One step forward and three back: a study of the patterns of interdisciplinary conceptual design

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Design activity during the conceptual phase of building projects is dynamic, vibrant and as a result, chaotic in appearance. Iterative, or cyclic, design progression is often criticised as 'going round in circles'. However, design is a learning activity and, owing to the complexity of contemporary building projects, it is often only by moving ahead to improve problem definition, 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. Yet 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 results in design team fragmentation and ultimately, adversarial relationships. Over the last two years the University of Cambridge has been working with a number of industrial collaborators in a study of conceptual design. During a series of workshops the activities of designers have been monitored and plotted graphically. This paper discusses the patterns of progression that have been recorded, and discusses their causes. Additionally, the paper speculates on the possible improvements in efficiency that could result from designers having an improved understanding of the iterative structure of conceptual design.

Introduction

An overview of the design environment

Design activity, particularly at the early stages of a project, is recognised, typically, as being dynamic, highly iterative and essentially non-linear. However, under the rigours and pressures of the contemporary project environment, designers are being urged to undertake early design activity in a far more programmable, and thus manageable, fashion. Within this environment iterative, or cyclic, design progression is often criticised, with the concept of 'going round in circles' being one that is generally discouraged (Hickling 1982). 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 of the problem, before taking a step back to re-address a problem with improved understanding, that the design process can progress (Lawson 1980). This is possibly the most commonly recognised type of iterative design progression among design researchers and practitioners alike. However, there are many other types of iterative design progression that are common to early stage design activity. For the last two years the MDP (Mapping the Design Process during the conceptual phase of building projects) research project being undertaken at the Department of Architecture, Cambridge University, has, in close collaboration with a number of construction industry firms, endeavoured to improve understanding of conceptual design activity. The research team has gathered empirical evidence which suggests

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that, although every design project is unique, there are commonalties within the iterative structure of periods of design progression across projects. This paper will describe briefly the genesis of a framework for conceptual design before describing the results, from seven individual design teams, of using the framework to track design progression. The resulting maps of design activity are then discussed and analysed to unravel and reveal the iterative trends within conceptual design progression.

Synopsis of framework and model genesis

A literature survey, encompassing upward of 200 texts starting with the early design methods literature that lead to the formation of the Design Research Society in the mid-1960s, provided a wide and far-reaching outline of the pre-existing knowledge of design. This, along with reviews of process models both within and beyond construction (Macmillan, Steele, Austin, Kirby, Spence 1999a), interviews with designers about case histories, and observations of workshops where interdisciplinary teams of designers were observed during the concept phase of a design project, enabled a preliminary framework for concept design (shown in figure 1) to be devised (Macmillan *et al,* forthcoming). This comprised: i) a standard framework describing five design phases that are generic from one project to the next; and ii) at the lowest level, a structured set of 12 generic design activities in which project specific tasks, knowledge, and data could be stored. The framework was developed to be flexible and adaptable, to accommodate different types of project, client, and design environment, while still offering a structure to which project specific sub-models can be connected.

This framework was utilised subsequently as a means of tracking the conceptual design progression of seven individual interdisciplinary teams. Six of the teams were monitored over the course of two 'Designing together' workshops (Austin, Steele, Macmillan, Kirby, Spence - 1999, Austin *et al* - forthcoming; Steele, Macmillan, Austin, Kirby, Spence - 1999). The first involved designers from AMEC Capital projects, a multi-disciplinary organisation collaborating in the research; the second involved designers from each of the MDP project's industrial collaborators (including AMEC).

The design exercise within the two-day workshop involved the design of a window façade system for the re-cladding of 1960's office buildings. Upon completion of the exercise on day two, the teams were given 30-minutes to present their concept proposals and describe the design processes followed.

Upon analysing the patterns of design progression of the workshop teams it became apparent that iterations across the activities and phases of the design processes that were recorded during the workshops fitted within a higher level of iteration representing the entire conceptual design phase.

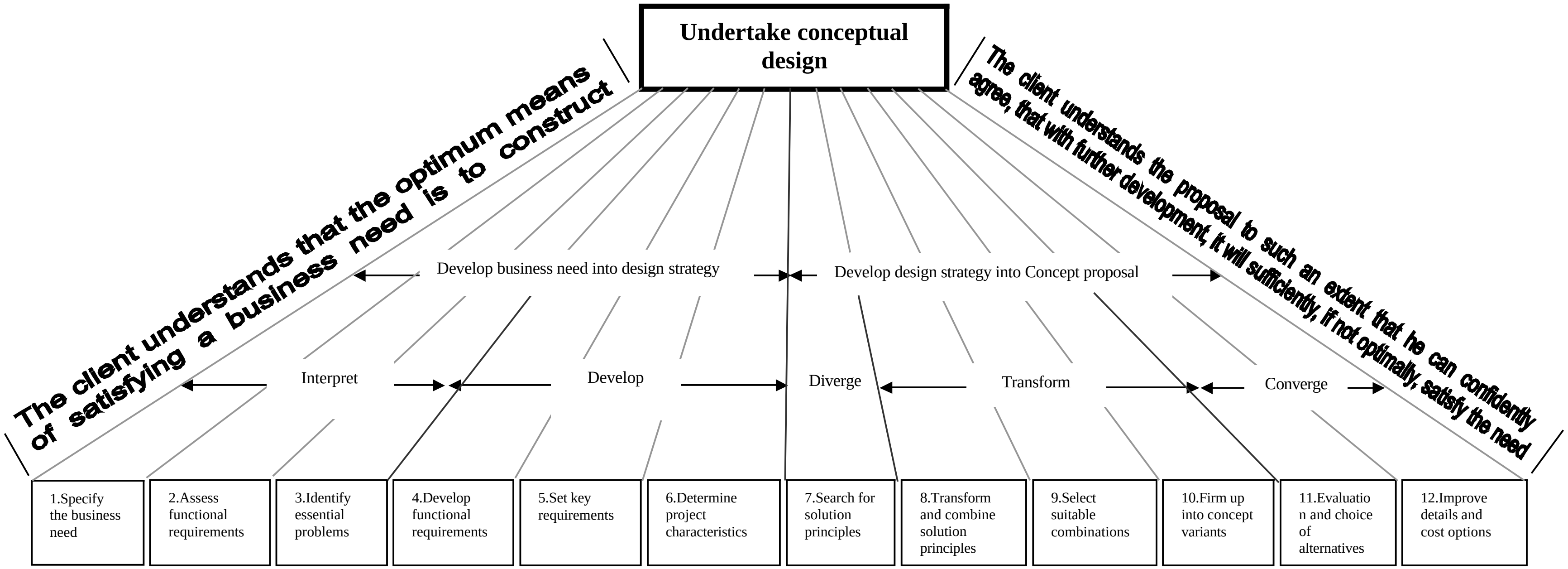


Figure 1 The preliminary conceptual design framework model

In light of this finding the preliminary design framework model was developed into a more realistic representation of the conceptual design phase (figure 2).

