TOWARDS A MODEL OF DESIGNING WHICH INCLUDES ITS SITUATEDNESS

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

Keywords: design model, function-behaviour-structure, situatedness

Introduction

Our knowledge of designing comes from many sources. [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 then utilise the context to disambiguate the meanings.] Until relatively recently knowledge of designing has come from either well-informed conjectures about how humans design or introspection by designers (Asimov, 1962; Jones and Thornley, 1962; Broadbent, 1973). The introduction of formal methods from logic, mathematics and operations research into models of designing opened up numerous alternate approaches to the treatment of design processes (Alexander, 1964; Mitchell, 1977; Radford and Gero, 1988). More recently, concepts from artificial intelligence have extended the range of approaches available to describe and model designing – both human designing and certain design processes carried out inside computers (Coyne et al, 1990). However, approaches based on artificial intelligence concepts are still largely based on conjectures about putative human designing behaviour. Most recently, tools from cognitive science have started to provide some more insight in human designing (Akin, 1986; Lawson, 1990; Cross, Christiaans and Dorst, 1996). As we find out more about how humans design we are able to construct models of increasing explanatory power; models which form the basis of computational systems which either mimic designing or provide aids to designing. As discussed below, models with explanatory capabilities can become theories. In all of this endeavour, however, a number of assumptions have remained constant. Primary amongst these is the notion that designing is an act comprised of different processes, implying that time is involved. Thus, designing is more than conceptual leaps of the "aha" kind; this is not to imply that such acts do not play a role in designing but rather that designing is much more than conceptual leaps.

The *Shorter Oxford English Dictionary* defines theory in a number of ways:

1. a scheme or system of ideas or statements held as an explanation or account of a group of facts or phenomena;
2. a hypothesis that has been confirmed or established by observation or experiment and is propounded or accepted as accounting for the known facts;
3. a statement of what are held to be the general laws, principles or causes of something known or observed;
4. systematic statement of the principles of something; and

5. a hypothesis proposed as an explanation, hence a mere hypothesis, speculation or conjecture (“theory” used loosely).

It is hard to claim that a theory of designing could satisfy any of the first three of these definitions since insufficient is known and agreed upon about the acts of designing to provide details of the phenomena to be accounted for. Thus, a theory of designing is likely to belong to either the fourth or fifth definitions. Yoshikawa (1981) in describing the development of his General Design Theory (Yoshikawa, 1979) stated that one problem was “... due to the fact that the process of design has been less understood. It is difficult to abstract the process itself from the practical designing activity even for designers.” However, Yoshikawa’s General Design Theory clearly fits within definition 4, whereas the vast majority of other theories would best fit into definition 5, ie speculation or conjecture.

A model is a representation of some thing and as such is descriptive. As a consequence the model itself makes no claim for explanatory power. However, the boundary between a theory (of the definition 4 or 5 kind above) and a model is not as clear as the above descriptions would suggest. Often, models of designing have extensional explanatory capacities or may simply be used as an explanation. In which case the model becomes the theory. We shall adopt this last view: a model with explanatory capacities becomes a theory of the fifth kind. Hence, we shall use the term model in this paper to refer specifically to a theory of this kind except that we shall claim that such a theory, when based on the evidence increasingly available to us moves towards a theory of the first kind, ie, a scheme or system of ideas or statements held as an explanation or account of a group of facts or phenomena.

In the remainder of this paper we commence by outlining some important models of design before introducing some recent insights into human designing which have the potential when incorporated to explain some of the missing characteristics of earlier theories and models of designing. We then proceed to show how such theories and models can be augmented to include some of these characteristics. In particular we introduce the notions of “situatedness”, “emergence” and “constructive memory” as important concepts for any theory of designing.

Models/Theories of Designing

We make the same assumption as before: designing is a sequence of acts which may be described through processes. The act of designing has attempted to be modeled at various levels of abstraction. Perhaps the earliest of the widely accepted models of designing is by Asimov (1962) who divided all the designing processes into three classes:

analysis
synthesis
evaluation.

He and others ordered these as processes as shown in Figure 1.

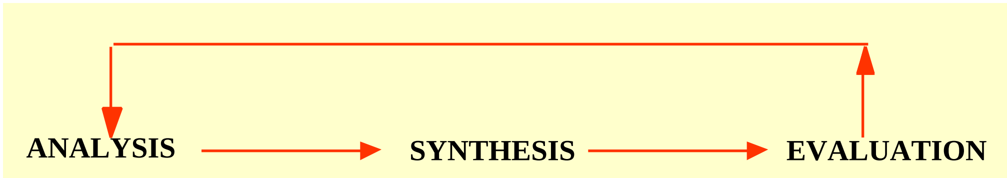


Figure 1. The analysis–synthesis–evaluation model.

