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**RESPONSE TO KEYNOTE**

# Quo vadis, design space explorer?

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**Abstract**

The paper presents aspects of designer action that stress cognitive strategies for effective design problem solving, under the headings of exploration and representation. It proposes that links among design moves and shifts between design arguments are of prime importance in exploration and the design space should accommodate and expose them. The primacy of self-generated representations in the form of free-hand sketches and the role of arbitrary visual stimuli as supporting design reasoning is introduced. The expositions lead to the conclusion that the design space should be conceived as a multilevel and multifacet construct that supports on the spot experimentation and provides essential feedback not only regarding designs, but also concerning the process of designing.

**Keywords:** Design Space; Exploration; Links Among Design Moves; Representation; Shifts in Argument Modality

## 1. INTRODUCTION

"Whither Design Space" by Woodbury and Burrow is a cogent and comprehensive review of a rich body of research on the design space. We have opted to bring to the discussion some additional concerns rather than respond directly to points raised in the paper. In essence, we would like to help place the exploring designer in the center of the scene. We propose to do so by broadening the notion of exploration and basing it on a more cognition-oriented footing than on a computational one, and in parallel, we wish to extend the range of representations that are admitted into the design space and focus on the complex relationships among them. Implications for the design space are perforce sketchy, and the computational consequences are not elaborated.

## 2. DESIGNER AS EXPLORER

We take the premise that exploration is a good model for designer action as a good approximation. Exploration is part of an *inquiry* the designer undertakes, or, in Schön's (1983) terms, a multilevel experiment: "[there are] . . . three levels of experiment—exploration, move testing, and hypothesis testing" (p. 153). The inquiry or experiment is of the kind conducted on the fly: "The logic of on the spot experiment is threefold, and rigor in hypothesis testing is in the service of affirmation or exploration" (Schön, 1983, p. 156). Hypotheses can be tested only if they have been preformulated, which is congruent with the notion of intentionality in design representation expressed by Woodbury and Burrow. In other words, design exploration is preceded by a preliminary phase in which the designer educates him or herself about the problem at hand by way of gathering information and possibly forming a stance toward it. The designer does not reach the exploration phase empty handed, but equipped with questions, wishes, and hypotheses that are established at the outset of the inquiry. It is this that guides the designer's exploration, during which the hypotheses at the higher level, and the moves made while producing representations at a lower level, are being tested.

When ready, the designer sets out to seek a solution to the design problem as framed initially,[1] and embarks on an

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[1] In this paper we adopt the view that designing is a kind of problem solving, where problems enjoy a very liberal and wide definition. Design problems belong, according to this view, to the category of ill-defined and primarily ill-structured problems; sometimes they are even classified as wicked problems (e.g., Rittel & Webber, 1973; Lawson, 1980/1997, 2004; Cross, 1982; Cuff, 1991; Buchanan, 1992; Goel, 1995). An elaboration of the definition of designing as problem solving is beyond the scope of this paper.

exploration. The nature of the exploration depends largely on the firmness of the hypotheses with which one starts (some designers do not develop hypotheses until later on), as well as on the designer's values, knowledge, experience, and sense of adventure (not to mention real-world constraints such as deadlines). The breadth and depth of exploration vary dramatically from one case to another, and with them vary the number of alternative solutions, or partial solutions, that are being produced. Design space researchers, and design researchers at large tend to take it for granted that the more alternatives the better, that is, quantity breeds quality. We must take issue with this view, based on empirical evidence and on historic analysis.

Historically, we notice that celebrated designers developed designs that are quite close to each other in nature and appearance. In modern architecture two great Franks, Frank Lloyd Write and Frank O. Gehry, serve as cogent examples: their buildings are easily recognizable because they bear a strong stylistic resemblance. Alvar Aalto designed buildings that despite very different purpose, location, and size, shared a fanlike basis for floor plans, leading critics to coin the expression "fan-motif" (Quantrill, 1983) to describe the phenomenon. We are not talking of a modern innovation: the developers of shape grammars have drawn our attention to, for example, kinship among Palladio's villas, and historic architectural styles exemplify the same trend at a wider cultural scale. Other design disciplines, as well as art, provide countless examples as well.