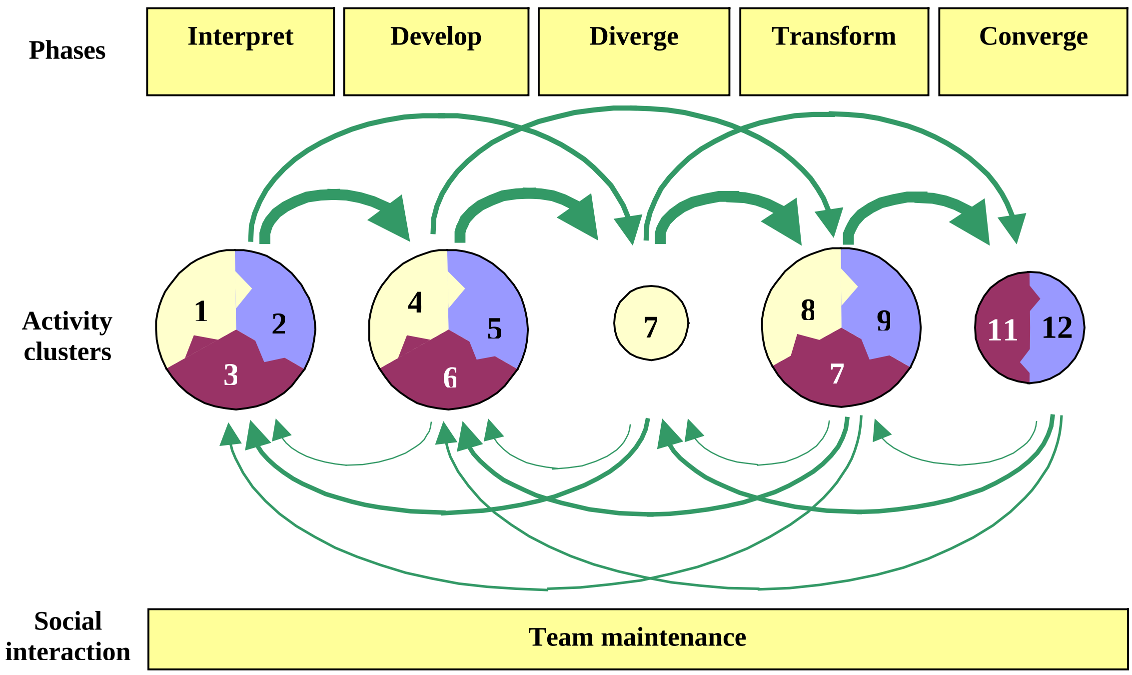


Figure 2 Reinterpreted conceptual design framework model

The seventh and final team was tracked over the course of a conceptual design workshop on a live project in industry (Macmillan, Steele, Austin, Kirby, Spence, forthcoming). This workshop, which aimed at developing a concept proposal for an airport terminal, also allowed a preliminary web-based design support system to be trialled; details of this component of the research are provided elsewhere (Steele, Macmillan, Austin, Kirby, Spence, forthcoming).

The patterns of design progression that were produced are illustrated and discussed in the remainder of this paper.

Patterns of Design progression

The theoretical waterfall

Traditionally, models of the design process comprise sets of stages, phases or activities that are followed linearly during design activity; an example of which is the RIBA Plan of Work for Design Team Operation (1969), which, although developed some 30 years ago, remains the most widely referenced model of building design. Typically, this type of model appears to imply that the components of design are of broadly equal duration and importance; this is represented graphically in figure 3**.**

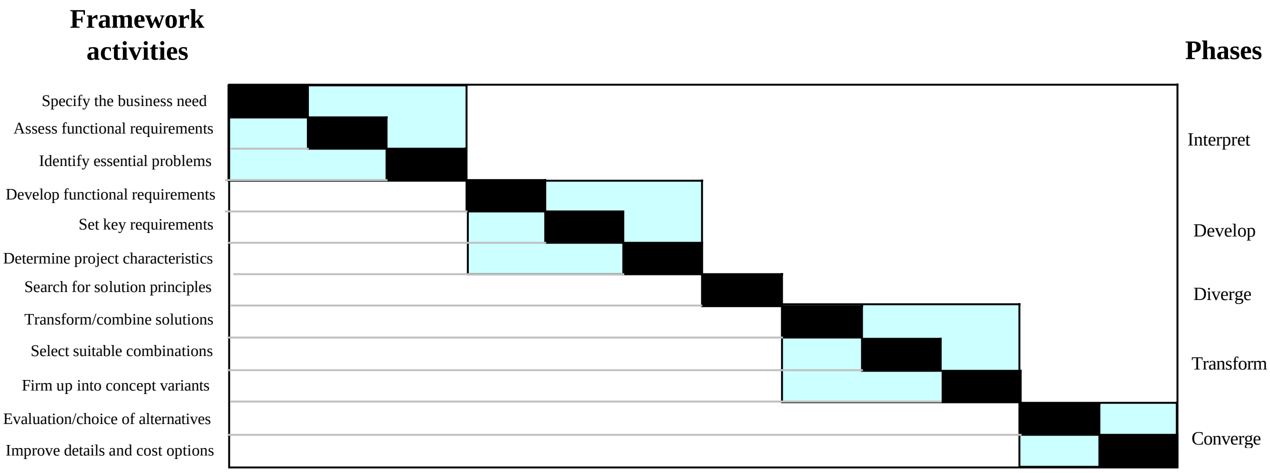


Figure 3 Theoretical representation of phases of the design process

However, when the conceptual design framework is used to track the design progression of interdisciplinary teams in practice, a far more complex set of relationships between activities is discovered. Over the course of the research project seven design teams have been observed and detailed descriptions of their actual design progression have been recorded. The maps of design progression, which are illustrated and discussed in the following section, provide insights into the nature of interdisciplinary conceptual design activity. Additionally, a number of trends and commonalties have become apparent which suggest that, although the patterns of design progression are unique to particular teams within particular working environments, elements of design activity, and the reasoning behind them, are ubiquitous.

Actual patterns of design progression

Team 1

Although a linear sequence of phases was pre-defined by team 1 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.

