CHARTERED INSTITUTE OF BUILDING SERVICES ENGINEERS
NATIONAL CONFERENCE 1999, HARROGATE, UK.

Using training workshops to map interdisciplinary team working

Simon Austin[1], John Steele[2], Sebastian Macmillan[2], Paul Kirby[2], Robin Spence[2]

(1) Department of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU. Telephone 01509 222608. Fax 01509 223981. Email: S.A.Austin@lboro.ac.uk

(2) The Martin Centre for Architectural and Urban Studies, Department of Architecture, University of Cambridge, 6 Chaucer Road, Cambridge, CB2 2EB, UK. Telephone 01223 331713. Fax 01223 331701. E-mail: sgm24@cam.ac.uk

Contemporary building projects are increasingly complex and demand close integration between the design of the building services and the fabric. The early stages of the design process, when alternative concepts are being generated and the least promising are eliminated, are recognised as crucial, since they define the parameters within which the whole project will be constrained. AMEC Design, a large practice of building service engineers, surveyors, architects and other building design professionals is committed to interdisciplinary teamwork at the conceptual phase of design, and is participating with other construction organisations and with the University of Cambridge in research to map the process of design at the concept phase. Workshops for design team members are run regularly by the company as part of its staff development programme. A recent workshop provided an opportunity to monitor interdisciplinary design teams and to develop an initial 12-phase model of the conceptual design process. The process as observed was clearly non-linear, implying the need for models which allow flexible interpretations. Future revisions will be followed by further testing in similar workshops, and eventually its application on live projects.

Introduction

As an interdisciplinary design practice, AMEC Design is committed to interdisciplinary working from the early stages of design projects. Inspired by several of their staff having attended the University of Cambridge Interdisciplinary Design in the Built Environment course, AMEC have introduced Designing Together workshops as training exercises for their designers, away from the pressures and interruptions of the office. The company is also participating in a research project, with the University of Cambridge and other industrial collaborators, which is part funded by the Engineering and Physical Science Research Council, and whose objective is to map the design process at the concept stage, as reported at the last CIBSE conference (Parker and Steele 1998). Design team working at a recent workshop has been monitored to provide data for the development of the process map.

The Designing Together Workshop

The two-day 'Designing Together' Workshops are held regularly at Barleythorpe Hall management training centre. Their aims are to foster an understanding among the participants of the various skills owned by the different professions, as well as to: i)

increase the standard of design integration; ii) enhance future 'seamless' design; iii) provide an environment where designers can practice innovation without risk and; iv) develop meeting and presentation skills. The workshops are led by an experienced facilitator who, coincidentally, has a construction background.

This paper describes a workshop held in September 1998. Fifteen participants from the major design professions attended and, for most of the event, worked in three teams of five, as shown in Table 1.

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 1 Team member disciplines

After basic introductions, a short design exercise for the design of a newspaper was carried out to encourage team members to get to know one another. This is a curtain raiser for the main exercise, undertaken during the rest of day-one and day-two, which involves the design of a window façade system for the recladding of 1960's office buildings. A short presentation was made about the history of windows to introduce the topic. At this point the designers were also introduced to several ‘design techniques’, such as brainstorming (shown in table 2). These techniques were introduced in the design literature in the 1960s (French 1971, Jones 1982, Cross 1989) as tools to broaden the number of solutions designers might consider and to help them evaluate alternative potential solutions more rigorously.

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 2 Design techniques introduced at the workshop

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 judged provided the teams with feedback about their proposals. And the facilitator commented on the team members individual presentation styles.

Monitoring team design processes

Continuous monitoring of the three teams was undertaken during the main design exercise. This involved members of the research team taking detailed notes of the activities being undertaken, the interaction of the team members and the application of the prescribed design techniques. 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 compared in table 3. A preliminary set of standard phases, which were developed from these details, is also described. Table 4 compares the actual design processes followed by the respective teams as recorded by the research team.

