Is there a specific type of knowledge associated with design?

A. T. Purcell Sydney University, Australia
K. S. Sodersten Sydney University, Australia

Abstract

This paper is concerned with the question of whether or not there are forms of knowledge that can be regarded as unique to design. On the basis of protocol studies of architects designing we identify three types of knowledge that may be considered as candidates for design knowledge. These we refer to as interpreted and embodied knowledge, compiled knowledge and strategic knowledge relating to the use of design representations. Each of the potential types of knowledge addresses a core problem in design how to move from knowledge that is abstract and conceptual to a representation of that knowledge in physical form.

Is there a specific type of knowledge associated with design?

Introduction

"There is no evidence that the results of such experiments are of interest to designers or educators and attempts at applying methodologies derived from such analysis have failed over three decades."

This is taken from a referees report on a recent grant application concerned with innovation and high level expertise in design. Needless to say the grant application was not successful. However this comment presents a challenge to design researchers. Is design research simply concerned with understanding the design process? As a basic research area it has considerable legitimacy. Design is a paradigmatic example of ill-defined problem solving and ill-defined problem solving represents a central and under-researched aspect of human cognitive capacities. Design can also be associated with innovation and creativity, again fundamental human capacities. However we, along with many if not all design researchers, want our field to be both a strong area of basic research and to have it contribute to the education of designers and the practice of design. The challenge is – how can design research contribute in these areas? This paper is an attempt to begin to chart the relationship between design research and design education. In particular we want to address the question of the nature of design knowledge. This particular issue was brought into focus through our development of a new undergraduate program that was based on the results of design research and recent research in the area of teaching and learning.

Design and ill-defined problems

Before addressing this question directly we would like to focus initially on the general nature of ill-defined problems and on a specific facet of design as ill-defined problem solving. In our view it is the ill-defined nature of design problems which is at the core of both the importance of design research as basic research and equally is at the core of design education. The nature of ill-defined problems has been discussed extensively (Simon,1973; Reitman, 1964; Goel, 1995), however the basic characteristics of such problems are that the statement of the problem is incomplete and there is no single correct or even optimal solution. These basic characteristics have a number of consequences, for example the problem solver must discover what is relevant to the problem before or while developing the solution. In the context of design these are important issues but another equally important characteristic is introduced. The statement of a design problem is both incomplete and its content is not directly related to the specific physical characteristics of the artefact (or the representation of the artefact) that must be the end result of the process. If the designer is asked to design a house for a specific family on a particular site, the statement of the problem has no direct relationship to nor does it directly constrain the physical attributes of the house that might be designed.

Not only does the statement of the problem not specify any physical attributes but the information related to the issues that might be identified as relevant is generally at a more abstract or conceptual level and it too does not directly relate to specific physical attributes of the design. For example such a problem would involve issues to do with materials, structural systems, construction methods, the experiential attributes to be associated with the home and many others. The knowledge that is available in each of these areas simply provides possibilities that would have to be made concrete or realised by the designer in the particular attributes of the building. Moving between the abstract and conceptual and the physical differentiates design of physical artefacts from other forms of ill-defined problem solving and, creates great difficulties for design students and it is the ways of dealing with this problem we will argue that generates the types of knowledge that are specific to design.

Design knowledge

Designed artefacts and the designers who produce them can be situated within a number of contexts. A designed artefact, because it exists in the world, has a set of relationships with various aspects of that world. For the purposes of this discussion we will refer to these aspects of the world as environments and these are illustrated on the right of the diagram below. Once it is manufactured or built, a designed artefact exists within a physical, biological, human and many other types of environment. These environments are typically associated with bodies of knowledge that are the result of research activities designed to understand what they are made up of, how they work and so on. A designed artefact can be examined from the point of view of how it fits into these various environments using this knowledge that is it can be evaluated. This is recognised within the diagram by the arrows in the diagram linking the object with the various environments. While this type of analysis and evaluation can be carried out independnantly of the designer (or a design student) the knowledge that is involved could be used by the designer.

