"Simon Says": Design is Representation

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We owe our insights into design cognition to Herbert Simon. In the 60's after having revolutionized the fields of economics, decision making, and management, Herb Simon set out to establish the emerging disciplines of cognitive science and artificial intelligence. Towards the end of the 60's a young architecture faculty by the name of Charles Eastman arrived from the West coast into the brash and *avant garde* intellectual environment of the newly renamed Carnegie Mellon University. One of the first things he did was get Simon involved in the then hot Environmental Design Research Association (EDRA) conference of 1969. Simon wrote the introduction to the proceedings, culling from his seminal work, *The Sciences of the Artificial,* and his early days of lecturing architecture students at IIT, under Mies van der Rohe. He established the foundations as well as the inspiration for many more who would follow Eastman's early lead in deciphering design cognition.

In his EDRA proceedings article, Simon said:

1. that representation of design problems holds the key to their solution.
2. that the complexity of design can be tamed by representing problems in smaller more manageable and potentially well-defined sub-problems.
3. that the packaging of information that goes on the human memory systems is universal, and
4. that the style of the designer is a function of her process.

Upon this foundation, the emerging area of the psychology of architectural design was built.. A lot has happened since then.

1.1 Modest Beginnings

Design cognition has had a modest beginning. In 1969 Eastman completed the first protocol study of design. This study reports on the behavior of several designers asked to redesign a bathroom under experimental conditions. Surprisingly, the findings are fresh and illuminating even today. Eastman's conclusions reveal observations about design representations, subjects' problem identification behavior, and problem decomposition. He states that

> "the most important general finding from [his] studies... has been the significance of representational languages to problem-solving ability." (pp. 30)

The versatility of the human designer in using and combining diverse representations and media are discussed. Eastman reports that

> "one of the strengths of the human problem-solver is his ability to use several representations -- words numbers, flow diagrams, plans, sections, perspectives -- to represent, compare, and manipulate information;"

and further states that any man-machine system to aid the designer must recognize his reliance on multiple representations (pp. 30). Eastman also indicates that

> “most methodologies are in fact new representations that allow explicit comparison of information not previously relatable. Like other representational languages, they augment intuitive design rather than replace it..” (pp. 30)

Eastman’s paper continues to reveal other interesting findings and shortcomings. He indicates that during the problem identification process experienced designers bring to bear on the problem at hand a complex repertoire of constraints and they rapidly structure it. He states that these studies do not help in understanding the different design phases that a project must go through, nor do they engage in the finer grain analysis that is needed to delineate important points of design cognition.

Finally, he indicates the lack of evidence on how novices and experts differ in their approaches to design. These shortcomings are just as valid for our understanding of these issues today as they were then.

1.2 Science and Architecture

Simons notion of *The Science of the Artificial* in reality blurs the distinction between design and science. This approach, as in many of Simon's other characterizations, is focused on constructing a simpler view of a complex phenomenon by drawing on similarities. Arguably, however, architecture is not science and *vice versa.* Scientists seek what **is**. They strive to isolate the "best" and the most superior option. Architects on the other hand seek what **ought to be**. They try to narrow down their options by satisfying what they can.

While scientists seek the truth, architects do the opposite. They try to persuade the world to accept those things that they have been speculating about in their wildest dreams. Architects, as opposed to scientists, stake their claim on the basis of *situated persuasiveness*. They argue not that their solutions are absolutely inescapable but that they are the most supportable ones under the circumstances of given problems. The solution they foresee merely has the promise of satisfying the requirements of the problem (Simon, 1973).

This is far different from the stand of the scientist or the engineer, for that matter, who must make her argument on the basis that all other conceivable possibilities have been exhausted and an objective measurement of the *best choice* can be made. Karl Popper (1963) articulates the scientist’s mode of operation in his theory of *Falsificationism*. The only way of knowing if a scientific theory would hold is to put it to the most stringent tests. This requires that the scientist sincerely and vigorously become an antagonist to her own theories. By being the severest critic of them she has a chance of eliminating the worst criticism that can be thrown at them. This is a quest of search for the truth, the absolute truth. The truths that architects seek are temporal ones that are situated in a specific context. In the face of time and resource restrictions they have to make do with what they have. This is why their expertise is a *tour de force* in finding the needle (the spectacular solution) in the hay stack (of possibilities).

