The Backtalk of Self-Generated Sketches

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Introduction

Drawing and sketching are activities all humans engage in, at some level or another, as of a very young age (if not deprived of the sense of sight). In developed societies, toddlers use drawing implements to make marks on paper. In less-developed societies, children and adults use sticks to draw on sand. Why do children draw? It seems that for a child, drawing is a form of play, with developmental benefits similar to those of both symbolic play and construction games (play typology instituted by Piaget and Inhelder[1]). Most people acquire enough drawing skills during childhood to make graphic production an accessible strategy whenever pictorial representation is more effective than linguistic representation in communication and reasoning. For some communication and reasoning tasks, however, ordinary drawing skills are not sufficient, just as linguistic skills acquired during childhood are not necessarily adequate for sophisticated verbal and written expression tasks. A better command of language makes for better orators and reporters, and a better command of drawing skills makes for better illustrators and decorators. A special class of representational skill, linguistic or graphic, is the one needed for inventive purposes: this is the case of the poet, the visual artist, and the designer. The inventive process does not require wider skills: not necessarily a larger vocabulary or unlimited graphic techniques. Rather, what is required is an ability to use the representational act to reason with on the fly. Usually, this is a "front edge" process in which partial and rudimentary representations are produced, evaluated, transformed, modified, refined, and replaced by others if need be, until their maker is satisfied with the results. The unique thing about such processes is that, since they involve ill-structured problem-solving, it is not clear at the outset where the process is leading to, and what the end result might be.

In this paper, it is our purpose to look at the way in which sketching assists in generating ideas and strengthening them by interpreting the "backtalk" of a sketch in progress,[2] or one that has just been completed. We use a developmental axis to illustrate our claims. We start with children and show how they "read" new information off their sketches or drawings, and use it to define or refine the rationale for their representations. We then show how designers habitually practice a similar process in the early idea-generation phase of the design process.

1 J. Piaget and B. Inhelder, *The Psychology of the Child* (New York: Basic Books, 1969).

2 D. A. Schön, *The Reflective Practitioner* (New York: Basic Books, 1983).

First Scribbles

Children under the age of three years produce scribbles to which they are able to attribute after-the-fact representational meaning.[3] In fact, they do not attach meaning to a whole drawing, or scribble, but to parts of it that comprise angular curves.[4] Researchers found that two graphic schemas are involved in the making of these early scribbles: smooth-inertial and angular-intentional curves. The latter require a slower production speed and a change in direction, and result in breaking points and more closed shapes, which are believed to be richer, that is, to convey more information than smooth lines. Young children who were asked to interpret line sections in drawings, attributed representational meaning to angular curves, whereas smooth lines were referred to in nonrepresentational terms (such as "line" or "circle"). However, the representational signification was suggested only when a child referred to a drawing he or she had just completed. Earlier drawings by the same child and drawings by a peer (or an adult) received a different or no representational interpretation. In addition, the attribution of meaning when it occurred was seldom spontaneous and for the most part, was given in response to a question. These findings lead to the conclusion that a very young child does not intentionally make a symbolic representation, but reads representational meaning into it after its completion. Although a certain amount of arbitrariness certainly is present in such "readings" (a different or no meaning given when revisiting the drawing later), they are not entirely arbitrary. Proportions of enclosed figures were reminiscent of those of the signified objects: for example, a narrow, oblong curve signified a banana, whereas a rounder one stood for a bulky object, such as a car.

Somewhat older children produce preplanned representational drawings, and are particularly skilled when depicting favorite objects, people, or scenes that they draw repeatedly. Inventories of such favorite entities include several standard items (e.g., person, house, sun, tree) using conventional schemas, which appear to be largely universal. However, when attempting to represent something new, or when experimenting with new materials or media, children abandon their conventional representation behavior.[5] The experimental drawing is more concerned with the act of drawing, and when experimenting, children are likely to attribute after-the-fact interpretations of their drawings.

Thus, it appears that even at age two, before a child produces preplanned representational drawings, he or she is able to infer representational meaning from certain elements of a self-produced scribble. The nature of the attributed meaning derives from two sources: the properties or shape of the figure referred to, and entities the child is preoccupied with (toy, food, family, etc.). Later on in childhood, experimentation and uncertainty trigger similar inference of representational meaning, as the experimental act produces results which are not entirely anticipated. In what

3 See, for example, H. Werner and B. Kaplan, *Symbol Formation* (New York: Wiley, 1963).

4 All references to young children's drawings pertains to E. Adi-Japha, I. Levin, and S. Solomon, "Emergence of Representation in Drawing: The Relation Between Dynamic and Referential Aspects," *Cognitive Development* 13:1 (1998): 25-51.

5 NR. Smith, "How a Picture Means" in D. Wolf, ed., *New Directions for Child Development* 13 (San Francisco: Jossey-Bass, 1979), 59-72.

follows, we show that these characteristics of graphic production are especially robust. They are maintained through adulthood, and are exploited by expert sketchers in the process of designing. To fully appreciate the way in which sketching actually engenders meaning, we describe and analyze in detail one vignette from an older child's drawing activity.

