factor, F , depends upon the size, shape and nature of the opening and the value of the Reynolds number appropriate to the flow through the opening.

For openings with a typical cross-sectional dimension greater than about 10mm (i.e. most purpose built ventilators including air-bricks, open windows and doors etc.) F may be regarded as constant for the range of pressure differences which are normally expected, and is conventionally termed the discharge coefficient, C_d . For such openings, equation A4.1 may be written in the form:

$$Q = A C_d \left(\frac{2\Delta p}{\rho} \right)^{0.5} \dots \dots \dots \text{A4.2}$$

where:

C_d = discharge coefficient

The theoretical value of C_d for a sharp-edged opening is 0.61 and it is common practice to refer other openings, for which the airflow is governed by the square root of the pressure difference, to this value. Measurements of flow rate and applied pressure difference are used to calculate an equivalent area assuming a discharge coefficient of 0.61. This approach is particularly useful where the nature of the opening makes the determination of its geometrical area difficult.

For small openings, such as the cracks around openable windows, the form of the factor F is much more complex². However, for most practical applications equation A4.1 may be replaced by a simple power law expression of the following form:

$$Q_v = L C_i (\Delta p)^n \dots \dots \dots \text{A4.3}$$

where:

Q_v	= volume flow rate through small opening	litre/s
L	= length of opening (crack length)	m
C_i	= infiltration coefficient	litre/s m
n	= exponent relating volume flow rate to applied pressure difference	

where:

- Δp = pressure difference Pa
- h_a = height of air column m
- t_1, t_2 = temperature of air column 1, 2 etc. °C

For the range of temperatures found in practice, equation A4.6 approximates to:

$$\Delta p = 0.043 h_a (t_2 - t_1) \quad \dots \quad \dots \quad \dots \quad \text{A4.7}$$

The values in Table A4.2 have been calculated from this expression for a range of temperature differences and variations in height.

Table A4.2 Pressure differences due to stack effect.

$(t_2 - t_1)$ / (°C)	Pressure difference (P_a) for the stated vertical difference in height (m)				
	5	10	20	50	100
-10	-2.2	-4.3	-8.6	-22	-43
0	0	0	0	0	0
10	2.2	4.3	8.6	22	43
20	4.3	8.6	17.0	43	86

PREDICTION OF NATURAL VENTILATION AND INFILTRATION RATES

General

In principle, the airflow through a building and the ventilation rates of individual spaces within a building can be determined for a given set of weather conditions (i.e. wind speed, wind direction and external air temperature) if the following are known:

- (a) the position and characteristics of all openings through which flow can occur,
- (b) the detailed distribution of surface mean pressure coefficients for the wind direction under consideration,
- (c) the internal air temperatures.

In practice, because equation A4.1 and its simplified forms are non-linear and because of the number of flow paths likely to be present in any but the simplest building, solutions can only be obtained by computer methods. A number of programs, varying in degree of sophistication, for predicting natural ventilation and infiltration are available and some preliminary trials to validate these against measured data from full-scale buildings have been undertaken⁵. However, the predictions of such programs are only as accurate as the input data, as set out above and these are rarely known for existing buildings, far less for those at the design stage.

However, the magnitude and characteristics of natural ventilation and infiltration can be demonstrated by examining simplified situations. This is dealt with in the following sections.

Natural Ventilation Rates

Figure A4.1 represents a section through a simple two-dimensional building in which internal divisions are ignored and the openings are as shown. The openings are considered to be large, hence the flow through them is governed by equation A4.2. The equivalent areas are indicated and these may be taken as the minimum cross-sectional area perpendicular to the flow for large openings such as windows and doors. Table A4.3¹ gives experimentally determined values for a number of common types of smaller, purpose-built openings. Table A4.4^{1,3} shows schematically the expected air flow patterns for different conditions and gives the formulae from which the natural ventilation rate can be calculated.

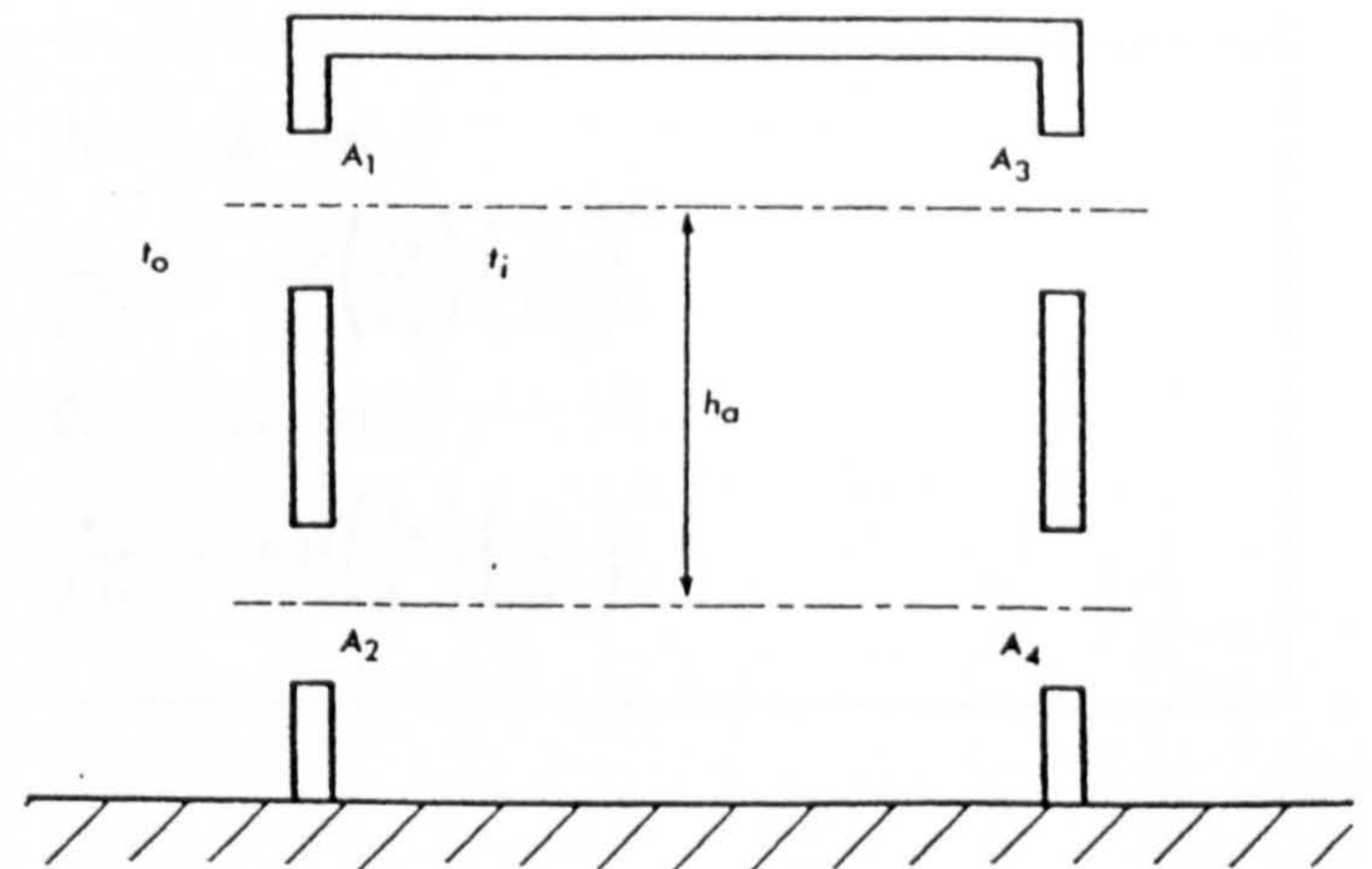


Fig. A4.1 Section through simple building – internal divisions ignored; see Table A4.4.

Table A4.3 Equivalent areas of ventilation openings.

Type	Overall size /mm	Equivalent area /mm
Air brick, terra cotta, square holes	225 × 75	1 400
Air brick, terra cotta, square holes	225 × 150	4 300
Air brick, terra cotta, square holes	225 × 225	6 400
Air brick, terra cotta, louvres	225 × 150	2 000
Air brick, terra cotta, louvres	225 × 225	4 300
Air brick, cast iron, square holes	225 × 75	7 200
Air brick, cast iron, square holes	225 × 150	12 700
Air brick, cast iron, square holes	225 × 225	19 600
Air brick, cast iron, louvres	225 × 75	3 100
Air brick, cast iron, louvres	225 × 150	11 300
Air brick, cast iron, louvres	225 × 225	19 200
Typical internal louvres grille	225 × 75	2 400
Typical internal louvres grille	225 × 150	7 200
Typical internal louvres grille	225 × 225	10 700

Table A.4.4 Cross ventilation of simple building.

Conditions	Schematic	Formula
(a) Wind only		$Q_w = C_d A_w u_r (.1 C_p)^{0.5}$ $\frac{1}{A_w^2} = \frac{1}{(A_1 + A_2)^2} + \frac{1}{(A_3 + A_4)^2}$
(b) Temperature difference only		$Q_B = C_d A_B \left(\frac{2.1 t h_a g}{(t_i + 273)} \right)^{0.5}$ $\frac{1}{A_B^2} = \frac{1}{(A_1 + A_3)^2} + \frac{1}{(A_2 + A_4)^2}$
(c) Wind and temperature difference together		$Q_T = Q_B \text{ for:}$ $\frac{u}{\sqrt{.1 t}} < 0.26 \left(\frac{A_B}{A_w} \right) \left(\frac{h_a}{.1 C_p} \right)^{0.5}$ $Q_T = Q_w \text{ for:}$ $\frac{u}{\sqrt{.1 t}} > 0.26 \left(\frac{A_B}{A_w} \right) \left(\frac{h_a}{.1 C_p} \right)^{0.5}$

The formulae given in Tables A4.4 and A4.5 illustrate a number of general characteristics of natural ventilation, as follows:

- (a) The effective area of a number of openings combined in parallel, across which the same pressure difference is applied, can be obtained by simple addition.
- (b) The effective area of a number of openings combined in series, across which the same pressure difference is applied, can be obtained by adding the inverse squares and taking the inverse of the square root of the total.
- (c) When wind is the dominating mechanism the ventilation rate is proportional to wind speed and to the square root of the difference in pressure coefficient. Thus, although ΔC_p may cover a range of 10:1, this implies a range of only about 3:1 in the resulting ventilation rates.
- (d) When stack effect is the dominating mechanism the ventilation rate is proportional to the square root of both temperature difference and height between upper and lower openings.