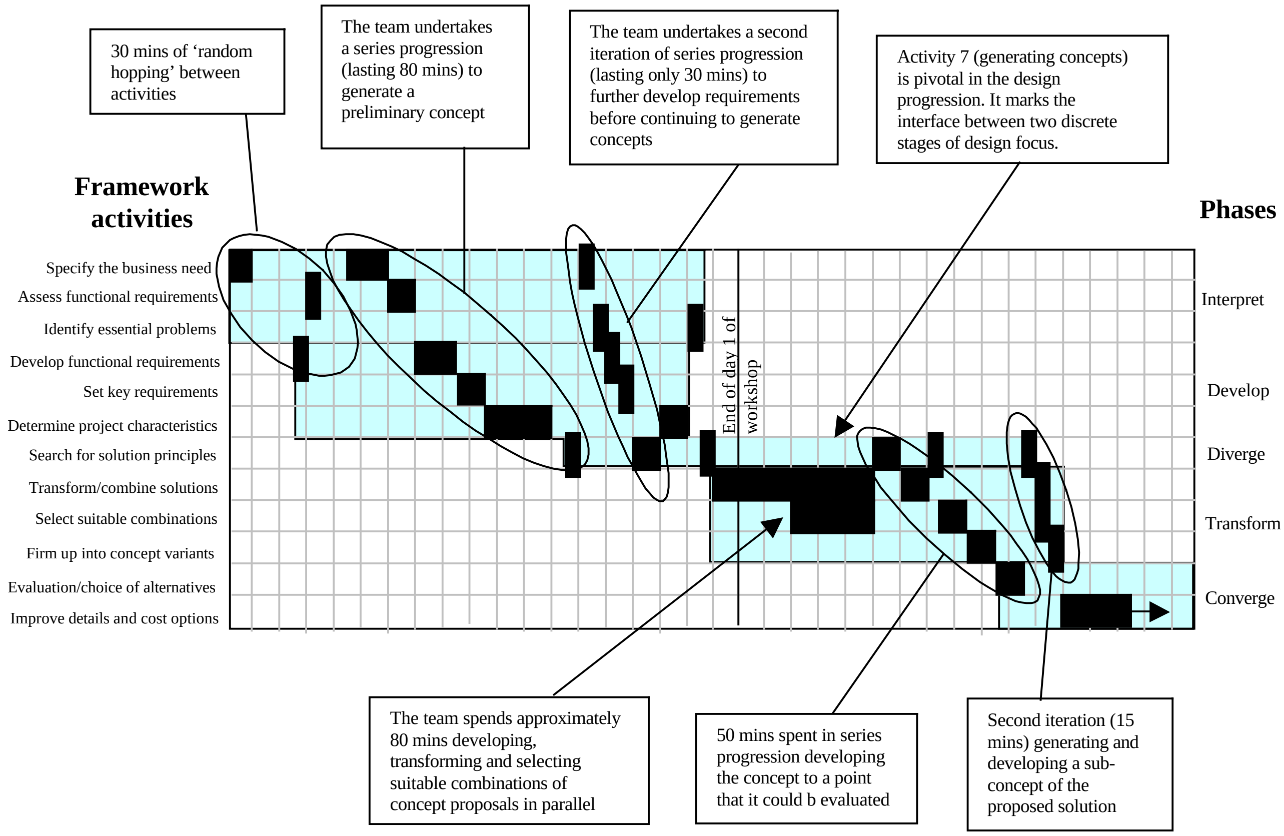


Figure 4 Pattern of progression of team 1

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.

Team 2

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.

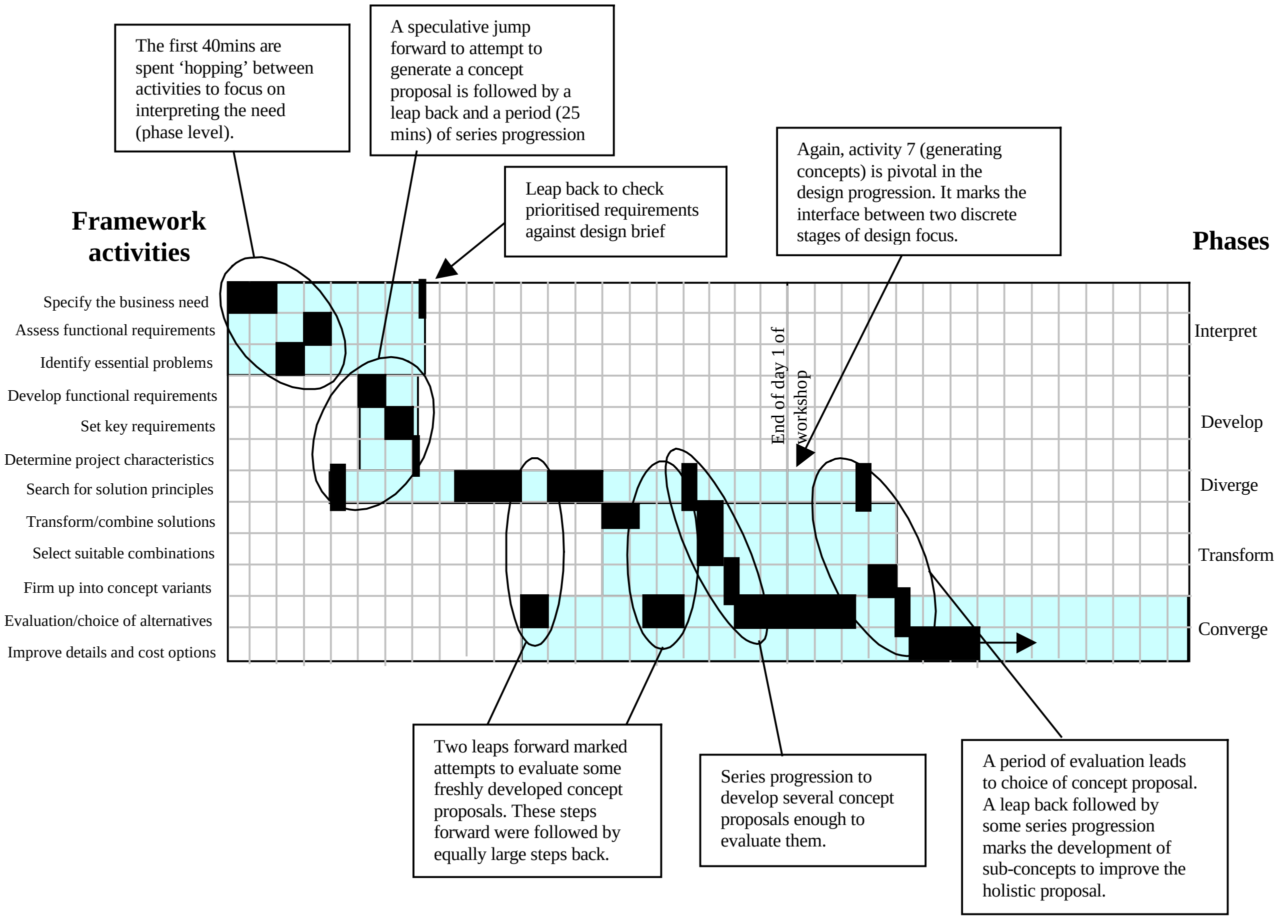


Figure 5 Pattern of progression of team 2

The team members appeared to be compatible and as a result, collaborated well throughout the course of the exercise.

Team 3

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.