Invention in Drawing

Naomi is nine years and seven months old. When she was younger (four to five years old), she liked to use building blocks to build "models," which also included improvised components such as small toys and various found objects. In these creations, she represented familiar buildings or sites (e.g., her home town), often with additional features that she must have desired to see added such as, in one instance, a swimming pool.[6] Protocols of conversations with Naomi indicate that the additional, invented features were clearly intentional, although their inclusion in the construction may not have been premeditated.[7] This pattern, observed in three-dimensional representation, appears to be preserved in later two-dimensional representation as well. Let us examine an example from Naomi's documented drawing activity.

Naomi, now a fourth grader, likes to draw and she is open to new, exploratory activities. She welcomed an opportunity to participate in what was termed "a drawing game." In this game, she is shown a picture (source) and she reacts to it by making a drawing (target), while talking out loud. Each game session is recorded and yields a protocol. The present source is a photograph [Figure 1] depicting three persons sitting on a bench. A man and a woman [M and W1, respectively] joined in an embrace, and another woman [W2] who leans her elbow on the man's shoulder. The photograph shows the backs of the three figures, a water body they face and a narrow built-up strip of the bank on the other side of the water body.

> Naomi described the picture and its meaning as follows: ...And a man and a woman [W1] embracing, and another woman [W2], with a miniskirt, and this picture gives me this feeling that there are a man and a woman who are in love, and there's this woman, [who is] terribly ... She ... looks at the sea and thinks these deep thoughts to herself, imagining that she [W2] was with them, as if the other woman [W1] were not there... And the woman [W2] imagines she is with him ... . She wishes that, one day, the [other] woman [W1] would die and she [W2] would be with him; or that they would break up and she [W2] would be with this man. This man, he is back from the army, you can see his uniform. And that she [W2] would be with him and the [other] woman [W1] would be jealous....

6 G. Goldschmidt, "Development in Architectural Design" in M. B. Franklin and B. Kaplan, eds., *Development and the Arts: Critical Perspectives* (Hillsdale, NJ: Erlbaum, 1994), 79–112.

7 Experiments with nine-to ten-year-old children who built three-dimensional "models" that represented invented houses for a heroine of a well-known children's story, yielded similar tendencies (see Goldschmidt, "Development").

Figure 1 (above)
Source photograph.[8]

Figure 2 (right)
Naomi's target drawing.

Naomi now proceeds to make a drawing "about the things she [W2] imagines": her being with the man, while the previous girlfriend [W1], now rejected, looks on with envy. She starts by drawing a long bench, then she draws a couple—a man and a woman [M and W2] who stretch their arms towards one another. After the details are rendered (clothing, the man's beard), she adds another woman [W1], with a cartoon-style bubble that elucidates her thoughts ("Why did you leave me and choose her?" in Hebrew). Naomi completes her drawing with a water body, buildings on the other bank (she confirms the scene takes place in the site shown in the source photograph), and she adds a large sun (upper left corner) and a cloud (above buildings). The drawing is reproduced in Figure 2.

Source and Target Representations

We would now like to compare the two representations—the source photograph and Naomi's target drawing. We are particularly interested in Naomi's commentary on features of her drawing that are not traceable to the source photograph.

Naomi swings between standard symbols and drawing conventions, and representational features that are neither standard nor conventional. Standards include the depiction of the sun and cloud, but also some of the clothing items. For example, since she identifies the man in the photograph to be a soldier, she is upset when she discovers she had forgotten to draw his cap at first, and insists on adding it later. Facial expressions also are a case in point: an example is the way in which she draws the persons' mouths, to indicate the mood they are in:

> "... this one [W1, right] is sad, you can tell by the mouth. I made the mouth twisted downwards. And her [W2, left], the mouth twisted upwards."

8 Courtesy of W. C. Rauhauser, Untitled Photograph, in catalog of *The Family of Man* (Exhibition curator: Edward Steichen) (New York: Maco Magazine Corporation for The Museum of Modern Art, 1955), 130. Black and White, $6^1/_2$" x $6^1/_4$".

Of particular interest are instances in which Naomi used a convention, but one that is at odds with the photographic depiction. We would like to dwell on two examples: the buildings in the drawing, and the way in which hair is represented. The buildings Naomi draws are rather prominent—much more so than the ones in the photograph, which are barely hinted at. The buildings must have held a special meaning for her, as she starts her description of the photograph with them, before any mention of the "actors" in the scene. In the drawing, however, the buildings are added at the end. While drawing the buildings she says:

> "And then there are these towns one saw in the back. These buildings... . Everything was lots of tall buildings. It's this kind of town, of the past."

The experimenter asked what a "town of the past" was, and Naomi replied that they have "lots of tall towers." The experimenter, who sought to reach a better understanding of the appearance of tall buildings in the scene, asked about them again in the debriefing after the session. Naomi explained: "That's how I wanted it.... I saw [in the photo] the tall towns...quite high. Like from far away." She seemed to not comprehend what it is that the experimenter could have possibly failed to understand. Since she could not have inferred her vision of "tall towns" from the photograph, the experimenter speculated that she could have been under the influence of a previous "drawing game" played a few hours earlier, in which the source was a painting by Heronimus Bosch that features towers. She asked: "Do you think it could have something to do with the former picture, about which you said it was like many years ago?" Naomi answered: "No, there is no connection." Influence of the Bosch painting would have explained Naomi's image of an old town with tall buildings. If this is incorrect, as Naomi insisted, we have no information that could explain this move. We must conclude that interest in old and tall buildings that originated elsewhere penetrated the process, and was acted out in this drawing. As we shall see, several other moves Naomi made were not a direct consequence of the given information (photo), but rather her own interpretation of what was embodied in the source, reinforced by information she "imported" from extraneous sources.