When wind and stack effects are of the same order of magnitude their interaction is complicated. However, to a first approximation, for the simple case illustrated, the actual rate may be considered equal to the larger of the rates for the two alternative approaches, taken separately. This is shown in Table A4.4 (c).

Whereas Table A4.4 deals with a situation in which cross ventilation is uninhibited by internal partitions, Table A4.5 deals with the opposite case, in which there is no cross ventilation and all air exchange must take place across openings in one wall. This is typical of the summertime situation for offices or classrooms adjoining a central corridor, the doors to which are kept closed.

Measurements⁶ have shown that the magnitude of the resulting 'single-sided' ventilation, while smaller than cross ventilation with similar areas of opening under comparable conditions, can be large enough to contribute to natural cooling with normally sized windows. Table A4.5 gives formulae which enable ventilation rates to be calculated for wind and stack effect. It is suggested that calculations are carried out using both formulae and the larger value taken. The formula for wind represents a minimum which will be enhanced up to threefold for certain wind directions.

Table A.4.5 Internal spaces with openings on one wall only.

Conditions	Schematic	Formula
(a) Due to wind		$Q = 0.025 A u_r$
(b) Due to temperature difference – two openings		$Q = C_d (A_1 + A_2) \left(\frac{\sqrt{2} \cdot c}{(1+c)(1+c^2)^{0.5}} \right) \left(\frac{\Delta t h_o g}{(\bar{i} + 273)} \right)^{0.5}$ $c = \frac{A_1}{A_2}$
(c) Due to temperature difference – one opening		$Q = C_d \frac{A}{3} \left(\frac{\Delta t h_o g}{(\bar{i} + 273)} \right)^{0.5}$ <p>If opening light is present:</p> $Q = C_d \frac{A}{3} J(\phi) \left(\frac{\Delta t h_o g}{(\bar{i} + 273)} \right)^{0.5}$ <p>Where $J(\phi)$ is given by Fig. A4.2.</p>

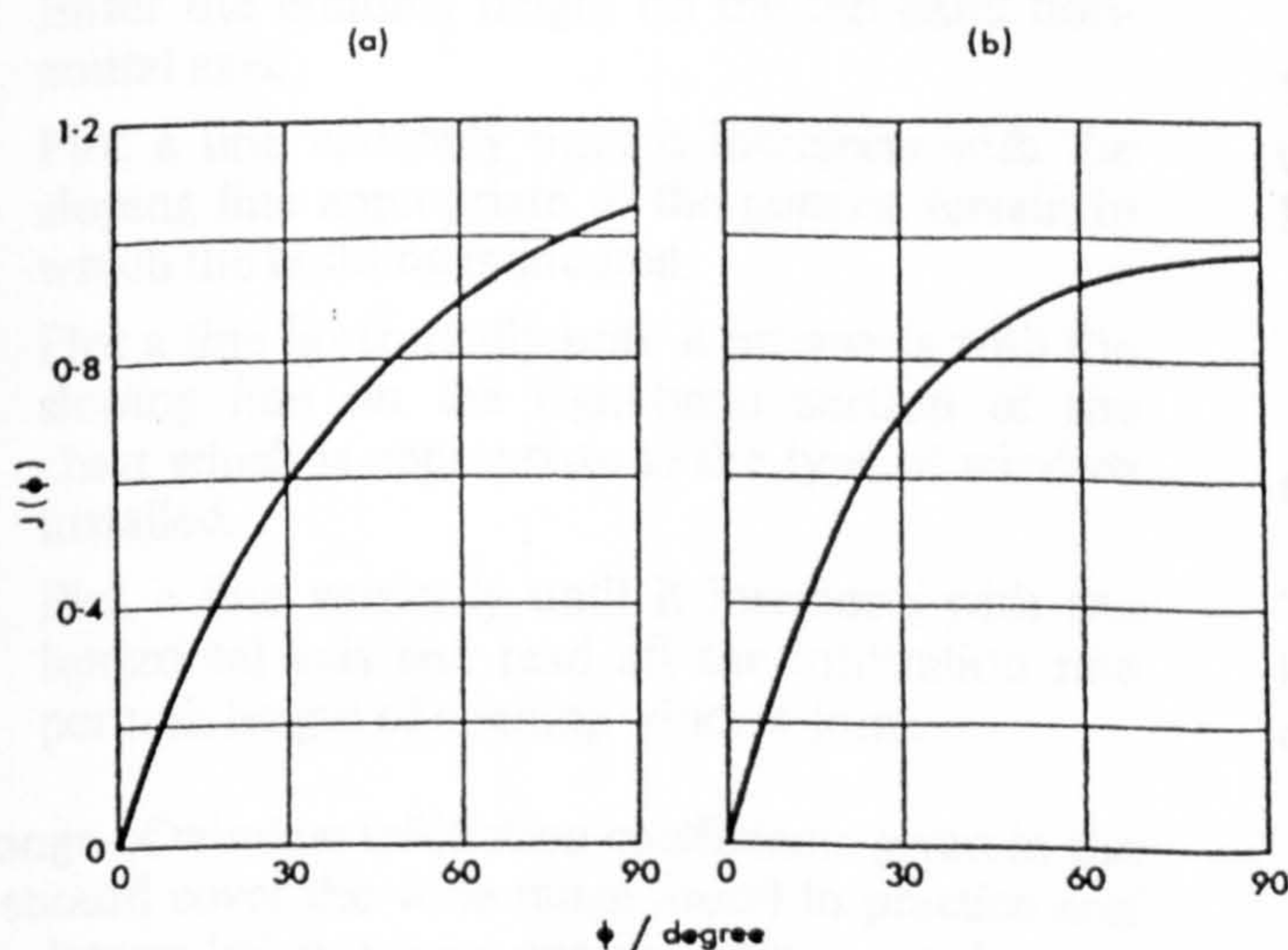


Fig. A4.2 Variation of $J(\phi)$ with angle of opening for: (a) side-mounted casement windows, (b) centre-pivoted windows.

Infiltration Rates for Design Purposes

Introduction

For design purposes the following procedure⁷ may be used where the building layout and window leakage characteristics are known. If these data are not available empirical values may be used, such as those tabulated later in this Section.

Infiltration Chart

The likely infiltration rate in a rectangular building may be determined by using the infiltration chart, Figure A4.3, which provides the basis of a simple technique for estimating infiltration from a knowledge of wind speed, building height, location and window characteristics.

The chart has been constructed on the basis of the following assumptions:

- (i) The difference in pressure coefficient across the building is 1.1.

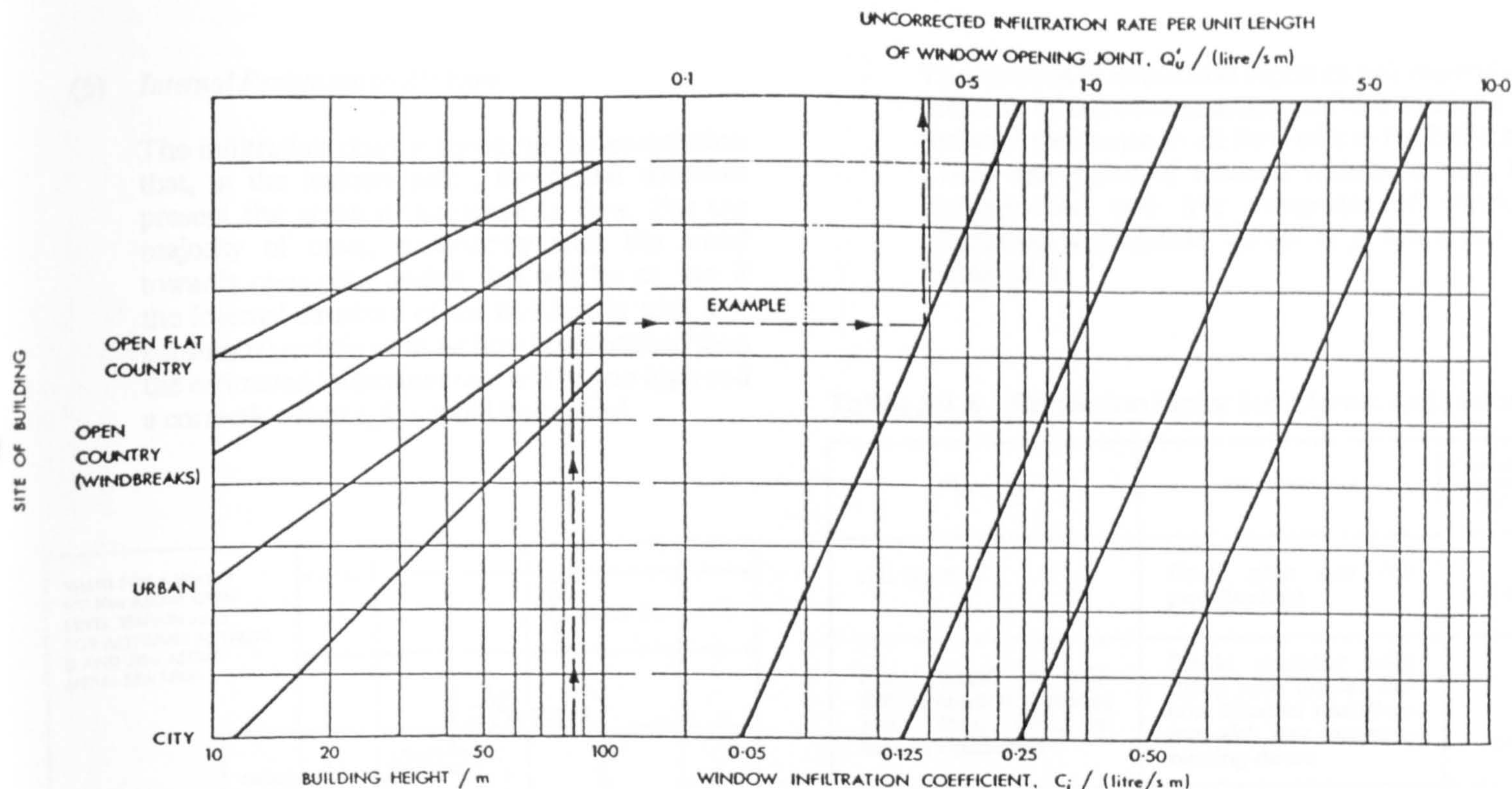


Fig. A4.3 Infiltration chart.