What does this teach us regarding explorations the designers in point conducted? We can conjecture that those designers were *a priori* satisfied with an exploration that is well bounded and limited in breadth, in favor of depth. The effort goes into reinterpretation and creation of variation within a theme, probably with the use of tacit and flexible rules. That such rules may exist is, of course, clear from the production of designs once the rules are explicated, as demonstrated, for example, by the production of "Palladian villas" by Mitchell and Stiny (1978) or dwelling complexes à la Siza by Duarte (2001). Successful designers reinterpret their designs and the universal concepts that led to them and aspire to maximize their benefit by stretching the application of forms, shapes, and their organization in a variety of problem settings. This is efficient in terms of effort that must be invested because the designer may use shortcuts based on deep acquaintance with motifs and well-practiced routines. It is also less risky, in terms of success aspirations, than when a whole new scheme of concepts coupled with forms must be explored and possibly found to be unsatisfactory. Treading the solid ground of an already largely familiar "world" (in the Goodmanian sense; see Goodman, 1978) buys one the time and peace of mind to undertake an in-depth exploration of yet another facet, or a higher level, of a certain set of formalisms. Referring to such practice Anderson (1984) wrote about architects' "research programs," which are developed as designers carry over sets of concepts and forms that convey them from one project to another. Anderson's analysis was exemplified by the work of several known architects.

Empirical studies have shown that student designers who spend much of the time allotted to an assignment to the generation of widely different alternative solutions do less well than students who come up with a leading idea early on and spend most of their time refining it (e.g., Rodgers et al., 2001; Goldschmidt & Tatsa, 2005). This is not necessarily at odds with Akın's finding that "expert designers display a typical strategy of *breadth first, depth next* in solving problems" (Akın, 1999; see also Woodbury & Burrow Keynote), because the units and grain of analysis may not be of a kind[2]; this is a crucial methodological issue that we cannot clarify at present.

We see, then, that successful designers, whether world-known architects or novice students, conduct a hierarchical exploration within a deliberately limited territory of an appropriate space: the goal is refinement, richness, fullness of expression of a "strong idea," that is, coherent and well-developed design rationale. This strategy does not prioritize a maximum number of alternatives; indeed, it is in line with the observation that "designers typically consider a very small number of alternatives in their work" (see Woodbury & Burrow Keynote). We ask, is this indeed due to "cognitive limits," an explanation favored by Woodbury and Burrow? We propose that there is another explanation: it is advantageous to consider a limited number of alternatives. This proposition requires explication.

In our view, the essence of design exploration is best captured by describing how designers reason as they explore. We see design reasoning as resting on two types of cognitive strategies. First, maximizing the rate of interlinking among design moves, and second, making frequent shifts between the consideration of physical aspects of the entity that is being designed (e.g., form, material, color), which is roughly the equivalent of "state" in the design space, and the rationale of those aspects. We shall briefly introduce the notions of move linking and argument shifting in design reasoning.

### 2.1. Interlinking design moves

Whereas in chess it is very clear what a move is, in design the notion of move is more equivocal and must be defined. We define a design move as the smallest step that repositions the designer in his or her exploration. From our cognitive perspective, such a step is very short: its average duration is a few seconds. If expressed verbally a move must be semantically coherent. A move may be more or less complex, and can often be divided into smaller units that

[2]"Units of analysis" denote the units into which the database (i.e., empirical evidence such as recordings of verbalization) is parsed. These can vary in scope from parts of sentences to several sentences. "Grain of analysis" signifies the level of detail established for a specific investigation.

we call arguments. Arguments are not necessarily semantically complete entities. For example, the move: "a brighter background will enhance the figure" is a step forward in the design of a display. It is composed of two arguments that in themselves are not semantically complete and cannot qualify as moves: "a brighter background" and "will enhance the figure."