The second example of "imported" information concerns the representation of hair. Unlike in the photo, the women in the drawing have long, straight hair. In the debriefing the experimenter asked Naomi: "...both have long hair, right?" Naomi replied: "Yeah. That's how it says that they are women...." Her answer reminds us of her representation of the women's mouths, intended to inform us in what mood they are. The experimenter asked Naomi to look at the photo again and asked: "Is it like that in the photo as well?" Naomi replied with confidence:

> "In the photo—no, one has curly hair [W2] and the other has her hair gathered, sort of [W1]....But [in my imagination] she [W2] sees herself prettier than her [W1]."

She went on to explain that "...she [W2] sees the other [W1] like with long hair, and not very much hair." The experimenter asks whether a lot of hair is prettier, and Naomi confirms: "Yes, like in her [W2] opinion."

This exchange points to two conventions that Naomi apparently maintained: first, that long hair signifies a female figure in a pictorial representation; and second, that the longer the hair and the more there is of it, the prettier the depicted figure is supposed to be. Naomi did not remember that a few weeks earlier she attempted a portrait of the experimenter, who happens to have curly hair. In the portrait her hair was straight. When asked about it Naomi said, in congruence with her current statements, that this was how you drew a woman's hair. But she also added that she had drawn it this way because she did not know how to draw curly hair. The convention is therefore double-fold: it reflects Naomi's aesthetic values on the one hand, but on the other hand it bears evidence to her representational repertoire, which is limited and is not intended to reproduce reality but to interpret it using a set of predefined symbols.

This is a cogent example of the way in which Naomi constructs—designs, if we prefer—a situation whose elements are inferred from the source, from her memory, and from her repertoire of conventions equally forcefully. She subscribes to the view that female figure representations should exhibit straight hair, and this becomes an overriding imperative. Whether the knowledge and the conventions she relies on are valid or not, is of no relevance in terms of what gets represented.

Next, we look at the way in which Naomi dressed the women in her drawing. The seemingly naïve dresses turn out to be very surprising from a representational point of view. Clothing is an essential property of human figure representation. Naomi was attentive to what the persons in the photograph are wearing: she immediately noted that one of the women [W2] wears a miniskirt, and that the man is in uniform. When she drew the man she commented that he had "...[a] short-sleeved shirt. Pants." (As we have seen, she later added his cap which she had forgotten while drawing the soldier.) She proceeded to draw his present sweetheart [W2]:

> "With a dress. I made a dress with a large heart in the middle. She is a little fat, because she is pregnant.... Yes. That's how I want it. That's what she dreams."

She added the rejected former girlfriend [W1] and drew a heart on her dress, too. In the debriefing, the experimenter returned to this issue and asked why the girlfriend [W2] had a dress with a heart. Naomi explained:

> "Because she loves him. And she is pregnant. As if she were his wife.... And the other one loves him too, that's why she [too] has a dress with a heart. The other one, too."

The experimenter wondered: "But the one who is his girlfriend or his wife has a big heart, and the other one has a small heart?" Naomi came up with an unexpected answer, which she elaborated on when the experimenter asked what made her think that the woman was pregnant:

> "...Besides, she is pregnant...." "First I made the tummy, like this, and also too swollen, so I thought OK, I won't say she isn't pregnant from him, 'cause she's his wife...that's what I imagine she wants."

Sketching as Modulator of Problem Space

In addition to what we may learn about the remarkable grasp of the state of human affairs by this 9-year-old, we also gain a wonderful insight into her representational behavior. As a matter of convention, she draws a dress. The dress appears rather "swollen" to her, so she decides that it would make sense to attribute the swelling to a pregnancy. We do not know whether an event in her life made the connection between man and woman and a pregnancy a particularly attractive idea, or one that she was preoccupied with. But the most interesting thing about her statement is the fact that she decided on the pregnancy interpretation because the dress was accidentally drawn too large. In other words, this was not a premeditated notion, but one that resulted from Naomi's reading of what Schön called the drawing's "backtalk." [9] She also stated, when asked about the big heart on one woman's dress versus the smaller heart on the other's, that in the latter case "there was no room": the dress was not drawn wide enough to place a big heart in it. The interpretation was not based on information contained in the stimulus or source photograph, but it was congruent with the meaning she attributed to the depicted scene and therefore could be adopted easily. It also is possible that it was the experimenter's question that triggered the pregnancy response. If so, Naomi's after-the-fact attribution of meaning to her represented figures resembles that of the younger children described above, and we believe that this is indeed the case.

Naomi illustrates a principle stating that "one reads off the sketch more information than was invested in its making." [10] When a sketcher, in this case Naomi, starts sketching, he or she often has only a vague and rudimentary idea of what is about to be represented. As the activity of sketching proceeds, new (graphic) relationships are created on the sketching surface. If the sketcher is attentive to them, he or she may see in them clues to further meanings that can be read into the representation: this frequently is the case in early stages of the design process, as we shall relate later on.

