# Designing as reflective conversation with the materials of a design situation

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*The paper considers what it means to capture design knowledge by embodying it in procedures that are expressible in a computer program, distinguishing several possible purposes for such an exercise. Following the lead of David Marr's computational approach to vision, emphasis is placed on 'phenomenological equivalence' — that is, first defining the functions of designing, and then specifying how people design.*

*The paper goes on to describe design phenomena that a computational strategy of this kind would have to reproduce. All of them are integral to a view of designing as reflective conversation with the materials of a design situation, and depend on the idea of distinctive design worlds constructed by the designer. These phenomena include: the designer's seeing–moving–seeing, the construction of figures from marks on a page, the appreciation of design qualities, the evolution of design intentions in the course of the design process, the recognition of unintended consequences of move experiments, the storage and deployment of prototypes, which must be placed in transaction with the design situation, and communication across divergent design worlds.*

*Considered as performance criteria for a phenomenologically equivalent computational designer, these phenomena are formidable and threatening. Considered as performance criteria for the construction of a computer-based design assistant, however, they may be highly evocative.*

*Keywords: designing, design knowledge, phenomenological equivalence, design phenomena, computer-based design assistants*

The paper begins with a set of propositions.

Design research, in its artificial-intelligence (AI) version, is an attempt to capture design knowledge by embodying it in procedures that are expressible in a computer program.

Design knowledge is knowing in action, revealed in and by actual designing. It is mainly tacit, in several senses of the word: designers know more than they can say, they tend to give inaccurate descriptions of what they know, and they can best (or only) gain access to their knowledge in action by putting themselves into the mode of doing, as, to take an example of another, perhaps more familiar, kind of skill, a touch typist, who cannot say offhand just where all the letters are on the keyboard, can begin to type, even on an imaginary keyboard, and thereby find the T just underneath the second finger of the left hand, the L just underneath the fourth finger of the right hand, and so on.

Symbolic, procedural representations of tacit design knowledge are bound to be incomplete or inadequate in relation to the actual phenomena of designing, as the paper will try to show. However, whether this matters depends on the purpose of the exercise, i.e. whether one seeks

- to achieve a design output, given some input, as well as, or better than, designers ordinarily do it, but without particular reference to the *ways* in which they do it; this is the Turing test, more or less, and it will be called 'functional equivalence',
- to reproduce *how* people actually go about designing; this will be called 'phenomenological equivalence',
- to assist designers in their designing,
- to provide an environment for research aimed at understanding how designers design.

The most ambitious purpose would be to build an AI-design version of David Marr's computational theory of vision[1]. For Marr, an information-processing approach to vision meant defining the information-processing tasks carried out in vision, with 'explicit statements

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about what is being computed and why' being made (see Reference 1, p 19). His formulation of the goal of the visual computation was basically that of getting from images on the retina to useful descriptions of the shapes and organization of objects in space. This, he thought, required the specification of a sequence of representations that corresponded to the sequence that he attributed to human vision, 'starting with descriptions that could be obtained straight from an image but that are carefully designed to facilitate the subsequent recovery of gradually more objective, physical properties about the object's shape' (see Reference 1, p 36). In short, the challenge that Marr set was that of first defining the *function* of seeing, and then specifying *how* people see. The purpose of his computational theory of vision combined functional and phenomenological equivalence.

The design phenomena described in this paper can be considered as being preliminary to the specification of the kinds of information-processing task that are carried out in designing, as Marr specified them for vision. Designers, it will be argued, are in *transaction* with a design situation*; they respond to the demands and possibilities of a design situation, which, in turn, they help to create. The author's phrase 'reflective conversation with the situation' refers to a particularly important kind of design transaction, with several family-resembling meanings that will be illustrated below.

The following are some of the main points that will be discussed:

- The design situation is a material one that is apprehended, in part, through active, sensory appreciation. This is true both when the designer is on site, and when he or she operates in the virtual world of a sketchpad, scale model or computer screen.
- Through the active sensory appreciation of actual or virtual worlds (especially, in the examples in this paper, by drawing), the designer constructs and reconstructs the objects and relationships with which he/she deals, determining 'what is there' for the purposes of design, and thereby creating a 'design world' within which he/she functions†.
- A design world may be unique to a designer, or it may be shared with a larger design community; to what degree unique or shared is always an open question, to be explored anew in each instance of designing. Certainly, the more a design episode is innovative, i.e. the more it changes the world or the way that the world is perceived, the more it is likely, in the first instance, to be unique to the designer.
- Designing is primarily social (certainly in architecture, with which the paper is mainly concerned, although not only here). The agents of design are individuals who occupy institutional roles, in interaction with one another. Hence, designing is a communicative activity in which individuals are called upon to decipher one another's design worlds.

Students of designing can avoid dealing with design worlds and their construction only by assuming counter-

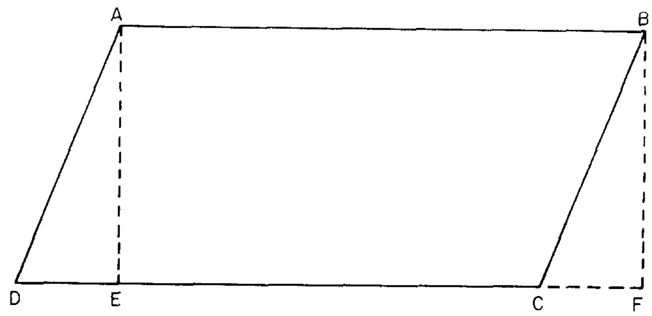


*Figure 1. Finding the area of a parallelogram*

factually that objects and relationships are given as 'inputs' with the first presentation of a design situation. This assumption reflects what the Marxists have called 'historical revisionism': reading back onto the beginning of a process what has emerged only at its end.

To see what historical revisionism means in the context of human thought and action, consider Max Wertheimer's well known discussion of the finding of the area of a parallelogram[4]. Imagine a student examining the figure of a parallelogram, and asking herself for the first time how to find its area (see Figure 1).

Some people who work on this problem come sooner or later to see that the figure can be altered to include two triangles (AED and BFC in Figure 1), the first being formed by dropping an altitude from point A, and the second being formed by dropping an altitude from point B, and extending the base DC to meet it. They see that the triangle AED can be carried over to fill the 'hole' created by triangle BFC, the parallelogram thereby being made into a rectangle, whose area can be found (if the student already knows about this) by the base being multiplied by the height. In other words, the initially strange problem of finding the area of a parallelogram can be converted to the familiar problem of finding the area of a rectangle, *if* the student is able, through her work on the problem, to see in the parallelogram the elements and relationships described above. However, this vision characteristically comes later on in the process, if it comes at all. Historical revisionism would here consist in reading back onto the beginning of this process what emerges only at its end.

Historical revisionism is, the author believes, widely practised by the proponents of artificial intelligence.