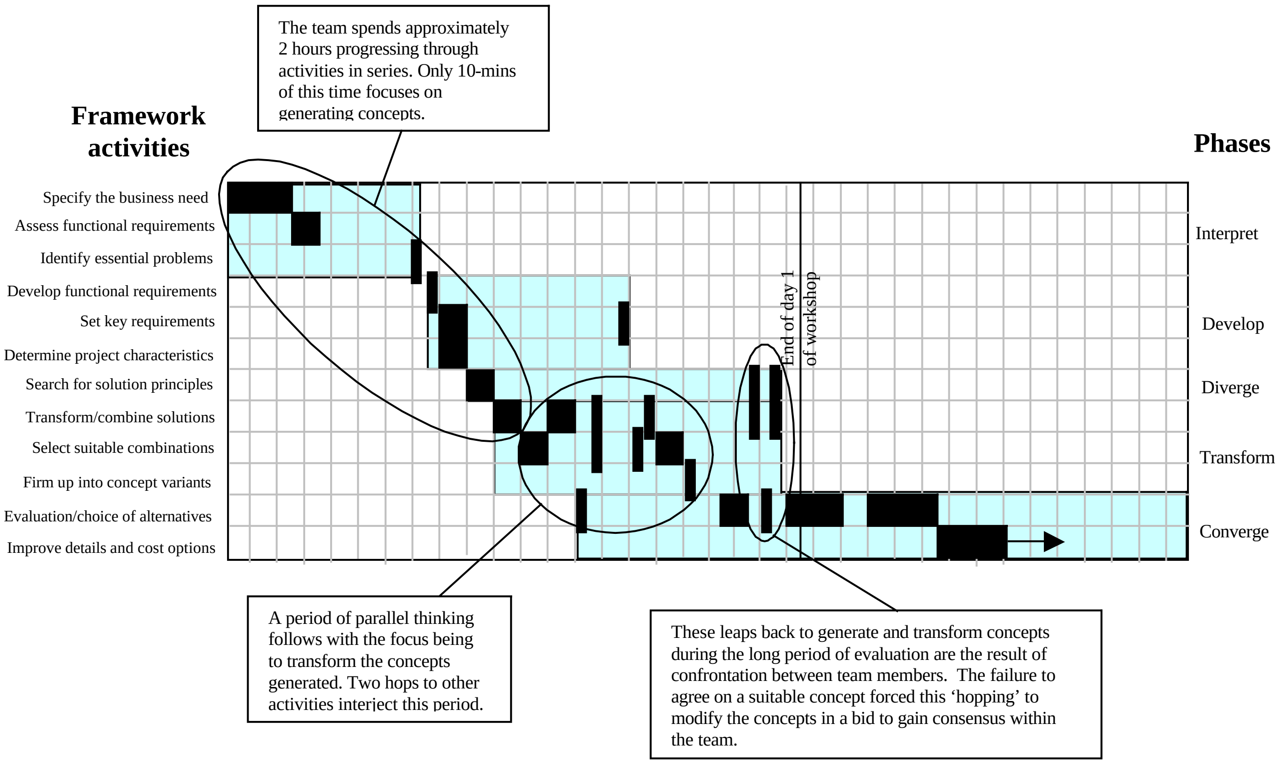


Figure 6 Pattern of progression of team 3

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.

Team 4

The team tended to 'hop' between activities. However, although the iteration appears miscellaneous in manner, a noticeable sequential pattern is apparent.

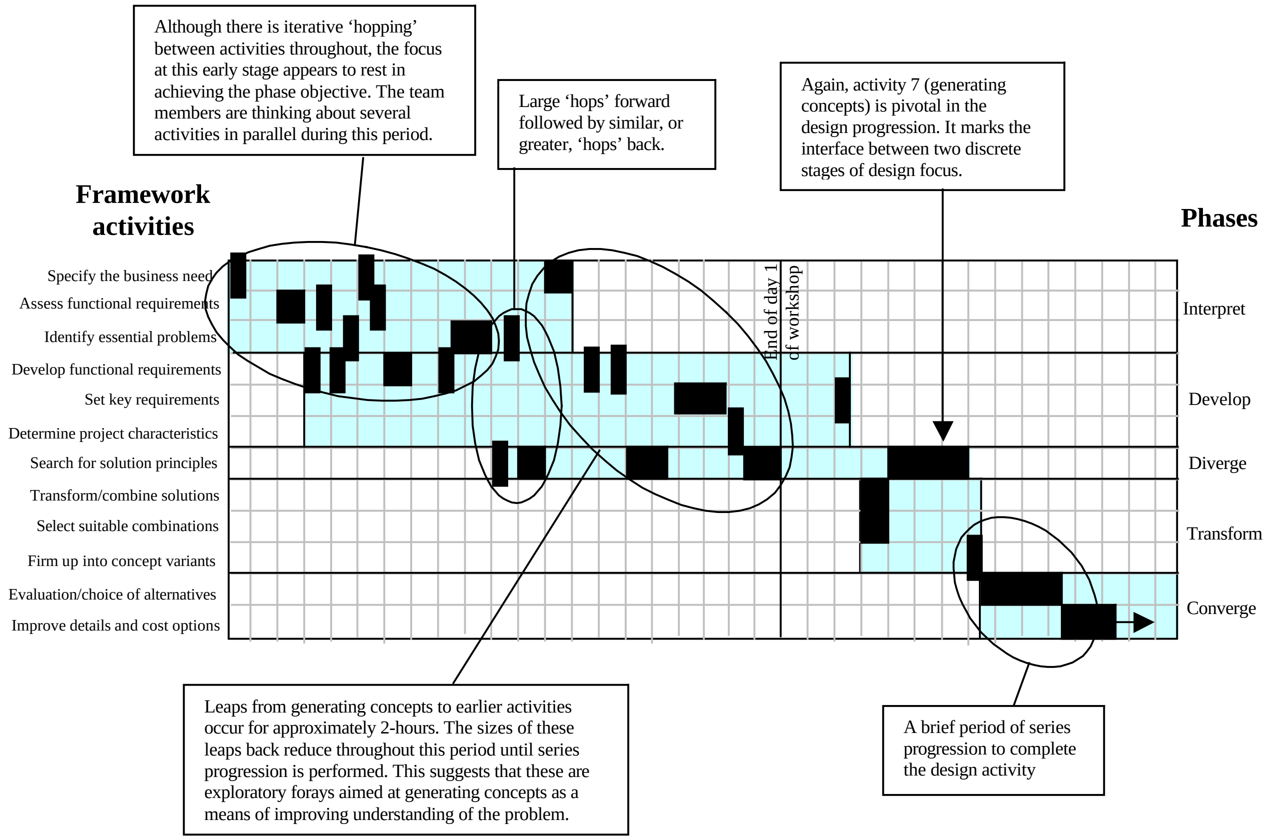


Figure 7 Pattern of progression of team 4

There was a clash of personalities within the team that lead 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.

Team 5

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 mid-way through the process. This represents a period of transformation and selection of concept proposals.