9 Schön, *The Reflective Practitioner.*

10 G. Goldschmidt, "On Visual Design Thinking: The Vis Kids of Architecture," Design Studies 15:2 (1994): 158-74, cit. 164.

The added meanings enrich the rationale of the representation and a "story" (scenario) is developed. The more "layers" there are to the story, and the more "supportive evidence" can be built up through the details of the representation, the more consistent and credible, and therefore more powerful and "better" the story is. The ability to infer information from the self-generated sketch and to use it in order to enhance the sketcher's ability to deal with a task or problem at hand may be seen as an expansion of the problem space within which the individual is working. As new arguments are generated and the story is being developed, it acquires a rationale of its own, with implications for the problem and its possible solution. As we shall see presently, sketching activity also may restrict the problem space. Therefore, we see the activity of sketching as modulating the problem space.

Two further examples from Naomi's protocol illustrate the way in which sketching modulates the problem space. The first has to do with multiple justification. A case in point is the hearts Naomi drew on the dresses. For all we know, they may have originated from a mere wish to decorate the dresses, although it is quite possible that they were intended from the outset as symbols of their owners' love for the man. However, whereas the hearts' varying size reflects disparities in the ladies' relationships with the man, we, also are told that the size difference results from a technical dissimilarity between the spaces in which the hearts were to be inserted. (Incidentally, an unbiased observer may find the two dresses equally wide or "swollen.") In addition to demonstrating that the actual act of sketching produces new information that becomes a supplemental, dynamic resource, this episode reveals how important it is to the sketcher to build a strong rationale for his or her emerging story, or interpretation, through multilayering. This tendency is frequently displayed in design-related sketching, where a scenario is created that elucidates and justifies the designer's decisions and choices.

The second example of problem space modulation has to do with representational techniques. In parallel with the use of conventions (e.g., the way in which the mouths and hair are drawn), Naomi deviates from the source photograph in accordance with what her skills allow her to do. In her drawing, the persons appear to be standing, whereas they are seated in the original depiction. A standing position is the default portrayal mode of the human figure, and easier to represent than a sitting figure. Had she been asked, it is conceivable that Naomi would have said that she drew them standing because she did not know how to draw reclining or sitting figures (similar to her earlier "confession" regarding her inability to represent curly hair). Likewise, Naomi drew her figures in profile, while in the photo "you see it only from behind." Whereas the default representation of the human figure tends to be a frontal view, Naomi was a sufficiently skilled sketcher to be able to use the

profile mode. This was a better choice in this case because it made it easier to draw the figures stretching their arms and looking at one another. Had Naomi been less skilled, the representation may have been reduced to a frontal view that possibly could be less expressive. Technical skill and choices of technique therefore may contribute to either the expansion of representational expression (profile), or they may constrain them (standing position only). In the next section, we shall discuss how generic sketching evolves into a professional design activity, and we shall show how sketching skills may enhance design-like invention, whereas the lack of such skills may actually restrict design problem-solving.

Sketching Skill and Design Expertise

Paper and the Advent of Sketching

Sketching has a relatively short history: we detect its origins to the late-fifteenth century in Europe, an age of innovative developments in the arts and sciences, supported by inventions and novel technologies. One of the most important inventions of the renaissance was moveable-type printing, leading to the establishment of printing presses first in Rome (in 1467) and later elsewhere in Italy and throughout Europe.[11] The rapidly developing book printing trade paved the way for a growing paper industry, since the demand could no longer be met by handmade paper. It did not take long before artists and designers (who were one and the same, for the most part) started to consume paper for the purpose of making drawings. Since paper of good quality became affordable and readily obtainable, artists availed themselves, for the first time, of the luxury of making study drawings, better known as sketches. The desire to experiment, and to revise and look for alternatives which the activity of free-hand rapid sketching supported, of course was in perfect harmony with the innovative spirit of the renaissance. Therefore, the assimilation of sketching into artistic and design practices was quick to occur. Most appropriately, the incomplete, partial, rapidly hand drawn images on paper that we refer to as study sketches were called "pensieri,"[12] meaning "thoughts" in contemporary Italian. Sketches were then, and still are today, an aid to thinking and, we maintain, under certain circumstances, their making is thinking itself.

There is a marked difference between the way in which sketching on paper is utilized by different sketchers. As we have seen, young children do not make study sketches: they make drawings that represent objects, scenes, and events, real or imaginary. Older children and adults continue to make drawings with similar objectives, but they also attempt to represent abstract concepts via diagrams, patterns, and symbols. They draw to depict and describe complex configurations that are better conveyed through pictorial images than through words, and they engage in sketching in preparation for a neater finished rendering. None of these activities

11 F. Ames-Lewis, *Drawing in Early Renaissance* (New Haven, CT: Yale University Press, 1981).

12 E. J. Olszweski, *The Draghtsman's Eye: Late Renaissance Schools and Styles* (Cleveland, OH: Cleveland Museum of Art/Indiana University Press, 1981).

matches our definition of study sketching, which is practiced by individuals who attempt to conceive of a new entity, be it a work of art, a building, a technically-oriented invention or novel artifact, or a scientific concept. The description and specification of the new entity that is being brought into being in those instances entails shapes and forms. The sketcher represents candidate shapes and forms, their parts and features, and relationships among them. Freehand sketching is rapid and direct, and therefore cognitively economical, and provides instant feedback: the sketcher can enter into conversation with his or her materials. [13] Because a search process takes place, the sketcher normally is highly sensitized to possible clues, including unintended configurations that result from his or her sketching activity, and which can potentially trigger development. Naomi's pregnant woman, as a result of a dress that has been drawn a little too wide, is a cogent example. We must also add that, since the problem the sketcher is trying to solve often is rather complex, the search comprises multiple steps, and normally numerous representations are produced, sometimes in long series of sketches.

