DESIGNING AS REFLECTIVE CONVERSATION WITH THE MATERIALS OF A DESIGN SITUATION

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Introduction

I shall begin with a set of propositions.

Design research, in its AI version, is an attempt to capture design knowledge by embodying it in procedures expressable 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, tend to give inaccurate descriptions of what they know, and can best (or only) gain access to their knowing-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 located 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 I shall try to show. But whether this matters depends on the purpose of the exercise -- whether, that is, we seek,

(1) 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 I shall call it "functional equivalence."

(2) To reproduce how we actually go about designing; this I shall call "phenomenological equivalence."

(3) To assist designers in their designing.

(4) 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 (Marr, 1982). For Marr, an information processing approach to vision meant defining the information processing tasks carried out in vision, making "explicit statements about what is being computed and why." (Marr, p.19) His formulation of the goal of the visual computation was basically to get from images on the retina to useful descriptions of the shapes and organization of objects in space. This, he thought, required specifying a sequence of representations corresponding to the sequence 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." (Marr, p.36) In short, the challenge Marr set was first to define the function of seeing and then to specify how we see. The purpose of his computational theory of vision combined functional and phenomenological equivalence.

The design phenomena I shall describe in this talk can be considered as preliminary to specifying the kinds of information processing tasks carried out in designing, as Marr specified them for vision. Designers, I shall argue, are in transaction with a design situation;[1] they respond to the demands and possibilities of a design situation, which, in turn, they help to create. My phrase, "reflective conversation with the situation," refers to a particularly important kind of design transaction, with several family-resembling meanings that I shall illustrate below.

These are some of the the main points I shall go on to discuss:

o The design situation is a material one, 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.

o Through active sensory appreciation of actual or virtual worlds (especially, in my examples, by drawing), the designer constructs and reconstructs the objects and relations with which he deals, determining "what is there" for purposes of design, thereby creating a "design world" within which he functions.[2]

o A design world may be unique to a designer or may be shared with a larger design community -- to what degree unique or shared being always an open question, to be explored anew in each instance of designing. Certainly, the more a design episode is innovative -- the more it changes the world or the way we perceive the world -- the more it is likely, in the first instance, to be

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[1] I use this term in John Dewey's sense (Dewey and Bentley, 1949).

[2] I use the terms "design world" and "worldmaking" in the spirit of Nelson Goodman's Ways of Worldmaking (Goodman, 1978).

unique to the designer.

o Designing is primarily social (certainly in architecture, with which I shall be mainly concerned, though 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 counterfactually that objects and relations 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.

In order to see what historical revisionism means in the context of human thought and action, consider Max Wertheimer's well-known discussion of finding the area of a parallelogram (Wertheimer, 1945). Imagine a student examining the figure of a parallelogram, asking herself for the first time how to find its area.

Figure 1. Finding the Area of a Parallelogram

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 formed by dropping an altitude from point A, the second 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, thereby making the parallelogram into a rectangle whose area can be found (if the student already knows about this) by multiplying base times 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 I have just described. But 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, I believe, widely practiced by the proponents of artificial intelligence.

Now I shall go on to illustrate and describe the design phenomena to which I have just alluded. My illustrations will be drawn from three kinds of studies I have carried out over the past ten years or so, together with colleagues at M.I.T. -- 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 consists of 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. In a second kind of study, William Porter and I have administered a design exercise to a number of practicing architects, recording their thinking-out-loud and their drawings as they work on the exercise. A third kind of study has 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 I have drawn).

A designer sees, moves and sees again.[3] Working in some visual medium -- drawing, in my examples -- the designer sees what is "there" in some representation of a site, draws in relation to it, and sees what he has drawn, thereby informing further designing.

In all this "seeing", the designer not only visually registers information but also constructs its meaning -- identifies patterns and gives them meanings beyond themselves. Words like 'recognize', 'detect', 'discover', and 'appreciate'

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[3] This section is drawn from "Kinds of Seeing and Their Functions in Designing," by the author and Glenn Wiggins, MIT, mimeo, 1988.