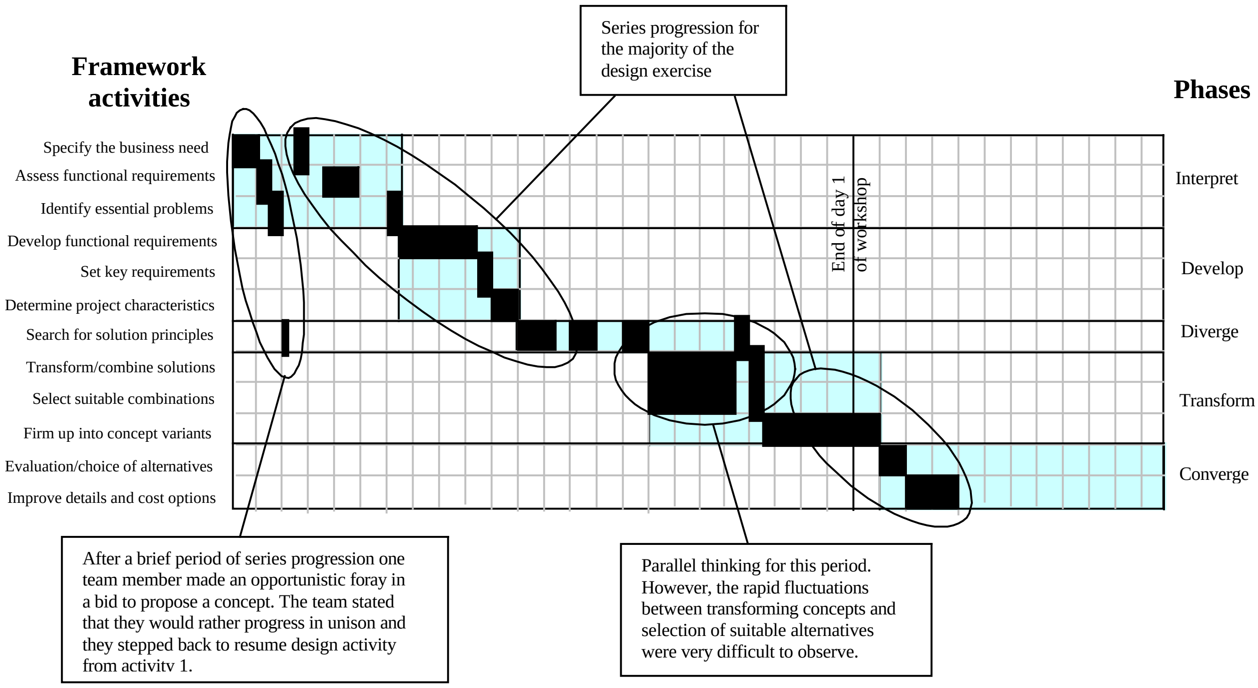


Figure 8 Pattern of progression of team 5

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'.

Team 6

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.

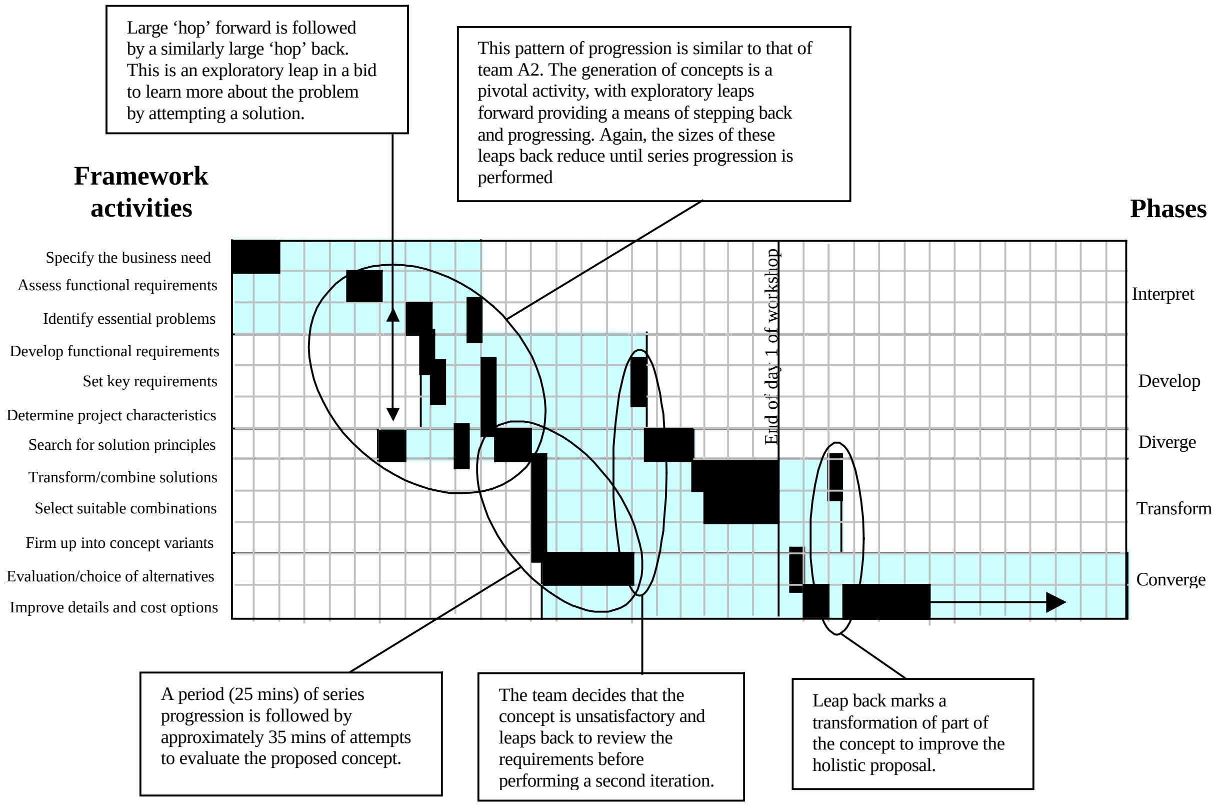


Figure 9 Pattern of progression of team 6

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.

Team 7

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 is followed by a brief exploratory step to generate concepts before stepping back to resume a fairly linear progression.

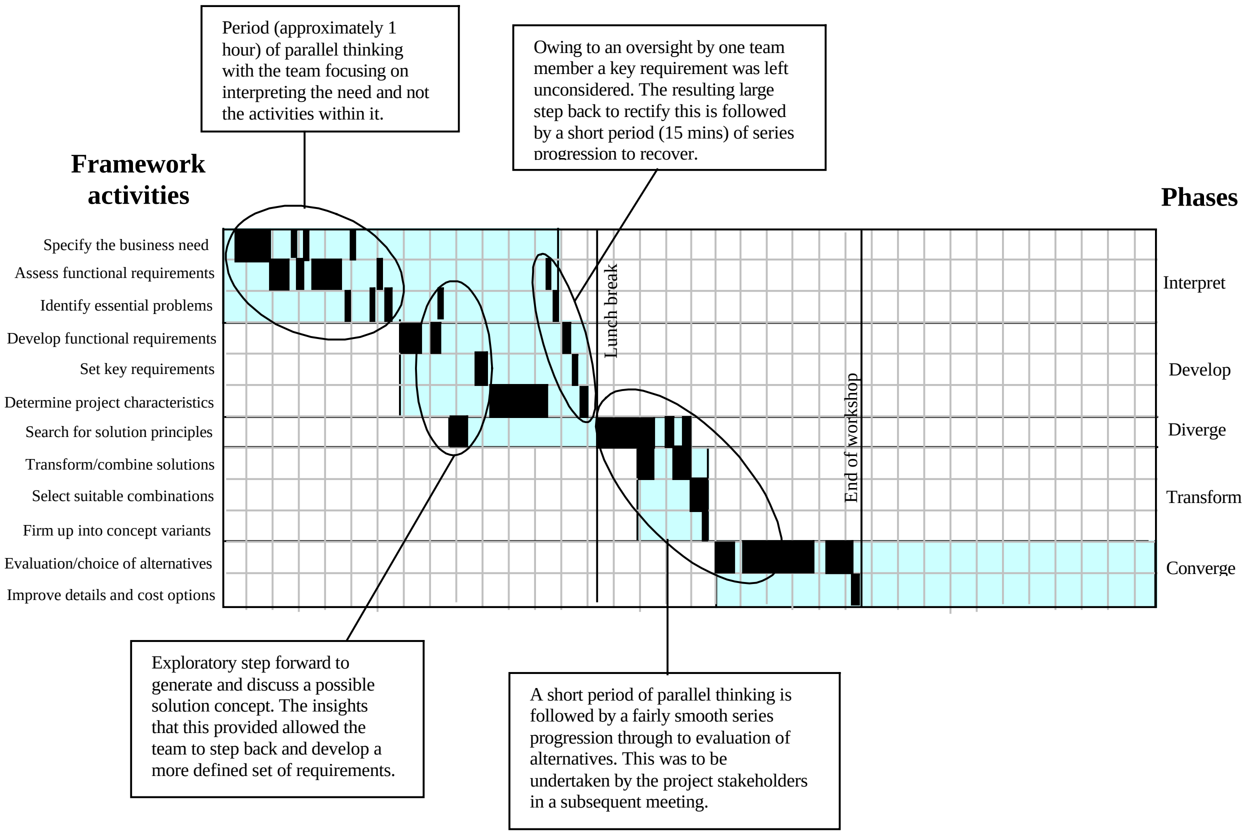


Figure 10 Pattern of progression of team 7

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 an oversight on the part of an individual. Thus, the design time spent performing this iteration could well have been avoided.