How useful sketching is in search processes of this kind depends to a large extent on the designer's skill. Sketching skill comprises two independent components. The first is fluency: it is required for the sketcher to be able to use sketching without having to spare attention to the actual production processes. In that sense, exercising sketching skills resembles exercising any other skill. The second component of the skill applies only to designers of three-dimensional artifacts: a good command of the system of orthogonal projections. Orthogonal projections, another renaissance innovation, enable the precise and complete description and specification of any object on the basis of simple mathematical rules. It is the foundation of technical drafting that is used in engineering, architecture, and other design disciplines to describe and later to manufacture artifacts or construct closures for space. Among others, it enables the representation of aspects of artifacts and spaces that otherwise are impossible or very difficult to visualize. In Evan's words: "Few things have had greater historical significance for architecture than the introduction of consistent, coherent parallel [orthogonal] projection into architectural drawing...." [14] A skilled sketcher (in the context of design) is one who is trained in the use of orthogonal projections, and whose fluency of production extends to include the representation of configurations using this system. Without it, the sketcher's studies are confined to "exterior" and readily visible aspects of the entity that is being designed. A truly skilled sketcher can be expected to take considerable liberties when making study sketches, such as the prioritizing of certain projections, shortcuts and incomplete representations, hybrid representations, and so on.

13 Schön, *The Reflective Practitioner;* D. A. Schön and G. Wiggins, "Kinds of Seeing and Their Function in Designing," *Design Studies* 13: 2 (1992): 135-56.

14 R. Evans, *The Projective Cast: Architecture and Its Three Geometries* (Cambridge, MA: MIT Press, 1995), 108.

Papert's Dilemma

The expert sketcher therefore is someone who can make and manipulate representations fast and with great ease while choosing the most appropriate projection(s). If he or she is a designer, this skill is indispensable in the search that is part of, indeed the most significant part of, the design process. The following vignette will illustrate this point. Seymour Papert (prominent MIT Media Laboratory professor emeritus) is an amateur cook who, according to his own testimony, spends considerable time in his kitchen and values its spatial and visual qualities. [15] He described a problem he did not know how to solve: he lives in a small apartment in which the kitchen was an internal space, not adjacent to an exterior wall and, therefore, without a window. A hallway with a window along its side separated the kitchen from the exterior wall, so Papert cut a large opening into the partition between the hall and the kitchen, hoping to command an outdoors view across the hallway while working in the kitchen. The result was disappointing, because the vista he gained was more limited than he expected. In explaining this to a designer, he used a simple plan of the kitchen and hallway that he was able to draw quite confidently. He was very surprised when the designer suggested that they needed a different representation, and proceeded to sketch an approximate section on the basis of Papert's plan and description. On the section it was easy to point out which dimensions controlled the view Papert possibly could obtain (height of kitchen counter, windowsill, etc.). For the designer, this was a very simple problem and recourse to a sectional drawing was an obvious move. To Papert, a most original and creative thinker in other fields, and not a stranger to a drawing implement, it had not occurred that studying his problem required a representation other than a plan.

The Primacy of Sketching

Imagery has been acclaimed as the most useful cognitive faculty in tasks that require the solving of novel, design, and invention-like problems. [16] Some researchers have claimed that imagery is, in fact, so powerful that paper-based sketching is redundant in designing.[17] We propose that this is not the case, at least not when problems are complex, and we will present empirical evidence to this effect.

Imagery and Sketching

Goldschmidt[18] has proposed that, in the context of design, sketching serves as an extension of imagery; she refers to it as "interactive imagery." Other researchers of design advance similar claims.[19] This characterization implies a circular feedback loop between two kinds of pictorial representation: internal representation in imagery, and external representation on paper or some other sketching surface. In this view, mental images inform the making of a sketch, but the sketch-in-the-making includes "autonomous" properties that result

15 Personal communication, 1988.

16 E.g., G. Kaufmann, *Imagery, Language and Cognition* (Bergen: Universitetsforlaget, 1980).

17 U. A. Athavanker, "Mental Imagery as a Design Tool" in R. Trappl, ed., *Cybernetics and Systems Research '96: Proceedings of the Eleventh EMCSR* (Vienna: Austrian Society for Cybernetics, 1996), 382-7.