Now the design phenomena mentioned above will be illustrated and described. The illustrations are drawn from three kinds of study carried out by the author over the past ten years or so with colleagues at the Massachusetts Institute of Technology, USA, notably William Porter, John Habraken and Glenn Wiggins of the Department of Architecture, Jeanne Bamberger of the Music Section, Edith Ackermann of the Media and Technology Laboratory, and Larry Bucciarelli of the Science, Technology and Society Program. One kind of study consisted in observing and recording what studio masters and their students say and do together in architectural design studios, as they try to teach and learn architectural design, respectively. In a second kind of study, William Porter and the author administered a design exercise to a number of practising architects, and recorded their thinking out loud and their drawings as

*This term is used in John Dewey's sense[2].
†The terms 'design world' and 'worldmaking' are used in the spirit of Nelson Goodman's *Ways of Worldmaking*[3].

they worked on the exercise. A third kind of study made use of a variety of design games.

## SEEING–DRAWING–SEEING

A designer's knowing in action involves sensory, bodily knowing. The designer designs not only with the mind but with the body and senses, a fact that poses an interesting challenge to computers. As Herbert Simon once remarked, computers are sensorily deprived (although Simon has not drawn from this observation the same conclusions that the author has drawn).

A designer sees, moves and sees again*. Working in some visual medium (drawing, in the examples in this paper), the designer sees what is 'there' in some representation of a site, draws in relation to it, and sees what he/she has drawn, thereby informing further designing.

In all this 'seeing', the designer not only visually registers information, but also constructs its meaning; he/she identifies patterns, and gives them meanings beyond themselves. Words such as 'recognize', 'detect', 'discover' and 'appreciate' denote variants of seeing, as do such terms as 'seeing that', 'seeing as' and 'seeing in.' This process of seeing–drawing–seeing is one kind of example of what is meant by the phrase designing as a reflective conversation with the materials of a situation.

A very simple example, a microcosm, of this process will be considered. In fact, all of the examples in the paper are simple, for the very good reason that once one begins to study them, they are found to be enormously complex.

Imagine a first-year design studio in a department of architecture†. The studio project is the design of a school, for which the students have been given both a programme and a site. They have been working on this project for about a month when the studio master, Quist, sits down next to one of the students, Petra, to conduct a design review. Petra begins by describing how she has had 'trouble getting past the diagrammatic phase'. Then, in response to Quist's question 'what other big problems are there?', she sets out the following account of her process to date:

> I had six of these classroom units, but they were too small in scale to do much with. So I changed them to this more significant layout (the L shapes). It relates grade one to grade two, three to four, and five to six grades, which is more what I wanted to do educationally anyway. What I have here is a space which is more of a home base. I'll have an outside/inside which can be used and an outside/outside which can be used – then that opens into your resource library/language thing.

Let it be assumed for the moment that this snippet of drawing (see Figure 2) and description represents the *whole* of a design process. How shall it be described?

First, Petra describes a *move* that she has made. Beginning with the 'six classroom units' (she does not say how she got to them in the first place), she has found them 'too small in scale to do much with', and she has changed them into the L shapes — 'this more significant layout'.

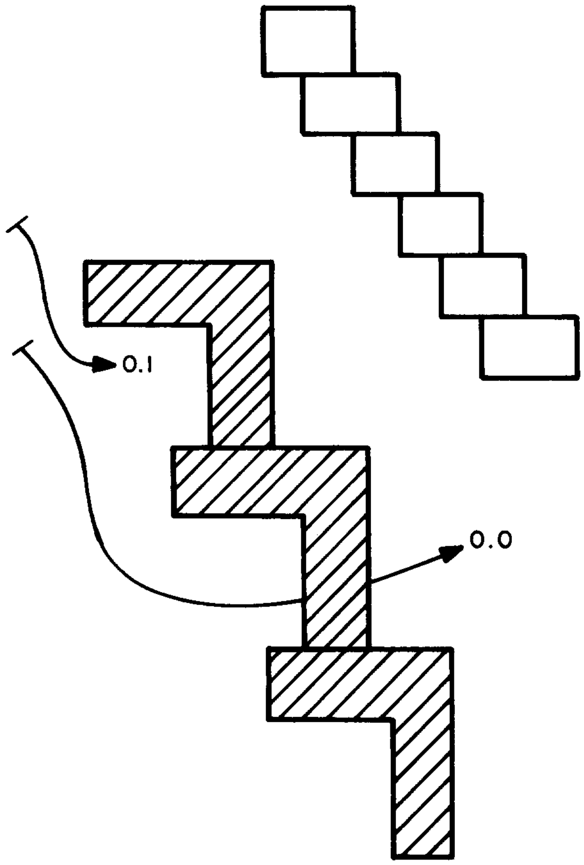


*Figure 2. Petra's drawing*

What is meant by a 'move' is just such a change in configuration as Petra now describes in words and has made earlier in her drawing. This move of hers can be seen in two ways: first, as an accomplished transformation, a shift from one drawn configuration to another, and second, as the act of drawing by which the transformation is made.

Petra's move begins with a particular way of seeing the first configuration: 'six of these classroom units'. Her way of seeing them involves a judgment of quality: she finds them 'too small in scale to do much with'. Hence, she changes them to the L shapes, which she sees as 'this more significant layout'.

With her first visual judgment, Petra has set a problem: 'too small in scale'. She makes her move in order to solve this problem, and, with her subsequent description, 'this more significant layout', she expresses a second judgment, namely that the problem she initially set has now been solved. Petra's judgments are acts of *seeing*. She sees that the six classroom units are too small in scale to do much with, and she sees that the three L shapes are more significant (clearly, she means to indicate that they are more significant in scale, whatever other significance they may also turn out to have). Her design snippet can be schematized as *seeing–moving–seeing*.

In this schema, two senses of the word 'see' are involved. In the first, Petra 'sees what is there'. She literally sees the classroom units that she has drawn (and she sees them as a coherent pattern — a point that will be returned to). The word 'see', in its second sense, conveys a judgment about the pattern 'seen' in the first sense. The two senses are merged in Petra's statement that 'they

*This section of the paper is drawn from **Schön, D and Wiggins, G** 'Kinds of seeing and their functions in designing' Massachusetts Institute of Technology, USA (1988) (mimeo).

†The data on which this case is based were collected by Roger Simmonds, during his time as a doctoral student at the Massachusetts Institute of Technology.

were too small in scale to do much with'. In a single act of seeing, she both visually apprehends the configuration and judges its scalar quality.

Petra's designing depends on her ability to make just such normative judgments of quality, and to see what is bad and needs fixing, or what is good and needs to be preserved or developed. In the absence of such qualitative judgments, her designing would have no thrust or direction; it would be entirely unmotivated. She would be able neither to set problems nor to tell when she had solved them.

Two features of such judgments should be noted. First, as Chris Alexander pointed out[5] long ago, one's ability to recognize qualities of a spatial configuration does not depend on one being able to give a symbolic description of the rules on the basis of which one recognizes them. For the purposes of designing, it is only necessary to recognize when something is mismatched to a given context, and when a move makes that something better or worse in relation to its context. In this instance, Petra does more. She not only recognizes a mismatch, but also names the quality in relation to which she recognizes it.