The design team comprised individuals that had worked together previously on projects of this type for the same client. Consequently, there was a good team dynamic from the outset and no real confrontation between members.

Trends within the patterns of progression

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.

Series and parallel progression

In analysing figures 1 to 7 it appears as if steps between activities mean exactly that - that each of the activities are considered in isolation of the others for that 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 member thinks about becomes irrelevant as long as the focus of their individual thinking aims at achieving the objective (activity) – their thought processes will be very different but their objective in thinking is synchronised. Thus, depending on the manner in which the steps were taken (two types are identified in figure 11 – based on the design progression of team 7) it is the suggestion of the authors that 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 at different levels of the framework.

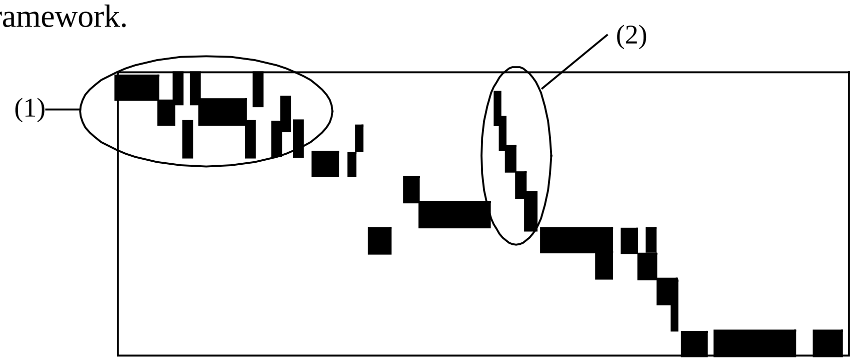


Figure 11 Differentiating between parallel and series focus

Figure 11 illustrates two very different types of iteration. 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 11 could be reinterpreted as figure 12 below.

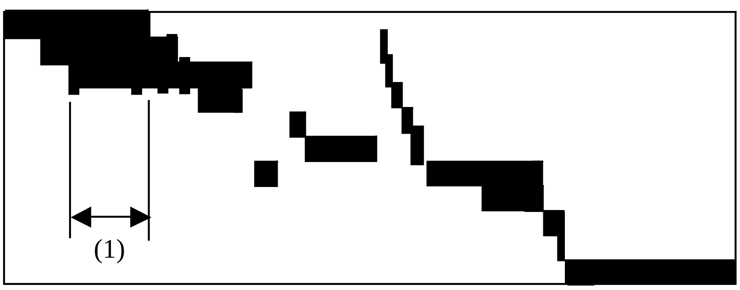


Figure 12 Reinterpretation of figure 11 given differences in periods of design progression

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 always the case. However, it is important to recognise that the dominant form of design progression was observed to be steps forward sequentially (series progression), followed by a leap back over several activities before entering series progression again.

Speculative progression: Stumbling versus exploration

Typically, if there is a large jump forward over a number of activities, e.g. 2 – 7 it is followed by a similarly large step back (7 – 2, 7 – 3). This type of sporadic leaping can been described as speculative progression and is driven by speculative thinking (illustrated in figure 13). This type of progression, which is common in the patterns of design progression illustrated previously, suggests that either:

- The team members have progressed hastily and, upon realising that they did not do enough background investigation to achieve the objective (effectively), are forced to step back to the original activity out of necessity; or…
- The step was taken, for example, to attempt a solution, to improve problem definition before stepping back to address the earlier activity with improved knowledge.

If the latter is the case, then it is assumed that the problem must be ill-defined and as a result, there is some underlying rationale behind the sporadic stepping between activities. If the former is the case the latter will occur, to some extent, by default. However, this represents a stumbling progression in design terms and it could be described as neither effective nor efficient design behaviour – it is purely a symptom of having designers who do not understand fully the high level design phases and activities.

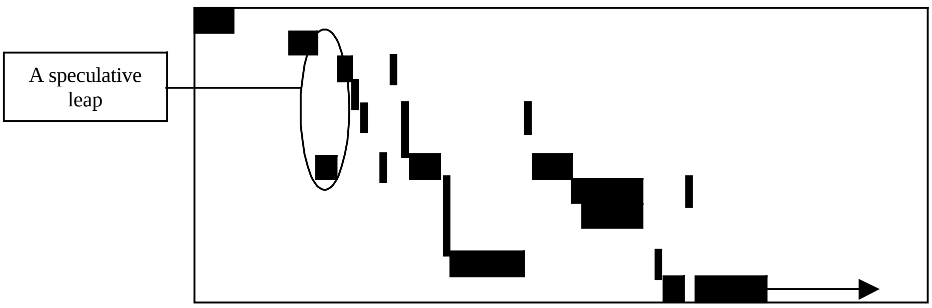


Figure 13 Speculative design progression

Reiterative 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. When this has occurred, our monitoring shows four possible causes for the large jumps back:

i) an oversight – thus a needless iteration that could be avoided;
ii) lack of recording a decision;
iii) recognition that an earlier assumption was either incorrect or poor;
iv) checking to see if the previous work was correct.

Whichever the case, in the workshops it is common to see this pattern repeat until an appropriate design has been generated (figure 14 – a representation of the pattern of progression of team 1.)

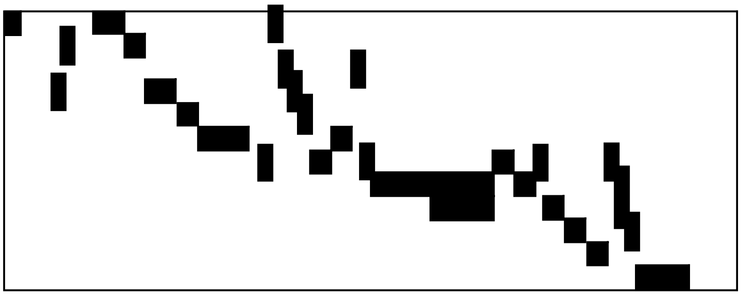


Figure 14 Reiteration as a driver of design progression

Changing gradients of series progression

When reiterative design progression occurs during design activity (an example of which is illustrated in figure 14) it is apparent that the gradients of the series progressions, i.e. the length of time spent reiterating through the same activities) are inconsistent. Although it may be expected that the second iteration would be steeper than the first (since some learning has taken place), in practice two common patterns occur: the second iteration has either i) a reduced gradient (type A); or ii), as has been described, an increased gradient (type B).