This is also identified in the diagram by a link to the designer and student. This relationship could take a number of forms. For example the knowledge could inform the design process or the knowledge could be used to evaluate the design as it evolves. However the knowledge that exists in these areas is typically abstract and conceptual seeking to represent the underlying laws and principles in the area. Because the designer is concerned with a specific situation for which a physical object must be developed, there is a gap between the knowledge that is relevant to the design and how that knowledge can be introduced into physical form as discussed above. It is possible to reason from first principles as indicated in the diagram. However there will always come a point where the designer has to move to a specific physical form. Once this has been done it is then possible to assess and evaluate what is proposed but the question is do designers actually design in this way and is this an answer to the question what is design knowledge. If they do act in this way it would appear that there is not a specific knowledge that is associated with design. Rather the knowledge that informs design is the use of existing knowledge from other domains unless that is there is a form of knowledge associated with the step from the abstract to the physical and this is one issue we will pursue in the following discussion.

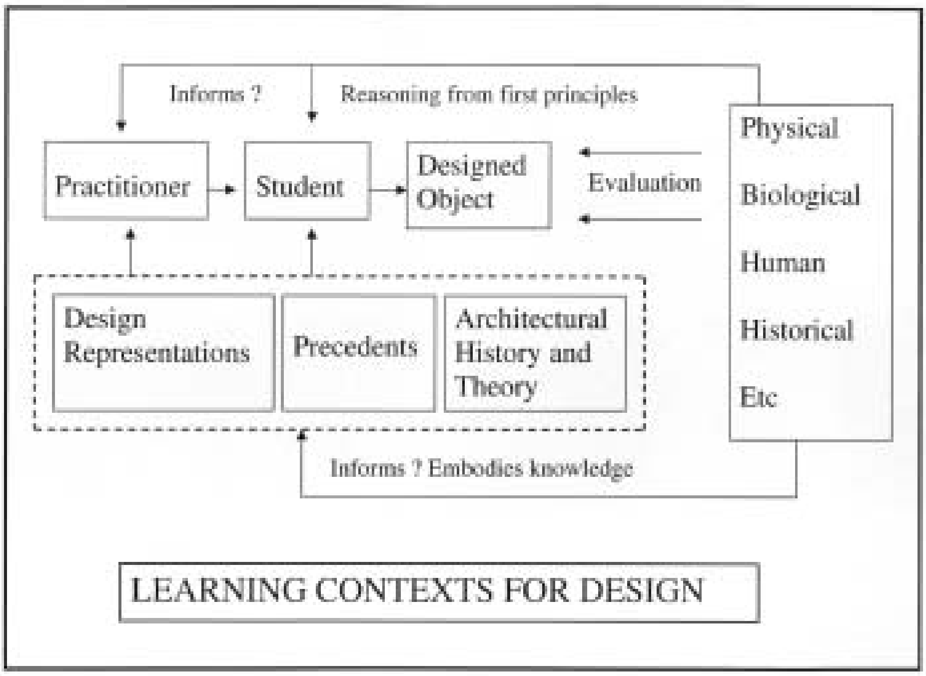

Figure 1: Contexts for designers and designed artefacts

However the diagram also identifies another context within which a designer / student and a designed artefact are situated. These are, in the case of architecture, architectural history and theory, precedents and design representations. A particular designed artefact is a part of and therefore related to all other designed (and possibly not designed) examples of the type and designed artefacts generally. Some existing designs can be considered to be exemplary or at least worthy of study that is they come to be considered as precedents. Often the content or knowledge associated with architectural history is concerned with such precedents, the designers who produced them and the cultural context they existed within. Designers are clearly concerned with precedents and design students are often told to look for precedents. The question is - what is the relevance of precedents and does this relevance constitute a type of design knowledge? This issue will be examined in the following discussion. Finally it is clear that designers use many different forms of representations - simple block diagrams, unstructured plans and sections, three dimensional representations, physical models, detailed and explicit plans and sections and so on. In one sense these are skills and can be taught as skills. While there is knowledge involved in these skills, it would not seem to be a knowledge particularly associated with design. However it is possible that the strategic deployment of these skills could involve a form of design knowledge and this issue will also be examined in the following discussion.