- (ii) The wind speed is that exceeded for 10% of the time.
- (iii) Flow through window cracks is of the form given in equation A4.3.
- (iv) The exponent, n , for flow through window cracks is 0.63.
- (v) The geographical location is assumed to give a 50% wind speed of 4 m/s.
- (vi) The window leakage characteristics are assumed to be identical on both sides of the building.

The sequence for using the chart is as follows:

- (a) Enter the building height on the left-hand horizontal axis.
- (b) Plot a line vertically until it intersects with the sloping line appropriate to the general terrain in which the building is situated.
- (c) Plot a line horizontally until it intersects with the sloping line on the right-hand section of the chart which is appropriate to the type of window installed.
- (d) Plot a line vertically until it intersects with the horizontal axis and read off the infiltration rate per unit length of opening window joint.

The range of window infiltration coefficients given in the chart should cover the wide range found in practice and enable interpolation where specific values are known. Table A4.6 lists upper limit values for different types of metal framed windows. In general a pessimistic estimate of window infiltration coefficient should be made to allow for infiltration through other small gaps in the building fabric.

Table A4.6 Air infiltration through windows.

Window type	Window infiltration coefficient for pressure difference of 1 Pa, C_i / (litre/s m)
Horizontally or vertically pivoted—weather stripped	0.05
Horizontally or vertically pivoted—non-weather stripped	0.25
Horizontally or vertically sliding—weather stripped	0.125
Horizontally or vertically sliding—non-weather stripped	0.25

Where appropriate, other more specific criteria may be used in place of Table A4.6 such as those defined in BS6375⁸.

Correction Factors

To determine an infiltration rate appropriate to a particular building it may be necessary to apply the following corrections to the rate obtained from Fig. A4.3.

(a) Geographical Location

In Figure A4.3 the geographical location is assumed to give a 50% wind speed of 4 m/s. The 50% wind speed for any chosen location may be found from Fig. A4.4, and where this differs from 4 m/s a correction factor, f_1 , may be determined from Table A4.7.

The crack length per unit area of glazing is given by:

$$L_r = \frac{\Sigma L}{2(a + b)h} \dots \dots \dots \text{A4.13}$$

where:

- ΣL = total crack length for building .. m
- a, b = plan dimensions of building (glazed facades) m
- h = height of building m

The representative area is given by:

$$A_{rep} = (a^2 + b^2)^{0.5} h \dots \dots \dots \text{A4.14}$$

The representative area may be thought of as the area through which the air passes from one side of the building to the other, and this depends on the number of walls in which openable windows are located, see Fig. A4.5.

For a building with sealed end walls (usually a long rectangular building) the representative area is the area of one of the glazed faces. In the case of a building with openable glazing on all four sides, the representative area is that of the vertical diagonal plane; this makes allowances for the increased overall infiltration with wind approaching at an angle other than perpendicular to one of the building faces.

The total rate of infiltration so derived will be the maximum expected at the design outdoor conditions and this value may be used in the calculation of heating load imposed on the central boiler.

For convenience, Table A4.10 gives values of the representative area for various building configurations.

Table A4.10 Representative areas.

$\frac{a}{b}$	$\frac{(a^2 + b^2)^{0.5}}{2(a + b)}$	A_{rep}	See figure
Any value if end walls are unglazed	0.5	ah	A4.5a
With glazing on all facades:	10	$10bh$	A4.5b
	4	$4.1bh$	
	2	$2.2bh$	
	1	$1.4bh$	A4.5c

Example

Find the total rate of infiltration and the infiltration in individual rooms for the purposes of sizing the central boiler plant and the room appliances in a twenty-storey rectangular plan building of 50m x 20m x 85m high, located in an urban area in central England. The building incorporates 5m x 5m x 3m high offices around its periphery and a central open-plan area at each floor level. Metal, horizontally-pivoted windows are fitted on all four sides of the building such that the length of opening joint (weather stripped) per unit area of glazing is 1.5m/m².

From the infiltration chart (Fig. A4.3) the mean pressure difference is determined for the building height of 85m (indicated by broken line on chart). The horizontal line is then traced until it crosses the line for the appropriate window infiltration coefficient, in this case, 0.05 litre/s m (see Table A4.6). A vertical line is projected from the point of intersection to the right-hand scale giving an uncorrected infiltration rate per metre of window-opening joint of 0.39 litre/s m.

This value is multiplied by 0.8 to correct for internal resistance, assuming that each office has a single door leading to the central area (see Table A4.8). Thus the basic average infiltration rate per unit length of opening window joint becomes:

$$Q'_b = 0.39 \times 1.0 \times 0.8 = 0.31 \text{ litre/s m}$$

(a) *Individual Rooms*

Multiplying Q'_b by the length of window-opening joint in the external wall of each office gives the average rate of infiltration for that office.

Thus infiltration rate for each room is:

$$Q_r = 0.31 \times 1.5 (5 \times 3) = 7.0 \text{ litre/s}$$

The infiltration rate should be adjusted for height of the room above ground level using Table A4.9. This shows that at the lowest floor the ventilation is 20% above average, the adjustment decreasing linearly to mid-height and zero thereafter.

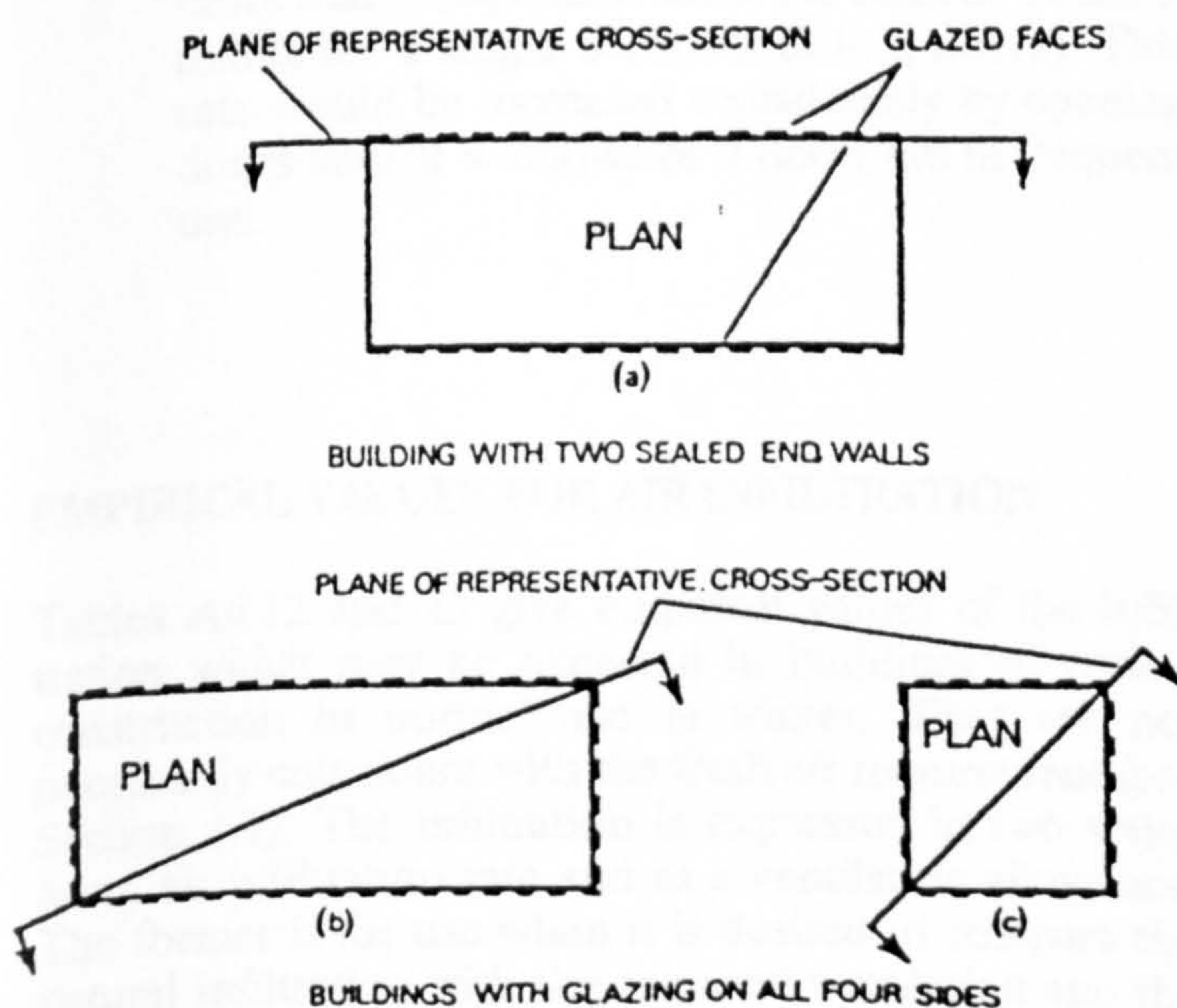


Fig. A4.5 Representative cross-sections.

Table A4.13 Rates of air infiltration on which heat loss calculations for factories should be based where number of occupants is unknown.

Construction	Air infiltration rate (h ⁻¹)	Ventilation allowance (W/m ³ K)
Multi-storey, brick or concrete construction:		
Lower and intermediate floors	1	0.33
Top floor with flat roof	1	0.33
Top floor with sheeted roof, lined	1 ¹ / ₄	0.42
Top floor with sheeted roof, unlined	1 ¹ / ₂	0.50
Single-storey unpartitioned spaces:		
Brick or concrete construction:		
Up to 300 m ³	1 ¹ / ₂	0.50
300 to 3000 m ³	³ / ₄	0.25
3000 to 10 000 m ³	¹ / ₂	0.17
Over 10 000 m ³	¹ / ₄	0.08
Curtain wall or sheet construction, lined:		
Up to 300 m ³	1 ³ / ₄	0.58
300 to 3000 m ³	1	0.33
3000 to 10 000 m ³	³ / ₄	0.25
Over 10 000 m ³	¹ / ₂	0.17
Sheet construction, unlined:		
Up to 300 m ³	2 ¹ / ₂	0.75
300 to 3000 m ³	1 ¹ / ₂	0.50
3000 to 10 000 m ³	1	0.33
Over 10 000 m ³	³ / ₄	0.25

Note: The rates of air infiltration given in this Table are those to be allowed for heat loss calculation, but additional allowances must also be made for exceptional conditions such as are produced by large doorways and ventilators, and also where the processes carried on require additional ventilation for the extraction of dust, fumes or other impurities.