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 I mean by designing as a reflective conversation with the materials of a situation.

I want to take a look at a very simple example, a microcosm, of this process. In fact, all of my examples are simple, for the very good reason that once I begin to study them I find them enormously complex.

Imagine a first-year design studio in a department of architecture.[4] The studio project is the design of a school, for which the students have been given both a program 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?", 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.

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[4] The data on which this case is based were collected by Roger Simmonds during his time as a doctoral student at MIT.

Figure 2. Petra's Drawing

Let us assume for the moment that this snippet of drawing and description represents the whole of a design process. How shall we describe it?

First of all, Petra describes a move she has made. Beginning with the "six classroom units" (she does not tell us 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." What we mean 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 <u>seeing</u>. She sees that the six classroom units are too small in scale to do much with, and 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 <u>seeing-moving-seeing</u>.

In this schema, two senses of the word 'see' are involved. In the first, Petra "sees what's there." She literally sees the classroom units she has drawn (and sees them as a coherent pattern -- a point to which I shall return). 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, "They 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, to see what's bad and needs fixing, or what's 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 long ago (Alexander, 1968), our ability to recognize qualities of a spatial configuration does not depend on our being able to give a symbolic description of the rules on the basis of which we recognize them. For purposes of designing, we need only 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 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 may 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 I shall call a "move experiment" -- just because of her subjective judgments of scalar significance. Judging her first configuration as "too small in scale to do much with," she makes her move -- changing it 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 in order to discover that her experiment has "worked" or, as I shall say, 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. And 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 refers in his writings to the appreciative systems through which they are made (Vickers, 1978). He posits, in effect, systems of beliefs, values, norms, prizings, possessed by individuals, sometimes shared by groups or by whole cultures, on the basis of which we make our positive and negative judgments of phenomena. He is careful to point out, following Alexander, that appreciations are expressed in acts of judgment that we are able to make tacitly, without necessarily being able to state the criteria on the basis of which we make them.

Drawing on Vickers's idea of appreciative systems, we can reformulate Petra's move experiment. We can say 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 has 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. Beginning 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", separate from (but adjacent to) the "L" that containes grades three and four -- something she says she "wanted to do educationally anyway."

She has created here a space -- presumably the whole space made up of the three L's -- which is "more of a home base." And she has created two kinds of spaces (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. And 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.

We can now spell out a more complete account of the conditions under which a move experiment like 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 she has made. One might also say that her ability to <u>recognize</u> 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 Petra intended to produce with her move and the qualities she finds she has unintendedly produced, are of very different kinds. "Scale" or "significant scale" is a quality of spatial configurations that belongs to a domain that might be labelled "form." It is a term peculiar to architecture as well as to other plastic arts -- painting, sculpture, photography, for example -- and it is <u>compositional</u> in nature. Whether or not a given configuration is significant, or significant enough, depends, at least in part, on its relations 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. In order to function as a home base, a space must serve as a special 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 defined both by their relationships to building shapes and by the kinds of uses that can be made of them. And 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 program for a school.

Petra begins to work in one domain, the formal one. It is, however, in the other domains 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, why she does not work simultaneously in many domains? To this question there are two answers, closely coupled.

First of all, 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 in order to discover the other consequences and qualities she later identifies as affected by her move.

Second, there is the question of complexity, a feature essential to designing. We are not designing when we merely place one book on top of another, for example, but we are designing when we arrange books on a shelf with an eye to such criteria as ease of access, grouping of books by subjectmatter or author, and juxtaposition of books by size or color. When we design, we deal with many domains and many qualities within domains; our 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 our limited information processing capacity, we cannot, in advance of making a particular move, consider all the consequences and qualities we 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 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, harnessing the remarkable human ability to recognize more in the consequences of our moves than we have anticipated or described ahead of time.