Interpreted or embodied knowledge

One of these types of design knowledge is what we refer to as interpreted or embodied knowledge. In order to illustrate what we mean we will use the contents of a protocol of a design session of an expert architect engaging in the design of a museum. This protocol has been used in an intensive examination of the cognitive processes involved in sketching during design (see, for example, Suwa, Gero and Purcell, 1998; 2000). The designer was video taped while designing but he was not asked to think aloud during the process. Because the focus was on sketching, it was considered that thinking aloud could interfere with the process. At the end of the design session, the designer was shown the video –tape and asked to say in as much detail as possible what he was thinking about while he was making each mark on the paper. From this material a detailed coding scheme was developed. Four broad categories of cognitive actions were identified: the physical, the perceptual, the functional and the conceptual. The following description of these categories is taken from Suwa, Gero and Purcell (1998).

The first category, **physical**, refers to actions that are directly relevant to physical depictions on paper. It consists of three actions. One is to make depictions on paper, such as diagrams, symbols, annotations, memos, and sentences. We call it 'D-action'. The second is the motion of a pencil or hands that do not end up with depictions. We call it 'M-action'. The third is to pay attention to the existence of previously-drawn depictions. We call it 'L-action'.

The second category, **perceptual**, refers to actions of perceiving visuo-spatial features of depictions, such as shapes or sizes of depicted elements and spatial relations among elements. We call it 'P-action'. For example, if a designer draws a new depiction near an existing one by attending to the spatial relation between both, the new depiction is coded as a D-action, his attention to the existing depiction as a L-action, and his attention to the spatial relation as a P-action. This P-action is viewed as having occurred dependent on the D-action and the L-action. This way, P-actions have inherent dependency on physical actions.

The third category, **functional**, refers to actions of thinking of non-visual functional issues or abstract concepts with which designers associate physical depictions or their perceptual features. We call it 'F-action'. For example, if a designer attends to a spatial relation between two regions and associates it with a view from and to both places, his thought on "view" is coded as a F-action. This way, functions or abstract concepts are not actually given in the appearance of elements and relations, but suggested by it. Therefore, F-actions have inherent dependency on physical actions and/or P-actions.

The fourth category, **conceptual**, refers to actions that deal with non-visual information which is not inherently suggested by the appearance of elements and relations. There are three types. The first is to evaluate the aesthetic value of design decisions made by P- or F-actions. We call it 'E-action'. The second is to set up goals. We call it 'G-action'. A goal is sometimes set up by being triggered by P- or F-actions, or sometimes as the subgoal of an existing goal. Once a goal is set up, it in turn gives birth to other actions, i.e. G, F, P or physical, in a top-down way. The third is to retrieve knowledge for making inference. We call it 'K-action'.

This coding scheme allowed all of the verbal material produced by the designer in identifying what they were thinking about while they were drawing to be coded. These four categories (and their sub-categories not presented here) can therefore be regarded as identifying four types of design knowledge. The first point to be made is that reasoning from first principles does not appear in this coding scheme just as it does not appear in any of the other design protocols we have collected. The knowledge used in design therefore is not directly based in the various disciplines that can be shown to be related to designed artefacts. This conclusion needs to be treated with some caution as there may be variation between different design disciplines with some, such as engineering using basic knowledge from the discipline more directly in the process (see Lawson, 2001). The categories of the coding scheme can however be examined to see if they can give indications of what knowledge is involved in design.

The first, the physical, can be seen as reflecting knowledge about what physical representations are meaningful and useful and this issue of the use of design representations will be discussed in a separate section of the paper. It is also apparent that these representations are ways in which physical forms can be developed that relate to the specific design situation. That is it is a way of dealing with moving between the under-specified, conceptual statement of the problem to a representation of a physical form that can be developed.