Second, Petra's judgment is *hers*. It is, to this extent, a subjective judgment. Other designers might not agree with her. For example, some of them might find her six classroom units quite significant enough. The point is not that Petra's judgment is wrong. A survey of expert designers might show that her judgment is entirely consistent with good design practice, or with certain principles governing the uses of scale in design. The point is, rather, that, as long as her judgments of significant scale are internally consistent, at least in this design episode, their 'subjectivity' is no obstacle to her designing. On the contrary, Petra's snippet of designing can be understood as a kind of *experiment*, a kind that will be called a 'move experiment', just *because* of her subjective judgments of scalar significance. Judging her first configuration as being 'too small in scale to do much with', she makes her move, changing the configuration to the L shapes, and finds the new layout 'much more significant'. Conceivably, she *might* have found that the change in configuration brought no improvement in significant scale. Having seen the problem and made her move, she might discover that she had *not* succeeded in solving the problem. She has to see the results of her move to discover that her experiment has 'worked', or that her move has been *affirmed* rather than *negated.* Her experimentation is an 'objective' process, in the sense that she can make mistakes and become aware of them. It is her ability to make subjective judgments of quality that renders this kind of objectivity possible.

Clearly, designing depends on such qualitative judgments. Geoffrey Vickers speaks of them as *appreciations*, and he refers in his writings[6] to the *appreciative systems* through which they are made. He posits, in effect, systems of beliefs, values, norms and/or prizings that are possessed by individuals and/or sometimes shared by groups or whole cultures, on the basis of which positive and negative judgments of phenomena are made. He is careful to point out, following Alexander, that appreciations are expressed in acts of judgment that can be made tacitly, without it necessarily being possible to state the criteria on the basis of which they have been made.

With Vickers's idea of appreciative systems being drawn upon, Petra's move experiment can be reformulated. It can be said that, on the basis of her initial appreciation of the six small classroom units, she formed the *intention* of changing them to a more significant layout. She then made her move, and discovered, through her appreciation of the new configuration, that she had *realized* her intention. To this extent, her move was affirmed. It is worth noting that her intention was not fully established at the beginning of her design process, but evolved through her appreciation of an intermediate design product. Her intention developed in 'conversation' with the process by which she transformed her design. An evolving intention is one of the *outputs* of her designing.

It would not be correct, however, to say that Petra's move experiment consists of nothing more than the formulation and realization of an intention. On the contrary, one of the most striking features of this snippet of designing is the role in it of the discovery of certain *unintended* consequences. Having begun with the intention to produce something of more significant scale, Petra finds that she has also done other things. She has spatially grouped proximate grades so that, for example, grades one and two are placed next to each other in the same L, which is separate from (but adjacent to) the L that contains grades three and four — something that she says that she 'wanted to do educationally anyway'.

She has created here a space, presumably the whole space made up of the three Ls, that is 'more of a home base'. Also, she has created two kinds of space (outside/inside and outside/outside) that she finds 'usable'.

These discovered consequences of her move were not part of her intention for it. Nevertheless, having drawn the L shapes, she sees that she has done these things. Also, it is clear, in context, that she finds qualities in them that she judges to be desirable. Indeed, she offers this additional description of the L-shaped layout as a further justification for her move.

A more complete account can now be spelled out of the conditions under which a move experiment such as Petra's is affirmed: the intended consequences of the move are achieved, and its unintended consequences are judged desirable. In colloquial terms, 'You get what you intend, and you like what you get'.

In this snippet of seeing–moving–seeing, then, Petra detects unintended, as well as intended, consequences of her move, and judges, or appreciates, their qualities. One might say that her appreciative system enables her to recognize unintended consequences and qualities of the change that she has made. One might also say that her ability to *recognize* features of the new configuration gives her access to parts of her appreciative system that might not otherwise come into play in this design episode.

Significantly, the qualities that Petra intended to produce with her move, and the qualities that she finds that she has unintentionally produced, are of very different kinds. 'Scale', or 'significant scale', is a quality of spatial configuration that belongs to a domain that might be labelled 'form'. It is a term that is peculiar to architecture as well as to other plastic arts, for example painting, sculpture and photography, and it is *compositional* in nature. Whether a given configuration is significant, or significant enough, depends, at least in part, on its relationships to other configurations around it in some context considered as a formal composition. One might say, for example, that a spatial element of a particular size and shape is too small in scale even though it exists in a purely abstract composition, with no reference to objects in the world outside it.

On the other hand, 'home base' seems to refer to a feelingful quality of places. To function as a home base, a space must serve as a spatial sort of place for those who use it, and they must experience it in a special way. 'Outside/inside' and 'outside/outside' refer to kinds of spaces that are defined by both their relationships to building shapes, and the kinds of uses that can be made of them. When Petra says that the L shapes 'relate grade one to grade two', and so on, she refers to functions of spaces that have particular meanings within the programme for a school.

Petra begins to work in one domain, the formal one. It is, however, in the other domain listed above that she discovers the unintended consequences and qualities of her move. One might ask why she does not include all of them in the formulation of her original intention, and why she does not work simultaneously in many domains? To this question, there are two answers, which are closely coupled.

First, at the point of conceiving and undertaking her move, Petra does not seem to have been *aware* of all the domains that would be affected by it. She begins with attention to 'significant scale', and needs to see what she has drawn to *discover* the other consequences and qualities that she later identifies as having been affected by her move.

Second, there is the question of *complexity*, a feature that is essential to designing. One is not designing when one merely places one book on top of another, for example, but one *is* designing when one arranges books on a shelf with an eye to such criteria as ease of access, the grouping of books by subject matter or author, and the juxtaposition of books by size or colour. When people design, they deal with many domains and many qualities within domains; their moves produce important consequences in more than one domain. In the extreme case, a move informed by an intention formulated within one domain has consequences in all other domains. Because of the limited information-processing capacity of humans, they cannot, in advance of making a particular move, consider all the consequences and qualities that they may eventually consider relevant to its evaluation.

If Petra had initially formulated her problem in terms of all the consequences and qualities in all of the domains that she eventually found worthy of mention, the problem-solving task confronting her would have seemed overwhelmingly complex. Working initially in one domain, however, she can allow considerations in other domains to enter into her work piecemeal, as she discovers the unintended consequences of her moves. The sequential, conversational structure of her *seeing–moving–seeing* enables her to manage complexity, and it harnesses the remarkable ability of humans to *recognize* more in the consequences of their moves than they have expected or described ahead of time.

## SEEING PATTERNS

In the example just described, there is a kind of seeing that is so fundamental that it can easily escape notice: the seeing of marks on a page as a spatial figure. For example, Petra's move experiment depends on her seeing the string of six small squares on the page, each of them touching and being set off from its neighbours, as a figure. (In fact, such a figure has been conjured up by the very words just used; it would be very difficult to describe these marks *without* conveying a reference to a figure.) Then, she sees the three L shapes as a figure, seeing them as Ls rather than as steps or as incomplete rectangles, for example. She sees them also as a coherent layout, which in turn enables her to see how the L-shaped array groups grades one and two, creates an inside/outside, and so on.