We can capture moves (and consequently establish arguments) by documenting verbal design behavior on the fly and this is done by recording designer speech: normal conversation in the case of a design team, and "think-aloud" speech in the case of an individual designer. Transcribed verbalizations become a protocol, which can then be analyzed using an appropriate protocol-analysis method.[3] Verbal output is not a precise record of the verbalizer's thinking, yet it is a close approximation; in fact, the closest we have access to at present. Today design sessions are often recorded using video cameras, making it possible to capture nonverbal behavior as well. Designers typically produce sketches while working, and video recordings capture those sketches and the process of their making, yielding richer protocols. We shall return to the making of sketches later in this paper.

Once a protocol is parsed into its constituent moves,[4] it is analyzed using the method that best fits the purpose of the analysis. Very often moves are encoded using a scheme of categories that is established to suit specific research goals. Data regarding encoded moves serves as a basis for various statistical tests (e.g., frequencies of move types). In our studies of links among design moves we do not classify or encode moves (however, encoding is possible and has been practiced by other users of the system). Rather, we look at the pattern of links they generate among themselves. The protocol is divided into design episodes (or other units) of up to approximately 100 moves. For each such episode the existence of potential links is examined for every pair of moves. Starting with the second move, each move is coupled with each previous move, to establish whether a link exists between them. The answer to the question "Is there a link between move $n$ and move $n - x$," can be answered only with "yes" or "no," and the answer is based on careful consideration of the contents of the moves and on the use of educated common sense. Let us go back to the move we used above as an example, assuming it is the second in a sequence of three moves:

*Move 1* The figure [in this display] is not prominent enough, can something be done about it?

*Move 2* A brighter background will enhance the figure.

*Move 3* How about simply enlarging the figure?

To determine possible links, we start with move 2, which is checked against move 1. There clearly is a link between the two moves, as move 2 is a direct response to a question posed in move 1. Now we go to move 3. Is there a link between it and move 2? The answer is no; although both regard the figure in the display, move 3 concerns its size whereas move 2 considers its background. Therefore, there is no link between move 3 and move 2. When checked against move 1, we find that there is a link, as move 3 also responds to the question in move 1. For $n$ moves the number of examinations is $n \times (n - 1)/2$. For 100 moves the number of examinations is therefore: $100 \times 99/2 = 4950$. Establishing links is clearly a very labor intensive process, and therefore we try not to exceed 100 moves in a single design episode, and as a result, the methodology is geared toward the analysis of relatively short episodes only.

Once we identify and notate all links we get a clear picture of the link pattern in the analyzed episode. We can count the links and establish a *link index* (number of links divided by the number of moves), which attests to the density of links, but we can also confirm where the links reside. We can spot moves or clusters of moves that generated the highest number of links: we have empirical evidence that it is in those moves that we should look for breakthroughs in the process of designing. Indeed, we can propose, with due caution, that design creativity is correlated with the amount of highly interconnected moves in a design exploration; these moves are called *critical moves* (e.g., Goldschmidt, 2003*a*; van der Lugt, 2003; Goldschmidt & Tatsa, 2005). We can also encode the links and find out what the role of particular types of links is in a design exploration (van der Lugt, 2001). The number and pattern of links among design moves allows us to better understand design reasoning, especially by way of comparing processes by different designers or design teams. We can detect differences between, for example, experienced and inexperienced designers, or followers of one design strategy and those who use a different approach. We may be able to comment on cognitive styles and mental models and their role in design exploration by looking at links.

