Conceptual Designing as a Sequence of Situated Acts

John S Gero

Key Centre of Design Computing
Department of Architectural and Design Science
University of Sydney NSW 2006 Australia
john@arch.usyd.edu.au

Abstract. This paper introduces conceptual designing within an F-B-S framework. It then goes on to describe a number of models of designing before introducing the notions of situatedness and situated acts. The remainder of the paper describes the role of situatedness and situated acts in conceptual designing. It attempts to show that a number of otherwise difficult design phenomena are modelable using situatedness and situated acts. A demonstration example concludes the paper along with some of the research issues this view of designing brings with it.

1 Introduction

Designing is taken to be a mixture of activities and tasks but the vast majority of views of designing are that it is an activity, i.e. it involves distinguishable processes which occur over time. [We will use the word ‘designing’ as the verb and the word ‘design’ as the noun in order to distinguish between these two, rather than use the word ‘design’ for both and utilise the context to disambiguate the meanings.] This commencing idea about designing is not to imply that notions such as ‘inspiration’ play no role but rather that they are not the bulk of the design activity. It is common to distinguish classes of design activity and group them. One common grouping is into conceptual and detail designing.

An important characteristic of conceptual designing that is missing in detail designing is that in conceptual designing not all that is needed to be known to complete a design is known at the outset, i.e. part of the process of designing involves finding/determining what is needed. It is common to distinguish non-routine from routine designing based on this conception. This is not to imply equivalence between conceptual and non-routine designing and between detail and routine designing but rather to suggest that they share common ideas.

The foundation of models of designing using concepts from artificial intelligence and systems theory is that any model is composed of variables and processes. One common description of an outline for designing is the Function–Behaviour–Strucure (F–B–S) framework [1]. The variables required in a design process can be grouped into the three categories of function, behaviour and structure and the various design processes connect them and transform one into the other, Figure 1. Design processes available from this figure include:

formulation: F –> B_e
synthesis: B_e –> S via B_s
analysis: S –> B_s
evaluation: B_s <–> B_e
documentation: S –> D
reformulation - 1: S –> S'
reformulation - 2: S –> B_e'
reformulation - 3: S –> F' via B_e

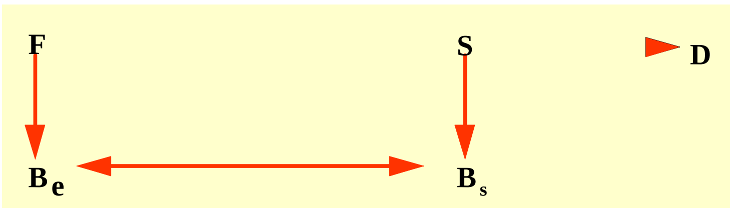


Fig. 1. The *Function–Behaviour–Structure* framework as a basis for models of designing, where B_e = expected behaviour; B_s = behaviour derived from structure; D = design description; F = function; –> = transformation; and <–> = comparison (after [1])

Another foundational concept in developing models of design is the concept of a state space. Here a state space is a representation of all the possible states that could exist if all the design processes legally operated on all the variables. It can be seen, here, as a representation of all possible solutions. These two sets of ideas: F–B–S framework and state spaces provide the opportunity to describe and develop a variety of models of designing. The remainder of this paper is concerned with very briefly describing a number of models of designing before moving to the notion of situatedness as an extension of existing design models, an extension which has the capacity to broaden our conception of the role of artificial intelligence in designing.

2 Models of Designing

In this section we introduce a number of well-known and lesser-known models of designing in order to be in a position to draw a distinction between them and designing as a sequence of situated acts.

2.1 Designing as Search

Search as a computational process underlies much of the use of artificial intelligence techniques when applied to designing [2], [3], [4]. The basic and often implicit assumption in designing as search is that the state space of possible designs is defined a priori and is bounded. The state space to be searched maps onto structure space in the F-B-S model and the criteria used to evaluate states map onto behaviours. The designing processes focus on means of traversing this state space to locate either an appropriate or the most appropriate solution (depending on how the problem is formulated). The advantages of modeling designing as search include the ability to search spaces described symbolically rather than only numerically. The assumption that the space is defined prior to searching relegates this model to detail or routine designing.