The second category, the perceptual, can also be interpreted as a form of knowledge. The designer uses the physical representations to identify and operate on visuo-spatial features of the drawings. The knowledge involved here is how to how “look at” such drawings in this way. Teaching someone how to make the various types of visual representations that are used will not necessarily teach them how to “look at” the drawings in a way that allows the progressive development of the specific physical attributes of the final artefact. What they need to be taught is how to notice and use visual features of elements in the sketch such as size, shape and texture; spatial relations amongst elements such as proximity, remoteness, alignment, intersection, connectedness; organisational relations amongst elements such as grouping, uniformity/similarity, contrast/difference and implicit or emergent spaces that exist between elements. Because these perceptual categories are linked to the physical this discussion is also relevant to the later discussion of design representations.

The other two categories – functional and conceptual actions – we would argue represent what we have termed interpreted and embodied knowledge. This type of knowledge has two characteristics. First it has a conceptual component but this is associated with knowledge of the way that concept can be embodied or what it implies in terms of physical form. In the above example the idea of a view is relatively abstract but it is associated with particular physical characteristics that are represented in the drawing and the designer recognises. Presumably this is possible because the knowledge that the designer has is the association between views and certain physical attributes that create views. In addition the designer must also have as part of this bundle of knowledge, other knowledge relating to why views are important. This is essentially derived from the basic knowledge found in for example environmental psychology about the psychological functions of views. The designer may not be aware of this basic knowledge but may only have the bundle of knowledge that represents its interpretation and embodiment. Similar analyses can be made of the categories of conceptual actions in the coding scheme.

The second characteristic of this type of knowledge is that it is often based on the individuals design experience or on the analysis of precedents. To illustrate this we will use an example from a protocol of an architect who had been engaged in a design activity during which he had not been allowed to draw. Following this session there was a structured interview with the architect part of which involved the him comparing and contrasting his experience during the design session with his usual way of designing. The architect had found designing under these conditions particularly difficult and was unhappy with the result because sketching for him was an essential part of his way of designing. Part of the interview revolved around whether or not he used visual imagery while designing. He was adamant that he did not and that he used what he referred to as memories. To illustrate what he meant he described how he had made a detailed study of Louis Barragan and somewhat unusually particularly of Barragan's plans. This study resulted in him having a very detailed understanding of how characteristics of Barragan's plans and the physical characteristics of the resulting buildings produced experiential outcomes that he valued. When he was designing he did not have a visual image of barragan's plans or particular buildings but the memory that represented this particular type of knowledge he had gained based on his study. Sketching was vital because the memory informed the sketch that was related to specific characteristics of the design problem he was working on. These memories are clearly interpreted knowledge based on precedents and study by the designer. The precedent does not directly enter into the design process but only on the basis of the memories constructed by the designer.

Clearly these are only illustrative examples. However they at least identify what could be a type of knowledge that can be classified as design knowledge and so could form the basis for research to establish whether this type of knowledge has some generality and to characterise it more completely.

Compiled knowledge

While much of the existing design research has focused on the early, conceptual stage of the process, a considerable proportion of a complete design process involves design development and detailing. During this part of the process designers use another type of knowledge, what we are referring to as "compiled" knowledge. This type of knowledge is found in handbooks, workbooks, data sheets and trade catalogues. In one respect this knowledge similar to the interpreted knowledge discussed in the previous section. This is because it is derived from the basic knowledge areas and is embodied in representations of physical forms. However the basis of the compiled knowledge is not the individual designer's learning and experience. Rather the author takes basic knowledge and develops its application in a specific setting. For example the diagram below presents information about the amounts of space that have to be allocated to accommodate tables seating different numbers of people, arranged in different spatial orientations with allowances for circulation in restaurants and cafes (taken from De Chiara, Panero and Zelnik, 1991).