It is not surprising that our notion of links bears a strong affinity to the notion of connections between design states and associated terms like search threads, or paths, within the design space. Therefore, we shall try to illuminate issues related to links or connections during exploration in our commentary on the design space in Section 4. In this section we want to proceed by concisely introducing the notion of shifts among design arguments. Whereas interlinking moves can be seen as a generic problem solving strategy for ill-structured problems, shifting between the design's "physicality," or state, at a given moment, and its rationale, may be regarded as a domain-specific cognitive strategy in design

[3]Think-aloud experiments have been conducted by psychologists interested in problem solving for almost a century; the Gestalt psychologists, in particular, conducted such experiments. The invention of the tape recorder some 60 years ago has, of course, facilitated the production of protocols, and protocol analysis as a research methodology has gained universal acceptance in recent years. See, for example, Ericsson and Simon's (1984/1993) influential *protocol analysis*.

[4]To do so one has to have sufficient design expertise to understand what the designer is doing.

problem solving. As we shall see later, this, too, has implications for the design space.

### 2.2. Shifts between states and their rationale

In the design space all design states are representations of physical aspects of a designed entity. Of course, they may be partial, incomplete, vague, or schematic, but this does not affect their status as legitimate representations that are seen as states. Usually the representations are analog, that is, they take the shape of two- or three-dimensional depictions, subject to the reservations above, of the physical entities in question. Complimentary arguments elicited by designers, which are geared to support physical representation are not represented as states. Let us refer to move 2 in our example above, which is parsed into two arguments:

*Argument 1* A brighter background

*Argument 2* will enhance the figure

In this example argument 1 can be represented as a state (technically, the representation of "brightness" may depend on the availability of sophisticated representational tools, but it is perfectly possible to do so). By contrast, argument 2 is of a different kind: it presents a fairly abstract notion, one of enhancing a figure. Any depiction would be a tentative embodiment of the abstract concept of enhancement. Argument 2 is the rationale for a possible proposition, in this case the actual proposition in the twin argument (i.e., argument 1) in the above move. Whereas physical aspects are represented (or can be represented) as depictions, the rationale cannot normally be represented pictorially and uses symbolic representation, usually language.

We propose that arguments be encoded according to a scheme that includes two categories: rationale, and physical aspect(s) or proposal (tentative, partial, vague, etc.; Goldschmidt, 2001).[5] In analyzing design protocols we have found that the number of arguments of the two types in design episodes is roughly equal (Goldschmidt, 2001). It is therefore important to realize that design exploration is a complex activity in which proposals are considered against their rationale. We postulate that admitting all arguments into the design space, and not just states that represent one type of argument, will enable a much richer study of exploration, because we may learn something from the way in which designers meander between the types of arguments, that is, shift from one to the other (Goldschmidt, 1997).

The study of arguments and shifts between argument types, or modalities, leads to interesting conclusions. We found that moves that include more than one argument start with either modality, and the probability that a move would start with one or the other modality is roughly 50% (Goldschmidt, 2001).[6] If we cast the physical-rationale representations into *if-then* terms, it means that the following modes of reasoning are equally frequent:

*Mode 1* *If* [the background were brighter]
*Then* [the figure would be enhanced]

*Mode 2* *If* [the figure is to be enhanced]
*Then* [the background should be brighter]

The implication for design exploration is that one can specify what one wants to achieve and then come up with a proposition that satisfies the specification, or conversely, one may propose a solution and then check whether it satisfies requirements. In designer lingo, the question whether form follows function or function follows form exemplifies the possible reversibility of order of reasoning in designing. Our finding that designers start their design moves using both modalities in the same design episode shows that the variability in this matter is not merely a question of personal preferences (or cognitive style), or problem type. Rather, it appears to be inherent in design thinking, possibly due to the human dual-reasoning system, by rules and by similarity (e.g., Pothos, 2005). Rules in this comparison correspond to rationale whereas similarity, which usually refers to perceptual information, corresponds to physical aspects. The starting points of exploratory steps within the design space could commence one way or the other, and at the end of the day the explorer will have used the same number of arguments of both modalities.