2.2 Designing as Planning

Planning here is taken from its conception in artificial intelligence as the determination of the sequence of actions required to achieve a goal state from starting state. It is a natural consequence of the existence of a well-structured search space. Planning has been used to model design [2], [5]. It also takes the same assumptions that designing as search does and therefore can only be considered as a model of routine designing.

2.3 Designing as Exploration

Designing as exploration takes the view that the state space of possible designs to be searched is not necessarily available at the outset of the design process. Here designing involves finding the behaviours, the possible structures and/or the means of achieving them, i.e. these are only poorly known at the outset of designing [6]. Exploration may be viewed in two ways. It may be viewed as a form of meta-search: the designer searches for state spaces amongst the set of possible predefined state spaces. It may viewed as a form of construction where each new state space bears some connection to the previously constructed state space(s). This form of exploration cannot be reduced to meta-search. Exploration connects with the ideas of conceptual or non-routine designing: not specifying or even being able to specify at the outset all that needs to be known to finish designing. Designing has been recognized as belonging to the class of problems called “wicked” problems [7].

2.4 Other Models of Designing

Other models of designing based on artificial intelligence or cognitive science concepts are generally either a specialization or a generalization of the models described above. Often they focus on some aspect of the model, often it is a procedural aspect.

Of particular interest here are two concepts: "reflection in action" and "emergence". The first of these refers to the notion that a designer does not simply design and move on but rather reflects on what he is doing and as a consequence has the capacity to reinterpret it. Schon [8] has called this a designer "carrying out a conversation with the materials". Implicit in these important ideas are the seeds for what will be described in Section 3. Emergence, which is a related concept to reflection, is "seeing" what was not intentionally put there [9], [10]. Reflection and emergence have evidentiary support from protocol studies of designers [11].

3 Situatedness and Constructive Memory

The lack of the models listed in Sections 2.1, 2.2 and 2.3 to adequately model our current view of designing has brought the need to develop models which include such concepts as reflection and emergence and processes which match those of exploration in Section 2.3. Work in cognitive science and related areas has developed two sets of ideas that have the capacity to augment, rather than displace, our current models to bring them closer to our needs. The two sets of ideas fall under the areas of "situatedness" and "constructive memory".

Situatedness [12] holds that "where you are when you do what you do matters". This is in contradistinction to many views of knowledge as being unrelated to either its locus or application. Much of artificial intelligence had been based on a static world whereas design has as its major concern the changing of the world within which it operates. Thus, situatedness is concerned with locating everything in a context so that the decisions that are taken are a function of both the situation and the way the situation in constructed or interpreted. The concept of situatedness can be traced back to the work of Bartlett [13] and Dewey [14] who laid the foundations but whose ideas were eclipsed for a time.

Constructive memory holds that memory is not a static imprint of a sensory experience that is available for later recall through appropriate indexing [15]. Rather the sensory experience is stored and the memory of it is constructed in response to any demand on that experience. In this manner it becomes possible to answer queries about an experience which could not have been conceived of when that experience occurred. "Sequences of acts are composed such that subsequent experiences categorize and hence give meaning to what was experienced before" John Dewey [14]. This view of memory fits well with the concept of situatedness. Thus, the memory of an experience may be a function of the situation in which the question, which provokes the construction of that memory, is asked. These two short introductions to situatedness and constructive memory suffice to allow us to now utilise these ideas in the development of our understanding of designing.