Seeing patterns

In the example I have just described, there is a kind of seeing so fundamental that it can easily escape notice: seeing marks on a page as a spatial figure. For example, Petra's move experiment depends on her seeing the string of 6 small squares on the page, each touching and set off from its neighbors, as a figure. (In fact, I have conjured up such a figure in the very words I have just used; it would be very difficult to describe these marks <u>without</u> conveying a reference to a figure.) Then she sees the three L-shapes as a figure, seeing them as L's rather than as steps or as incomplete rectangles, for example -- seing 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 <u>gestalt</u>ings, of marks on a page involves grouping elements, creating boundaries between some kinds of elements and others, recognizing same and different, and appreciating kinds of organization. These processes seem to be extremely -- perhaps fundamentally -- difficult to reproduce in a computer program, as anyone who has tried to do so 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 I administered to a group of practicing architects. We showed the architects this "footprint" of a branch library,

<u>Figure 3. The Library Footprint</u>

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, whom I'll call Harry, saw the figure in terms of "end" entrances (1, 2, 4 and 5) and "middle" entrances (3 and 6). The end entrances he called "simple" and "direct", pointing out that placing the entrance there meant achieving easy visibility from the street, tight control, and an easily understandable order of spaces behind the entrance. On the other hand, the middle entrances, 3 and 6, he called "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. This very simple <u>gestalt</u> of the footprint, in which end entrances and middle entrances were grouped and set off from each other, Harry achieved in the first few seconds of work on the problem. It was central to all his subsequent reasoning.

A second architect, whom I shall call 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." And this formulation of it led him to focus on the problem of continuity between pods and middle, pointing out that "the pods tend to break off and become discontinuous with that middle." And later on, when he suggested how the desirable continuity between pods and 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 L's back to back."

Figure 3.1 Two L's Back to Back

And when he saw it 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 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 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 in order 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.]

<u>Figure 4. Clara's Sketch</u>

> 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.

This "displacement" Clara discovers 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. But as she draws her solution, she unexpectedly notices the 5 foot displacement. In fact, the GF segment is the only 30 foot length of the building, all the others being 25 feet or modules of 25. As she approaches entrance 3 along GF, Clara "looks opposite" to the 5 foot jog at entrance 6. She then becomes aware of the "extra" 5 feet in the 30 foot length of GF and, corresponding to this, the 5 foot jog opposite at entrance 6. Later on, when she begins to consider entrance 6, her discovery of the 5 foot displacement re-emerges and becomes central to her rethinking of spaces for circulation and use.

In the process of exploring alternate 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 foot 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 <u>thing</u> that became critically important to her further designing. In this sense, her treatment of the library exercise shows her not only discovering but <u>constructing</u> the reality of a design situation. For designers share with all human beings an ability to construct -- <u>via</u> perception, appreciation, language and active manipulation -- the worlds in which they function. Designers are, in Nelson Goodman's phrase, worldmakers. Not only do they construct the meanings of their situations, materials and messages, but also the <u>ontologies</u> on which these meanings depend. Every procedure, every problem formulation, depends on such an ontology: a construction of the totality of things and relations that the designer takes as the reality of the world in which he or she designs.

Design worlds are constructed, as we have seen, in the course of a designer's seeing-moving-seeing. But designers also construct their design worlds through their transactions with the site, the available materials, the design task, and the prototypes they bring to the design situation. They do this through processes of appreciation, by which I mean both their active, sensory apprehension of the stuff in question <u>and</u> their construction of an order in that stuff which includes the naming and framing of things, qualities and relations.

I shall take up two further examples of designers' worldmaking: one, concerning materials; the other, 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 like 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, relations, and groupings, all of which enter into characteristically different design worlds.

It is worth noting that the concept of design world is closely related to that of style. It is a mistake to think about style as a relatively trivial add-on to the substance of design knowledge. When we consider, for example, the style of Frank Lloyd Wright's Usonian houses, or Mies Van Der Rohe's office buildings, we find characteristic elements used and combined according to characteristic relationships. David Billington has shown 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 (Billington, 1983). John Habraken has described the styles of post-and-beam construction, Pompeian houses, and 17th century Amsterdam town houses, where in each instance a family of characteristic elements are combined according to characteristic relationships, yielding a variety of formal possibilities (Habraken, 19B6).