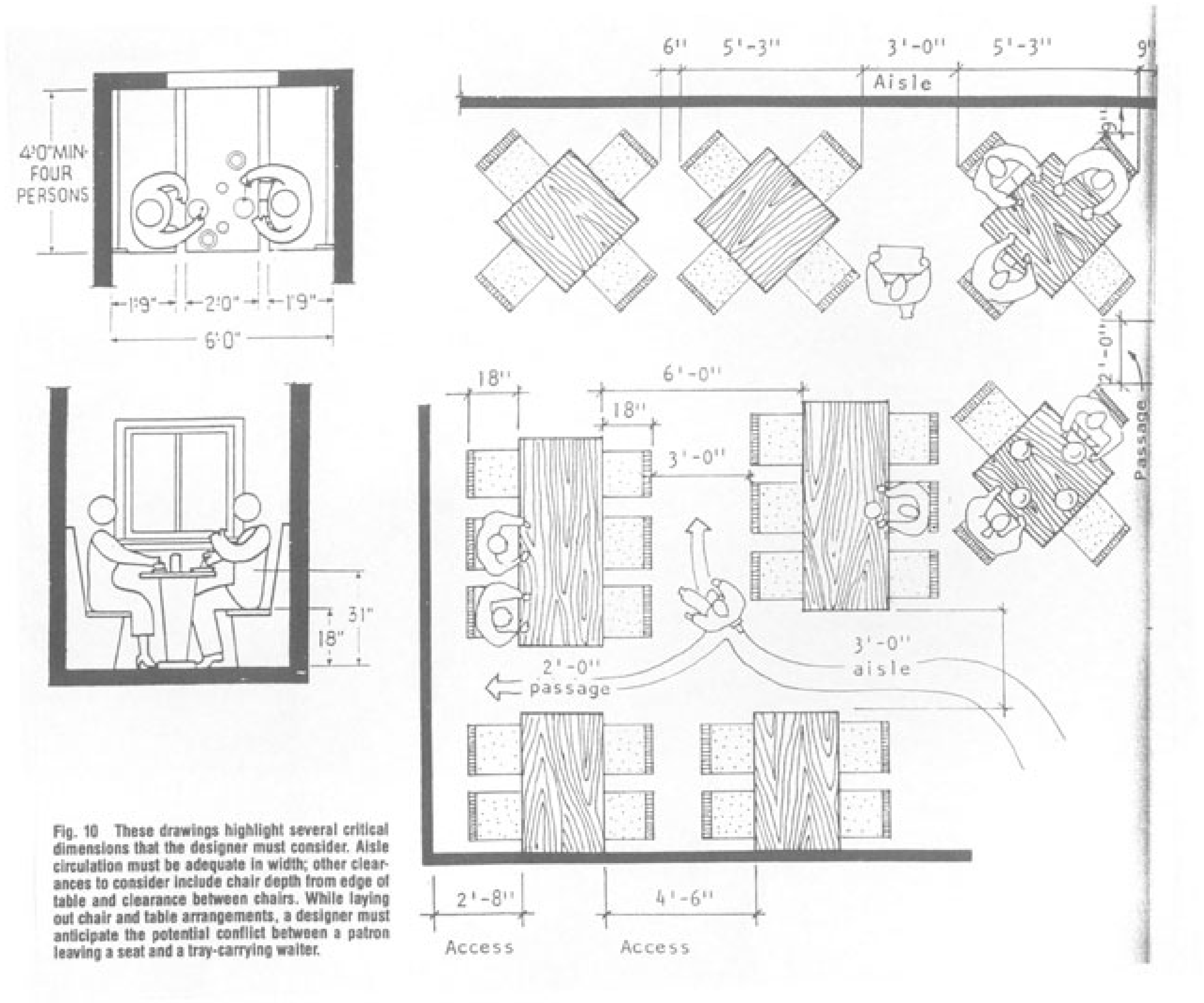

Figure 2: A simple café plan

What lies behind this diagram however is a considerable amount of knowledge in the area of ergonomics and human factors. For example the size of the table is related to how each of the objects is used in the set of activities associated with eating. A typical basic table setting in a restaurant would involve a knife, fork, spoon, main plate and side plate and glass. The ergonomic issues associated with using the knife, fork and spoon and their use (picking up and holding) are shown in this diagram.