Team (A): Team A pre-structured their design process up to and including 'Select design' in the early phases of the design activity. However, the phases after 'select design' represent a description of the process that was actually undertaken after the pre-defined stages were completed.

Team (B): The process outlined by team B is purely descriptive and was generated upon completion of the design exercise. The members of team B believed they had worked efficiently and effectively in the previous exercise without pre-structuring a process and as such, agreed to take this same approach again.

Team (C): Team C spent a long period of time generating a well structured design procedure at the start of the exercise, which stated the activities to be undertaken, time allocation for each activity, which day the activity was to be undertaken and who should undertake each activity. However, during the course of the exercise the team strayed from the prescribed process even though one team member attempted to guide the team throughout the design activity. The design process of team C is descriptive, being generated at the end of the design exercise.

Standard phases	Team A	Team B	Team C
Understanding the briefs requirements	Task debate	The Task Brainstorm design features (introduced by brief)	Common understanding of brief
Generate a mission statement	Vision statement Mission statement	Mission Statement	Mission statement
Identify 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
Assess and develop design factors/ requirements	Critical success factors (What are the issues?)	Existing methods of fulfilling the design brief	
Identify design drivers and constraints	Design Basis/ constraints		
Prioritise factors/ requirements			Weight factors from brief
Generate design concepts/solutions	Concept drawings	5 Concept solutions	Brainstorm concepts to address factors: -External visual impact Internal considerations
Group/combine solution concepts		Evaluation (of preliminary proposals)	Group factors to allow scoring of schemes
Select suitable options		2 solutions	Identify broad options
Evaluate/choose options	Select design	Detailed review of solutions Preferred scheme	Use 'pros and cons' to assess options Choice of option
Development, improvement and review of final option	Resolve issues with design Assign tasks for deliverables Generate deliverables Final internal design review Final amendments	Detailed design review	Develop option
Present final proposal	Present design proposal		

Table 3 Comparison of design processes outlined by the teams

An extensive literature search has already been undertaken of design process maps both within and beyond construction. This search investigated maps from both industry (RIBA Plan of Work-1969, VDI 2222-1973, BAA project process-1995) and academia (Salford Process protocol-1996, Markus and Maver-1970, French-1971, Hubka-1982, Pahl and Beitz-1988, Cross-1989, Jones-1992). When combined with the described and observed processes from the monitoring of this workshop it has been possible to develop a preliminary 12-phase framework of conceptual design activity (shown in figure 1). Elsewhere we compare the elements of this framework model with other process models from both architecture and engineering (Macmillan, Steele, Austin, Spence and Kirby 1999).