Each of these patternings, or *gestaltings*, of marks on a page entails the grouping of elements, the creation of boundaries between some kinds of element and others, the recognition of 'same' and 'different', and the appreciation of kinds of organization. These processes seem to be extremely, perhaps fundamentally, difficult to reproduce in a computer program, as anyone who has tried has discovered.

A further illustration of how designers appreciate figures in the marks on a page is provided by William Porter's design exercise, an exercise that he and the author administered to a group of practising architects. They showed the architects the 'footprint' of a branch library shown in Figure 3a, and gave them the following instructions:

> A library association of the Commonwealth of Massachusetts has this generic footprint that they use for branch libraries throughout the State, typically in suburban locations. All these are one-story buildings. The association hands the footprint to architects, and asks that the various libraries be designed to fit it. They use the 6 generic entrances marked 1 to 6 . . . They have had problems with entrances, and so they have come to you, as a consultant, to analyse their entrances for them and give a set of guidelines for the architects that will have to design these buildings. They want to know what each entrance implies as to siting of the building, the massing, the internal organization, and whatever else seems to you to be important . . . The dimensions of the footprint are 100 feet from K to B and 80 feet from B to G.

The first architect, called Harry, saw the figure in terms of 'end' entrances (entrances 1, 2, 4 and 5) and 'middle' entrances (entrances 3 and 6). He called the end entrances 'simple' and 'direct', pointing out that the placement of the entrances there meant the achievement of easy visibility from the street, tight control, and an easily understandable order of spaces behind the entrance. On the other hand, he called middle entrances 3 and 6 'complex' and 'poetic'. Harry was the one subject who took the idea of 'guidelines' seriously. He argued that most architects are not very good, and would be unable to handle anything other than the simple entrances; the poetic complexity of the middle entrances would be reserved for the very good architects. Harry achieved this very simple *gestalt* of the footprint, in which the end entrances and middle entrances were grouped and set off from each other, in the first few seconds of work on the problem. It was central to all of his subsequent reasoning.

A second architect, called Benny, saw the footprint differently. He saw it in terms of what he called 'peninsular places at the ends' surrounding a middle; later, he called it a 'middle with pods at the sides'. This formulation of it led him to focus on the problem of continuity between pods and middle, pointing out that 'the pods

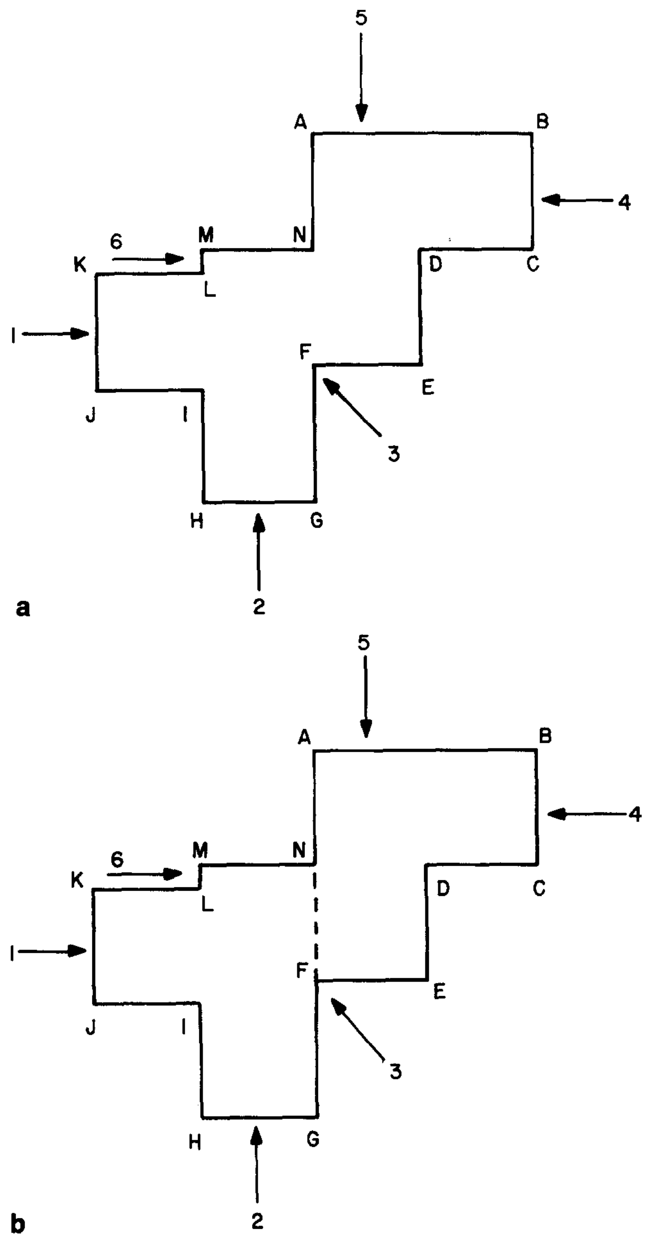


*Figure 3. Library; (a) library footprint, (b) two Ls back to back*

tend to break off and become discontinuous with that middle'. Later on, when he suggested how the desirable continuity between the pods and the middle could be achieved, he spoke of it as 'in fact the relationship that one would try to get between all three pods and the middle space'. This problem, again, was central to his reasoning.

At a certain point, however, he became aware of how he had been seeing the figure, saying 'I seem to be seeing it as three pods surrounding a middle'. It occurred to him then that the figure could be seen differently, for example as 'two Ls back to back' (see Figure 3b). When he saw it in this way, he set a new problem, saying 'one might think of the right-hand L as being one big use space, but, if so, one has to worry about the lack of any space to move in between the two of them'.

Thus, on the basis of the figure perceptually constructed from marks on a page, the designer sets and solves the problem that informs his/her further designing, illustrating again the process of seeing–moving–seeing.

A third architect, Clara, illustrates in her process something beyond this: a gradual process of discovery through which she gets what she calls 'a sense of the dimensions' of the space represented by the library footprint. What she learns through her initial move experiments informs not only her next move, but much of her subsequent designing, and it illustrates the way in which discovering and designing may be reciprocally interconnected.

Clara begins by considering entrance 3 in relation to the lengths of wall one would need to pass by to reach it. She says, early in her protocol,

> Again, I wouldn't come in in parallel to the EF direction because I think you've gone by too much of the building. In other words, the distance then is 50 feet that you have to walk by.
>
> You finally get to the entry and the building has slowly stepped toward you, and it's not enough — since it's equal steps, it really isn't much — you end up having to float a great deal before you can actually get to the library. [She sketches this approach (see Figure 4).]
>
> So that 3, if it runs parallel to G and F, seems to be more comfortable as a direction to move in, because I have that building edge adjacent to me.
>
> It's interesting that there's a 5 foot displacement in here. I'm beginning to get more of a sense of those dimensions.