For three decades now researchers have been responding to what Simon says. One of the key areas of study that he has been advocating is understanding individual differences between experts and novices. I have, in a study published in 1986(a) observed that experts possess larger chunks (as predicted by performance in other domains such as chess, Chase and Simon, 1973). Experts also use a hybrid search strategy of *breadth-in-depth*. When experts search through alternatives they generate many more new problem structures, or formulations, than non-experts (Akin, 1986b) within the same time frame. This result holds even in cases where an early solution is found and there still is time to design. In dealing with different cognitive task domains, there are notable differences between puzzles, decision problems, and design (Akin and Akin, 1997). I also observed that, in problem solving and puzzles, restructuring is less frequent but strategic in leading to a solution. The explicit relationship of a newly defined representation to the solution set is often a prerequisite for success.

1.3 Representation

Studies of architectural cognition concern themselves with a few overarching issues: *representation, strategic behavior,* and *innovation.* Simon's influence has been most pronounced in the area of representation where we find several sub-issues. For example representation can be decomposed into the principal categories of analog and symbolic representation.

a. Analog versus Symbolic Representation

Some representations are better suited to solve certain problems. The argument about the value of appropriate representations has been made more powerfully in the area of problem solving than in most other areas. Based on isomorphic representations used in presenting identical problems, differences in problem understanding and problem solving have been observed (*Tower of Hanoi* versus *Tea Ceremony,* Newell and Simon, 1972; *Mutilated Checkerboard*, Kaplan and Simon, 1990**)**. The Tea Ceremony problem, for example, which is an isomorph of the Tower-of-Hanoi problem, appears to be more difficult to solve than the latter. This is largely due to its presentation (or representation) in the narrative form as opposed to the colored pegs and discs of the Tower-of-Hanoi problem.

Problem representation is a critical tool that influences problem solving independently of field or discipline. Larkin (1983) described these as *physical* or *naïve* representations. Naïve representations depict, for example, problems of Physics through everyday objects in relation to one another (pulleys and ropes, rollers and inclines). We will call these *analog* representations.

The expert, on the other hand, describes the same situation through *physical* entities, such as forces, energy and the like. She sets up mathematical relationship between these entities, such as FORCE = MASS*GRAVITY*HEIGHT. The proper solution of almost all such problems may initially use *naïve* representations but ultimately depend on the construction of accurate *physical* representations. We will call these *symbolic* representations.

In the architectural domain, a similar condition can be seen in the example of the stacking and blocking problem. Given a problem of clustering of building functions into logical groups and sub-groups, the nodes of a bubble-diagram can be extremely useful in creating a (naïve) representation of these functions. In comparison, a matrix of numerical values accurately indicate the spatial distance between pairs of functions. The twist in this comparison is that the matrix format is not the most suitable one for the designer. Most designers prefer to work with bubble diagrams due to the ease of direct manipulation of functions and their relationships. Alternatively, the matrix representation is preferred, while solving the problem algorithmically. While we can identify the equivalents to analog and symbolic representations in design, their relation to domain knowledge is not as obvious.

Architects and other designers working with graphic media deal with multiple representations. Architects primarily rely on *analog* representation as a primary environment of work. They depict everyday objects in space through drawings, sketches, physical and electronic models. The power of *analog* representations is based on the directness of their correspondence to reality, the accuracy with which they simulate objects and the evaluation of important design performance issues they enable, such as composition, contextual congruency, and constructability. This is why there has been such an emphasis on sketching, in architectural education and practice. Researchers interested in describing this process and building computer systems around them have proposed new models. Goel (1992), for example, describes the logic behind drawings that are used in ill-structured problems. The ambiguous nature of these representations, in fact, helps in the process of exploring ill-structured problems. Goldschmidt (1991) speaks directly about the symbiotic relationship between internal (cognitive) and external (analog) representations and shows how the give and take between them is critical for pushing design forward. Finally, Larkin and Simon (1987) show the importance of analog representations even for problem solving domains outside of design.