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- ⁸ BS 6375: Part 1: 1983, Classification for weather-tightness (including guidance on selection and specification), BSI, London, 1983.

Appendix VI

Team Thinking Tools booklet

Introduction

The purpose of this booklet is to provide a collection of tools and techniques that can be used to facilitate team thinking and problem solving. The tools are designed to be used in a variety of settings, including meetings, workshops, and training sessions. The tools are intended to be used by teams of all sizes and in a variety of industries. The tools are designed to be used in a variety of ways, including as a starting point for discussion, as a framework for analysis, and as a means of generating ideas.

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Team Thinking Tools (T-3s)

Introduction

In this document you will find six 'Team Thinking Tools' (T-3s). These have been compiled and developed from a number of existing tools found in the design domain to encourage you to explore their potential as new ways of thinking about how to solve design problems. This 'Designing Together' workshop presents an ideal opportunity for you to try them out in a risk-free environment away from the pressures of your normal work.

It is believed that these tools may form the basis of a 'toolkit' of approaches to encourage innovative thought and introduce rigorous assessment to ensure that design options chosen for further development at the early stages of design are those with the most promise.

Pre-cursor to introduction of the T-3s

The successful designer will always have to apply some degree of individuality, in terms of rationality (evaluation) and intuition (creativity), if any design problem is ever to be solved. According to Jones (1992); 'The way in which the mixing of judgement and calculation is to be achieved is not settled, except for a particular problem and a particular person It depends upon the quantity of objective evidence available and upon the skill and experience of whoever is to do the mixing'.

It is apparent therefore that the individual designer, or a design team, must utilise a strategy that works for them. The work of Parmee (1996) has shown that several problems arise when attempting to integrate a design strategy into conceptual design. These difficulties include firstly, 'the appropriate representation of the design concepts and components' which allows 'the generation of alternative designs' and the formulation of 'an appropriate evaluation function in order to assess, in a meaningful manner, the relative fitness of these alternatives'. The purpose of T-3s is to provide this stimulation to generate alternatives and the means to evaluate them.

The primary benefit that a design team can achieve in agreeing upon a design process, while integrating a number of compatible T-3s is that it implicitly encourages the participants to think about the integration of interdisciplinary design issues. This in itself goes some way to addressing the problems outlined by Parmee, while additionally reducing the designer's preoccupation with his or her individual specialist discipline, instead provoking 'universal' thought about the problem at hand across the disciplinary domains.

You should find that the use of this selection of T-3s releases the expertise of the entire team rather than simply that of a few of its members. There is no hard and fast combination of design techniques that will work for all designers, on all problems. Rickards (1981) has stated that, in order to create the optimum design strategy, 'a matrix should be drawn up of techniques (T-3s) against problem types to suggest combinations in complex situations. Selection will be influenced by the nature of the problem, but also by the time available, degree of training, and size and composition of the group'.

Cross (1989) provides a wonderful analogy of the design strategy, which is based on football. He states that a design team, like a football team, must have a strategy. According to Cross, 'The football team's strategy for defeating the opposition will consist of an agreed plan to use a variety of plays or moves (i.e. T-3s, techniques, methods). During the game the, the choice of a move, and whether or not it is successful, will depend upon the specific circumstances, on the skill of the players, and on the response of the opposition'.

Cross elaborates further on this analogy, emphasising the importance of the team coach to the success of the team; 'The repertoire of moves used in a game is partly decided in advance, partly improvised on the field, and also amended at half time by the team coach. The coach's role is important as he maintains a wider view of the game than the players who are on the field. In designing it is necessary to adopt a similar role from time to time, in reviewing the project's strategy and progress'.

Thus, it is apparent that before attempting to undertake any actual design work *per se* the designer(s) must 'design' a flexible design strategy with which to approach the problem, in the form of a number of methods that seem most appropriate to the design problem as it evolves. This is summarised by Cross (1989), who states that a design strategy should provide the design team with two things:

1. A *framework* of intended actions within which to operate, and
2. A management *control* function enabling you to adapt your actions as you learn more about the problem and its responses to your actions.

The key question to ask at this point is - is it difficult to produce a useable design strategy? At present, the answer seems to be yes. The reason for this lies in the fact that the true nature of the design problem cannot be fully understood until an attempt has been made at a solution, and to do this the design team must first have been formed. It is only as the team members begin to interact, and their personalities and prejudices become more apparent, that the strengths and weaknesses of the unit can be diagnosed and appropriate design techniques can be prescribed. As Jones (1992) explains, 'there is not enough yet known about the behaviour of designers, or design problems, to attempt an explanation that could be verified by observation and experiment. We can only classify and speculate in the hope of making it easier to understand what it is that makes the construction of an effective design strategy, in which rational and intuitive methods are combined, so difficult for many people to do and for anyone to explain'. The tools offered here, part rational and part intuitive/creative, should encourage reflection on the processes of invention and design and be useful in their own right.

This document provides guidance on the nature and use of a number of T-3s that can be applied during creative and evaluative periods of the conceptual design phase.

The Creative T-3s

The Creative Design T-3s

According to Morgan (1993); 'In organisations there are many things that seem to work against good ideas and change. We need to change the way we structure work to allow us to tap into our one untapped natural resource - our people'. In stating this Morgan is referring to the creative minds of the workforce in general, and this is primarily what the creative T-3s attempt to do; tap into the creative aspects of the designer's mind.

Probably the most influential writer on creative thought is Edward de Bono, who has generated many techniques to aid in the promotion of lateral thinking. These T-3s, which have been described as 'creative problem solving techniques' (CPSTs) by Rickards (1980), have been applied within a very diverse field of industries and have met with a relatively high level of success. As de Bono (1992) explains, 'most of these tools have been shown to work systematically and effectively through years of use with different people in different cultures. There is no question that these tools do work'. According to Cross (1989) 'they (creative T-3s) generally work by trying to increase the flow of ideas, by removing the mental blocks that inhibit creativity, or by widening the area in which a search for solutions is made'. A definition that has been elaborated by Rickards, when he describes a CPST as being 'a set of procedures that can be deliberately introduced as an attempt to stimulate novel and relevant ideas or solutions to problems (during individual work or as part of a meeting)'.

The following pages provide an overview of several of the creative design techniques.

1.

Forced Analogies

Aim:

To stimulate ideas by encouraging comparison with unrelated items.

Additional Information:

Creative thinking often draws on analogical thinking - on the ability to see parallels or connections between apparently dissimilar topics. '*Forced analogies*' is a very useful and fun method of generating ideas. The principle behind it is the comparison of the problem with something else that has little or nothing in common with the task at hand, the aim being to provide the designer with new insights as a result.

Forcing relationships is one of the most powerful ways to develop new insights and new solutions. A useful way of developing the relationships is to have a selection of objects or cards with pictures to help you generate ideas. Choose an object or card at random and see what relationships you can force.

Forced analogies like brainstorming can be a group activity where the individuals attempt to build and develop creative solutions to a problem, without criticising any suggestions made. The difference between *forced analogies* and *brainstorming* is that the aim in *forced analogies* is to work towards a particular solution, rather than generating a large number of ideas.

Procedure:

1. Select a group of individuals with a diverse knowledge base, flexibility of thinking, and experience.
2. The group should analyse the problem, in an attempt to make the strange seem familiar and then to make the familiar strange. Some examples of analogies are: -
 - **Direct** -(*worldly*) these are usually found by seeking a biological solution to a similar problem i.e. 'Velcro' fastening was originally created through a direct analogy to plant burrs.
 - **Personal** -(*unworldly*) the team try to imagine what it would be like to use themselves as the system or component being designed i.e. how would I operate if I were a computerised filing system?
 - **Symbolic** -(*bodily*) poetic metaphors and similes are used to relate aspects of one thing with aspects of another i.e. the 'friendliness' of a computer, the 'head' and 'claw' of a hammer, a 'tree' of objectives.
 - **Fantasy** -(*abstract*) these are impossible wishes for something to be achieved in a 'magical' way i.e. 'what we really need is for the bumps in the road to disappear beneath the wheels' (suspension system).
3. The analogies are used to open up lines of development, which are pursued as hard and as imaginatively as possible by the group.

Typical Application

According to Jones, forced analogies appears to suit only the middle stages of designing. However, the technique may be not only applicable to, but also highly effective in, initial concept generation. This T3 is intended to throw up a general solution to a recurrent problem, but in this application it will be used to encourage innovative thought.

Ease of Use:

Typically *forced analogies* best suits a group that is open minded and prepared to be imaginative.

Shaw (1986) has shown that a good pattern of action to encourage this type of thinking may involve observing a relatively trivial occurrence in nature, understanding the performance of some clever product or transferring knowledge gained in work performed in one field to that of another.

Shaw explains that if such a pattern is followed repeatedly by an individual, in time it can and will lead to improved creative ability.

Example:

Assume that the problem is to invent a means of cleaning the façade of a high rise building. All pre-conceptions are banished, with the aim being to think across the problem while letting the imagination 'run wild'. The following is a synopsis of a discussion of the problem:

'Right, well I suppose you could make every separate façade panel revolve like a window can, so you could have a twist-and-clean cladding panel'.

'Yes, and if they were like the revolving doors in supermarket entrances you could have a different panel every 90 degrees. You could have a choice of four panels depending on what mood you were in and clean the three that weren't being used'. (Direct analogy mechanism)

'When we get dirty we just have a bath. Why don't we just get it to clean itself?'

'What, like give it a bar of soap and a sponge and ask it to take a shower when it feels a little dirty?!'
(Personal analogy)

'Yes, almost. A car windscreen can do it. Let's just put an enormous set of windscreen wipers on the side and hey presto! Or even give each separate façade panel a wiper of its own. Why not?' (Direct analogy)

'Wait a minute, I'll tell you what. Lets phone 'rent a ghost' and ask them to send us an apparition that will fly around the outside of the building cleaning as it goes! We might even save some money if it has it's own bucket and sponge!' (Fantasy analogy)

'Let's just train a giant spider; now that's a possibility!' (Fantasy analogy)

'Yes. We could get it to crawl (Symbolic analogy) around the building cleaning as it goes. In this way it could travel anywhere on the building façade cleaning any part easily'.

