Constructive Memory in Design Thinking

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Abstract. This paper introduces the concept of constructive memory as a framework for the modeling of design thinking. It describes some recent results from empirical studies of designing to show a gap exists between our models of designing and these results. The paper presents constructive memory and its associated concept of situatedness as potential foundations for increasing our understanding of design thinking.

Keywords. Constructive memory, emergence, situatedness, models of designing, design theory.

Introduction

Models of designing have largely been founded on either introspection or extrospection. There has been insufficient experimental data on the phenomenon we call "designing" to provide a solid empirical foundation on which to found both theories and models. Of course, this has not prevented researchers from positing both theories and models of designing. (We will use the word "designing" as the verb and "design" and the noun; rather than using context to disambiguate the meaning of the single word "design".) However, recently there have increasingly been empirical results. The phenomenon of designing indicated by these results appears to be both rich and complex and is often not in accord with some of the models. in current usage. In this paper we briefly indicate some of these recent empirical results before introducing the concept of "constructive memory" as a means of explaining some of the phenomena observed and introspected about designing and design thinking.

The empirical results are indicative of the class of data currently becoming available. The work on constructive memory is an outgrowth of recent thinking in cognitive science and artificial intelligence. The work on constructive memory is itself founded on much earlier ideas.

Recent Empirical Results About Designing

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.

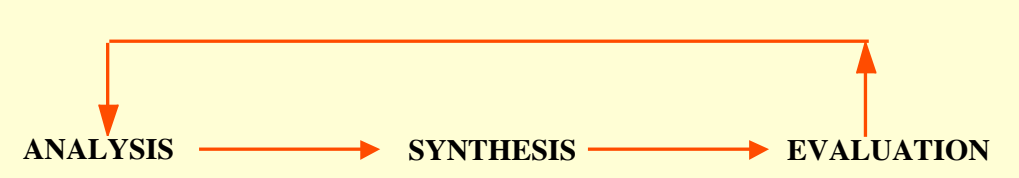


Fig. 1. The analysis–synthesis–evaluation model.

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.

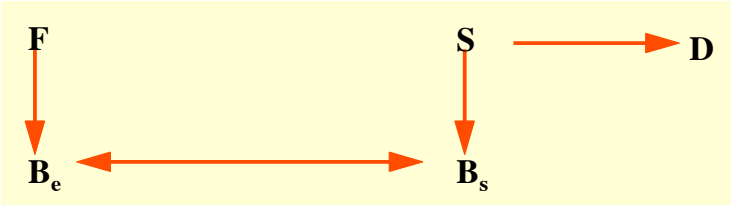


Fig. 2. The F–B–S model, where the behaviour is bifurcated into expected behaviour, B_e, and behaviour derived from structure or actual behaviour, B_s; D represents the documentation, ie the formal output of designing; □ = transformation and □ = comparison.

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

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

Most recent empirical results about designing have come about through the use of either concurrent or retrospective protocols (van Someren, Barnard and Sandberth, 1994). 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 decile of the design session as a percentage of the total activity.

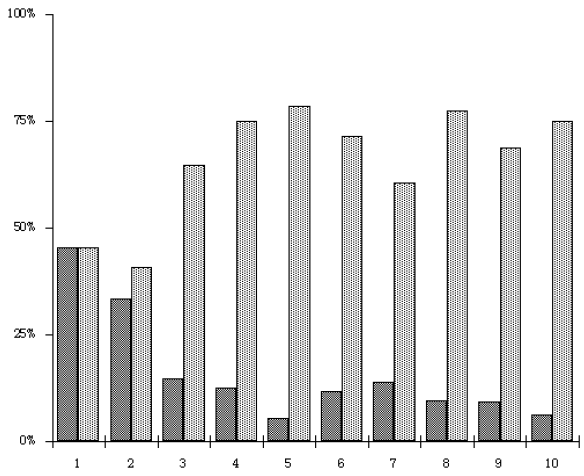


Fig. 3. Transitions between analysis, synthesis and evaluation phases, plotted for each decile of the design session as a percentage of total activity. Dark shading: evaluation analysis; light shading: evaluation synthesis (McNeill et al, 1998).