Our interest in shifts between argument modalities stems from the understanding that designers realize that no design solution can be acceptable unless its suitability to the purpose for which it was developed can be clearly demonstrated. In other words, a design is satisficing (to use Simon's term) only if its rationale is convincing. Because a design solution is composed of many interconnected partial solutions at different levels, it is important to ensure that as one proceeds to construct this complex structure of solution components, each is supported by a viable rationale that helps avoid conflicts, or aids in resolving them if they are detected. Frequent shifts between argument modalities is the strategy designers use to ensure that their processes stay in line. Therefore, despite differences among the two types of arguments, we see them as having the same standing in the design space; if rationale has hitherto been seen as the thread that connects states, we would like to propose a radical change in this model, which we shall elaborate in Section 4.

[5]Designers become sidetracked sometimes, and their thinking and verbalization can be fragmented and disorderly. Thus, we find verbalizations that are not clearcut in terms of our two categories. Our binary encoding system deals with phenomena of this sort by allowing "hybrid" arguments which, when counted later, are attributed to the two main categories in equal numbers (see Goldschmidt, 2001).

[6]We studied one individual and one team, in design episodes comprising several dozens of moves each. In the case of the team, the number of moves starting with a physical aspect argument was slightly, but significantly, higher (59%).

Before we do so, we briefly comment on the nature of amplification of designer exploration through the mode of representation.

## 3. AMPLIFICATION: SELF-GENERATED REPRESENTATION AND OTHER STIMULI

Representations of physical aspects of the designed entity are pictorial, for the most part (although linguistic substitutes may, in simple cases, be quite satisfactory: e.g., an object is *said* to be round, or red, or made of a soft material). However, *architecture parlée*, or "spoken architecture" is a pejorative expression denoting an unconsummated architectural idea that does not go beyond a statement of intentions. The aim of any design exploration is to arrive at an adequate pictorial representation of the entity that is being designed, at one level or another. Pictorial representations that are elicited during explorations (two and three dimensional) can take many forms: drawings of various kinds, photos, paintings, objects at hand (impromptu representations) and *objets trouvés*, abstract spatial compositions, scale models, and so on. Representations may be references that are "imported" into the exploration from elsewhere (books and periodicals, digital sources, personal archives), or they may be produced by the designer on the fly. Among the latter, rapid sketches are the most frequently encountered, and they play a very prominent part in the process of designing.

That free-hand sketching is a contributing activity in the course of designing is suggested by the fact that it has been practiced by architects and other designers for over five centuries, and is still a "must" for most designers, including many who are proficient users of drawing software. Fish and Scrivener (1990) and Fish (2004) have shown that sketching amplifies inner representation in the form of mental imagery, and Goldschmidt (1991) followed suit by claiming that sketching can be seen as "interactive imagery." These and subsequent studies (e.g., Suwa & Tversky, 1997) stressed the joint utilization of internal and external visual representation as a preferred cognitive apparatus in the service of design thinking. According to Goldschmidt (2003*b*), self-generated sketches are particularly effective in designing (or shall we say design exploration) because they are so easy to produce and sketchers can best read information off their own sketches, to which they are highly tuned and in which they can find cues due to unexpected and unintended emerging configurations. Here we propose that not all design moves are premeditated, and insights are sometimes the outcome of lack of intentionality (even randomness) in experimentation by a creative explorer. In addition sketching, in the hands of experienced sketchers, is very rapid and therefore particularly economical in terms of cognitive resources. Sketches can be produced using shortcuts of any type and their production need not follow any rules. The importance of sketching is underlined by Schön's concept of inquiry (Schön, 1983), which we quoted at the outset of this paper. Schön describes inquiry as an "on-the-spot experiment." The claim, then, is that as opposed to passive attention to representations that are being visited, active experimentation engages the designer at quite another level. Any learning theory will support the superiority of "hands-on" involvement in an effort to learn or create something.