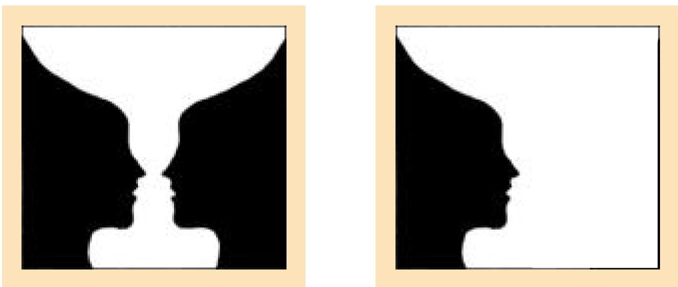
4 Situatedness, Constructive Memory and Designing

If we claim that conceptual or non-routine designing involves more than the searching, in however a well structured a fashion, of a state space of possible designs a question arises about what bases may there be to support the idea that there exist processes which do more than work within a single defined state space. We already have some processes that modify the state space of possible designs although not necessarily in a situated manner. These processes include analogy [16], case-based reasoning [17], and emergence [10] amongst others. What these processes lack is a unified framework within which they may be understood to operate. Further, they do not accord well with a view which is based on situatedness and constructive memory which we claim offers an opportunity to develop a model which accords with our current understanding of designing.

4.1 Situatedness and Designing

In conceptual designing the designer works with his experiences, his knowledge and his conception of what is in front of him – the situation – in order to determine what may be described more formally as, the variables which go to contribute to the function, behaviour and the structure of the resulting design. The particular behaviour and structure variables are not only chosen a priori but are produced in response to the various situations as they are encountered by the designer. What the designer has done previously, both prior to this design and during the current process of designing affects how the designer views the situation and what memories he constructs and brings to bear on the current situation.

Figure 2 shows graphically the notion of how a situation affects what can be "seen". In Figure 2(a) where two black human-like heads in profile are drawn, a white vase can be seen to emerge. Here, the two human-like heads provide the situation within which the emergence occurs. However, when only one black human-like head in profile is drawn no vase emerges. Here, the single human-like head in profile provides the situation. Clearly, in this example, the situation controls the emergence.



(a) (b)

Fig. 2. (a) Two black human-like heads in profile, reflections of each other create the Fig. 2.situation where a white vase can be seen to emerge; (b) a single black human-like head on the same background does not create the same situation and therefore no emergent vase can be found

The notion of situatedness is not necessarily tied to any particular representation (such as the graphical example in Figure 2). However, each representation has the potential to provide different situations and as a consequence different interpretations of what the situation is. Figure 3 provides an example of multiple representations of the floor plan of a building. Twelve alternate representations are shown but many others exist. Some of the representations favour certain interpretations over others. For example Figure 3(b) number 4 is readily situated to be interpreted as a figure plus ground which can be easily reversed along the lines of the example in Figure 2. The other representations do not lend themselves to this situation. Similarly representation Figure 3(b) number 6 can be situated to be interpreted as a grid. Grids can be moved and the entire direction of the resulting design may well be changed with this interpretation. Situations can provide a context within which a designer can interpret or reinterpret his developing design.

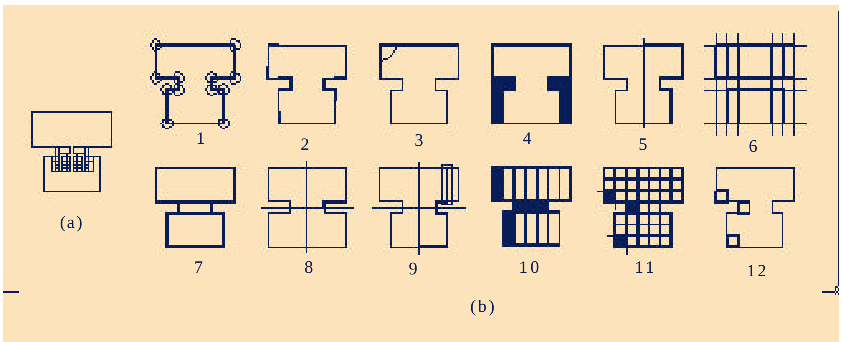


Fig. 3. Multiple representations of a building floor plan: (a) primary floor plan; (b) 1 to 12, multiple possible representations of the floor plan shown in (a) [18]

What is the role of situatedness in designing? Situatedness can be seen as a means by which the designer changes the trajectory of the developing design. Different situations provide different opportunities to move in different directions. Just as in Figure 3 what is the situation and what is being focussed on with the situation as background or context is not given but is a function the interpretation of the designer of what is in front of him. This is an important notion because it provides insight into why conceptual designing often leads in unexpected directions. Also, it may be an explanation of why designing is not a predictable act.