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.

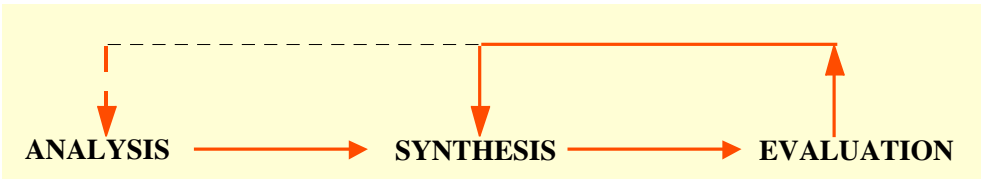


Fig. 4. Revised Asimov model taking account of recent studies of human designers.

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 again 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 (of which there will be more later) and theirs and other studies provide strong evidence for this form of designing. Suwa, Purcell and Gero (1999) have found that designers when sketching revisit their sketches after a while they sometimes make unexpected discoveries, Figure 5.

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

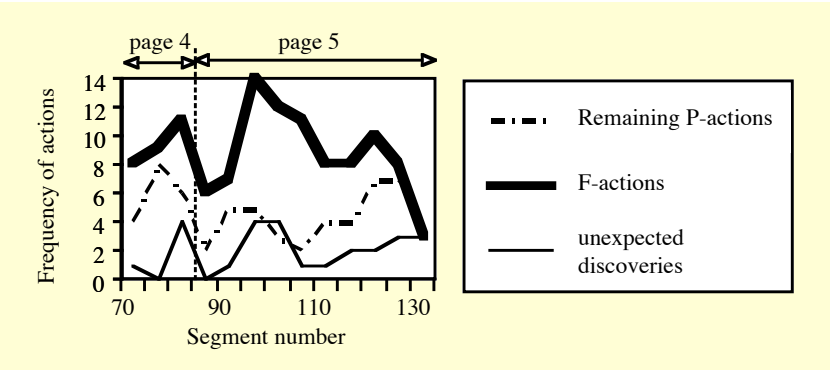


Fig. 5. Correlation between unexpected discoveries and functional cognitive actions (F-actions) as opposed to purely perceptual actions (P-actions) in a design session. Segment number refers to the segments in the protocol and the page number refers to the pages of sketching (Suwa, Purcell and Gero, 1999).

These and other studies imply that there is a gap between the simple process models of designing and the empirical results. The gap is located at the "reinterpretation" and "unexpected discovery" acts. The next sections attempt to begin to provide a foundation for bridging this gap.

Constructive Memory and Situatedness

In 1896 Dewey (Clancey, 1997)) published a seminal work on human memory which languished after a while and was only rediscovered relatively recently. In that work he introduced the concept which today is called "constructive memory". This concept is best exemplified by a quote from Dewey via Clancey:

> "Sequences of acts are composed such that subsequent experiences categorize and hence give meaning to what was experienced before".

The implication of this is that memory is not laid down and fixed at the time of the original sensate experience but is somehow a function of what comes later as well. It may be viewed as follows. Sensate experience is stored as an experience. Memories are constructed initially from that experience in response to demands for a memory of that experience but the construction of the memory includes the situation pertaining at the time of the demand for the memory. The effect of this is that the memory is not just a function of the original experience it is also a function of what has happened since the original experience and of the situation which prevails when the demand for the memory is made. Each memory, after it has been constructed, is added to the experience so that the experience is augmented by memories of it. These memories require processing of the experience as opposed to factual recall of aspects of the experience. These we will call "fact memories" rather than just "memories". New memories of the experience are constructed as a function of the original experience, the previous memories of it and the current situation. New memories can be viewed as new interpretations of the augmented experience.