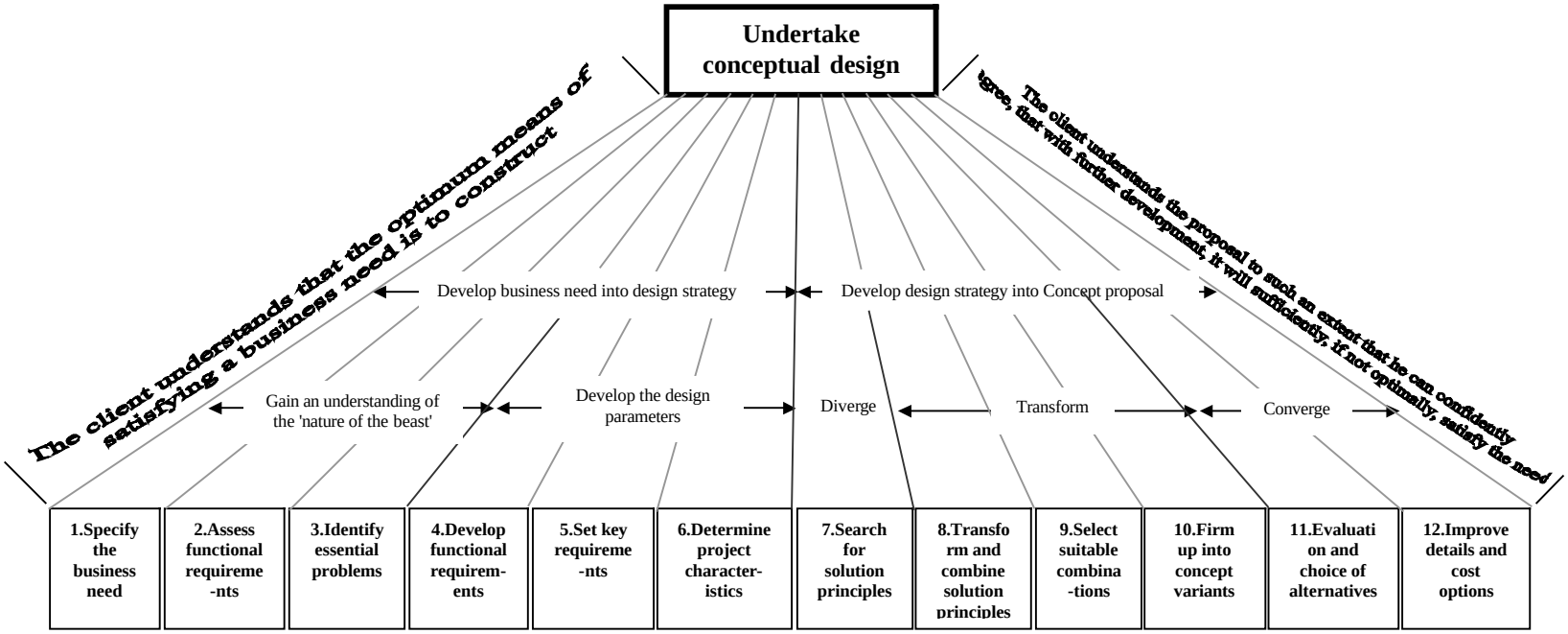

Figure 1 The preliminary conceptual design framework model

Theory versus practice

Conventionally, models of the design process based around a sequence of related activities imply that one phase follows another, and that each phase is of broadly equal duration and importance. We can represent this graphically as in figure 2 below.

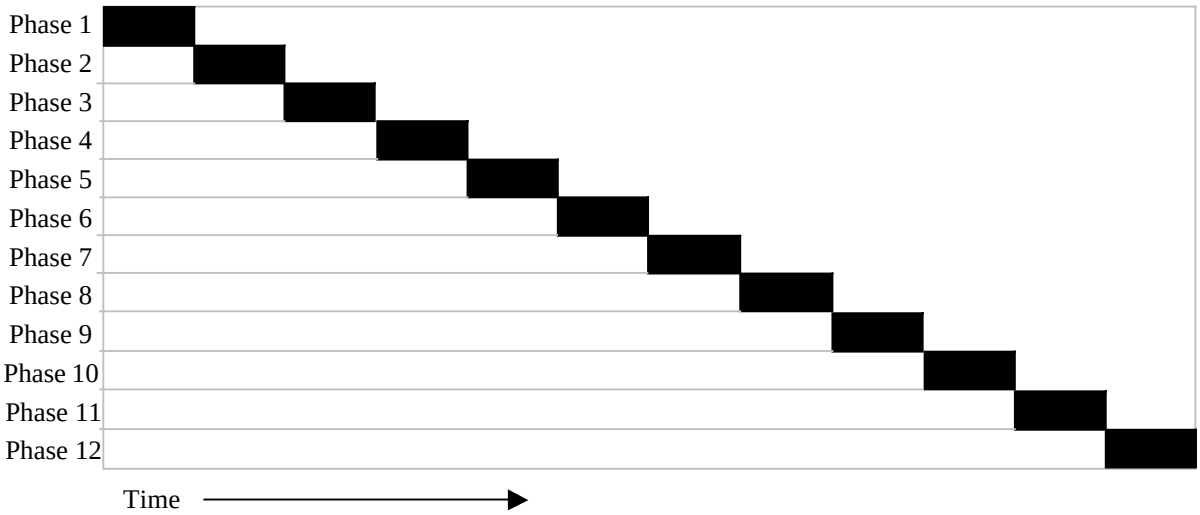

Figure 2 Theoretical representation of phases of the design process

However, when we use this framework to analyse the monitored data from the design teams we discover a more complicated picture of the activities and the relationship between them. Figures 3, 4 and 5 provide a detailed outline of the actual design activity undertaken by the teams during the design exercise as defined by the framework model.