Clara discovers this 'displacement' as she explores how a pedestrian might best approach entrance 3. As she draws, she feels that the approach along the axis BCDE is too long (50 feet), and, because of the way the building's walls are stepped along this axis, one ends up 'floating'. Here, she has set a problem, which she solves by opting for the 'more comfortable approach' along axis GF. However, as she draws her solution, she unexpectedly notices the 5 ft displacement. In fact, the GF segment is the only 30 ft length of the building, all the others being 25 ft or modules of 25 ft. As she approaches entrance 3 along GF, Clara 'looks opposite' to the 5 ft jog at entrance 6. She then becomes aware of the 'extra' 5 ft in the 30 ft length of GF and, corresponding to this, the 5 ft jog opposite at entrance 6. Later on, when she begins to consider entrance 6, her discovery of the 5 ft displacement reemerges, and becomes central to her rethinking of spaces for circulation and use.

In the process of exploring alternative approaches to entrance 3, Clara vicariously explores the edges and spaces of the building. Her ability to move through the spaces of a building by moving a pencil through the spaces of a drawing, or to travel vicariously through a remembered or projected place, is a critically important architectural skill, and a significant piece of what, as a student of architecture, she has learned to do. Thanks to her ability to see and travel in the drawing as though she were seeing and travelling in the building, her move experiment is also a voyage of discovery.

## DESIGN ONTOLOGY

In one sense, the 5 ft displacement that Clara noticed is there to be discovered. However, not everyone who tried the library exercise discovered it. Clara did. She noticed it, named it, and made of it a *thing* that became critically important to her further designing. In this sense, her treatment of the library exercise shows her not only

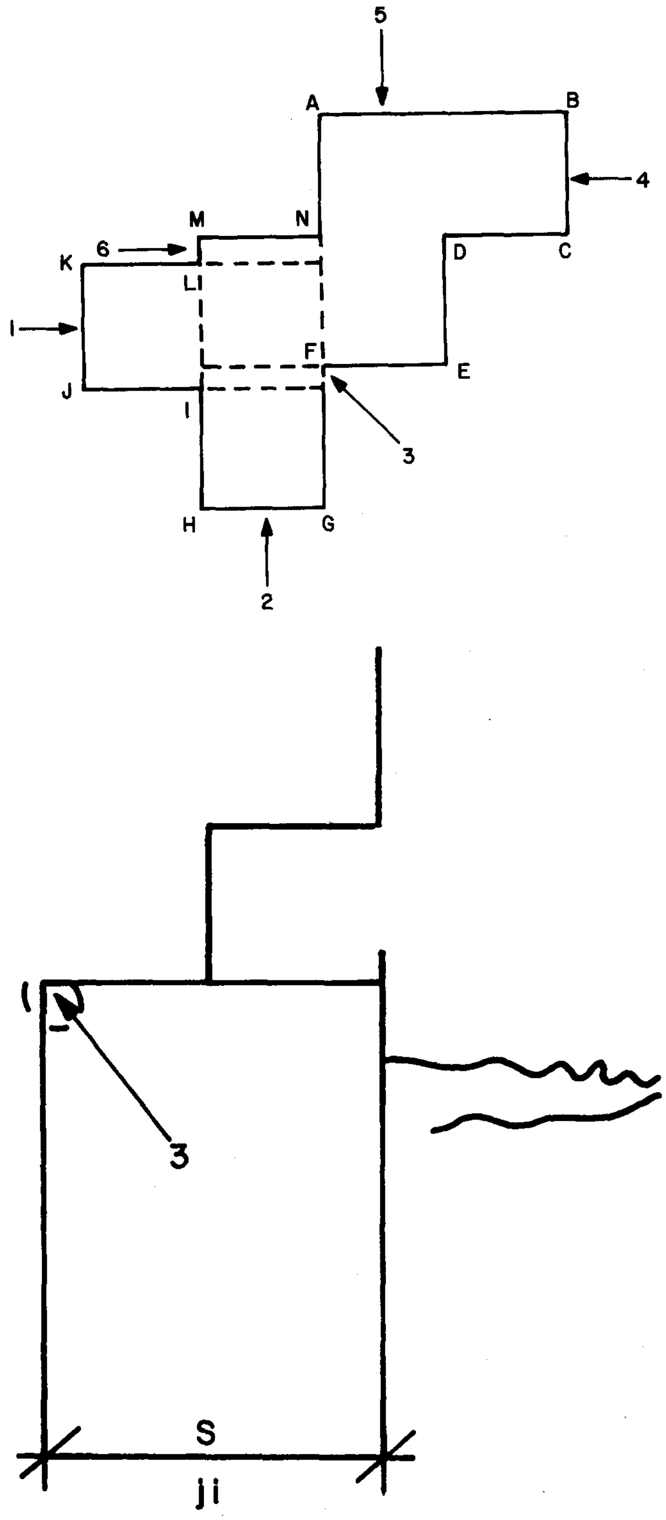

Figure 4. Clara's sketch

discovering but *constructing* the reality of a design situation. For designers share with all human beings an ability to construct, *via* perception, appreciation, language and active manipulation, the worlds in which they function. Designers are, in Nelson Goodman's term, worldmakers. Not only do they construct the meanings of their situations, materials and messages, but also the *ontologies* on which these meanings depend. Every procedure, and every problem formulation, depends on such an ontology: a construction of the totality of things and relationships that the designer takes as the reality of the world in which he or she designs.

Design worlds are constructed, as has been seen, in the course of a designer's seeing–moving–seeing. However, designers also construct their design worlds through their transactions with the site, the available materials, the design task, and the prototypes that they bring to the design situation. They do this through processes of appreciation, by which is meant both their active, sensory apprehension of the stuff in question, *and* their construction of an order in that stuff that includes the naming and framing of things, qualities and relationships.

Two further examples of designers' worldmaking will be discussed: one concerns materials, and the other concerns prototypes.

## MATERIALS

Designers deal, among other things, with material objects such as wooden trusses, steel girders and reinforced concrete beams. From one point of view, nothing could be more solidly real than things such as these; they are just what they are. On the other hand, given a stock of available materials, different designers often select different objects, and even appreciate the 'same' objects in different ways, in terms of different meanings, features, elements, relationships and groupings, all of which enter into characteristically different design worlds.

It is worth noting that the concept of the design world is closely related to that of style. It is a mistake to think about style as a relatively trivial addon to the substance of design knowledge. When, for example, the styles of Frank Lloyd Wright's Usonian houses, or Mies Van Der Rohe's office buildings, are considered characteristic elements are found to be used and combined according to characteristic relationships. David Billington has shown[7] how the design of bridges evolved in the 19th century as their designers came to see and exploit in new ways the potentials inherent in reinforced concrete. John Habraken has described[8] the styles of post-and-beam construction, Pompeian houses, and 17th-century Amsterdam town houses, in which, in each instance, a family of characteristic elements are combined according to characteristic relationships, yielding a variety of formal possibilities.