18 G. Goldschmidt, "The Dialectics of Sketching," *Creativity Research Journal* 4:2 (1991): 123–43.

19 For example, J. Fish and S. A. Scrivener, "Amplifying the Mind's Eye: Sketching and Visual Cognition," *Leonardo* 23 (1990): 117–126; T. A. Purcell and J. S. Gero, "Drawing and the Design Process," *Design Studies* 19:4 (1998): 389-430; M. Suwa and B. Tversky, "What Do Architects and Students Perceive in Their Design Sketches? A Protocol Analysis," *Design Studies* 18:4 (1997): 385–403.

from emerging relationships among its elements (i.e., lines, dots, etc.), some of which may be unintended. These properties are interpreted in ways that are meaningful to the sketcher within the framework of the task, or within the problem-space in which he or she is working. In turn, these interpretations inform the generation of new mental images. Ascribing meaning to the unintended consequences of a rapidly made (freehand) sketch is what enables the sketcher to use it as a source of new information. This is what is meant by the previously quoted assertion claiming that "one reads off the sketch more information than was invested in its making." If we accept these premises, an inevitable conclusion is that sketching is a tool that has the potential to enhance design reasoning. This is the case particularly in the "front edge" conceptual phase, when the designer is actively searching for ideas and information that may help generate, or fortify, a design rationale and a design story. It therefore would appear that, by definition, using sketching or interactive imagery in developing design concepts has advantages over consulting only images, which fade away rather quickly. By way of extension, we therefore would assume that other kinds of creative invention in imagery also would benefit from the use of sketching.

Finke[20] has reported the results of an intensive research program on creative invention in imagery. The tasks his subjects were given consisted of combining three arbitrarily selected shapes into meaningful new items, in two or three dimensions. (Some shapes depicted objects, others described geometrical entities. In each experiment, three shapes were drawn from a set of 15.) Blindfolded subjects performed the task in imagery within two minutes. The resultant configurations, which were to represent useful objects, were then described and drawn by their authors, and assessed for their creativity by naïve judges. The findings indicated that people could easily make creative discoveries in imagery. This work inspired a whole line of research that has come to be known as "mental synthesis." As part of this research program, Anderson and Helstrup[21] also asked whether allowing people to sketch while using imagery to develop inventive creations enhances creativity. They concluded that there was no evidence that sketching added significantly to the rated creativity of imagery-based inventions. (They did find that the use of sketching facilitates a larger number of creations.) These results provoked additional studies regarding the same question. [22]

Kokotovich and Purcell obtained results similar to those of Anderson and Helstrup, with a few qualifications. In Verstijnen's studies, subjects were divided into expert and novice sketchers who undertook combinatory creation tasks styled after Finke. As in other studies, Verstijnen et al. found that equal creativity rates apply across conditions. The next step was to classify configurations made by the subjects into two categories, according to the moves that were made: combinatory and restructural. The former included

20 R. A. Finke and K. Slayton, "Explorations of Creative Visual Synthesis in Mental Imagery," *Memory and Cognition* 16 (1988): 252-7; R. A. Finke, *Creative imagery: Discoveries and Inventions in Visualization* (Hillsdale, NJ: Erlbaum, 1990).

21 R. E. Anderson and T. Helstrup, "Visual Discovery in Mind and on Paper," *Memory and Cognition* 21 (1993): 283-93.

22 See, for example, V. Kokotovich and T. Purcell, "Ideas, the Embodiment of Ideas, and Drawing: an Experimental Investigation of Inventing" in J. S. Gero, B. Tversky, and T. Purcell, eds., *Proceedings of the International Conference on Visual and Spatial Reasoning in Design* (VR'01) (Sidney: Key Centre of Design Computing and Cognition, University of Sidney, 2001), 283-98; I. M. Verstijnen, C. van Leeuwen, G. Goldschmidt, R. Hamel, and J. M. Hennessey, "Creative Discovery in Imagery and Perception: Combining Is Relatively Easy, Restructuring Takes a Sketch," *Acta Psychologica* 99 (1998): 177-200.

positioning of elements adjacent to others (horizontally, vertically, or diagonally), or inside of others. The latter comprised size variations among components, embedding, modification, subtraction (a component taking the shape of a void in another component), altered proportions, and complexity of junction (where one component penetrated another). These features of the configurations were counted and "transformation complexity" scores were assigned to the subjects (across trials). Results were then calculated for the two categories separately, and correlated with conditions (imagery with and without sketching) and expertise (experienced and inexperienced sketchers).

The distinction between combinatory and restructural moves turned out to be very revealing. Whereas no significant differences were found in the overall transformational complexity score between with-sketch and without-sketch conditions (as in Anderson and Helstrup, where no distinction was made between the two categories), this picture changed when the categories were pulled apart. Expert sketchers scored higher in restructural categories in the with-sketching condition than in the without-sketching condition; no effect was found on combinatorial scores. Novice sketchers did not score higher in one or the other category across sketching conditions. The main conclusion from this study is that "restructuring ... occurs when expert sketchers are allowed to sketch," [23] and we believe that this has most important implications for design.