The prominence of self-generated sketches notwithstanding, we have evidence that rich, arbitrary "imported" visual stimuli at the workplace contribute to the quality and level of creativity of a design solution (Goldschmidt & Smolkov, 2004). The level of contribution, however, appears to depend on the type of design problem in question. Malaga (2000) has shown that in idea generation (not directly design related), stimuli in the form of pictures have a stronger impact than stimuli in the form of words, and stronger also than combined picture and word stimuli. Nevertheless, it is safe to postulate that nonvisual stimuli may also contribute to design creativity at least to some degree, in the sense that any stimulation appears to cause at least some mental arousal that encourages more intensive information processing (preliminary empirical evidence to support this postulation does exist, but we shall not discuss it here[7]).

The reason for raising these issues here is related to the mode of representation in the design space. Is the design space a depository into which the designer or others routinely deposit representations encountered along their design activity? Or during exploration only (there are other instances in which designers elicit representations)? In other words, how is the design space updated, and to what extent may it include arbitrary "stimuli"? Is there a way to include free-hand sketches, and how and by whom should they be chosen? (In practice, the number of sketches that designers produce can be very large. Because of their typical partiality, vagueness and incompleteness they may be incomprehensible to a computerized or human "reader" whose task is to index, sort, or evaluate them.) If we cannot cope with messy sketches in the design space, and given that we know how influential they are, what does this mean regarding the quality of an exploration? Likewise, if we have evidence that arbitrary stimuli are beneficial to the exploration, how do we admit them into the design space to enrich the exploration and ensure that those portions of it that have never been visited before enjoy easy accessibility? Last, what might be the status of nonpictorial representations, such as words, in the design space?

At present we do not have answers to these questions. However, because we are aware of the nature of representations and the particular role of self-generated representations, we cannot ignore them and must find ways to allow the amplification of exploration through better handling of representations in the design space.

[7] Anat Litan, a Technion graduate student, is currently investigating the impact of the reading of texts on design creativity.

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## 4. CONCLUSIONS: IMPLICATIONS FOR THE DESIGN SPACE

The issues raised in Sections 2 and 3 are meant to point to what we see as unresolved problems in current design space theory, as presented in Woodburry and Burrow. The question we ask is how can the design space be a more viable construct, with a real potential to enhance exploration and thereby empower the designer?

We have started answering this question in Section 3, where we pointed to the need to better understand the way in which representations, and primarily pictorial representations, impact design reasoning. This apparently occurs on two different levels. First, an experienced designer whose professional persona has matured to be identified with a certain range of design solutions and tools that are crafted to support this range, needs support in deepening the variation that can be inferred from a limited number of rules and exemplars. Depth in exploration means recombinations and transformations of a preselected set of components (forms, for the most part) and organizational principles. Second, an adventurous designer, or one who wishes to expand his or her repertoire of basic motifs, requires support of a different kind, which will expose him or her to new sets of references that could serve as jumping boards to design concepts and ways to unfold them. In this case, breadth, and not depth, has the upper hand, and necessitates a different approach to the organization of the design space and navigation in it. The complexity of this issue stems from uncertainty regarding possible agents of space breadth. Let us consider the use of analogy, for instance. Woodbury and Burrow justifiably take it for granted that analogy is one way of exploring states and moving among them. Students of analogical reasoning point out that in some of the most poignant examples of problem solving using analogy, we are looking at between-domain transfer (Gentner, 1983). A prominent designer like Le Corbusier drew analogies for buildings from nature (crab shell), household items (wine-bottle rack), and ships. Is there a way to incorporate such representations, which were used only once for the most part and are not widely applicable, into the design space, other than in retrospect, when they are no longer relevant?