The example discussed is a design game that Jeanne Bamberger and the author had their students play in a course that they taught called Learning to Design and Design for Learning. In it, they gave the students three different construction systems: LEGO, Tinkertoys and Modula, a new system that had been designed for use by engineering undergraduates. Four of their students, Mimi, U-Chin, Rex and Bob, were asked to 'make something they liked' using each of the construction systems in turn. In a sense, then, these students had the same materials to work with. However, because each of them saw the materials in a different way, chose to use different items, singled out different features, and exploited different relationships between items and features, each student constructed a unique design world.

For example, the Modula set contained tubes. Mimi and Bob did not use them at all. U-Chin used them as

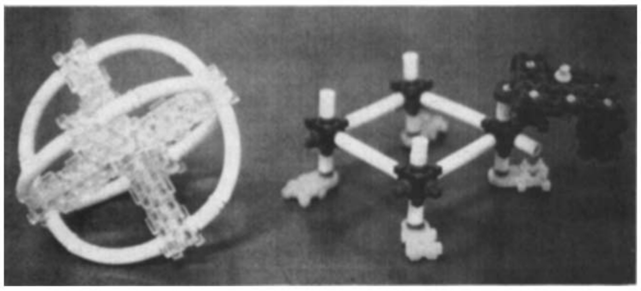

*Figure 5. Modula constructions of U-Chin and Rex*

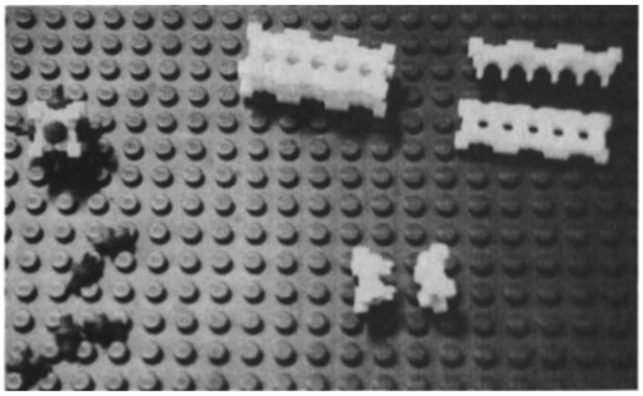

*Figure 6. Modula bricks*

though they were rigid beams (see Figure 5). Only Rex took advantage of their flexibility.

Each of the students put together different construction modules and connectors, out of which he or she made a larger building system. U-Chin found a blue cube and fitted it with club-shaped connectors, each of which were plugged into a hole on one surface of the cube. He said that this was 'neat', replicated it, and used it to make his structure. Rex also found the cube; however, he chose to make bricks out of the Modula pieces that were intended for that purpose, and assembled them, a brick being attached to each surface of the cube (see Figure 6).

Bob also made his own version of the brick-based modules, stringing them together with long rods (see Figure 7).

Choices of modules and connectors were associated with different interpretations of the design task. For example, Bob and Rex, both of whom made Modula bricks, had different ideas of what it meant to connect them together. Mimi used the Modula pieces more or less as they came, because, she said, 'I thought we were supposed to'. She built her structure piece by piece *in situ* (see Figure 8).

Bob and Rex used the hammer to make their bricks, but Mimi and U-Chin chose not to use it, Mimi because she said it seemed like 'cheating', U-Chin because he disliked the idea of making 'permanent connections', and both of them because they 'didn't like the noise'.

The choices of modules and connectors were also linked to prestructures, or prototypes, that the students brought to the task. Mimi, for example, had made her LEGO structure before her Modula one, and had placed her Modula structure on a LEGO base. She said 'I tried to make the Modula pieces into LEGO's'.

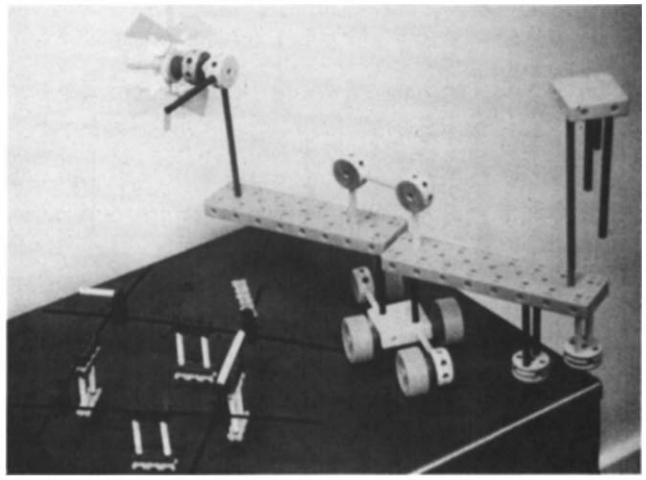

*Figure 7. Bob's constructions*

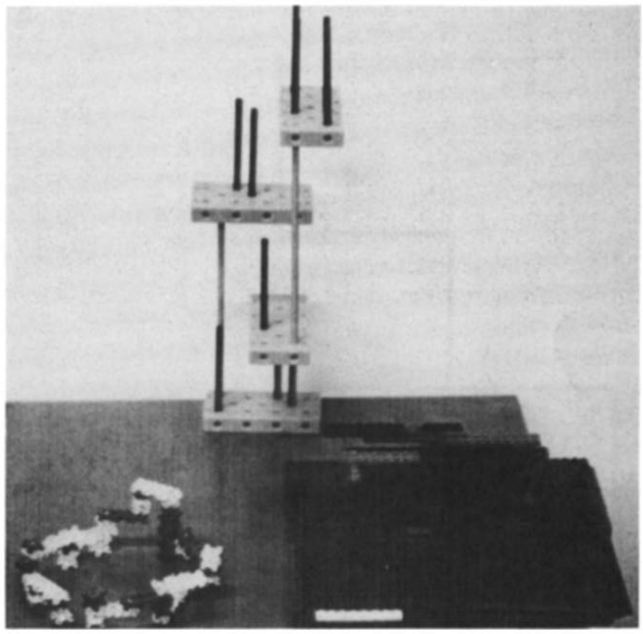

*Figure 8. Mimi's constructions*

The designers carried out a *double* design task. They constructed their own design worlds, as they played with and appreciated the materials in different ways, finding different things 'interesting', 'neat', 'noisy' or 'disagreeable', and selecting a few items, features and relationships from the daunting array of possibilities. *Within* their design worlds, they built particular structures.

From one point of view, the designers' selections were arbitrary, revealing (as in the case of the use or avoidance of the hammer) the influence of idiosyncratic tastes. From another point of view, however, the designers' selections were not arbitrary at all. First, selections were keyed to discoveries of particular features of the materials. Mimi found, for example, that, by joining individual Modula pieces with clublike connectors, she could make 'twisty joints', which she said she 'allowed herself to use' because 'that would be neat'. It is true that she just happened to like these joints, but she had to discover them to find that she liked them. In the second place, a certain pattern of appreciations tended to be consistently discernible across the structures made by any given designer; the author and his colleague found that, without knowing ahead of time who had made what, they could identify each designer's structures.