The example I shall discuss here is a design game that Jeanne

Bamberger and I had our students play in a course we taught called "Learning to Design and Design for Learning." In it, we 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 our 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. But because each of them saw the materials in a different way, chose to use different items, singled out different features, and exploited different relationships among 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 though they were rigid beams. Only Rex took advantage of their flexibility.

<u>Figure 5. U-Chin's and Rex's Modula Constructions</u>

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 plugged into a hole on one surface of the cube. He said 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 attached to each surface of the cube.

Figure 6. Modula Bricks

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

Figure 7. Bob's Constructions

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.

Figure 8. Mimi's Constructions

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."

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", selecting a few items, features and relationships from the daunting array of possibilities. And 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 of all, selections were keyed to discoveries of particular features of the materials. Mimi found, for example, that by joining individual Modula pieces with club-like 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 in order to find that she liked them. In the second place, a certain pattern of appreciations tended to be consistently discernable across the structures made by any given designer: we found that, without knowing ahead of time who had made what, we could identify each designer's structures.

Finally, once the designers had evolved their building systems, they generated problems whose solutions could be evaluated objectively, independent of think-so. (Similarly, in our earlier example, Petra's subjective appreciations of design qualities had provided an objective basis for evaluating the outcomes of her move experiments.) Rex, for example, once he had assembled his Modula bricks in a 3-dimensional cross around a single cube, wanted to interconnect the 6 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 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 in order 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 reguirements whose fulfillment was not merely a matter of subjective judgment. Although it was a designer's appreciations that determined which pieces he wanted to connect, his ability to connect them depended, at least in part, on the behavior of the pieces themselves. A designer's subjective (and, in this sense, arbitrary) appreciations shaped the problems he tried to solve. Once problems were set, however, the designer could discover by move experiments whether or not he 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 I have just described, it is clear that a "problem space" is not given with the presentation of design task: the designer <u>constructs</u> the design world within which he sets the dimensions of his problem space and invents the moves by which he 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 (Hillier and Leaman, 1973), more recently by John Habraken (Habraken, 1986), and more recently still by Alex Tsonis.[5] According to this view, designers have access to repertoires of prototypes, derived from their earlier experiences. Faced with a particular site and a design task, the designer selects one or more prototypes from his repertoire, seeing the site in terms of the prototype carried over to it, seeing the prototype in tbe 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

[5] In the course of a lecture given at the International Conference on Design Research, Delft, The Netherlands, in June, 1991.

reflective conversation with a design situation.

Rules, according to this view, are secondary phenomena derived from prototypes. The prototype is prior to the rule derived from it, just as legal precedents in appelate law are prior to the principles of judgment derived from them; as Geoffrey Vickers has observed (Vickers, 1978), 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, I have used a variant of a design game developed by John Habraken and his colleagues, the Silent Game.[6] 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 open-ended what a rule is, that decision being left to the builders, whose structures are used as evidence for interpreting their understandings of rules. B is then asked to continue the construction according to the rule he attributes to A. After B has done this, A is asked to determine whether he thinks B has "got" the rule. If so, A is asked to continue building in such a way as to violate the rule; if not, he is asked to continue building in such a way as to reaffirm the rule. While playing the game, all of the parties are forbidden to speak. Afterwards, they are asked to describe what they thought as they played.

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[6] This variant of the Silent Game was developed together with William Porter, Edith Ackermann and Bonne Smith, in the course of our Design Research Seminar, Fall, 1990.

In the game I shall describe 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. I shall consider only one play of the game, in which A was Fred, a computer scientist; B was Turid, an architect; and the observer was Bonne, also an architect.

Figure 9. What Fred Built

About this structure, 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, said that she made structures and "added on wheels," noting that "the wheels turned and there was no building on them."

Figure 10. What Turid Built

Fred, in response, made the following changes:

Figure 11. Fred's Changes

He said, "I added things [pointing to the LEGO pieces 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, focussed on "wheels that turned and are not built on," whereas Fred focussed on "odd angles."

Secondly, even when they focussed on the same elements and relations, 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 non-innumerable set of possible rules.