'Well, doesn't a drawing board mechanism do that when a horizontal slide is attached to the straight edge? (Direct analogy mechanism) That allows any point on the sheet of paper to be reached by the tiny point of a pencil. Proportionally speaking, I bet that is far more intricate than a sponge on a multi-storey office block!'

Thus, we begin to see a possible solution forming. A vertical runner and a horizontal runner that allow a mechanism for cleaning the façade panels to move over of a building surface.

For Further Reference See:

Gordon (1961)
Cross (1989)
Shaw (1986)
Jones (1992)

2.

Six Thinking Hats

Aim:

The T3 aims to promote fuller input from more people and 'separate ego from performance'.

Additional Information:

The six hats represent six modes of thinking and are directions to think rather than labels for thinking. That is, the hats are used proactively rather than reactively. Everyone is able to contribute to the exploration without denting egos as they are just using the yellow hat or whatever hat. The six hats system encourages performance rather than ego defence. People can contribute under any hat even though they initially support the opposite view.

The key point to remember when implementing this T3 is that a hat is a direction to think rather than a label for thinking. The theoretical reasons for using the '*six thinking hats*' are to:

- Encourage Parallel Thinking
- Encourage full-spectrum thinking
- Separate ego from performance

Procedure:

There are six metaphorical hats and the thinker can put on or take off one of these hats to indicate the type of thinking being used. This putting on and taking off is essential. The hats should not be used to categorise individuals, even though their behaviour may seem to invite this. When done in a group session, everybody wears the same hat at the same time and approaches the problem at hand from the viewpoint of the hat they are wearing at that time.

The hat classifications are:

White Hat thinking

This covers facts, figures, information needs and gaps. 'I think we need some white hat thinking at this point...' means, 'let's drop the arguments and proposals, and look at the data base'.

Procedure continued...

Red Hat thinking

This covers intuition, feelings and emotions. The red hat allows the thinker to put forward an intuition without any need to justify it. 'Putting on my red hat, I think this is a terrible proposal'. Usually feelings and intuition can only be introduced into a discussion if they are supported by logic. Usually the feeling is genuine but the logic is spurious. The red hat gives full permission to a thinker to put forward his or her feelings on the subject at the moment.

Black Hat thinking

This is the hat of judgement and caution. It is a most valuable hat. It is not in any sense an inferior or negative hat. The black hat is used to point out why a suggestion does not fit the facts, the available experience, the system in use, or the policy that is being followed. The black hat must always be logical.

Yellow Hat thinking

This is the logical positive, i.e. why something will work and why it will offer benefits. It can be used in looking forward to the results of some proposed action, but can also be used to find something of value in what has already happened.

Green Hat thinking

This is the hat of creativity, alternatives, proposals, what is interesting, provocation's and changes.

Blue Hat thinking

This is the overview or process control hat. It looks not at the subject itself but at the thinking about the subject. 'Putting on my blue hat, I feel we should do some more green hat thinking at this point'. In technical terms, the blue hat is concerned with meta-cognition.

Typical Application

The six hats T3 is said to be most useful in a situation when argument is likely, when protagonists get locked into their positions and become more interested in winning or losing the argument than in exploring the subject. Its power is as a tool to bypass egos and to stop designers being negative persistently, while promoting the creation of space for positive and creative thinking. This T3 can be used systematically in an agreed sequence as part of a specific exercise or occasionally to ask someone for a different perspective, i.e. if someone is asked to 'stop being so negative' the person is likely to be offended. But if they are asked to 'try the yellow hat' then there is no offence.

Ease of Use:

The principles are easy to understand and as such, the six hats T3 is relatively simple to utilise.

For Further Reference See:

'Six Thinking Hats' (de Bono, 1986)

'Engineering Creative Design', (John Culvenor and Dennis Else, 1995)

3.

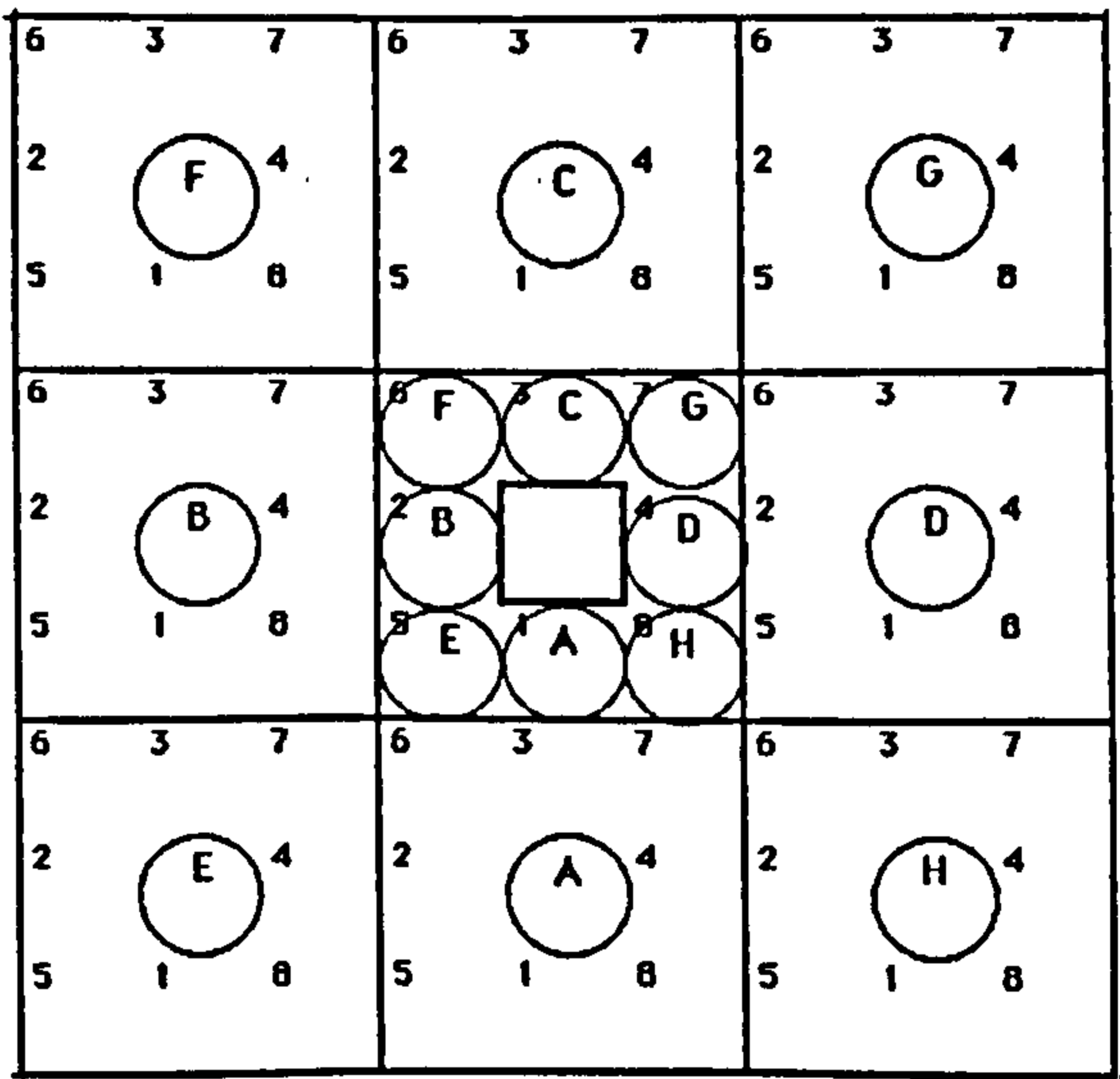
Lotus Blossom/Mind Map

Aim:

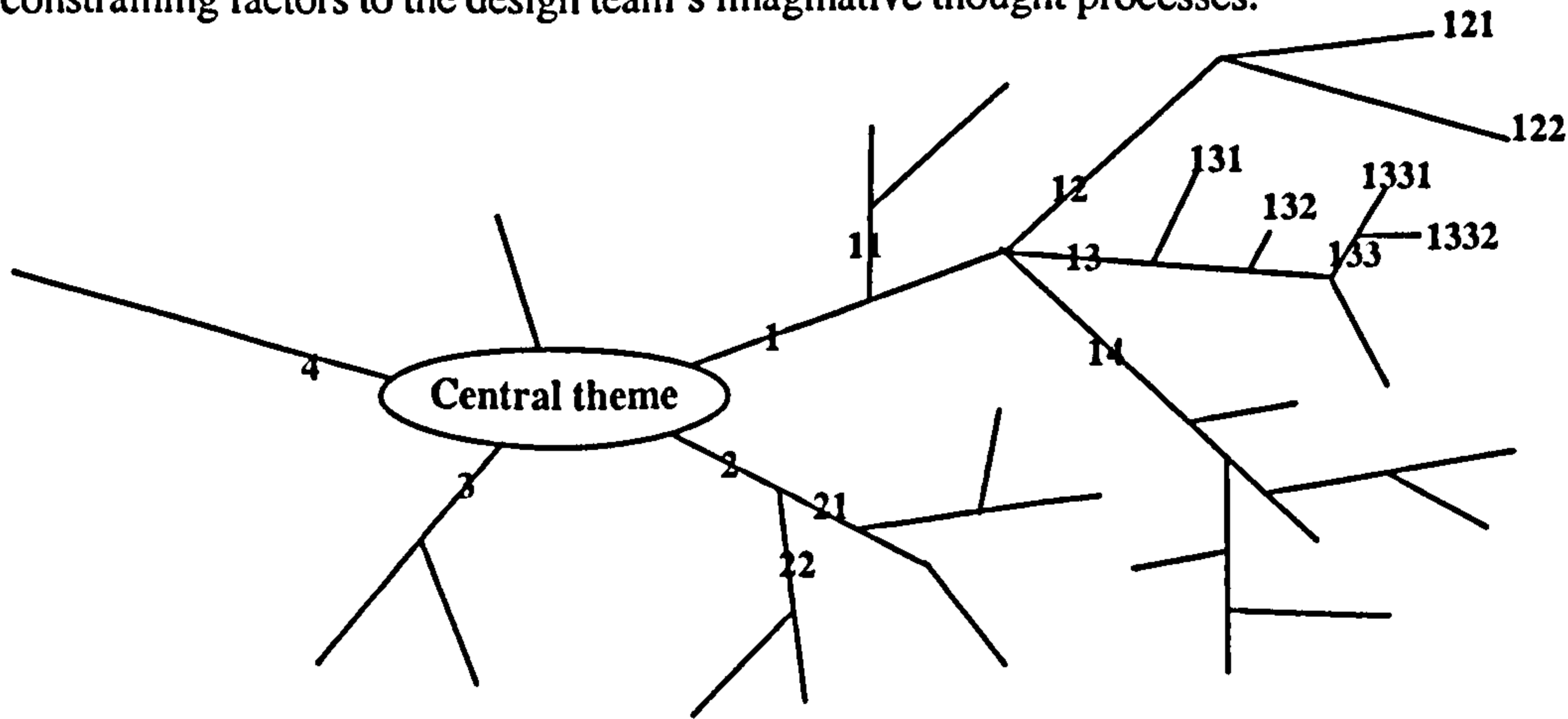
To direct the thought process, allowing leads to be investigated without breaking the designer's or design team's original train of thought. It simultaneously records the idea generation pattern.