Real world design tasks are obviously far more elaborate and "messy," and require more complex operations (and a larger inventory of candidate shapes to consider) than the two-minute, three-element synthesis tasks we have described. As we have shown, restructural operations involve a greater complexity (though not necessarily more sophistication) than combinatory actions. Therefore restructuring is all but a must in the solving of complex synthesis problems and in particular ill-structured problems, of which design tasks are an example. It is for this reason that Gestalt psychologists claimed that solving novel problems requires productive thinking, a process that involves restructuring of the problems.[24] Verstijnen et al. supplied empirical evidence that sketching is compatible with restructuring, where the problem requires visual manipulation and where the problem-solver is an experienced sketcher. It is our contention that it is the sketch's backtalk, and the ability of the sketcher to read meaning into it and discover new plausible interpretations of it, that makes this possible. That imagery has limitations compared to perception is well known and documented; consider, for example, our poor ability to reverse ambiguous figures in imagery. [25] When it comes to conception and the reasoning that it entails, imagery is a powerful tool. Kosslyn[26] maintains that a special case of attention-based imagery makes it possible to create images of novel entities that had never been perceived. We have shown, however, that in the hands of expert

23 Verstijnen et al., "Creative Discovery," 197.

24 Eg., K. Duncker, "On Problem Solving," *Psychological Monographs*, 58: 270 (1945): whole Issue; M. Wertheimer, *Productive Thinking* (Chicago: University of Chicago Press, 1945/82).

25 D. Chambers and D. Reisberg, "Can Mental Images Be Ambiguous?" *Journal of Experimental Psychology: Human Perception and Performance*, 11 (1985): 317–28.

26 S. M. Kosslyn, *Image and Brain* (Cambridge, MA: MIT Press, Cambridge, 1994).

sketchers, sketching stretches and sustains the "trial and error" exercises that imagery allows one to engage in, and increases the complexity of cognitive operations that can be performed. It therefore is a design resource that can be tapped when a task calls for it, and an emerging body of research appears to support this assertion.[27]

Reasoning With Self Generated Displays

What do designers say about the role of sketching in the idea-generation phase of their work? And how can we assess their insights into their own processes? We should start by saying that designers vary in respect to their sketching activity, both in terms of how much they sketch (and their preferred styles of sketching) and how useful they find it. In addition to individual differences, there also are domain characteristics (e.g., architects are known to sketch far more than engineers) and task differentials. We will limit our comments to sketching in the area of architectural design.

Architects like to surround themselves with visual displays that serve, we postulate, not merely as décor for the workplace, but also as potential sources for visual information (shapes, colors, spatial relations) that may be useful in a new design task. Casakin and Goldschmidt[28] have shown that providing architectural designers with visual displays increases the rated creativity of their design solutions. (A further increase in creativity scores is registered when subjects are explicitly asked to use analogy in conjunction with these displays in solving the given design problems.) We may associate these findings with results from MacKinnon's studies on personality correlates of creativity. [29] In these studies, architects (and particularly those rated "highly creative") scored higher than other professionals (including scientists and artists) in the Gottschaldt Figure Test, in which subjects are required to isolate and identify simple geometric shapes that are embedded in larger, more complex figures. Taken together, these findings appear to suggest that experienced architectural designers are in the habit of searching for "hidden" information in visual displays, which they know to be useful for their work.

If viewing ready-made displays is so useful, one may ask why do architects go to the trouble of making so many sketches? Should it not be sufficient for them to ensure themselves of an adequate supply of displays, and make use of them as needed? The answer to this question is not so simple. That sketching is a contributing factor is suggested by the fact that architects still choose to sketch, despite the availability of already existing displays. There may be several reasons for that including, for example, the pleasure that can be derived from this activity, and the ability to use sketching to test, and not only generate, ideas and concepts. However, we know that architects sketch long before they have testable ideas, and even when failure to reach desirable results

27 Eg., O. Akin and C. Lin, "Design Protocol Data and Novel Design Decisions" in N. Cross, H. Christiaans, and K. Dorst, eds., *Analysing Design Activity* (Chichester: Wiley, 1996), 35–64; M. Suwa, J. S. Gero, and T. Purcell, "Unexpected Discoveries and S-Inventions of Design Requirements: A Key to Creative Designs" in J. S. Gero and M-L. Maher, eds., *Computational Models of Creative Design IV* (Sydney: Key Centre of Design Computing and Cognition, University of Sidney, 1999).

28 H. Casakin and G. Goldschmidt, "Expertise and the Use of Visual Analogy: Implications for Design Education," *Design Studies* 20:2 (1999): 153–75.

29 D. W. MacKinnon, "The Personality Correlates of Creativity: A Study of American Architects" in P. E. Vernon, ed., *Creativity* (Harmondsworth: Penguin Books, 1970), 289–311.

fast enough leads to frustration and discontent. Therefore, we return to the hypothesis that sketching is useful in the generation of design ideas. What added value does sketching offer, as opposed to the scrutiny of other displays?

Two premises underlie our reply to this question. The first is simple and straightforward: we propose that sketches, too, serve as displays. We refer to them as self-generated displays. The second premise is a hypothesis: we propose that consulting self-generated displays is, for the most part, cognitively more economical than seeking useful information in other displays, whose potential to harbor such information varies randomly with the nature of those displays.