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

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, as 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 among 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 his second turn, for example, when Fred 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 as "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 humor, as above. But in another case it was not. Here 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 colored 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, I draw several lessons about designers' appreciation of prototypes. First of all, prototypes are inherently ambiguous, subject to multiple readings, each of which involves the construction of a different design world. Secondly, moves designed to clear up ambiguities resulting from differences in appreciation tend to be ambiguous in their own right. Thirdly, the achievement of a covergent, 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.

Conclusion

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

1. *What is it that a computer would have to do in order to achieve what I have called phenomenological equivalence?*

I think our 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 centrally involve the construction of design worlds. More specifically, the computer would need to be able to reproduce:

o the designers seeing-moving-seeing,

o the construction of figures from marks on a page,

o the appreciation of design qualities, which means that the computer must be programmed to contain an appreciative system comparable to a designer's appreciative system, o evolution of design intentions in the course of the design process, setting new design problems for solution,

o recognizing unintended consequences of move-experiments,

o storing and deploying prototypes, placing them in transaction with the design situation,

o communicating across divergent design worlds.

2. What would it mean for a computer-based design program to by-pass phenomenological equivalence in order to achieve functional equivalence -- producing outputs comparable to the those produced by human designers, given the presentation of comparable inputs?

Basically, this would mean by-passing 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, tracing rules to the prototypes from which they are derived.

I do not see how these transformations can be by-passed unless the computer-based design program operates within a single, prestructured and constant design world -- or perhaps a system of internally cross-mappable design worlds. We might ask, however, what relations such a design world would have to the design situations encountered by human beings?

We might think of this matter in two possible ways. First of all, the computer program might be thought to embody the invention of a fundamental design world -- a set of fundamental elements and relations -- from which all other, possible design worlds could be constructed through processes internal to the program. We might then ask, 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 employed by designers can feasibly be assumed as given and fixed. On the other hand, we might think of the users of the design program as being subject to social controls that compel them to accommodate to the computer's design world. We might then ask, With what relationship to their own appreciations and their own design worlds?

3. <u>What do these design phenomena signify for a computer-based design assistant</u>?

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

These are some examples of what such a computer-based design assistant might do:

o produce computer environments that enhance the designer's seeing-drawing-seeing,

o create microworlds that can be programmed to function as design worlds, extending the designer's ability to construct and explore them,

o provide a system that extends the designer's repertoire of prototypes, enhances his ability to explore them and bring them into transaction with particular design situations,

o create an environment that helps the designer to discover and reflect upon his 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.

REFERENCES

Alexander, Christopher, *Notes Toward a Synthesis of Form*, Harvard University Press, Cambridge, 1968.

8illington, David, *The Tower and The Bridge*, 8asic 8ooks, Inc., New York, 1983.

Dewey, John and Bentley, Arthur F., *Knowing and the Known*, The 8eacon Press, 8oston, 1949.

Goodman, Nelson, *Ways of Worldmaking*, Hackett and Company, Indianapolis, 1978.

Habraken, John, *The Appearance of the Form*, Atwater Press, Cambridge, Mass., 1986.

Hillier, Bill and Leaman, Adrian, "How is Design Possible? A Sketch for a Theory", Report of The Design Activity International Conference, August 29 - 31, 1973.

Marr, David, *Vision*, W.H. Freeman and Company, 1982.

Vickers, Geoffrey, Unpublished Memorandum, Division for Study and Research in Education, MIT, 1978.

Wertheimer, Max, *Productive Thinking*, The University of Chicago Press, Chicago, 1945.