Team A

Although a linear sequence of phases was pre-defined by team (A) 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.

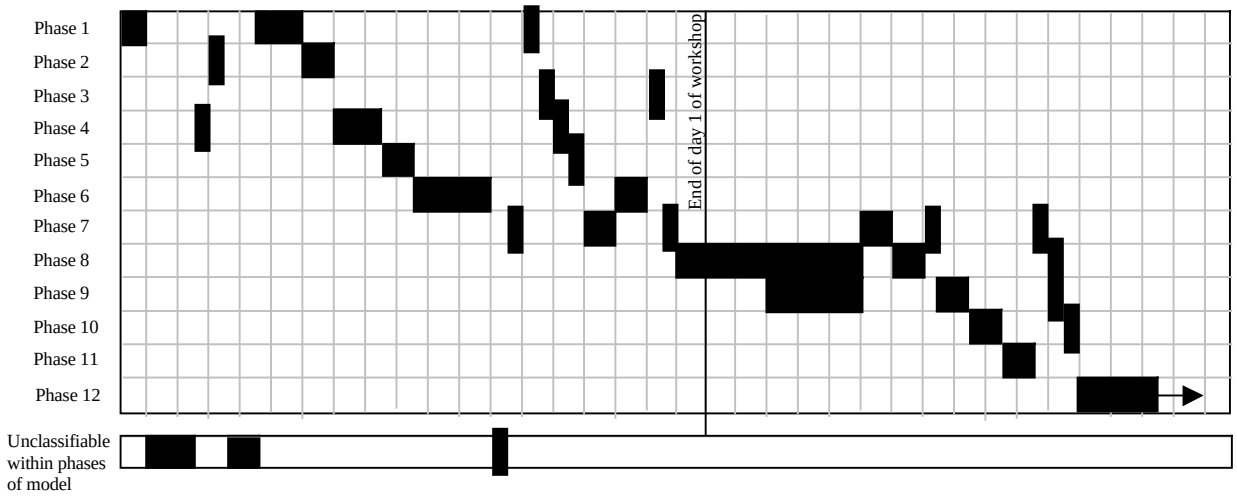

Figure 3 The actual design activity of team (A)

Team B

The pattern of design progression over the majority of the exercise lacks the linear iterative form portrayed by team (A). 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.