4.2 Constructive Memory and Designing

The interpretation of a situation is a function of what the designer knows and how the situation is represented. In the constructive memory view of the world each representation of a design, the most common one being an unstructured sketch or drawing, provides opportunities for the designer to reinterpret what is there and, therefore, to produce new ways of looking at what is there. This is akin to Schon's "conversation with the medium" [8]. Figure 4 shows, in a graphical form, the notion of constructive memory in design. A representation, which maps onto the notion of an experience, is interpreted using some structuring process (in some areas of design these are called "feature detectors"). As a consequence a new interpretation of what was there is produced, this maps onto memory. That new interpretation is added to the experience and is now available to be reinterpreted later as if it were part of the original experience.

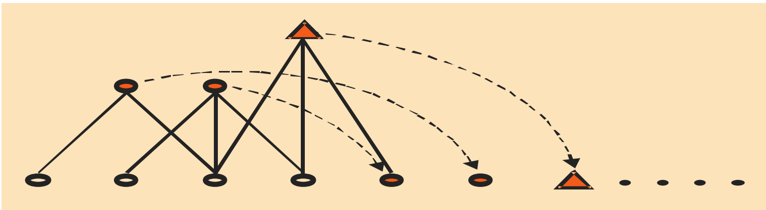


Fig. 4. The original design representation (experience), ○, are used to produce new interpretations of the design, ●, then the original and new interpretations are added as new representations and may be used later to produce further new interpretations, ▲, and so on

Consider, as an example, an initial shape that is being modified by a design system during the process of designing. The system has a representation of the shape that is the equivalent of the sensory experience. A memory of that shape can be constructed by acquiring some structure from that or an alternate representation of the shape. Let us represent the shape using a qualitative representation based on Q-codes [19]. Q-codes are a symbolic chain representational system where the symbols, with their values, represent qualitative aspects of the shape. Figure 5 shows some of the interpretations obtained by searching for structures in Q-code representations of various shapes. These structures map on to memory construction and can be added to the "experience" of those shapes. The labels are provided by humans.

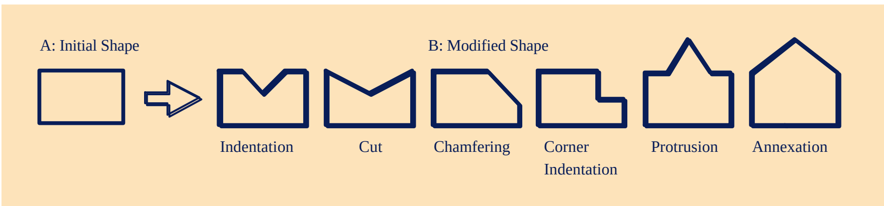


Fig. 5. Some interpretations, with their semantic labels, of modified shapes obtained by searching for structures in their Q-code representations [19]

The acquisition of structure is not the same as simply filing away responses. Structure derived from representation is "value adding" in the sense that knowledge which was not previously available has been produced and added to the system as part of the representation. This knowledge itself is situated. It carries with it aspects of the situation within which it was acquired. In this sense the process of situated learning in design is different to a simple application of machine learning.