Additional Information:

The Lotus Blossom involves starting with a central theme or problem and working outward, using ever-widening circles or 'petals'. Central themes lead to ideas that themselves become central themes, and so forth. The unfolding themes trigger new ideas and new themes.



Mind mapping again visually represents a designer's, or group of designer's, thinking and ideas on a subject, but it does so without dictating a specified number of creative input points. This T3 follows the same fundamental procedure as lotus blossom, but it does so without pre-structuring the pattern of thought, and as such, does not provide any constraining factors to the design team's imaginative thought processes.



In practice it is assumed that the design team will utilise the optimum version for them and as such, it is the responsibility of the team to decide which of the versions will produce the optimum level of creativity from the members involved.

Procedure:

Lotus Blossom

1. Write your central theme or problem in the diagram's centre.
2. Think of related ideas or applications and write them in the surrounding circles (those labelled A - H).
3. Use the ideas written in circles ADH as central themes for the surrounding boxes.
4. Try to think of eight new ideas involving the new central theme, and write them in the squares surrounding it. Use the idea stimulators to help you generate ideas. Fill out as many boxes as you can.
5. Continue the process until you've completed as much of the diagram as you can.
6. Combine elements of each of the boxes to generate solution options.

Mind mapping

1. Write your central theme or problem in the centre of a sheet of paper.
2. Think of a related ideas or applications and use these titles as the first branches or sub-sections of the central theme.
3. Consider each new sub-theme in depth and draw sub branches from this representing the design team's thoughts on relevant sub-sub sections.
4. Try to think of as many new ideas involving each sub-branch, and write them as sub-sub branches. Each idea branch route should be progressed until exhausted.
5. Continue the process until all branches have been exhausted of ideas.
6. Combine elements of each of the boxes to generate solution options

Typical Application

Both variations of this T3 can be used in any design activity where ideas need to be generated and recorded formally. The technique itself may be used with a rapid idea generating technique (such as brainstorming or synectics) for optimum results. It allows the design team to come up with a number of variations on the original theme, and then repeat this around sub-themes. In this way it records the design progression, while ensuring that the team design activity is co-ordinated

Ease of Use:

Neither of these T3s requires any formal training as such, but they do require the individual recording the generated data to have reasonable facilitation skills.

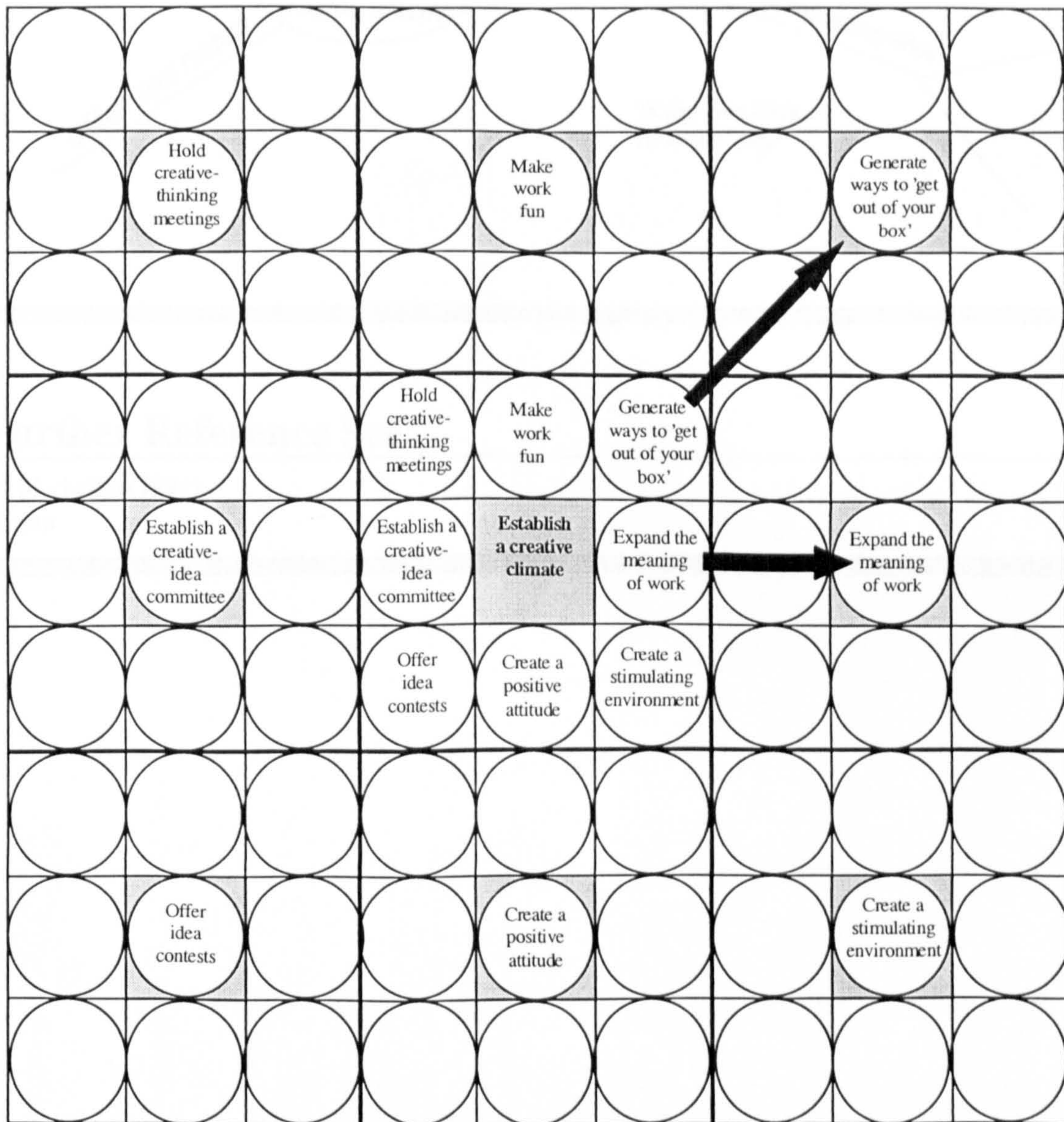
Example:

Lotus Blossom:

One company's central theme was 'establishing a creative climate'.

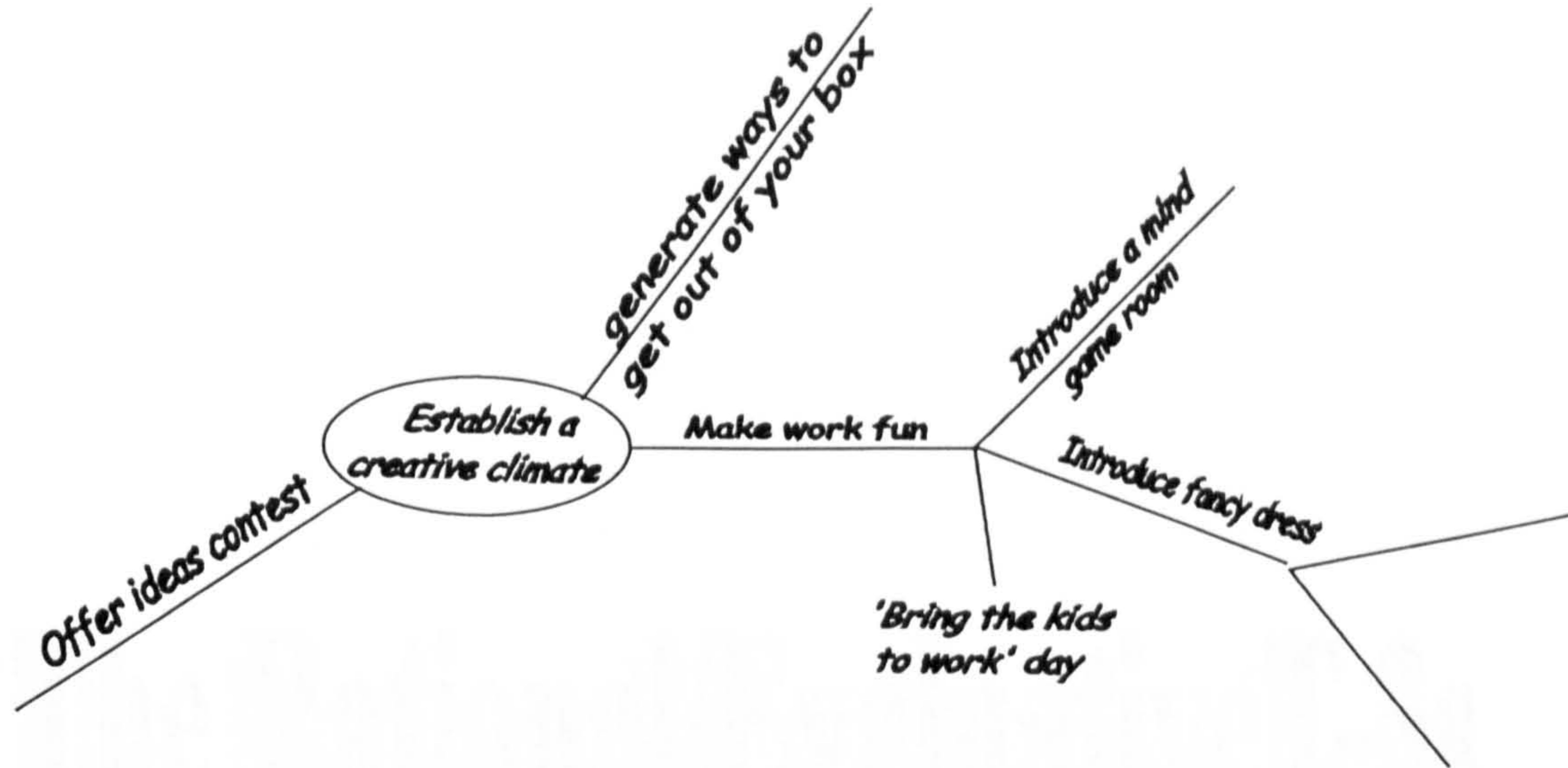
They surrounded this statement as shown in the diagram below.