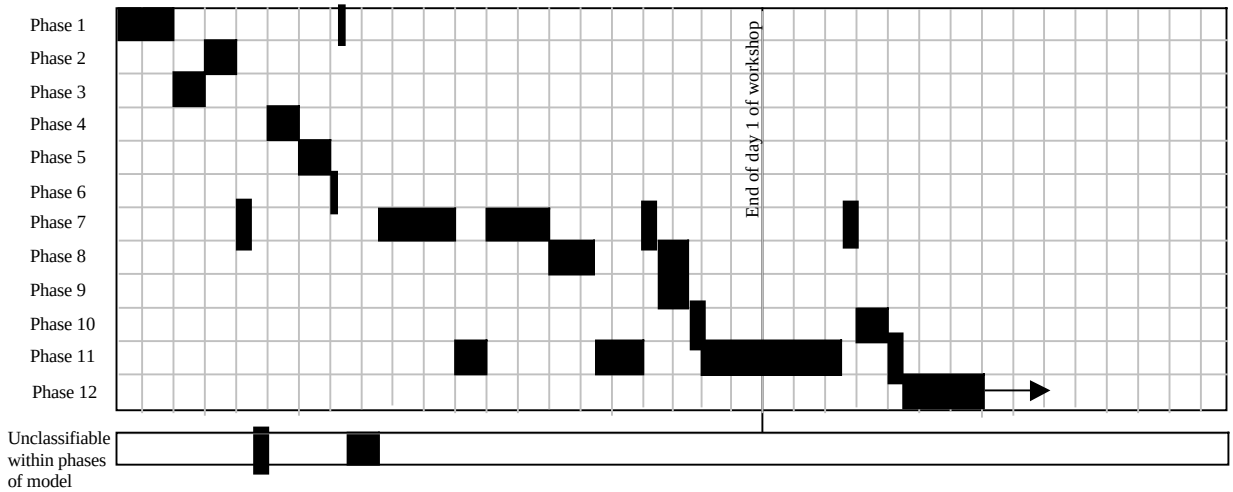

Figure 4 The actual design activity of team (B)

Team C

Team (C) 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. 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 phases of generation, transformation and evaluation 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 strong 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.

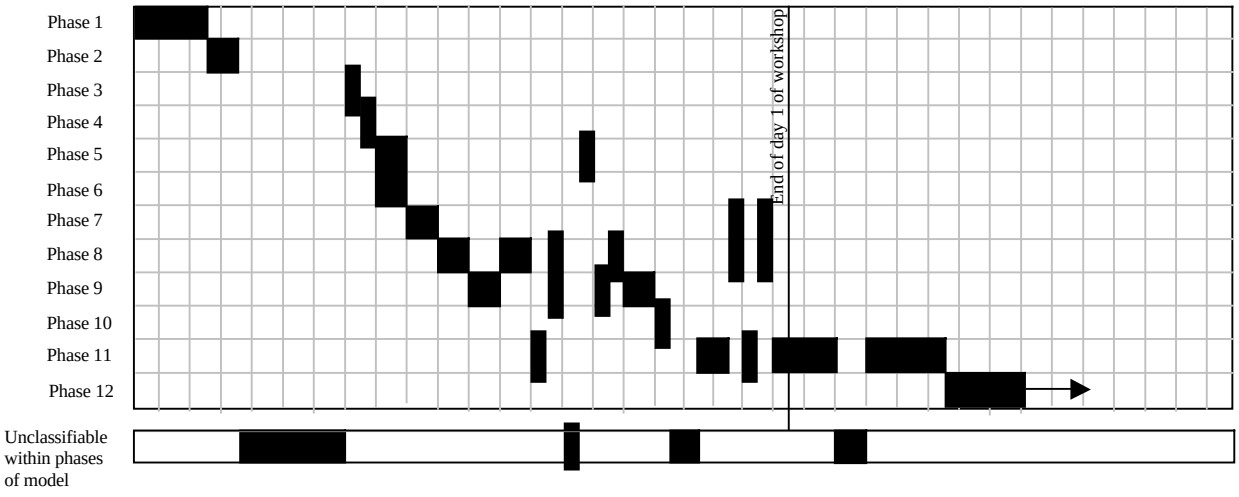

Figure 5 The actual design activity of team (C)

Synopsis of design proposals

This design problem has the advantage of requiring input from each of the design disciplines. 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 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 A and B proposed single systems that were flexible and adaptable to the needs of any client. Team C 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 design phases

The following table provides a breakdown of the percentage of time spent by the respective design teams in each of the phases undertaken during the course of the exercise. These percentages are compared graphically in figure 6.

			% of design time spent in each phase of the framework		
Phase name			Team (A)	Team (B)	Team (C)
Developing need into a design strategy	1	Specify the need	9.7	8.8	9.1
	2	Assess functional requirements	4.8	3.9	3.6
	3	Identify essential problems	3.2	3.9	1.8
	4	Develop functional requirements	8.1	3.9	1.8
	5	Set key requirements	4.8	3.9	3.6
	6	Determine project characteristics	11.3	1.0	1.8
Developing design strategy into concept proposal	7	Search for solution principles	11.3	23.5	7.3
	8	Transform and combine solution principles	29.0	9.8	23.6
	9	Select suitable combinations			
	10	Firm up into concept variants	4.8	5.9	1.8
	11	Evaluation and choice of alternatives	3.2	29.4	23.6
	12	Improve details	Not included in comparison		
Time unclassified by phases of model			9.7	5.9	21.8
Total spent in phases 1-6			41.9	25.5	21.8
Total spent in phases 7-12			48.4	68.6	56.4