When a team has progressed very quickly through a series of activities, any second iteration tends to take longer to perform than the first; a reduced gradient is apparent (figure 15). 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. This is particularly the case if the rapid progression takes place at the end of the design activity, leaving no time to undertake the second less-rapid iterative progression.

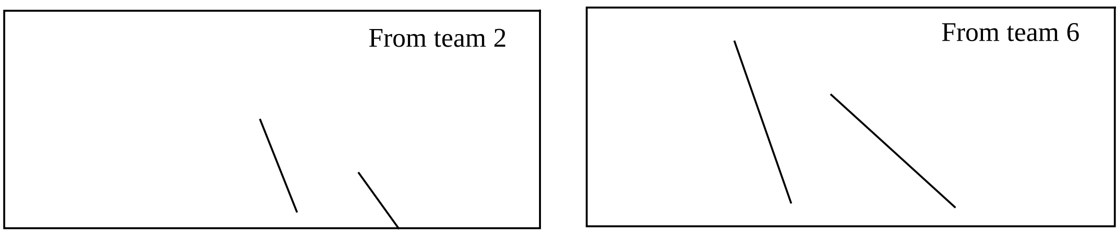


Figure 15 Illustration of reduced gradient (type A) of second iteration

Conversely, when a team has progressed slowly through a number of activities, any second iteration through those activities is performed far more quickly; an increased gradient is apparent (figure 16). The reasons behind this type of iteration have been outlined in the previous section.

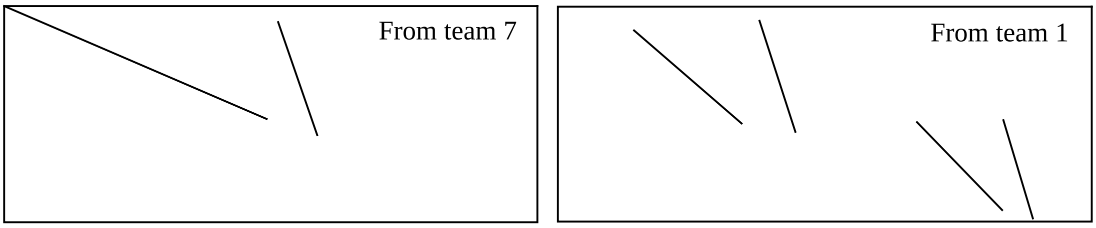


Figure 16 Illustration of increased gradient (type B) of second iteration

In outlining the differences between the types of reiteration it must be noted that no data has been gathered to suggest that one is more beneficial then the other. However, it is fairly obvious that the closer the team gets to the project deadline the riskier the performing of type A progression becomes. Thus, it appears that the optimum point at which to apply type A progression is at the outset of the project. Whereas type B progression can be undertaken throughout design activity with little, if any, risk to the success of the project. In fact, it may be more beneficial for the team to apply this type of iterative progression as a means of reflecting on their design activity and checking their evolving 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'. However, 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.

Affects 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 reiteration in order to be solved. Conversely, well-defined problems, typically, require far less re-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 can be described in terms of an iterative bandwidth based around the theoretical waterfall process (illustrated in figure 3).

An evolving degree of iteration: the iterative bandwidth

The previous section has identified differing types of design progression that characterise periods of conceptual design activity. 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 bring 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 12) 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 is described as the '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.

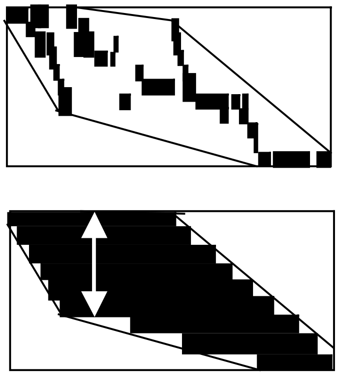
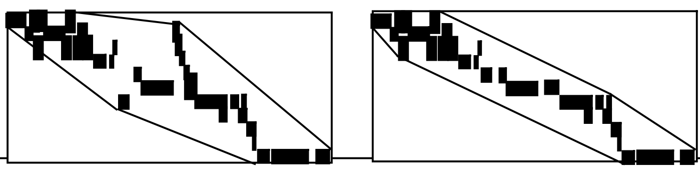


Figure 17 The concept of the evolving bandwidth – based on an ill defined problem

If this is related to the previous discussions on reasons for iteration it is apparent that the tighter the bandwidth becomes the fewer the number of activities that are enveloped, and thus addressed/considered, in parallel. Additionally, as the boundaries of the bandwidth move towards being parallel, the less the concertina effect on the activities, i.e. the number of activities being addressed in parallel (disregarding the ramping up at the outset, and down at the end) remains constant. The bandwidth should be thought about in the vertical (number of activities over a given time period), rather than the horizontal (length of time over which a single activity has been performed sporadically). This is a very important distinction to make as it ensures that sequential burst through activities are recognised as such, and not blocked together as a period in which the an activity was considered in parallel with a number of others.

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 team 7 verified this notion during a post-design discussion in stating that 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"*. Thus, it is not unreasonable to suggest that teams that have worked together previously on a certain type of project for a certain type of client, could fine-tune their design progression around characteristic iterations. This, in theory, could allow the bandwidth to be tightened over the course of a number of projects (figure 18), thus removing any wasteful iteration from future design activity.



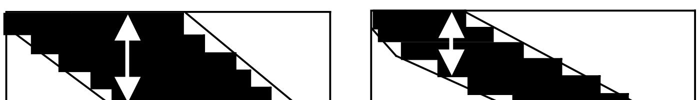


Figure 18 A reducing bandwidth resulting from improving understanding of the problem type – moving towards being well defined

Applying the bandwidth concept in design management

Our study to date has focused on the observation 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 follow a wide bandwidth (lots of iteration), while those addressing fairly well defined problems would be limited to a narrower bandwidth (less iteration). It may be possible to look at a design team, their experience on a particular project type, in a particular working environment; and set an expected bandwidth. If the design manager monitored the design team based on this bandwidth he could identify when they stepped outside and then ask them why. This would allow the reasoning to be fed forward onto the next project process of that type.