This model has been used to explain what it is that designers do when they are designing. The processes involved in this view of designing use a terminology which is no longer widely accepted. The term "analysis" has been replaced by "formulation" or similar terms and "analysis" is now used to refer to a precursor of evaluation.

Whilst there have been numerous related models developed and a number of formal theories as well as formal methods, the next one we shall describe is the function–behaviour–structure (F–B–S) model which abstracts the processes of designing even further (Gero, 1987; 1990; Umeda et al, 1990). The F–B–S model provides a framework into which design processes can fit, Figure 2.

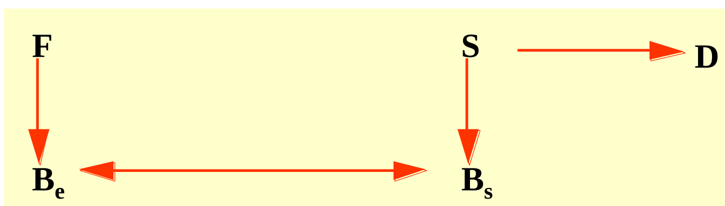


Figure 2. The F–B–S model, where the behaviour is bifurcated into expected behaviour, B_e, and behaviour derived from structure or actual behaviour, B_s; D represents the documentation, ie the formal output of designing; $\rightarrow$ = transformation and $\leftrightarrow$ = comparison.

The F–B–S model provides the framework for the following eight design processes:

1. formulation: $F \rightarrow B_e$
2. synthesis: $B_e \rightarrow S$ via B_s
3. analysis: $S \rightarrow B_s$
4. evaluation: $B_s \leftrightarrow B_e$
5. documentation: $S \rightarrow D$
6. reformulation - 1: $S \rightarrow S'$
7. reformulation - 2: $S \rightarrow B_e$
8. reformulation - 3: $S \rightarrow F$ via B_e

Processes 1 through 5 match well those which have appeared in earlier models. The class of processes represented by processes 6 through 8, although recognised, have not been well articulated in most models, partly because they have not be well understood. We will come back to these later in this paper. It is in these last three processes that the role of situatedness is dominant, although it is not the only place where it can occur.

Designing as Search

Search as a computational process underlies much of the use of artificial intelligence techniques when applied to designing (Coyne et al, 1990; Russell and Norvig, 1995). 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. However, the assumption that the space is defined prior to searching relegates this model to detail or routine designing.

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 (Gero and Coyne, 1987). It also takes the same assumptions that designing as search does and therefore can only be considered as a model to detail or routine designing.

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, ie. these are only poorly known at the outset of designing (Logan and Smithers, 1993; Gero, 1994). Designing as exploration provides another dimension to the F–B–S framework which 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 to produce a design. Designing has long been recognized as belonging to the class of problems called “wicked” problems (Rittel and Webber, 1973), exploration is an attempt to deal with this issue.

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, commonly 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 (1983) 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 later. Emergence, which is a related concept to reflection, is “seeing” what was not intentionally put there (Gero, 1996; Holland, 1998). Reflection and emergence have increasing evidentiary support from recent studies of designers.

Recent Insights Into Designing

Protocol studies of human designers are beginning to provide descriptions of some of the phenomena which have long been recognised but not adequately described. Further, some on designing and provide the basis for the examination of such behaviour in designing. We will primarily look at two such results and attempt to incorporate them in a model of designing. The first relates to Asimov's basic model while the second is somewhat more general and relates to the F–B–S model.

Extending Asimov's Analysis–Synthesis–Evaluation Model

Protocol studies of designers carrying out designing which have produced results of a task analysis of the processes have indicated that Asimov's model does not adequately capture some of the base activity. Let us examine Figure 3 where the transitions between the three phases of Asimov's model are plotted across each tenth of the design session as a percentage of the total activity.

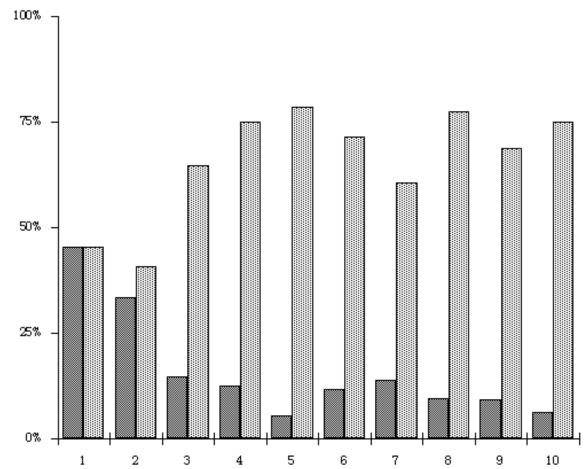


Figure 3. Transitions between analysis, synthesis and evaluation phases, plotted for each tenth of the design session as a percentage of total activity. Dark shading: evaluation –> analysis; light shading: evaluation –> synthesis (McNeill et al, 1998).