4.2 Conceptual Designing as a Sequence of Situated Acts

The concurrence of situatedness and constructive memory provides the basis for the development of a model of conceptual designing that is closer to our current views. The model, still founded on the F–B–S framework, allows us to address the processes that were previously not well addressed: reformulation processes. Reformulation, see Section 1, is the process which in some way changes what the design is about. It has three loci: the range of possibilities of structures which can be produced is changed; the range of behaviours for which a structure is designed for is changed; or the functions for which a structure is designed for is changed.

Reformulation type 1 (S –> S') is the best understood of the three reformulation processes and is the most explored. Case-based reasoning in design and structure analogy are examples of such processes although neither is necessarily a situated process in the sense described in this paper [17], [16]. Here new structure variables are introduced into the current design from outside it. The effect of this is to change the state space of possible structures.

Reformulation type 2 (S –> B_e') occurs when new behaviour variables are introduced into the current design from outside it. The effect of this is to change the state space of possible behaviours. This may have the effect of changing the location of the selected structure within the structure state space or it may require the addition of further structure variables in order to produce a satisfactory design. Much less work has been in this area although there is currently research being undertaken which uses concepts from co-evolution which can be seen a way to approximate this process [20], and other work which uses analogy to locate and insert new behaviours.

Reformulation type 3 (S –> F') occurs when new functions are introduced into the current design from outside it. The effect of this is to change the state space of functions. This may have the effect of changing the expected behaviours, if it does then it may, but not necessarily, require changes in the structure state space.

All three types of reformulation are often likely to be situated – they all commence with an existing structure, S_e, as the driver. Access to S_e is only available after it has been produced. The process of reformulation is an act, each new structure (new in terms of new values for existing structure variables or new structure variables) potentially provides the opportunity for a different reformulation. In this sense conceptual designing can be treated as a sequence of situated acts.

5 Examples

Let us consider two examples. The first concerns the notion of re-interpretation through rerepresentation and presnts the results of an implementation. The second concerns an example of emergence in structural engineering.

Consider the example of a system being presented graphically with a single triangle. First it is rerepresented as a set of possible features which then make it possible to construct a variety of 'memories' of it depending on which of the features is used in the memory, Figure 6.

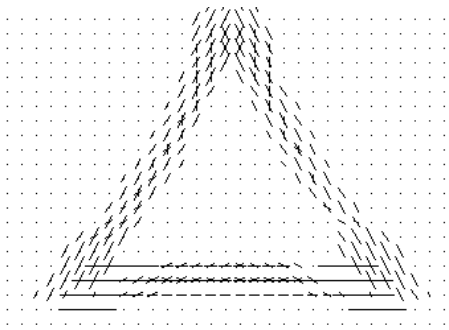


Fig. 6. The image of a single triangle being rerepresented as a set of possible features in the form of boundary contours.

That triangle and two others are located in space and, as a unique function of that situation, another triangle emerges using a model of the human vision system [21], Figure 7.

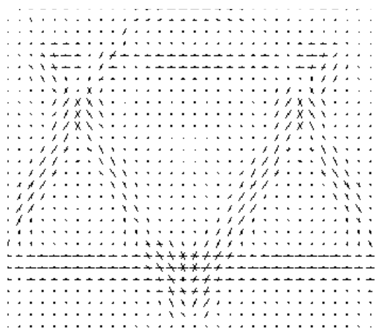


Fig. 7. An emergent triangle can be "seen" from the output of a situated vision system

The emergence of the triangle is a consequence of the results produced by the system but emergence is not built into the system. The system is a pre-attentive vision system, it is up to an "observer" outside the system to to "see" the newly emerged triangle, which can now be turned into a memory. The observer need not be a human.

Consider now a structural engineer designing the framing for a tall building. The engineer commences with a series of parallel two-dimensional frames, Figure 8. With these frames the engineer is carrying the wind load from the primary wind direction. As a consequence of the way the engineer sees these frames he designs and analyses them as two-dimensional frames.