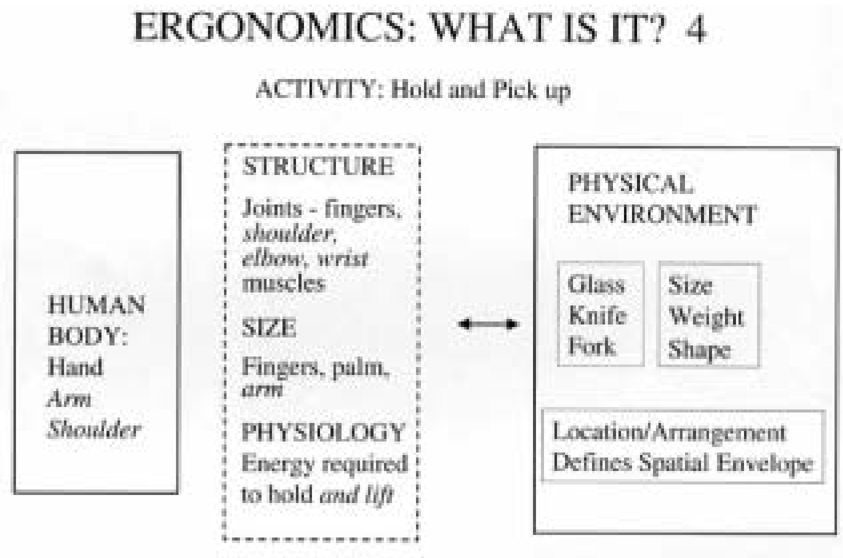

Figure 3: Ergonomic issues involved in picking up and holding a knife, fork, spoon or glass

Each of these has to be located on a surface in order to carry out the activity and consequently each would occupy an amount of space. Given that the eating implements are typically arranged in a specific way spatially another set of ergonomic issues become involved. For example the knife and fork go together. In order that the user can pick them up without disturbing the other, they have to be spatially separated. This spatial separation can be based for example on the width of the thumb. If the other elements in a typical table setting, a plate and a side plate, are introduced, further spatial requirements can be identified on the basis of ergonomic data. For example the spoon and the fork have to be sufficiently separated from the plate (again the width of the thumb could be used) so that they can be picked up without striking the plate or side plate. If the dimensions of the plate and side plate are now included, the combination of the spatial requirements of all the elements essentially defines the spatial envelope for a single person eating space. This basic space could then be aggregated to give the basic table dimensions for 2, 4 or six person tables.

This represents the basic spatial requirements for table area. However other sets of ergonomic issues are involved. The diner must sit at the table and so the chair and the diner positioned at the table will occupy space and this dimension has to be added to the spatial requirements of the table. Similarly the diner must move into and out from the table in order to be able to sit at the table. The distance that the chair has to be from the table to allow access (hip to knee dimension, thigh width) must then be included in the spatial envelope associated with the table. Finally circulation space giving access to the tables has to be included. This depends on shoulder / hip width and the number of people who will be moving through the space.

The diagram of the basic café plan shown above could be developed from this type of analysis in conjunction with a source of relevant ergonomic data such as that found in, for example, Diffrient, Tieley and Harman (1981). However while this diagram is based on this information, it is not immediately apparent that this is the case. For example the main dimensions given relate to the combination of the table and chairs located in the seated position. Why the table is that size and the fact that the space taken up by the chair when it is moved out from the table is taken as part of the circulation space except in the main ailse is not indicated in the diagram. In other words diagrams such as these that compile existing basic knowledge embody a number of assumptions and decisions and this represents the danger that is associated with their use both by practitioners and students. If they are just accepted and no attempt is made to understand their basis, their use can lead to faulty design where the specific design situation they are used in does not fit with some of these assumptions and decisions. Designers need to be able to use this type of design knowledge critically and design students need to be taught not only about their existence but how to evaluate them critically by identifying the assumptions and decisions involved. However compiled knowledge of this type clearly represents a form of design knowledge.

Strategic representations

Designers use a number of different ways of representing their designs such as diagrams, plans sections, elevations, models, CAD representations. Often in the educational context the emphasis seems to be on teaching how to do each of these types of representation that is as a skill. However one continuing theme in the design research area is the role that drawing and sketching in the design process (Goldschmidt, 1991, 1994; Suwa, Gero and Purcell, 1998, 2000). This research has demonstrated that the use of these types of representation plays a central role in both developing an understanding of the problem that is brought about by the ill-defined nature of design problems. This research also demonstrates that this understanding of the problem co-evolves with the development of solutions to the problem. Further these representations play a central role in unexpected discoveries relating to physical form and the identification of new goals that had not been previously recognised. Design representations therefore play a fundamental role in the design process far more than simply ways of documenting a design. Knowing how to use design representations in this way therefore constitutes another type of design knowledge. While the role of sketch drawings has received considerable attention and resulted in important insights, there is another aspect of the use of these representations that has received much less attention. We would argue that the design protocols on which these insights are based also reveal another important aspect of design knowledge. Designers switch between different forms of representation at different stages of the process and that this switching is strategic.