Emergence may be seen as one example of constructive memory in that it can be viewed as new interpretations of the experience. This conception fits well with Gombrich's view of emergence as seen in the works of artists and as shown in recent studies of designers.

> "In searching for a new solution Leonardo (da Vinci) projected new meanings into the forms he saw in his old discarded sketches" (Gombrich, 1966).

Figure 6 shows graphically this conception where memories are constructed from experience and earlier memories that in turn become part of the situation that affects the kinds of memories that can be constructed.

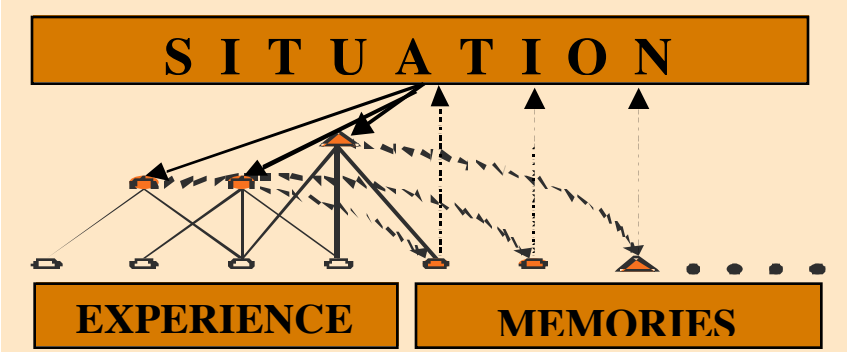
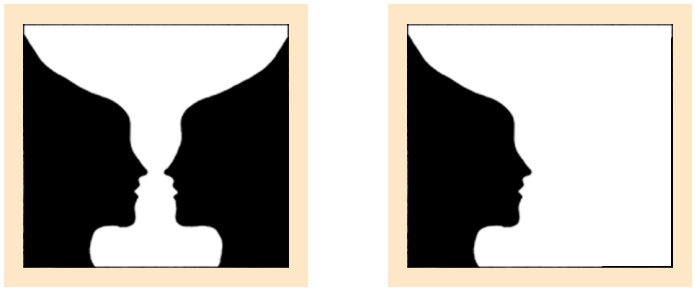


Fig. 6. The original experiences, ○, and the situation are used to construct memories of the experience, ●, then these memories are added as experiences and may be used later to produce further new memories, ▲, in conjunction with later situations and so on.

In Figure 6 we have introduced another idea from cognitive science, namely that of situation and situatedness. 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 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 (1932) and Dewey (1896) who laid the foundations. Situatedness allows for such concepts as emergence to fit within a well-founded and explanatory framework. Figure 7 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 along with constructive memory can be used to provide the basis of designing.



(a) (b)

Fig. 7. (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, Situatedness and Design Thinking

The concurrence of situatedness and constructive memory provides the basis for the development of our understanding of design thinking. The understanding, still founded on the F–B–S framework, allows us to address the processes that were previously not well addressed: the reformulation processes. Reformulation 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 constructive process in the sense described in this paper (Maher, Balachandran, and Zhang, 1995; Qian and Gero, 1996). 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 (Poon and Maher, 1996), 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 a constructive memory 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 we can understand designing as a sequence of situated constructive memory acts.

If we go back to the quote attributed to Dewey in the previous section we find an additional dimension. Not only does constructive memory produce new memories but it also allows us to reinterpret our previous experiences and memories in the light of our current views: "reinterpret the past through the lens of the present". This behaviour has been seen in empirical studies of designers. For example, Suwa et al (1999) describe how an architect during the designing of a museum emerged a visual axis and then used that visual axis as the driving idea. He did this not only for all his future designing activity but also by reinterpreting his past design ideas on the project in terms of this visual axis.

Acknowledgments

This work is supported by a grant from the Australian Research Council.

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This is a copy of the paper: Gero, J. S. (1999) Constructive memory in design thinking, *in* G. Goldschmidt and W. Porter (eds), *Design Thinking Research Symposium: Design Representation*, MIT, Cambridge, pp. I.29-35.