The question of on the spot experimentation by way of sketching is, of course, of particular magnitude. Should the design space limit the explorers who act within it to visitation of representations? Or should they be allowed to reconfigure and mold the space itself such that they would be able to freely manufacture and manipulate representations in it, with no regard to rules, and with the freedom to make shortcuts and discontinuous leaps? It seems to us that this should be allowed to happen, and it probably means that explorers should be able to move not only among "regions" in the space (e.g., previously explored provinces vs. terra incognita), but also among different levels that the space should comprise.

Possibly of even greater importance to the utility of the design space is the question of its constituent "inhabitants." We envision a space in which design moves and design arguments inhabit different strata of the space,[8] where links among moves and shifts between argument modes are displayed and serve as feedback. Simple quantitative feedback would allow the designer to assess not just the emerging design, if one comes into sight, but also his or her process. We can specify the proportion of critical moves that signal a productive process, and likewise we know that a link index that is lower than a certain baseline indicates an ineffective search. Monitoring arguments can ensure that the designer has not lost sight of design goals, because a candidate solution is checked against its rationale, and frequent shifts between argument modalities ensure that a "good fit" between the two continues to guide the exploration. The automation of analyses of this kind and the surfacing of feedback is a computational issue that we are in no position to address here.

Keeping in mind that arguments of the type "rationale" are often represented using language, we must ensure a wider representational gamut in the design space, and this may add to the computational complexity with which we propose to endow the design space. Needless to say, this is a formidable vision for the design space but one that we find worthwhile embracing.

We may want to start by trying to consolidate the various spaces that design research addresses. It is already questionable whether we make a good enough distinction between problem space and solution space, and writings about the solution space (e.g., Habraken, 1985) make it evident that the two spaces have been confounded at times. Recognizing the problem researchers have already suggested a merge between the two spaces (e.g., Maher et al., 1996; Dorst & Cross, 2001), and the next logic step would be to incorporate them into the design space. However, because the design space, at least in its current incarnation, is heavily computationally bound, it should be regarded as a joint cognitive system that we would like to see inclined toward the cognitive needs and preferences of the (human) designer. One of the implications is, for example, that the system should not be based on the notion that increasing the number of alternatives that the designer considers, or even views, is necessarily an advantage. Rather, we should prioritize a more sophisticated way to associate representations, including nongraphic ones, to one another to strengthen a solid and multilevel rationale for a design proposal. Likewise, we should endeavor to achieve a built-in process monitoring device that helps assess the activity of exploration on the spot. Consequently, the design space will have to be conceived as a multilevel, possibly multidimensional construct. We still have no good atlas of an optimal design

[8]We have made a first attempt in this direction (see Goldschmidt, 1997).

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space, but some of the maps that it should include appear to be in the works, and this is certainly encouraging.