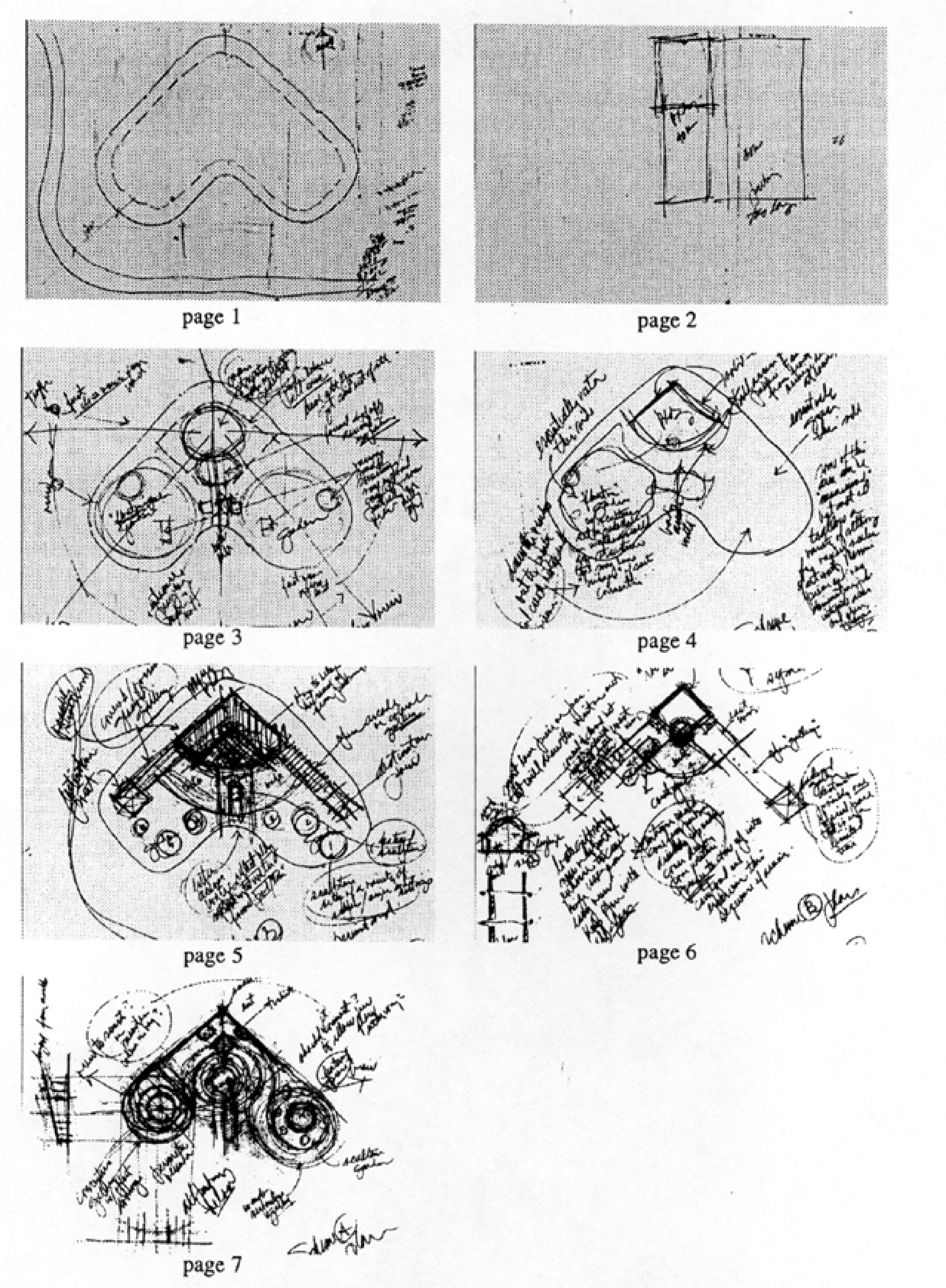

Figure 4: Part of a set of drawings produced by an architect during a design session