E.g.: Where they had written, 'generate ways to get out of your box' in the circle, they copied it into the corresponding outer circle and labelled it as such, where it became the central theme for the new box, and so on.



Example continued:*Mind mapping:*

Using the same example as above.

**For Further Reference See:**

Michael Michalko (1994)
Tony Buzan.

The Rational/Evaluative T-3s

The rational/evaluative design T-3s.

It is apparent that the T-3s outlined previously can, and will, aid in the production of creative concepts and ideas when non will come. But then the real work must begin; very broadly speaking, the concept must be evolved and developed to a stage when it is considered capable of being realistically evaluated against other feasible options, and then a choice must be made. These are the design developments that can be aided by the rational design T-3s. Here, we are concerned with a specific sub-set of the rational design T-3s: The evaluative T-3s.

Some consider the rational design T-3s to be the real design techniques; those which encourage a more stringent and systematic approach to design activity. However, this does not mean to say that the creative design aids described previously should be considered the exact opposite of the rational T-3s. In fact, 'rational methods often have similar aims to the creative methods, such as widening the search space for potential solutions, or for facilitating team work and group decision making' (Cross 1989), and therefore, 'creative methods and rational methods are complementary aspects of a systematic approach to design' (Jones 1992).

Many of the more creative designers are very unsympathetic towards the rational T-3s, as they feel that they can constrain innovative thought. Rational decision, it is argued, can be undertaken by a computer, and as such 'the picture of the rational, or systematic, designer is very much that of a human computer. A person who operates only on the information that is fed to him, and who follows through a planned sequence of analytical, synthetic and evaluative steps and cycles until he recognises the best of all possible solutions' (Jones 1992). However as Cross explains, 'this is a complete misunderstanding of the intentions of systematic design, which is meant to improve the quality of design decisions, and hence the end product'. He elaborates further in stating that 'rather than being perceived as a straightjacket, they (rational T-3s) should be seen as a lifejacket, helping the designer to stay afloat'.

The following pages provide an overview of several of the evaluative T-3s.

1.

Isolated option testing (IOT)

Aim:

To find the limits within which an acceptable solution or sub-solution lies as a means of testing a single option against a set of criteria.

Additional Information:

This technique represents the amalgamation of two individual techniques: *Boundary searching* and *pros and cons*. This hybrid combines the key attributes of the two individual techniques, generating a single T3 which allows a single solution and its elements to be tested against a set of pre-specified criteria. The key aims of applying this technique are to:

- a) Reduce the risk of having to repeat design activity because of design errors discovered later.
- b) Create room for manoeuvre between limiting dimensions so as to minimise subsequent compromises between conflicting requirements.
- c) Allow a single solution to be tested and evaluated without having any alternative solutions to compare it against.
- d) Generate design information that is usable for future similar design activity, as well as the project at hand.

There is little chance that the above aims will be achieved unless a concerted effort is made to plan rationally the search for dimensional boundaries.

The pros and cons with weighting element of this T-3 can be criticised owing to the fact that the pros and cons are not ranked prior to weighting. This is not undertaken because it is a quick evaluation tool, however if a more stringent procedure is felt to be required its inadequacies can be addressed by applying the T-3: *Ranking & weighting*.

Procedure:

1. Write a set of criteria that encapsulates the critical attributes, performance specifications and critical conditions that influences the solution or its elements.
2. Define, as accurately as possible, those particular sets of criteria in which uncertainty exists.
3. Define the range of options which satisfy the specified performance requirements of each of those criteria sets in which uncertainty lies.
4. Taking each criteria set in turn, the group members produce a list of the pros and cons of each particular option which satisfies the stated requirements sufficiently.
5. Each pro and each con is given a weighted score out of ten. This can be done by reaching group consensus through discussion, or taking each individual's weighting and calculating the average.
6. At the end of the exercise, the pros and cons are totalled respectively.
7. If the pros outweigh the cons then that option is worthy of further consideration, if the opposite is the case then the idea is disregarded completely. If the pros outweigh the cons in both cases then it is assumed that both are feasible options that will satisfactorily meet the specification requirements. As such, the pros and cons procedure must be repeated, but with both options being judged on the independent lists previously produced, as a means of comparing one option against the other.
8. The outcome of this procedure could well produce a compromised solution, which incorporates elements of each of the possible solution proposals and as such, is a feasible hybrid option.

Example cont....

Taking each criteria set in turn, the group members produce a list of the pros and cons of each particular option which satisfies the stated requirements sufficiently, and apply a weighting out of ten to each. At the end of the exercise, the pros and cons are totalled respectively.

(a) Rectangular Ductwork:

<u>PROS</u>		<u>CONS</u>	
Inexpensive	8	Requires high aspect ratio	7
Little or no loss of air	5	Difficult to install	5
Low noise	2	Additional cost of transport and installation	2
<hr/>		<hr/>	
<u>15</u>		<u>14</u>	

(b) Builders work voids:

<u>PROS</u>		<u>CONS</u>	
No hardware required	8	Must ensure air tight structural voids	9
Use pre-existing structure	4	Air must be channelled to some extent	5
No need to route ductwork	2	Very noisy system	4
<hr/>		<hr/>	
<u>14</u>		<u>18</u>	

Each option is initially considered independently. If the pros outweigh the cons then it that option is worthy of further consideration, if the opposite is the case then the idea is disregarded.

If the pros outweigh the cons in both cases then it is assumed that both are feasible options that will satisfactorily meet the specification requirements. As such, the pros and cons procedure must be repeated, based around the independent lists previously produced, as a means of comparing one option against the other.

In the example case option (a) should be forwarded, while option (b) should be disregarded.

For Further Reference See:

This 'hybrid' T3 has evolved from two individual techniques: *Boundary searching* and *pros and cons*. Users can refer to Jones (1992) for further information on the two techniques that were combined to produce it.

2.

Ranking and Weighting

Aim:

To compare a set of alternative designs through the application of a common scale of measurement.

Additional Information:

Totals arrived at by ranking and weighting can be misleading because scraps of information are being abstracted from reality and fitted together into arithmetical relationships that are probably different from their relationships in practice. However, the frequency with which *ranking and weighting* is used without suffering disaster suggests that these errors are not big enough to make a difference. But, the final decision must always rest in the hands of the design team and a discussion should always take place when results appear dubious.

The first stage of this T-3 is commonly known as *Paired comparisons* and is a form of *interaction matrix* analysis. As such, it can be applied at any stage of the design process where a choice must be made or an evaluation is required. It is probably the most simple of the various forms of matrix analysis that have been generated, which is why it is an ideal T-3 to introduce to newly formed design teams, as well as to designers who have little experience in the use of evaluative design methods.

Procedure:

This procedure can be utilised by a team working jointly, or alternatively each team member can work through the evaluation individually and then compare their results with the other team members.

1. Identify the objectives that the alternative designs are to satisfy.
2. If the objectives are to be ranked:
 - (a) Record on a matrix the preferred objective of each pair using a method such as an Interaction Matrix.
 - (b) Rank the objectives in order of their preference scores.
3. If the objectives are to be weighted:

Assign an index number to each objective to indicate its importance relative to the others, i.e. the first objective might be considered to be of value 60, the second of value 20, and the third and fourth of value 10 each.
4. Measure or estimate the degree to which each alternative design satisfies each of the ranked or weighted objectives.
5. Convert these measures or estimates to percentages, in the case of ranked objectives, and to values of the index numbers, in the case of weighted objectives.
6. Select the alternative design having either the preferred pattern of percentages or the highest total of weighting index numbers.

Typical Application:

Some people (Jones 1992) believe that these techniques are invalid, however, they may reduce the difficulty of taking decisions. Bearing this in mind, the technique can be applied to any design scenario as a means of evaluating several alternative solutions.

Ease of Use:

This T3 is very straightforward and, as such, should be quite simple for designers to grasp and apply. However, it is only a very crude form of optimisation and as such, does not negate the need for a full understanding of mathematical principles when applying numbers in an arbitrary fashion to a list of variables that are hard to measure.

Example:

The design team must select an HVAC system for an extension to a large office building. The possible system types that have been forwarded are:

1. Displacement system in extension.
2. Chilled beam with perimeter heating and fresh air units.

Identify the objectives that the alternative designs are to satisfy.

- a) Low noise emissions from system when working at full capacity.
- b) Low to medium prime cost expenditure.
- c) Life cycle costs are low.
- d) System is environmentally conscious.

Record on a matrix the preferred objective of each pair

(Construct table with objectives shown in corresponding rows and columns (an interaction matrix). Give each unit of the matrix a score as follows:

1=objective in row is preferred over objective in column.

0=objective in column is preferred over objective in row.

<i>Objectives</i>	a)	b)	c)	d)	<i>Totals</i>
a)	-	0	0	0	0
b)	1	-	0	0	1
c)	1	1	-	0	2
d)	1	1	1	-	3

Rank the objectives in order of their preference scores.

1st = d) System is environmentally conscious.

2nd = c) Life cycle costs are low.

3rd = b) Low to medium prime cost expenditure.

4th = a) Low noise emissions from system when working at full capacity.

To weight the objectives.

Allocate each objective with an importance weighting relative to the others based on the designer's or design team's judgement. For example: the 1st objective could be considered to be 3 times as important as the 2nd objective and 6 times as important as the 3rd & 4th objectives. As such, 1st will be considered to be of value 60, 2nd of value 20 and 3rd & 4th of value 10 each.

Example cont....

Measure or estimate the degree to which each alternative design satisfies each of the ranked or weighted objectives. Estimate the satisfactory nature of the objectives using an ordinal scale as shown below.