Table 4 A comparison of time spent in the respective phases of design

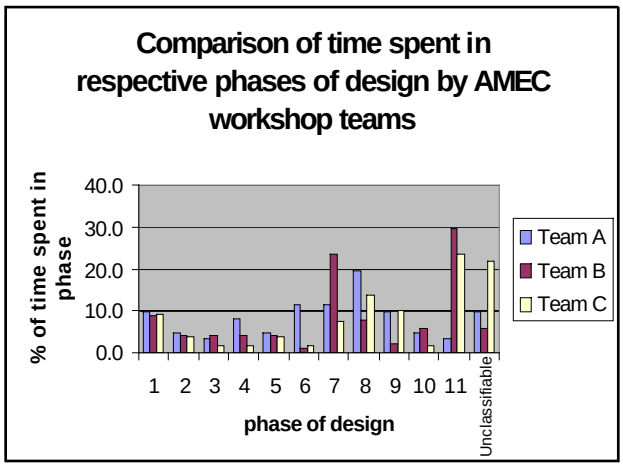

Figure 6

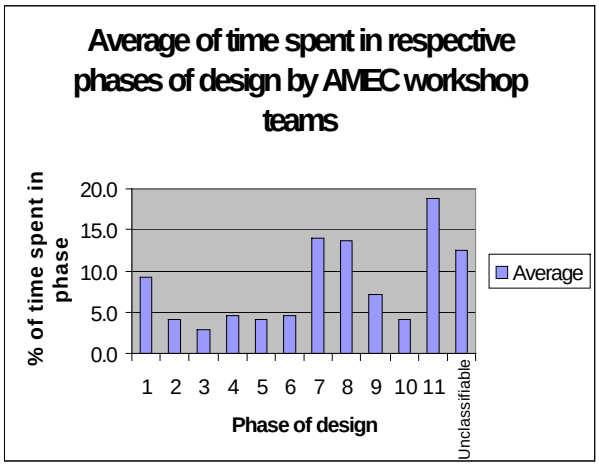

Figure 7

Description of activities unclassifiable within the existing 12-phase model

Team (A) shared their time almost equally between phases 1-6 and 7-12 where as teams (B) and (C) spent the major part of their design time in phases 7-12. However, by referring to figures 6 and 7 it can be seen that on average the larger proportion of actual design activity was spent generating, transforming/combining, and evaluating concept proposals. Between approximately 6% and 22% (see table 4) of the design

activities of the teams could not be classified within the phases of the conceptual design framework model. Table 5 summarises what this time was spent doing.

Team A	Team B	Team C
Discussions held in a bid to pre-structure a design process.	Discussion and allocation of elements of design for individuals or groups of individuals to address.	Discussion and agreement on the phases of the design process to follow.
		Development of the phases into the most efficient sequence, as perceived by the team members.
Discussions concerning the allocation of the workload.		The assignment of resources to complete tasks and the allocation of time periods to each phase.
	Allocation of time periods for producing the deliverables outlined in the brief.	Discussions held in an attempt to get the team to follow the pre-defined process (the team had begun to drift at this point in the opinion of one of its members).
Allocation of time and resources to undertake the design activities outlined.		Discussions about an issue raised by one of the team members concerning the prioritisation of the requirements in terms of value to the project and concerns about time remaining.
		Discussion held in a bid to force the team to undertake a final evaluation and agree on a single proposal to firm up.

Table 5 Design activities unclassifiable within framework phases

The majority of this time involved what could be summarised as self-management – defining procedures to be followed, assessing whether they are being followed, reviewing progress and keeping the team on course. On occasion, in response to confrontation, a team may spend time addressing dissatisfactions about procedures raised by individual team members.