Finally, once the designers had evolved their building systems, they generated problems whose solutions could be evaluated objectively, independently of think so. (Similarly, in the earlier example, Petra's subjective appreciations of design qualities had provided an objective basis for the evaluation of the outcomes of her move experiments.) Rex, for example, once he had assembled his Modula bricks in a 3D cross around a single cube, wanted to interconnect the six ends of the cross. He discovered, however, that there were no rigid pieces of the right size. As he began to work in a problem-solving mode, he got the idea of using the tubes, which he saw as being flexible, to connect the ends of the cross, or perhaps he noticed the flexibility of the tubes as he searched for suitable connectors. When he tried out this idea, and found that the tubes were not of the right length, he invented a way of joining short and long tubes to make connectors of the right size.

In short, as the designers played with the materials, formed different appreciations of them, evolved their own design worlds, and began to build their structures, they furnished themselves with functional requirements whose fulfilment was not merely a matter of subjective judgment. Although it was a designer's appreciations that determined which pieces he/she wanted to connect, his/her ability to connect them depended, at least in part, on the behaviour of the pieces themselves. A designer's subjective (and, in this sense, arbitrary) appreciations shaped the problems that he/she tried to solve. Once problems were set, however, the designer could discover by move experiments whether or not he/she had solved them.

All of this should be contrasted with the familiar image of designing as 'search within a problem space'. To the extent that designing resembles the examples just described, it is clear that a 'problem space' is not given with the presentation of the design task; the designer *constructs* the design world within which he/she sets the dimensions of his/her problem space, and invents the moves by which he/she attempts to find solutions.

## PROTOTYPES

Designing can be understood as a dialogue of prototype and site. This was the view expressed in the early writings of William Hillier[9], and more recently by John Habraken[8], and more recently still by Alex Tsonis*. According to this view, designers have access to repertoires of prototypes that have been derived from their earlier experiences. Faced with a particular site and a design task, the designer selects one or more prototypes from his/her repertoire, seeing the site in terms of the prototype carried over to it, and seeing the prototype in the light of the constraints and possibilities discovered in the site. This reciprocal transformation of prototype and site suggests a further sense of what it means to say that designing is a reflective conversation with a design situation.

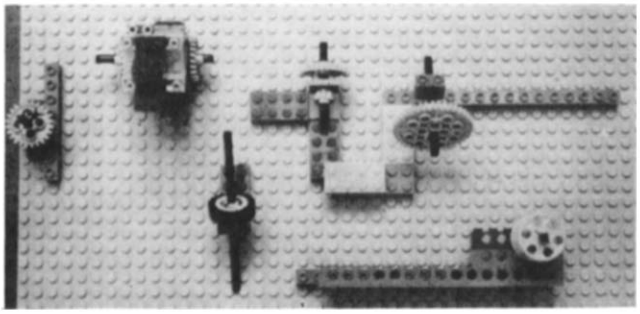

*Figure 9. What Fred built*

Rules, according to this view, are secondary phenomena that are derived from prototypes. The prototype is prior to the rule derived from it, just as legal precedents in appellate law are prior to the principles of judgment derived from them; as Geoffrey Vickers has observed[6], lawyers who seek to resolve their disagreements about the principles that should decide a case turn to precedent.

What is involved in grasping the rules inherent in a prototype? As a way of exploring this question, a variant of a design game developed by John Habraken and his colleagues, the Silent Game, is used†. This game calls for two builders A and B and an observer C. Out of a given set of materials, A is asked to make a construction that embodies a rule. It is left as open-ended what a rule is, that decision being left to the builders, whose structures are used as evidence for the interpretation of their understandings of rules. B is then asked to continue the construction according to the rule that he/she attributes to A. After B has done this, A is asked to determine whether he/she thinks that B has 'got' the rule. If A thinks B has, A is asked to continue building in such a way as to violate the rule; if A thinks B has not, A is asked to continue building in such a way as to reaffirm the rule. All of the parties are forbidden to speak while playing the game. Afterwards, they are asked to describe what they thought as they played.

In the game described here, LEGO pieces were the construction materials, and, as it happened, the players were made up of two kinds of people, architects and computer scientists. Only one play of the game is considered, in which A was Fred, a computer scientist, B was Turid, an architect, and the observer was Bonne, also an architect.

About the structure built by Fred (see Figure 9), Fred said

> I was playing with the constraints of LEGO, trying to get relationships that were not horizontal or vertical. I was trying to get these odd angles [diagonals] in . . . then there were things going up and sideways with angles and wheels.

Turid, describing what she had made of Fred's construction (see Figure 10), said that she had made structures

*In the course of a lecture given at the *International Conference on Design Research* Delft, Netherlands (Jun 1991).

†This variant of the Silent Game was developed with William Porter, Edith Ackermann and Bonne Smith in the course of the *Design Research Seminar* Massachusetts Institute of Technology, USA (Fall 1990).

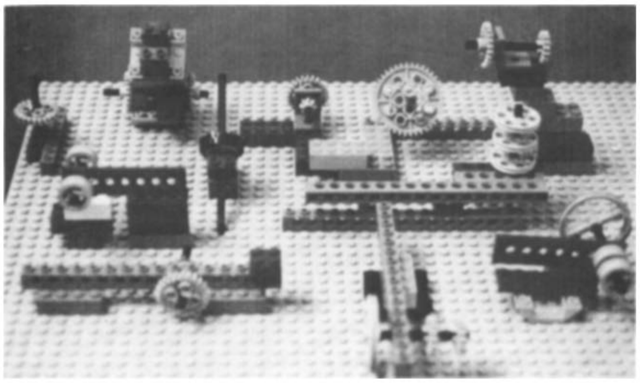

*Figure 10. What Turid built*

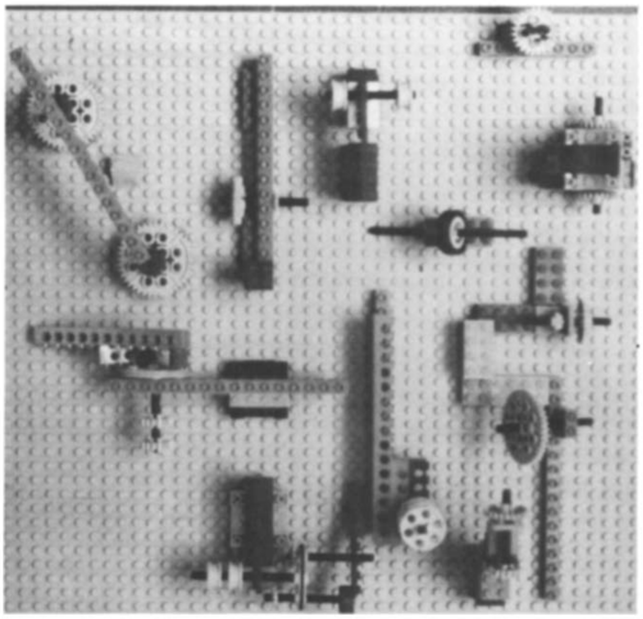

*Figure 11. Fred's changes*

and 'added on wheels', noting that 'the wheels turned and there was no building on them'.