In design, *symbolic* representations are also important. Designers are not only interested in geometric cmposition issues that can be simulated through analog representations. They also want to know about heat transfer, light and sound distribution, and transfer of loads and moments through materials. All of these phenomena require the kind of abstraction found in Physics problems. Consequently, the design process has to integrate symbolic and analog representations in order to solve multi-constraint design problems.

b. Dimensions of Architectural Representation

In architectural design, the range and scope of representations used during different stages of the process are broader than they are in other design domains. There are several reasons for this. One is the fact that situated problem solving areas are site specific. Architectural design in particular aspires to be integrated with its physical context. This requires that the site of a building be represented in a variety of forms, through contour maps, photographs, 3D sketches, traffic count histograms, and computer models. Furthermore, these representations remain relevant throughout the course of the design process.

Furthermore architecture is socially situated. In this regard, it shares common features with industrial design and information systems. All products are designed to fit a social context to varying degrees. A jet engine is visible to the public only from a distance, yet at times, it comes into close contact with humans, such as, in the case of the maintenance crew. Its design, however, is by and large a response to its technical requirements and not to its human interface. In contrast, a toaster is designed to respond to ergonomic needs of the user. More critically, a computer not only has to respond to ergonomic needs but also to the cognitive needs of the user.

Architecture, like these, accommodates the user along many dimensions: functional, psychological, cognitive, ergonomic, climatic, economical, and so on. Humans live around architecture but also in and on them. The behavior of the users is an integral part of the functionality of the object. Living in a building means that there is a cognitive, ergonomic, psychological and economic interaction with it on a continuous basis. No other artifact of human design can claim a similar range, scope, and directness of use by humans. Consequently an architectural design problem gets to be represented through a variety of man-environment interaction parameters: demographics of the user, their habits of interaction, clothing, privacy needs, and visual perception.

Architects then are faced with handling situated, multi-faceted, and multi-media driven representations that tend to persist throughout the entire design process. Unlike other disciplines the introduction of new and diverse sets of representations are encouraged and is even seen as the bane of the architect’s creative endeavor. *Thus architecture is a representation saturated problem domain*, more so than any other with which I am familiar.

c. Decomposing the complex problem

One of the most powerful strategies in taming complex problems such as design is to represent them through more manageable sub-problems. What, then, can we say about the architects ability to structure the design problem through decomposition. It is clear that architects are able to sensibly categorize a large number of buildings into constituent hierarchies. This, I postulate, provides the sub-problem schemata for structuring the architects search domain.

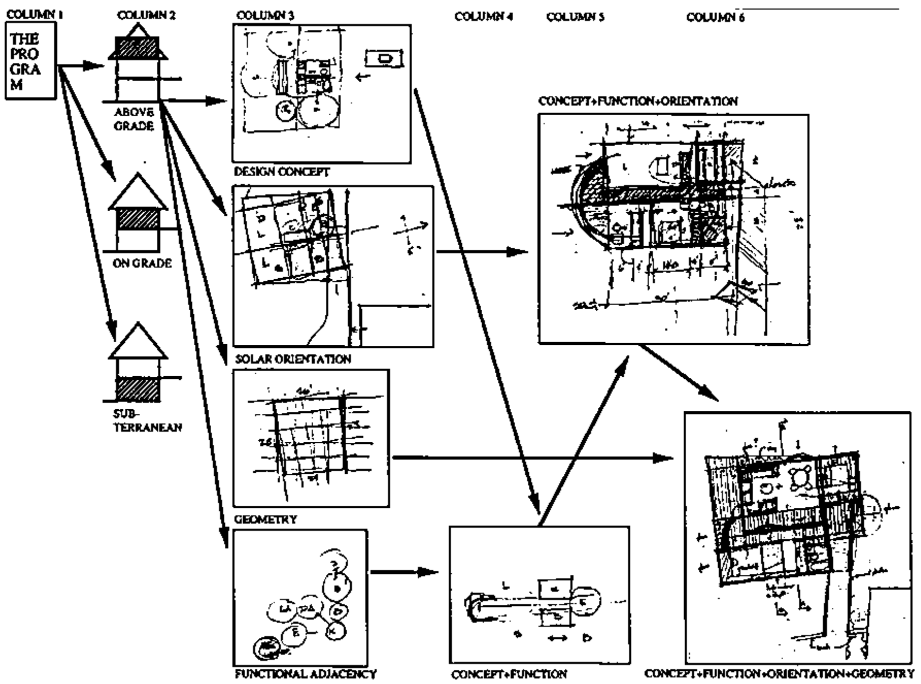

Figure 1: Pairwise integration of partial architectural design solutions (Akin, 1994)

In an earlier experiment I (1986b) showed that designers structure their search domains by major locational options (i.e., site location) against different organizational categories (such as, plan parti, topology, orientation, geometry). First, architects search *breadth-first* along the principal options. Then they develop one of the options in detail, *depth-first*, until all design categories are exhausted. I call this process *depth-in-breadth* search, a hybrid of the classical search strategies used in problem solving.