We can see that in the beginning of the design session that the designer not only follows evaluation by analysis but for an equal amount of time follows evaluation by synthesis. Already this behaviour is different to that "predicted" by Asimov's model. As the design session proceeds so this behaviour increasingly diverges from Asimov's model. Thus, in the last 75% of the time of the design session the predominant behaviour is not that predicted by Asimov at all since it is: evaluation followed by synthesis. The revised Asimov model now looks like that in Figure 4.

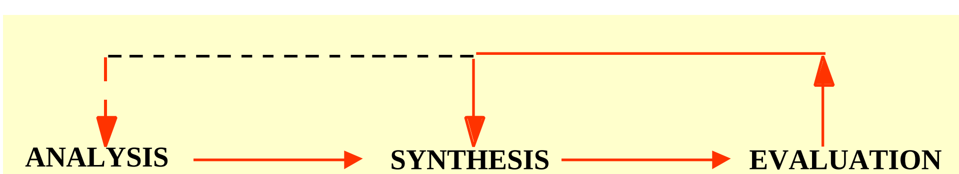
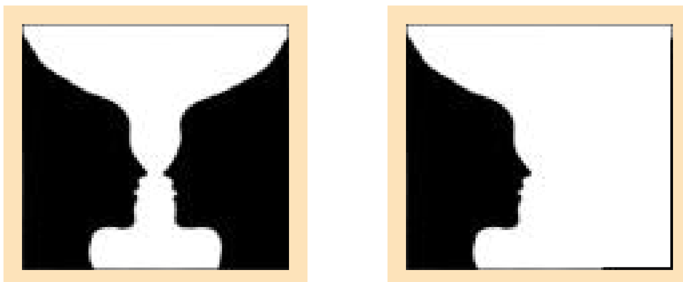


Figure 4. Revised Asimov model taking account of recent studies of human designers.

Situatedness in Designing

Situatedness (Clancey, 1997) 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 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 (1932) and Dewey (1896) who laid the foundations but whose ideas were eclipsed for a time. Situatedness allows for such concepts as emergence to fit within a well-founded and explanatory framework. Figure 5 demonstrates situated emergence – the notion of how a situation affects what can be "seen". The emergent white vase does not appear when the situation changes. Further, situatedness can be used to provide the basis of conceptual designing when we introduce another idea from cognitive science, namely that of "constructive memory".



(a) (b)

Figure 5. (a) Two black human-like heads in profile, reflections of each other create the 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.

Constructive memory holds that memory is not a static imprint of a sensory experience that is available for later recall through appropriate indexing (Rosenfield, 1988). 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 (1896). 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.

One area of design research based on cognitive studies of designers designing that is beginning to be examined is the use of sketches in designing. Protocol analysis is the primary tool to examine such cognitive processes in designing (Eckersley, 1988; Goldschmidt, 1991; Schon and Wiggins, 1992; Suwa and Tversky, 1996; Suwa, Gero and Purcell, 1998). Schon and Wiggins (1992) found that designers use their sketches as more than just external memory, they used them as a basis for reinterpretation of what had been drawn: this maps on to emergence and theirs and other studies provide strong evidence for this form of situated designing. Suwa, Purcell and Gero (1998) have found that designers when sketching revisit their sketches after a while they sometimes make unexpected discoveries, Figure 6.

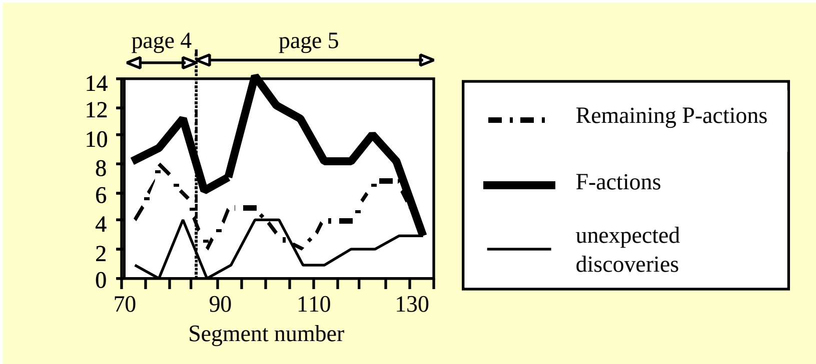


Figure 6. Correlation between unexpected discoveries and functional cognitive actions (F-actions) as opposed to purely perceptual actions (P-actions) in a design session. Segment number refers to the segments in the protocol and the page number refers to the pages of sketching (Suwa, Purcell and Gero, 1998).