Fred, in response, made the changes shown in Figure 11. He said

> I added things [pointing to the LEGO pieces that he had attached to her wheels, the free-standing yellow piece and the construction next to it] in order to make them have angles.

The players were surprised to discover how difficult it was for B to grasp the rule of construction intended by A, for A to infer then what B had 'gotten', and for B to read the meaning of A's responses. In short, the players were surprised to discover how difficult it was for a designer to read the (intended) meaning of a prototype, or to communicate reliably with other designers about the meaning of the prototype.

The sources of this difficulty lay in ambiguities, which were of several different kinds.

First, A and B were selectively attentive to different features of A's construction. Turid, for example, focused on 'wheels that turned and are not built on', whereas Fred focused on 'odd angles'.

Second, even when they focused on the same elements and relationships, the two builders often described them differently. What Fred called 'odd angles', for example, Turid called 'assymmetry, things out of balance'.

It was clear that a given construction could be interpreted in terms of more than one rule. Indeed, any given construction seemed to be interpretable, in principle, in terms of a noninnumerable set of possible rules.

Third, the builder sometimes discovered that he had embodied more in his construction than he had consciously intended. Thus, for example, when it was pointed out to Fred that he had built all his constructions with pieces of different colours, he said 'this was not a conscious rule, but I noticed that I couldn't have built anything with all one colour'.

Finally, the builders sometimes held different conceptions of a satisfactory rule. This point emerged with particular clarity when the builders represented the two fields of architecture and computer science. For example, Fred chose to build structures with 'odd angles' because, he said, he wanted to 'violate the constraints built into LEGO'; he was thinking in terms of constraints and their violation. Turid, however, saw the 'same thing' in terms of 'assymmetry, things out of balance', thinking not in terms of constraints, but formal qualities. In another play of the game, an architect, playing B, discovering that he had misconstrued the rule intended by A, a computer scientist, cried out that, although the rule intended by A had, indeed, occurred to him, he had rejected it out of hand because it seemed to him to be totally absurd.

The Silent Game can be used not only to illustrate the divergent interpretation of prototypes, but also to illuminate communication between the participants in a social design process. As the builders in the game tried to clear up ambiguities of the kinds described above, through their silent moves and their later verbal descriptions, they made a discovery that seemed profoundly shocking: what they had, at first, taken simply as the reality of the object turned out to be only one among several possible *views* of that object.

In Fred's second turn, for example, when he saw that Turid had not reproduced his 'odd angles', he attached LEGO pieces to her wheels. He explained that he wanted to 'make them have angles'. This astonished Turid and Bonne. They had read Fred's initial structures meaning that 'wheels must always be free-wheeling and you can never build on them', as Bonne said, and now the first thing that Fred did was 'to build on Turid's wheels to keep them from moving'. When this was pointed out to Fred, he said 'I didn't realize it!'. The women in the room then exclaimed 'he blocked her wheels!'.

Participants in the game not infrequently became attached to a particular reading of the prototype, and treated an alternative reading as a *threat*, which provoked an angry and defensive reaction. This was sometimes defused by humour, as shown above. However, in another case, it was not. In this case, A produced a layered structure that he later described as follows: 'the bottom layer consists of evenly spaced pieces, the second layer, unevenly spaced . . .'. B interpreted this structure as 'an alternation of single- and double-pegged connectors, vertically arrayed'. The observer interpreted A's structure as an alternation of coloured layers: the first layer was blue, the second red, and the third blue again.

When A took his second turn, he made use of a yellow piece. The observer asked why. A replied 'because it was the only piece of that kind that I could find', whereupon the observer blurted out 'I find that absolutely unacceptable!'.

From the playing of the Silent Game, the author drew several lessons about designers' appreciation of prototypes. First, prototypes are inherently ambiguous, and are subject to multiple readings, each of which involves the construction of a different design world. Second, moves that are designed to clear up ambiguities that result from differences in appreciation tend to be ambiguous in their own right. Third, the achievement of a convergent, collective reading of prototypes depends on reciprocal reflection among designers, reflection on objects, moves and descriptions, which may be subverted by the participants' attachment to particular readings, and their defensive reactions when their readings are called into question.

## CONCLUSIONS

What do these design phenomena signify for the application of artificial intelligence in design? The answer, as mentioned at the outset, depends on what one takes to be the purpose of the exercise.

*What is it that a computer would have to do to achieve what has been called phenomenological equivalence?*

The examples suggest that, in the most general terms, the computer would need to simulate the designer's transactions with the design situation — transactions that begin prior to the presentation of what are normally defined as 'design inputs', and that centrally involve the construction of design worlds. More specifically, the computer would need to be able to reproduce

- the designer's seeing–moving–seeing,
- the construction of figures from marks on a page,
- the appreciation of design qualities, which means that the computer must be programmed to contain an appreciative system that is comparable to a designer's appreciative system,
- the evolution of design intentions in the course of the design process, new design problems being set for solution,
- the recognition of unintended consequences of move experiments,
- the storage and deployment of prototypes, with them being placed in transaction with the design situation,
- communication across divergent design worlds.

*What would it mean for a computer-based design program to bypass phenomenological equivalence to achieve functional equivalence, producing outputs that were comparable to those produced by human designers, given the presentation of comparable inputs?*

Basically, this would entail bypassing certain troublesome transformations (from design situation to constructed design world, from measurable properties to design qualities, and from design qualities to the properties on which they are based), deriving from prototypes the rules embedded in them, and tracing rules to the prototypes from which they were derived.

The author does not see how these transformations can be bypassed unless the computer-based design programme operates within a single, prestructured and constant design world, or perhaps a system of internally crossmappable design worlds. It might be asked, however, what relationships such a design world would have to the design situations encountered by human beings?

This matter might be thought about in two possible ways. First, the computer program might be thought to embody the invention of a fundamental design world, a set of fundamental elements and relationships, from which all other possible design worlds could be constructed through processes that were internal to the program. It might then be asked how. A possible answer is that such a computer program would relate to a highly restricted situation, a narrowly defined chunk of a design process, where the design world used by designers could feasibly be assumed to be given and fixed. On the other hand, one might think of the users of the design program as being subject to social controls that compelled them to accommodate to the computer's design world. One might then ask with what relationship to their own appreciations and their own design worlds?

*What do these design phenomena signify for a computer-based design assistant?*

This question opens up a vast field of possibilities. Among the possible purposes for AI in design, a design assistant seems to be by far the most promising.

Some examples of what such a computer-based design assistant might do are as follows:

- produce computer environments that enhanced the designer's seeing–drawing–seeing,
- create microworlds that could be programmed to function as design worlds, extending the designer's ability to construct and explore them,
- provide a system that extended the designer's repertoire of prototypes, and enhanced his/her ability to explore them and bring them into transaction with particular design situations,
- create an environment that helped the designer to discover and reflect upon his/her own design knowledge.

The design of design assistants is an approach that has not in the past attracted the best minds in AI. Perhaps the time has come when it can and should do so.

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