Team member responses to design techniques

Table 6 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 useless.

Table 6 Team comments about techniques

Only three of the six design techniques 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.

Discussion

Team (B) did not structure the design procedure prior to the design being undertaken, yet the balanced nature of the team and its members allowed the design activity to flow smoothly and a feasible design was produced, evaluated and presented within the time constraints with relative ease. Conversely, team (C) spent a long period of time generating a structured design procedure at the start of the exercise, which included time allocation, when each activity was to be undertaken and who should undertake it. However, disagreement within the team made it difficult for them to agree on a single design proposal to work up in detail. A key influence on the success of a team seems to lie in having a group of individuals with compatible personalities, who work toward a common goal without conflict.

Summary of findings

Design process

- The design processes which teams perceive they follow during the conceptual phase of design are reported as a number of phases following sequentially in a linear fashion. In practice, the phases vary in duration and do not follow a simple pattern. Iteration is common.
- Having a team pre-define the process for themselves helps the members to adhere to a programme and work in accordance with it. Lack of a pre-defined process appears to result in unfruitful and opportunistic behaviour by the team or some of its members.
- Paradoxically, adherence to a pre-defined process did not (in this workshop) lead to better design proposals, nor reduce the time taken to complete the project.
- The two teams whose members worked well together produced integrated solutions. The other team, where conflict was apparent between its members, produced a kit-of-parts design solution. In this sense there was a clear link between the process and the product.
- The design framework developed to describe the sub-phases of the conceptual phase was supported by the findings of this workshop, but it fails to account for one key factor of successful design team working, - self-management by the design team.

Design techniques

- Designers prefer to utilise design techniques that they are familiar with.
- Designers report that techniques must be simple and easy to apply if they are to be utilised in practice.
- 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.

This workshop used teams drawn from a single organisation. Subsequently a similarly organised, and monitored, workshop drew together team members from the five organisations collaborating in the Mapping the Design Process research project. In a future paper we intend to report on this more complex workshop and what was learned from it in terms of both the emerging framework for the conceptual design phase, and the use of design techniques.

Acknowledgements

The industrial collaborators in this project are: AMEC Design; BAA, Hotchkiss Ductwork Ltd; Hutter, Jennings and Titchmarsh; Matthew Hall; and Pascall & Watson. Loughborough University is also contributing to the project.

References:

British Airports Authority (1995). *'The Project Process'*. BAA Plc. London.

BS 7000: (1989). *'Guide to Managing Product Design'*. British Standards Institute.

Cross N (1989). *'Engineering Design Methods: Strategies for Product Design'*. John Wiley & Sons.

French M J (1971). *'Engineering Design: The Conceptual Stage'*. Heinemann Educational Books.

Hubka V (1982). *'Principles of Engineering Design'*. Butterworth & Co.

Jones (1992). *'Design Methods (Second Edition)'* - Nan, Nostrand, Reinhold. NY.

Kagioglou et al (1998). *'A generic guide to the Design and Construction Process Protocol'*. The University of Salford.

Macmillan, S, Steele, J.L, Austin, S, Spence, R, and Kirby, P. (1999). *'Mapping the early stages of the design process - a comparison between engineering and construction'*. In Proceedings of 12th International Conference on Engineering Design (ICED). Munich, Germany.

Maver T.W (1970). *'Appraisal in the Building design process'*. In Engineering methods in environmental design and planning. M.I.T Press, Cambridge, MA.

Pahl G, Beitz W (1988). *'Engineering Design: A Systematic Approach'*. The Design Council-Springer/Verlag.

Parker A.D, Steele J.L (1998). *'Improving the Effectiveness of the Concept Design Process by Learning from Other Industries'*. In CIBSE National Conference '98 proceedings. Bournemouth, UK.

RIBA (1969).*'Plan of Work for Design Team Operation'*. Original Edition.

VDI-Richtlinie 2222 (1973). *'Konstruktionsmethodik, Konzipieren technischer Produkte'*. Dusseldorf: VDI-Verlag.