They concluded that "sketches serve as a physical setting in which design thoughts are constructed on the fly in a situated way".

These two short introductions to situatedness and constructive memory suffice to allow us to now utilise these ideas in the development of a model of designing which includes its situatedness.

A Model of Designing Which Includes its Situatedness

The F–B–S model provides a framework which remains unchanged by the introduction of situatedness into designing. The most obvious and most interesting place to locate situatedness is in the reformulation phase. Earlier we had listed eight design processes which we claimed covered designing. Of these eight processes three were concerned with reformulation (labelled processes 6, 7 and 8). The first of these, reformulation – 1, occurs when the structure state space is modified. Here the role of the situation is to provide opportunities to source new structure variables, Figure 7. Typical design processes here include analogy and induction. However, they are both dependent on the perception of what can be the source in both analogy and induction.

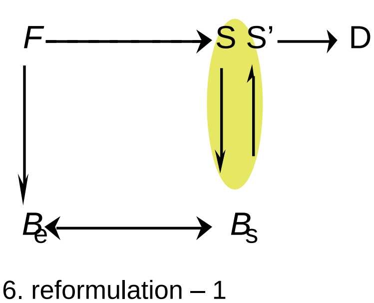
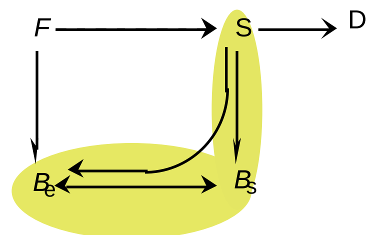


Figure 7. Transforming S to S' is based on the situation.

If we indicate such a situated transformation by ${}^{1}\tau_{s}$ we can model this as:

$$S' = {}^{1}\tau_{s}\ (S)$$

Design process 7, reformulation – 2, involves redefining what the expected behaviours are proposed since they bring with them their own ancillary behaviours. Alternately, new behaviours may be derived by analogy. Existing behaviours may be dropped if they are shown to play no discriminatory role.



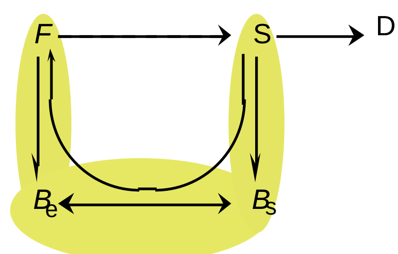
7. reformulation – 2

Figure 8. Transforming the expected behaviours is a function of the situation which exists in terms of the structure synthesised up to this point and the discriminatory capacities of the existing behaviours.

If we indicate such a situated transformation by ${}^{2}\tau_S$ we can model this as:

$$B_e' = {}^{2}\tau_S \ (B_e)$$

Design process 8, reformulation – 3, involves redefining what the functions are to be, Figure 9. Redefining functions for an artifact has the potential to change both the expected behaviours as well as the resulting structure. New functions are derived from the situation.



8. reformulation – 3

Figure 9. Redefining the functions or purposes of the artifact is dependent on the situation.

If we indicate such a situated redefinition by ${}^{3}\tau_S$ we can model this as:

$$F' = {}^{3}\tau_S \ (F)$$

This inclusion of situatedness into the F–B–S model provides the basis of a theory of designing which has the capacity to explain as well as describe. The extended F–B–S model can be used to develop tools which support designers whilst they are working at both the early and later stages of designing by providing a foundation on which to build. The design prototype formalism can be readily extended to include these notions of situatedness by adding situated processes into the framework. We have already seen that computational systems which depend on situatedness already exist. Examples of such systems are those which deal with emergence.

Take the case of a system which generates designs using an evolutionary approach. Here a generator is coded into the genes and designs are produced by expressing the genotype composed of those genes in some appropriate form. It is possible to discover emergent in that they would not necessarily appear without executing the designs and without these particular designs exisiting. It then is possible to reverse engineer the emergent features to produce new genes which are capable now of generating those previously ermergent features. This demonstrates both the applicability and utility of this model.

Acknowledgments

This work has benefited from discussion with many members and visitors of the Key Centre of Design Computing and is supported in part by grants from the Australian Research Council.