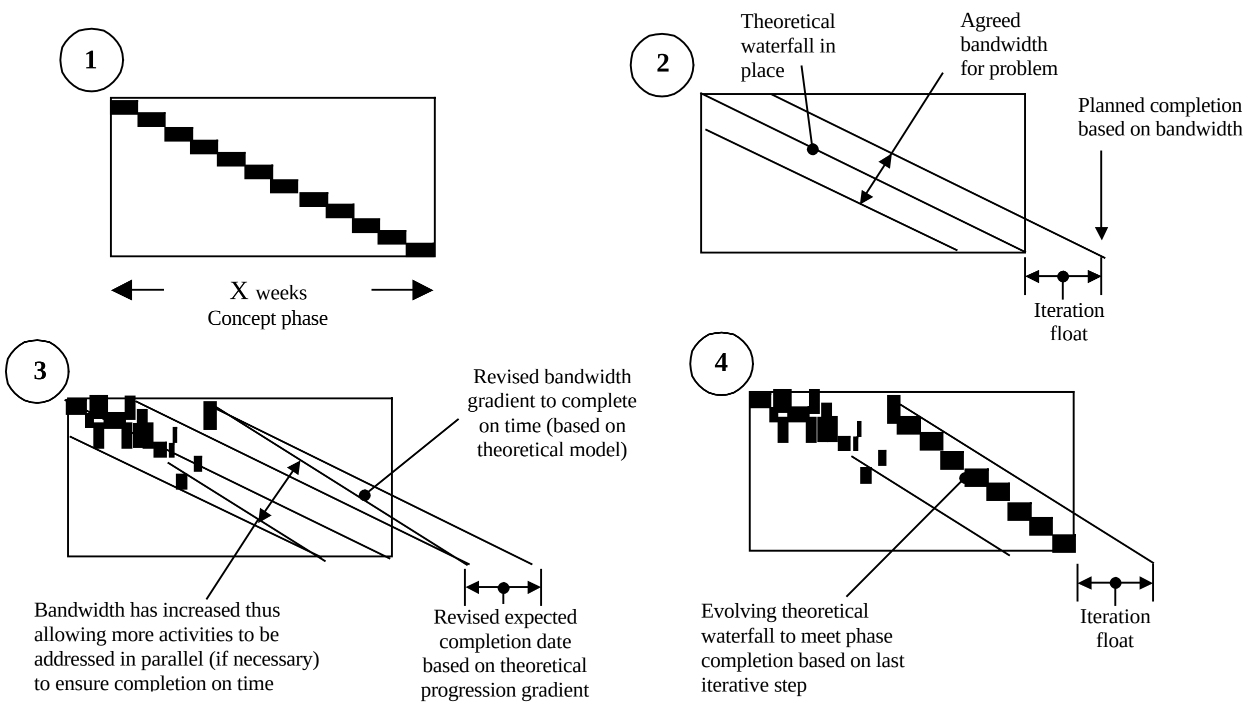


Figure 19 Prescribing bandwidth

This concept is based around attempts to manage design by controlling iteration around a datum constraint, e.g. the phase completion date. Iteration is allowed, and encouraged. However, if unsubstantiated jumps are logged, then reasoning is requested and the subsequent time for completion of each activity is reduced; and the team members are allowed to address more in parallel (should they wish to). 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 20) based around the model of conceptual design (shown previously in figure 2).

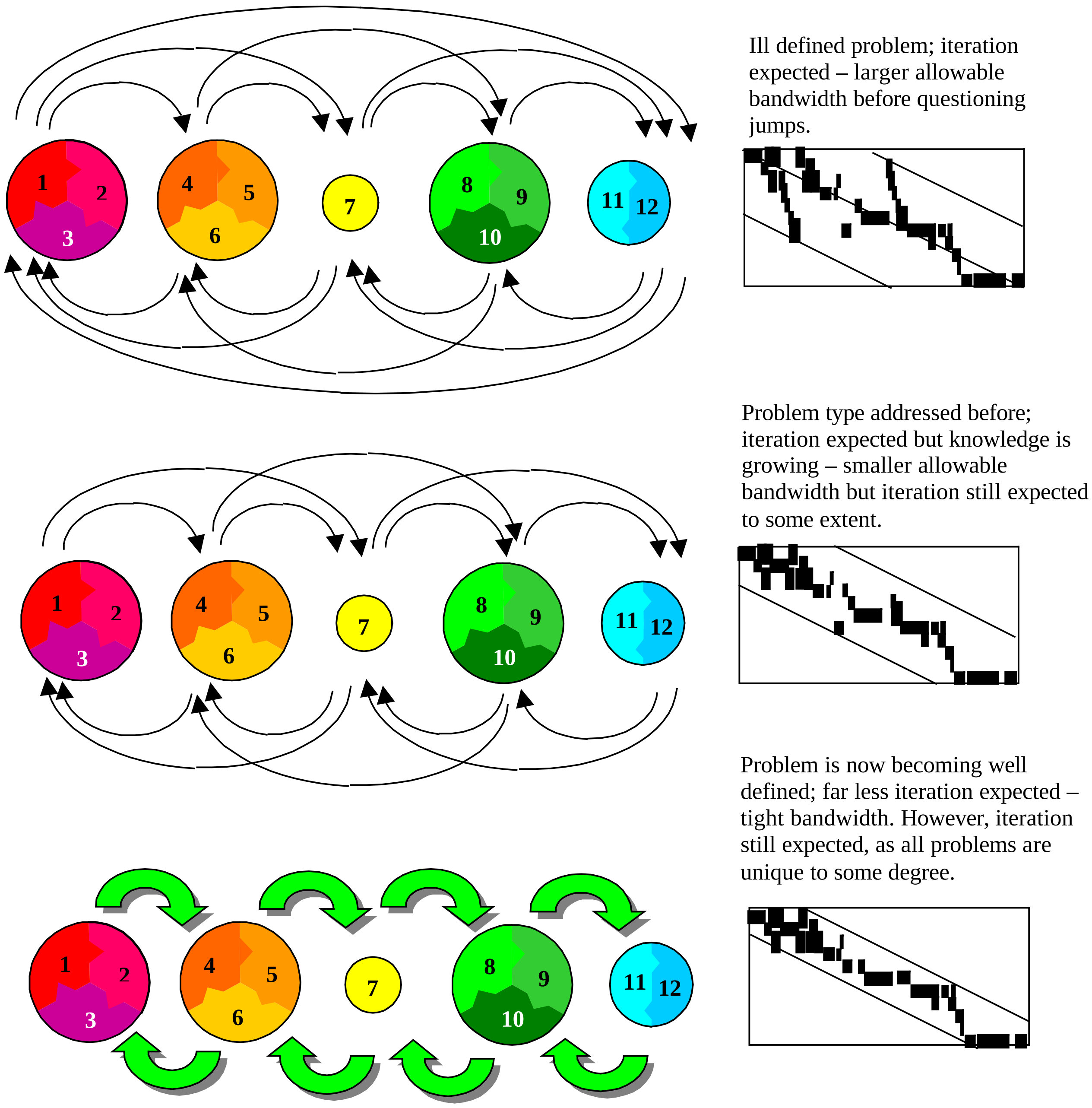


Figure 20 Iterative loops as the designator for bandwidth

Concluding remarks

The Mapping the Design Process project has provided an opportunity to monitor the design activities followed by interdisciplinary teams of designers during the concept phase of building projects. We have devised a simple graphical means of recording and displaying the pattern of progression through the activities that the teams followed. And we have used this to study and analyse these patterns in terms of the gradients and bandwidths of iterative working.

It seems highly appropriate that graphical methods are being 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. At best, these ideas about iteration, bandwidth and gradient might be passed back to designers to encourage them 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 workshop seven. 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. Its development and testing has been reported elsewhere (Steele et al, forthcoming) and one of the industrial collaborators is proposing to develop it further as part of their in-house management of design.

Finally, the numbers of design teams we have been able to monitor 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. We believe that the patterns we have identified are of considerable interest, but we have insufficient data to draw robust and generally applicable conclusions. We should be pleased to think that our ideas and methods might be the basis for further data gathering and analysis by others, adding flesh to the skeleton we have constructed.

Acknowledgements

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