This process can be seen to be operating in the series of sketches taken from a protocol of a design session with an experienced architect engaged in developing a sketch design for a museum discussed above (see, for example, Suwa, Gero and Purcell, 1998, 2000). The order of the sketches is as they occurred during the design session. It is quite clear that the designer is switching between different forms of representation. The first drawing is a very simple plan representing key features of the site. The second drawing is quite different, diagram that represents the different proportions of the areas that are to be associated with building and with external spaces. This is given in the brief but this drawing is a visual representation of the areas given numerically. The designer then switches again to a more detailed but still unstructured and ambiguous (in Goel's 1995) plan. The designer continues with this form of representation in fact developing two separate versions of the design. In moving from one sketch to the next the designer often transferred some aspects of an earlier sketch to a later sketch by tracing over the earlier sketch. All of the sketches contain annotations which become more detailed as the design develops. Clearly this series of switches is not random but motivated and we would argue that what motivates the changes is a form of knowledge. The interesting question is what is what is the nature of this knowledge, how can it be elucidated and then how can it be taught.

An examination of a number of other protocols from other design sessions with architects reveals both similarities and differences. The similarities lie in the strategic use of different forms of design representations. The differences lie in the types of design representations that are used. Some designers will move to a physical or CAD model as the design develops. Others use sections and plans and shift the scale at which these representations are drawn. What this indicates is both that the strategic use of design representations is a key part of the design process and that there is variation between designers in specific combinations of design representations that they use. We know from previous research (Goldschmidt, 1991, 1994; Suwa, Gero and Purcell, 1998; 2000) the outcomes associated with design representations but not the knowledge in this sense that drives it.

Conclusion

We would argue that the three types of knowledge we have identified do represent potential types of knowledge that can be regarded as design knowledge. What appears to link them all together is that they are ways of dealing with a fundamental problem in design – how to move from the abstract and conceptual to the physical. There are also indications that there may be differences between designers in relation to the particular ways in which the knowledge is deployed. This was apparent in the ways different types of design representations were used. It is also apparent in the results of some recently completed research on how designers start the design process. If design is to be both a area of basic research and have an impact on education and practice, development of a more complete characterisation of design knowledge and how it is used has the potential to make a significant contribution.

References

De Chiara, J., Panero, J. & Zelnik, M. (1991) *Time Saver Standards for Interior Space Design*. New York, Mc Graw – Hill.

Diffrient, N., Tieley, A.R. & Harman, D. (1981) *Humanscale* 7/8/9, Manual. Cambridge, Mass., Massachusetts Institute of Technology Press.

Goel, V.: 1995, *Sketches of Thought*. MIT Press, Cambridge.

Goldschmidt, G.: 1991, The dialectics of sketching, *Creativity Research Journal*, 4(2): 123-143.

Goldschmidt, G.: 1994, On visual design thinking: the vis kids of architecture, *Design Studies*, 15(2): 158-174.

Reitman, W. (1964) Heuristic decision procedures, open constraints, and the structure of ill-defined problems. I W. Shelley and G.L. Bryan, eds., *Human Judgements and Optimality*. New York: Wiley.

Simon, H.A. (1973) The structure of ill-structured problems. *Artificial Intelligence*, 4, 181-201.

Suwa, M., Gero, J. S. and Purcell, T. (1998) The roles of sketches in early conceptual design processes, *Proceedings of Twentieth Annual Meeting of the Cognitive Science Society*, Lawrence Erlbaum, Hillsdale, New Jersey, pp. 1043-1048

Suwa, M., Gero, J. S. and Purcell, T. (2000) Unexpected discoveries and s-inventions of design requirements: Important vehicles for a design process, *Design Studies*, 21, 539-567.