## REFERENCES

Akın, Ö. (1999). Variants of design cognition. In *Cognition in Design Education* (Eastman, C., McCracken, M., & Newstetter, W., Eds.), pp. 105–124. New York: Elsevier [referenced in Woodbury & Burrow keynote].
Anderson, S. (1984). Architectural design: a system of research programs. *Design Studies 5(3)*, 146–150.
Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues 8(2)*, 5–22.
Cross, N. (1982). Designerly ways of knowing. *Design Studies 3(4)*, 221–227.
Cuff, D. (1991). *Architecture: The Story of Practice*. Cambridge, MA: MIT Press.
Dorst, K., & Cross, N. (2001). Creativity in the design process: co-evolution of problem-solution. *Design Studies 22(5)*, 425–437.
Duarte, J. (2001). *Customizing mass housing: a discursive grammar for Siza's Malagueira houses*. PhD Thesis. Massachusetts Institute of Technology.
Ericsson, K.A., & Simon, H.A. (1984/1993). *Protocol Analysis: Verbal Reports as Data*. Cambridge, MA: MIT Press.
Fish, J. (2004). Cognitive catalysis: sketches for a time-lagged brain. In *Design Representation* (Goldschmidt, G., & Porter, W.L., Eds.), pp. 151–184. London: Springer–Verlag.
Fish, J., & Scrivener, S. (1990). Amplifying the mind's eye: sketching and visual cognition. *Leonardo 23*, 117–126.
Gentner, D. (1983). Structure-mapping: a theoretical framework for analogy. *Cognitive Science 7(2)*, 155–170.
Goel, V. (1995). *Sketches of Thought*. Cambridge, MA: MIT Press.
Goldschmidt, G. (1991). The dialectics of sketching. *Creativity Research Journal 4(2)*, 123–143.
Goldschmidt, G. (1997). Capturing indeterminism: representation in the design problem space. *Design Studies 18(4)*, 441–455.
Goldschmidt, G. (2001). Is a figure-concept binary argumentation pattern inherent in visual design reasoning? *Proc. Second Int. Conf. Visual and Spatial Reasoning in Design: Computational and Cognitive Approaches*, pp. 177–205.
Goldschmidt, G. (2003*a*). Cognitive economy in design reasoning. In *Human Behaviour in Design* (Lindemann, U., Ed.), pp. 53–62. Berlin: Springer–Verlag.
Goldschmidt, G. (2003*b*). The backtalk of self-generated sketches. *Design Issues 19(1)*, 72–88.
Goldschmidt, G., & Smolkov, M. (2004). Design problems are not of a kind: differences in the effectiveness of visual stimuli in design problem solving. *Proc. 3rd Int. Conf. Visual and Spatial Reasoning in Design* (Gero, J.S., Tversky, B., & Knight, T., Eds.), pp. 199–218.
Goldschmidt, G., & Tatsa, D. (2005). How good are good ideas? Correlates of design creativity. *Design Studies 26(6)*, 593–611.
Goodman, N. (1978). *Ways of Worldmaking*. Indianapolis, IN: Hackett.
Habraken, N. J. (1985). *The Appearance of the Form*. Cambridge, MA: Awater Press.
Lawson, B. (1980/1997). *How Designers Think*. Oxford: Architectural Press.
Lawson, B. (2004). *What Designers Know*. Oxford: Architectural Press.
Maher, M.-L., Poon, J., & Boulanger, S. (1996). Formalising design exploration as co-evolution: a combined gene approach. In *Advances in Formal Design Methods for CAD* (Gero, J.S., & Sudweeks, F., Eds.), pp. 1–28. London: Chapman & Hall.
Malaga, R.A. (2000). The effect of stimulus modes and associative distance in individual creativity support systems. *Decision Support Systems 29(1)*, 125–141.
Mitchell, W.J., & Stiny, G. (1978). The Palladian grammar. *Environment and Planning B: Planning and Design 5(1)*, 5–18.
Pothos, E.M. (2005). The rules versus similarity distinction. *Behavioral and Brain Sciences 28(1)*, 1–49.
Quantrill, M. (1983). *Alvar Aalto: A Critical Study*. London: Secker & Warburg.
Rittel, H.J.W., & Webber, M.M. (1973). Dilemmas in a general theory of planning. *Policy Science 4(2)*, 155–169.
Rodgers, P.A., Green, G., & McGown, A. (2001). Using concept sketches to track design progress. *Design Studies 22(5)*, 451–464.
Schön, D.A. (1983). *The Reflective Practitioner*. New York: Basic Books.
Suwa, M., & Tversky, B. (1997). What do architects and students perceive in their design sketches? A protocol analysis. *Design Studies 18(4)*, 385–403.
van der Lugt, R. (2001). *Sketching in design idea generation meetings*. PhD Thesis. Delft University of Technology.
van der Lugt, R. (2003). Relating the quality of the idea generation process to the quality of the resulting design ideas. *Proc. 14th Int. Conf. Engineering Design* (Folkeson, A., Gralén, K., Norell, M, &. Sellgren, U., Eds.), Stockholm: Design Society [CD].

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