Architects work iteratively. In the realm of design automation, this is often referred to as a weakness. Whereas in cognitive terms it is a human way of making complexity more manageable. The decomposition of the design problem, is only one facet of this. The other even more crucial aspect of dealing with complexity is the recomposition of a comprehensive design solution from partial ones.

Given that architects decompose their problems into coherent constituent hierarchies (at least for themselves), how, then, do they re-assemble these partial solutions into singular solutions. In an experiment I conducted in 1978, subjects were asked to design single-occupant residences. Figure 1 illustrates the space of partial solutions that were developed during one of these sessions. The node on the far left of the graph represents the problem brief and site information provided to the architect. The next column of nodes represent the three alternative locations considered by the architect: above-grade solution, on-grade solution, and subterranean solution.

The remainder of the graph represents the categories for which partial solutions are developed for the above-grade option. These consist of the *design concept*, *solar orientation*, *geometry*, and *functional topology*. In column 3 of Figure 1, the partial solution for the design concept is shown as a simple diagram representing a unit with a wet-core. The node, solar orientation, located below it in the same column shows that this partial solution is achieved by placing the daytime functions of the unit along the West and South sides and the night time functions along the East and South sides of the site. The irregular geometry of the site is resolved by overlapping two 24’x24’ squares of 6’x6’ grid patterns each, shown in the next node labeled geometry, below this one. This is seen as a planning grid incorporating the irregular site geometry into a more regular shape. The last node of column 3 labeled functional topology shows a bubble diagram, which places the various elements of the program in their proper relationships to one another. Each of the nodes of this column represents how individual criteria are satisfied through partial solutions. None, alone, however, represent the comprehensive design solution.

The comprehensive solution emerges at the very end of this 4-hour design session and is shown in the subsequent nodes to the right of column 3 in Figure 1. The links between these nodes show how this is accomplished. In the fourth column of nodes the concept and topology solutions are merged. Then this solution is merged with the solar orientation solution. In the next column, the architect begins to test the idea of merging geometry and dimensions into a yet new solution. At this point the designer realizes that the design is too large for the site. A new solution is developed by matching the current layout with the outline of the whole site. The sketch in the final column shows how the architect manages to integrate all partial solutions into a single comprehensive solution.

1.4 Conclusions

We have considered several important aspects of the architect's representation to be crucial for design. Architects rely on *analog* representations as a central feature of design discourse. Even though they also use *symbolic* representations, the integration of partial solutions into a singular solution is achieved in the context of analog representations.

Architects use a greater variety of representations and for a longer duration during the design process. Due to the situated and user dependent features of architectural design problems a plethora of representational formats and media are required. Lack of universally accepted representational standards contribute to the complexity of this picture.

Architects, while exploring solutions, rely on a greater number of alternative representations than other design professionals. It is possible that this is influenced, if not caused, by the emphasis and value architectural education places on creativity and unique designs. Architects continue to search for alternative solutions even when they have already developed satisfactory ones.

Phases of the design process in architecture do not follow a prescribed staging. Architectural problems are decomposed into sub-problems idiosyncratically rather than based on a globally adopted schema of how a building's constituent parts ought to be structured. As a result, architects seem to search first in breadth, developing major alternatives in order to structure the problem domain, before they search in depth with one of these principal alternatives.

Architects use a pairwise integration strategy to recompose the partial solutions generated into a holistic design. For example, the topological arrangement of functions on each floor can be matched with compositions of solids and voids on the building facade, or the facade may be integrated with a geometric constraint imposed by the site. These strategies are driven by designers' personal knowledge and skills, which have been developed through their own experiences.

1.5 References

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