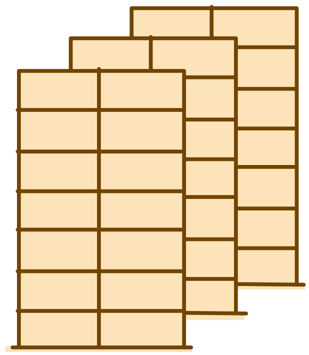


Fig. 8. The structural engineering component of a multistorey building being synthesised as a series of two-dimensional parallel frames

After the primary frames have been synthesised and the member properties determined, the engineer now attends to the lateral bracing by placing bracing beams at each floor connecting congruent joints of adjacent frames, Figure 9.

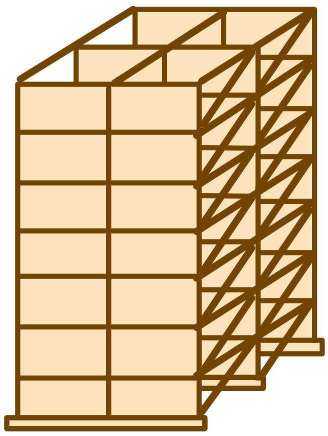


Fig. 9. Lateral bracing put in place by the engineer between the parallel two-dimensional frames

However, as the engineer inserts the bracing, he notices that the bracing produces a frame at right angles to the main frames and he decides to use the bracing as a frame. Further, having decided that there are now two sets of frames at rightangles to each other, he notices that the external frames can now be viewed as the facades of a tube building, Figure 10. As a consequence he examines the possibility of redesigning the entire lateral and vertical loadbearing system as a tube structure. This clearly has involved a re-representation of the wind bracing from bracing to lateral frames. Then, from the original frames and these lateral frames a tube structure emerges.

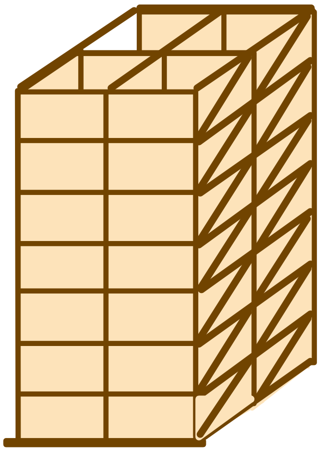


Fig. 10. The two sets of frames are now viewed as forming a tube structure

6 Discussion

Adding the notions of situatedness and constructive memory to the F–B–S framework provides the basis for a model of conceptual or non-routine designing. This model has the potential to meet our expectations of a model of conceptual designing. It is capable of dealing with those unique aspects of conceptual designing which involves working with incomplete information at the outset (the "wicked" problem syndrome) and providing the opportunity for radical changes in the trajectory of the development of the design as designing proceeds, Figure 11.

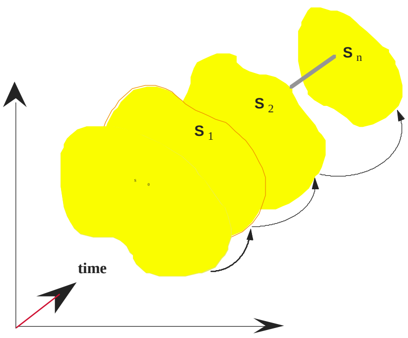


Fig. 11. The notion of conceptual designing as a sequence of situated acts modelled as a sequence of state spaces, which are interpreted as the situation; these state spaces change over time as the designer acts

What lies outside of this model is a set of unique processes capable of carrying out the three classes of reformulation within a situated and constructive memory approach. The methods of learning and applying situated knowledge are only now being developed, although there is currently some emphasis on developing approaches to handle emergence. The constructive memory approach is still in its infancy in the design research community, although we can readily see a place for it in expanding the role of case-based reasoning in designing and elsewhere [22]. What is needed is further research to develop the necessary processes to produce computationally feasible systems, which have the capacity to operate alongside human designers and to aid them in their designing in order to produce better designs.

Schon [23] summed up the concept of situatedness in designing succinctly as: “He shapes the situation ... his own methods and appreciations are also shaped by the situation”.

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