References

Akin, O. (1986) *Psychology of Architectural Design,* Pion, London.

Alexander, C. (1964) *Notes on the Synthesis of Form*, McGraw Hill, New York.

Asimov, M. (1962) *Introduction to Design,* Prentice-Hall, Englewood Cliffs, New Jersey.

Bartlett, F. C. (1932 reprinted in 1977) *Remembering: A Study in Experimental and Social Psychology*, Cambridge University Press, Cambridge.

Broadbent, G. (1973) *Design in Architecture*, John Wiley, New York.

Clancey, W. J. (1997) *Situated Cognition*, Cambridge University Press, Cambridge.

Coyne, R. D., Rosenman, M. A., Radford, A. D., Balachandran, M. B. and Gero, J. S. (1990) *Knowledge-Based Design Systems,* Addison-Wesley, Reading.

Cross, N., Christiaans, H. and Dorst, K. (eds) (1996) *Analysing Design Activity,* Wiley, Chichester.

Dewey, J. (1896 reprinted in 1981) The reflex arc concept in psychology, *Psychological Review* **3**: 357–370.

Eckersley, M. (1988) The form of design processes: a protocol analysis study, *Design Studies* **9**(2): 86–94.

Gero, J. S. (1987) Prototypes: A new schema for knowledge-based design, *Working Paper,* Design Computing Unit, Department of Architectural Science, University of Sydney, Sydney, Australia.

Gero, J. S. (1990) Design prototypes: a knowledge representation schema for design, *AI Magazine,* **11**(4): 26–36.

Gero, J. S. (1994) Towards a model of exploration in computer-aided design, *in* J. S. Gero and E. Tyugu (eds), *Formal Design Methods for CAD*, North-Holland, Amsterdam, pp. 315–336

Gero, J. S. (1996) Creativity, emergence and evolution in design: concepts and framework, *Knowledge-Based System* **9**(7): 435–448.

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

Holland, J. (1998) *Emergence*, Addison-Wesley, Reading Massachusetts.

Jones, J. and Thornley, D. (eds) (1962) *Conference on Design Methods,* Pergamon, Oxford.

Lawson, B. (1990) *How Designers Think*, Butterworths, London.

McNeill, T., Gero, J. S. and Warren, J. (1998) Understanding conceptual electronic design using protocols analysis (submitted).

Mitchell, W. J. (1977) *Computer-Aided Architectural Design*, Van Nostrand Reinhold, New York.

Radford, A. D. and Gero, J. S. (1988) *Design by Optimization,* Van Nostrand Reinhold, New

Rittel, H. and Webber, M. (1973) Dilemma in a general theory of planning, *Policy Sciences* **4**: 155–160.

Rosenfield, I. (1988) *The Invention of Memory*, Basic Books, New York.

Russell, S. and Norvig, P. (1995) *Artificial Intelligence,* Prentice-Hall, Upper Saddle River, New Jersey.

Schon, D. (1983) *The Reflective Practitioner*, Harper Collins, New York.

Schon, D. and Wiggins, G. (1992) Kinds of seeing and their functions in designing, *Design Studies* **13**(2): 135–156.

Suwa, M., Gero, J. S. and Purcell, T. (1998) Analysis of cognitive processes of a designer as the foundation for support tools, *in* J. S. Gero and F. Sudweeks (eds), *Artificial Intelligence in Design'98*, Kluwer, Dordrecht (to appear).

Suwa, M., Purcell, T. and Gero, J. S. (1998) Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions, *Design Studies* (to appear).

Suwa, M. and Tversky, B. (1996) What architects see in their design sketches: implications for design tools, *Human Factors in Computing Systems: CHI'96,* ACM, New York, pp. 191–192.

Umeda, Y., Takeda, H., Tomiyama, T. and Yoshikawa, H. (1990) Function, behavior and structure, *in* J. S. Gero (ed.), *Applications of Artificial Intelligence in Engineering V: Design,* Springer-Verlag, Berlin, pp. 177–193.

Yoshikawa, H. (1979) Introduction to general design theory, *Seimitsukikai* **45**: 906–926.

Yoshikawa, H. (1981) General design theory and a CAD system, *in* T. Sata and E. Warman (eds), *Man-Machine Communication in CAD/CAM,* North-Holland, Amsterdam, pp. 35–53.

This paper is a copy of: Gero, J. S. (1998) Towards a model of designing which includes its situatedness, *in* H. Grabowski, S. Rude and G. Grein (eds), *Universal Design Theory,* Shaker Verlag, Aachen, pp. 47-56.