Most ready-made visual displays that architects utilize are not specifically selected to suit a particular task. Reference material can be gathered, including precedents (e.g., images of buildings that belong to the same type), but these have no advantage over random material when it comes to clues for new ideas in terms of spatial configuration. Indeed, most celebrated works of architecture that have documented process histories appear to rest on ideas that can be traced to concepts and images found far away from the building type in question, and often outside of the realm of architecture altogether. The self-generated display has the advantage of control over what goes into its making (but not over what can be read off it!). It is, therefore, not random, or much less so than a ready-made display. Moreover, the expert designer knows from experience what kind of display might prove useful and, without curtailing his or her propensity for experimentation, may avoid a cognitively costly search from which no useful outcome may be expected. Designers know this intuitively.[30] Here is how one of them described her sketching behavior at the "front edge" of designing:

> I can't get very far with just thinking about it without drawing something...I tend to overlay when I use pencil...they [overlays] are usually pretty similar.... I also do a lot of erasing. I like to erase because I like to have a lot of lines on the page. I like fuzzy stuff. I can see things in it more than I can in harder-lined things. So, sometimes I just get a lot of lines out and then I start to see things in it. A lot of times, I pick up things I think are important. I put down potentials and then erase down to them.[31]

We see how this designer customizes her display to achieve properties that she knows are potentially promising for her way of working. We should note her preference for "fuzzy stuff"—ambiguity of representation—is a known characteristic of the problem-space in ill-structured problem-solving. It is useful because it helps defer commitment to a solution.[32] Of equal interest is the account of the use of overlays and the employment of an eraser. By using overlays, the designer achieves great flexibility in performing a variety of

30 Without elaborating on the concept of intuition and what it means to know something intuitively, we would like to offer the following insightful commentary by Harbot: "It [intuition] is a mix of constructs, such as imagery and narrative formation, with an underlying basis of experience... .Operationally, in this context [the role of conscious intuition in structured problem-solving activity], intuition is the process of imagining something that turns out to be true. By "true," I do not mean to imply correctness in the logical sense but only in the sense that the thinker is willing to act upon his or her conclusions." B. Harbort, "Thought, Action and Intuition in Practice-Oriented Disciplines," in R. Davis-Floyd and P. Sven Arvidson, eds., *Intuition: The Inside Story* (New York: Routledge, 1997), 129-44, cit. 135.

31 Goldschmidt, "The Dialectics of Sketching," 129.

32 V. Goel, *Sketches of Thought* (Cambridge, MA: MIT Press, 1995).

transformational acts she may choose to exercise and experiment with (e.g., shifting, rotating, and flipping over a layer in relation to other layers). It also supports experimentation in that layers may be easily removed (discarded or saved for future reference), should an idea prove futile.[33] The eraser allows her to delete whatever she decides to eliminate on a more permanent basis. Working with layers of trace paper on which one can make marks and erase them at will is very rapid and direct: no cognitive resources are invested in conversion from one representational system to another (e.g., computation language to graphic display or vice versa). Assuming that the sketcher is an expert and therefore fluent and a master of the language of orthogonal projections, this technique is most efficient in terms of the "mileage" one can expect from one's investment in representation. As a "bonus," sketching in general, and work with layers in particular, allows one to review the entire history of design moves in a given session concurrently. Revisiting concepts that were earlier abandoned for insufficient "design rationale" may become relevant later on when such a rationale is being constructed, and having a visible record of a previously entertained concept may help remember and reactivate it. These are the properties that make sketching so cognitively economical, and therefore so attractive to designers.

For our purpose here, the most important assertion in the vignette above is the designer's statement that she can "see things in it" [her fuzzy sketch] more than in harder-lined drawings. Hard-line drawings are produced according to strict rules, and they usually are made when a design has reached considerable coherence and completion. They are necessary in order to examine and test many of the properties of the design, but they lack the qualities that make sketches so economical and therefore are not used in the early idea-generation phase of designing. A hard-lined drawing can easily be made by anyone, not necessarily by the original designer. In a sense, it is then quite similar to any other display that is not self-generated, and no longer has the same potential for harboring unexpected clues (nor is it expected to have that potential). In contrast, the fuzzy, incomplete, and inaccurate rapid sketch works in a manner somewhat similar to a Rorschach test inkblot, into which one can read meanings that are obviously derived from sources other than the inkblot. The self-generated sketch talks back, and its backtalk reflects some of the sketcher's innermost, tacit, otherwise untapped knowledge, biases, concerns, and preferences.

As we have seen, the ability to interpret self-generated sketches and "excavate" them for information is inherent: children do it, and they start doing it as soon as they start to produce representations, as early as at age two. Experienced designers do not require an external prompt such as an experimenter's question to infer meaning from a sketch: they produce the sketch in order to

33 Goldschmidt, "Serial Sketching: Visual Problem Solving in Designing," *Cybernetics and Systems* 23 (1992): 191–219.

have a dialogue with it, and the sketch's backtalk is the reward they get for bringing it into being.

Conclusions

The special role of sketches in design processes is distinguishable from the role of other images and visual displays that are used to support the design process. Designers make sketches because the sketch is an extension of mental imagery, and therefore has the freedom of imagery to retrieve previously stored images and to manipulate them rapidly. At the same time, because it leaves a hard trace of these images on a visible surface, and because this is an additive process, the sketching surface soon contains unforeseen configurations and relationships among the graphic components. The resultant displays are open to new interpretations, and if one consciously looks for them, they can be generated with relative ease using additional input from the designer's memory structures. This is an inherent cognitive ability that we all share, and we have evidence that it is at our disposal as of a very young age. Designers cultivate this ability and exploit it, adding formal rules for efficiency and comprehensiveness of representation (e.g., orthogonal projections), because it benefits their idea-generation processes. At present, it is not yet clear whether mediated sketching such as is possible using computational tools can produce similar effects: this is a question that can and should receive high priority on our research agendas.

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