Score	Ordinal scale	Objectives			
		a)	b)	c)	d)
4	Definitely satisfied	Ch-b	-	Disp	Ch-b
3	Probably satisfied	Disp	Ch-b	Ch-b	Disp
2	Doubtful	-	Disp	-	-
1	Probably not satisfied	-	-	-	-
0	Definitely not satisfied	-	-	-	-

Convert these measures or estimates to percentages, in the case of ranked objectives, and to values of the index numbers, in the case of weighted objectives.

For the ranked objectives the percentages would be:

Objectives	% Score		
	Chilled Beam	Displacement	Max score
d)	$4/4 * 100=100$	$3/4 * 100=75$	100
c)	$3/4 * 100=75$	$4/4 * 100=100$	100
b)	$3/4 * 100=75$	$2/4 * 100=50$	100
a)	$4/4 * 100=100$	$3/4 * 100=75$	100
Average	87.5	75	

For the weighted objectives the index numbers would be:

Objectives	% Score		
	Chilled Beam	Displacement	Max score
d)	$4/4 * 60=60$	$3/4 * 60=45$	60
c)	$3/4 * 20=15$	$4/4 * 20=20$	20
b)	$3/4 * 10=7.5$	$2/4 * 10=5$	10
a)	$4/4 * 10=10$	$3/4 * 10=7.5$	10
Total	92.5	77.5	

Select the alternative design having either the preferred pattern of percentages or the highest total of weighting index numbers.

In this example both of the procedures specify the chilled beam as the optimum solution. However, in some cases it may be found that each procedure will specify a different option. If this is the case and the validity of the weighting system is doubted when its results are produced, the designers may be tempted to tamper with the index numbers.

This could be a wise thing to do if it reflects the fact that the design team has more information on which to base its evaluation, having seen the results of the original guesses.

For Further Reference See:

Jones (1992)

Dell'Isola (1982)

Parker (1996)

3.

Analysis of interconnected Decision Areas (AIDA)

Aim:

To identify, and to evaluate, compatible sets of sub-solutions to a design problem.

Additional Information:

AIDA is one of the most powerful and reliable T3s available. It is useful in reducing the amount of time that is wasted in cycling and re-cycling round a design problem (Jones 1992). Additionally, it can reduce the risk of overlooking a compatible set of sub-solutions that may solve a seemingly hopeless conflict of options.

Procedure:

1. Identify several feasible options in each decision area.
2. Indicate which options are incompatible with others.
3. List all of the sets of options that can be combined together without incompatibility.
4. When there is a single quantifiable criterion of choice (e.g. cost) find the compatible set of options that best satisfies that criterion.

Typical Application:

It is probably useful in any design problem that involves more than minor variations to previous designs but does require the prior existence of a stable problem structure. AIDA has been successfully applied to such diverse domains as the design of industrialised housing units and of machine tools.

Ease of Use:

It is relatively easy for designers to use however, as with other matrix based methods, it requires the designer to have skills in choosing the decision areas into which the problem is to be broken.

Example:

Jones (1992) in 'Design Methods' provides the following example: The design of a hand held writing implement.

Identify several feasible options in each decision area.

The major decision areas are assumed to be:

- a) *Transfer* - How to transfer the ink to the paper?
- b) *Replenishment* - How to replenish the ink reservoir?
- c) *Protection* - How to protect the ink transfer element when not in use?
- d) *Pocket position* - Which way to align the instrument in the pocket?

A number of sub solution are proposed to satisfy each decision area:

Transfer - A1, nib A2, ball-point
Replenishment - B1, suction refill B2, replaceable reservoir
Protection - C1, replaceable cover C2, retractable point
Pocket position - D1, point up D2, point down

Indicate which options are incompatible with others.

This can be undertaken conveniently using an interaction matrix (shown below):

Each compatible pair is given the score 1, and each incompatible pair is given the score 0.

<i>Objectives</i>		A1	A2	B1	B2	C1	C2	D1	D2
<i>Transfer</i>	A1			1	1	1	0	1	0
	A2			0	1	1	1	1	1
<i>Replenishment</i>	B1					1	1	1	1
	B2					1	1	1	1
<i>Protection</i>	C1							1	1
	C2							1	1
<i>Pocket position</i>	D1								
	D2								

The matrix is left blank in areas where there are combinations within a single decision area and where combinations are mirrored (symmetrically placed on either side of the diagonal).

The reasons for the three assumed incompatibilities shown are as follows:

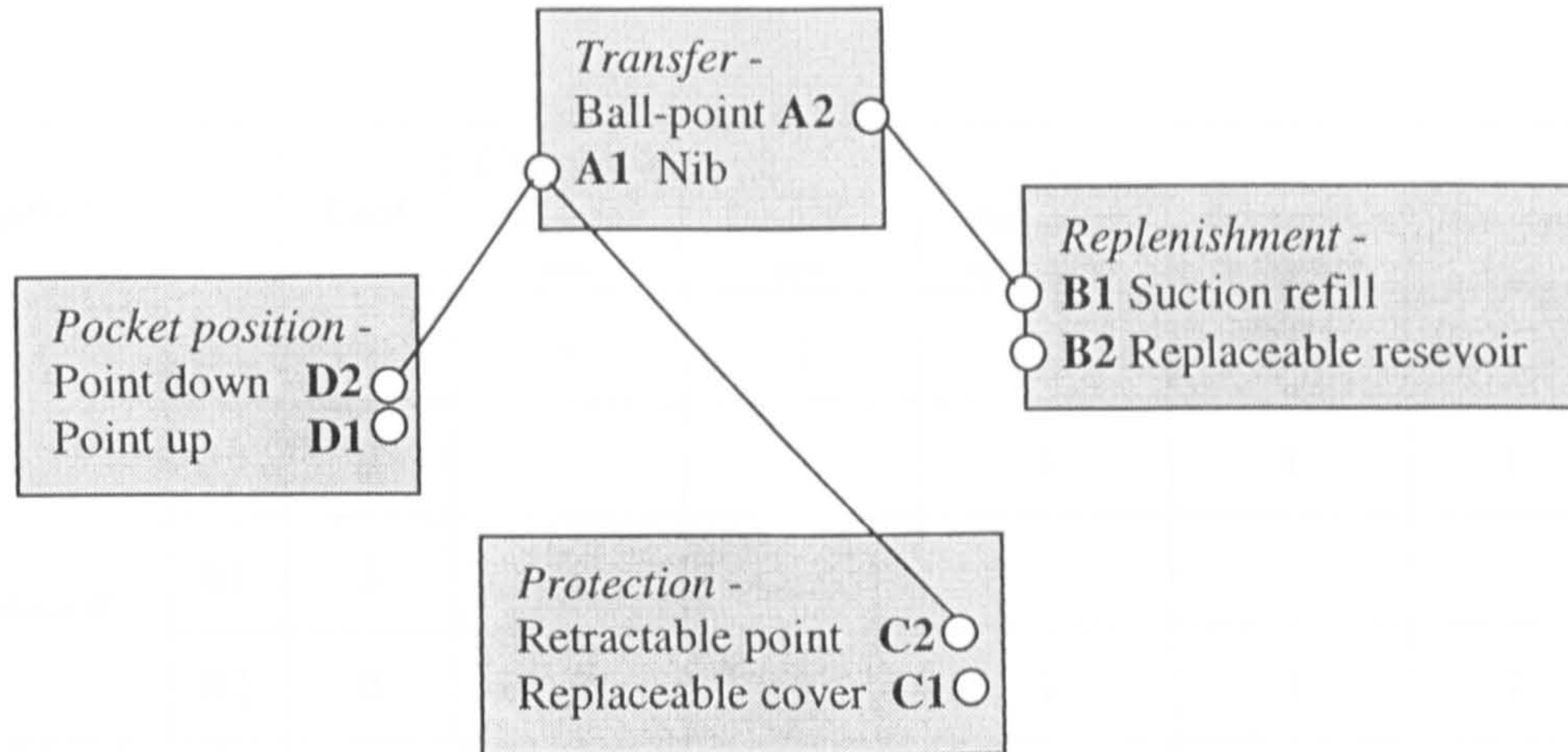
A1, C1 a nib requires a sealed cover where as a retracted transfer element is open to the atmosphere.

A1, D1 a nib leaks if it is stored nib down in the pocket.

A2, B1 ballpoint ink is too viscous for suction.

Example cont....

This can be shown graphically for ease of understanding, with each incompatible set linked by a line.



List all of the sets of options that can be combined together without incompatibility.

This example is small enough to allow all compatible sets to be listed manually.

A1B1C1D1	Conventional fountain pen
<u>A1</u> B1C1D2	Incompatible set
<u>A1</u> B1C2D1	Incompatible set
<u>A1</u> B1C2D2	Incompatible set
A1B2C1D1	Cartridge fountain pen
<u>A1</u> B2C1D2	Incompatible set
<u>A1</u> B2C2D1	Incompatible set
<u>A1</u> B2C2D2	Incompatible set
<u>A2</u> B1C1D1	Incompatible set
<u>A2</u> B1C1D2	Incompatible set
<u>A2</u> B1C2D1	Incompatible set
<u>A2</u> B1C2D2	Incompatible set
A2B2C1D1	Ballpoint with replaceable cover
A2B2C1D2	Possible new type of ballpoint pen (A)
A2B2C2D1	Possible new type of ballpoint pen (B)
A2B2C2D2	Retractable ballpoint pen

As can be imagined, with highly complex problems with a vast number of elements involved, a PC must be used to undertake the analysis.

When there is a single quantifiable criterion of choice (e.g. cost) find the compatible set of options that best satisfies that criterion.

Suppose that each of the options is independent of the others in terms of production cost. The cheaper of each of the options in each decision area is given the cost 0, while the more expensive option is given a cost equal to the difference in cost between the two options (the cost differences in this example have been estimated). The total costs of the compatible sets are then added up as a means of discovering which fits the criteria most effectively.

Example cont....

Options		Cost	Compatible sets					
			Fountain pen	Cartridge pen	Ball-point with cover	Retractable ball-point	New type (A)	New type (B)
Transfer	A1	4	1	1				
	A2	0			1	1	1	1
Replenishment	B1	3	1					
	B2	0		1	1	1	1	1
Protection	C1	0	1	1	1		1	
	C2	2				1		1
Pocket position	D1	0	1	1	1			1
	D2	1				1	1	
Total cost difference			7	4	0	3	1	2

As would be expected in this example, the ballpoint with cover turned out to be the cheapest option and the conventional fountain pen the most expensive.

For Further Reference See:

Jones (1992)

Luckman (1967)

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