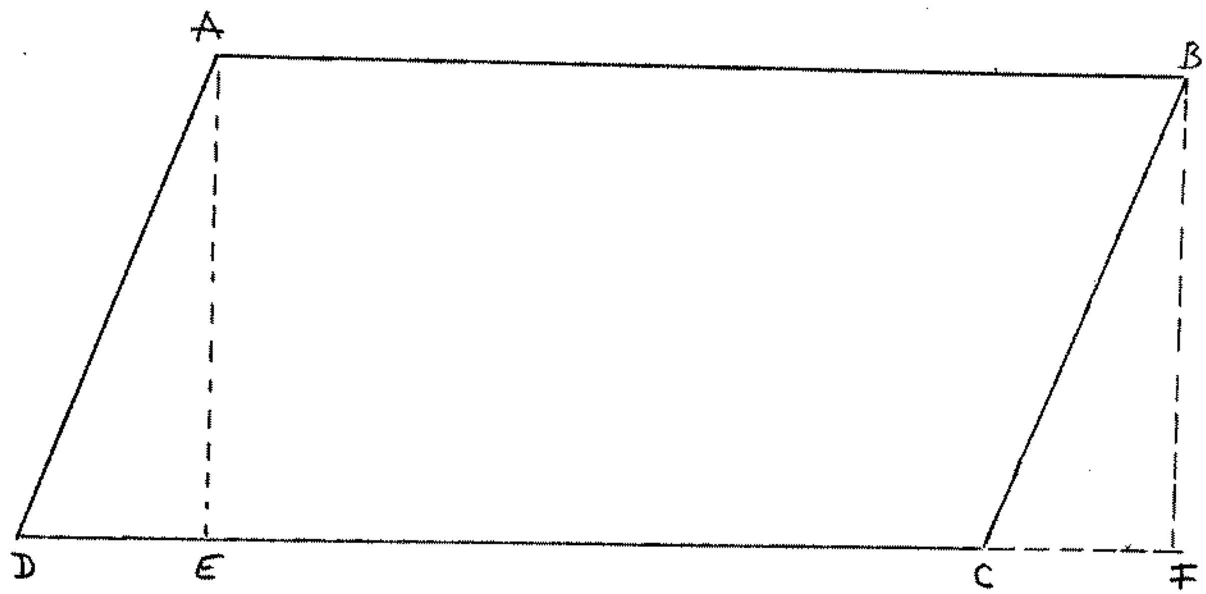
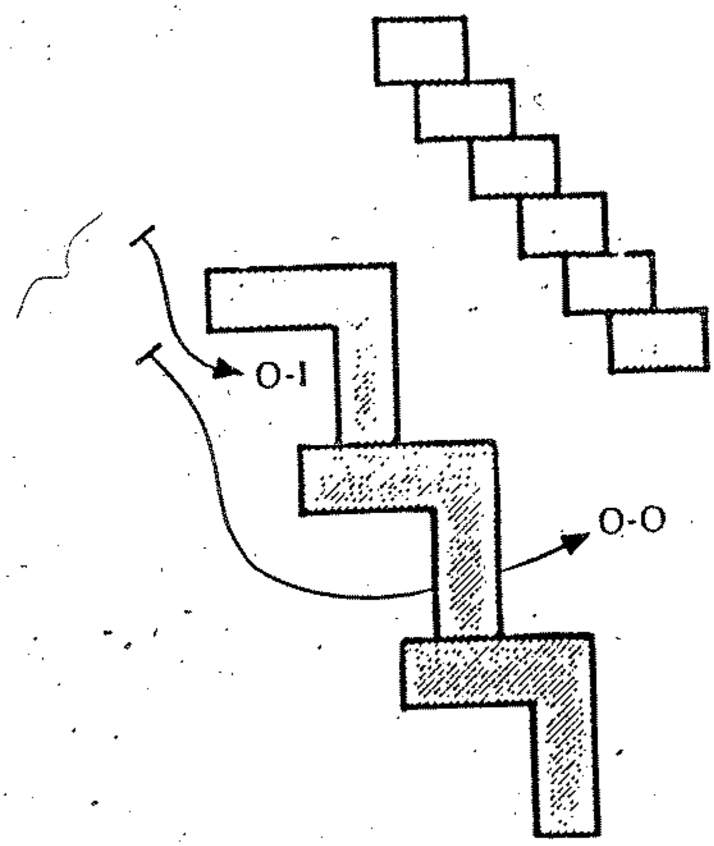


Figure 1



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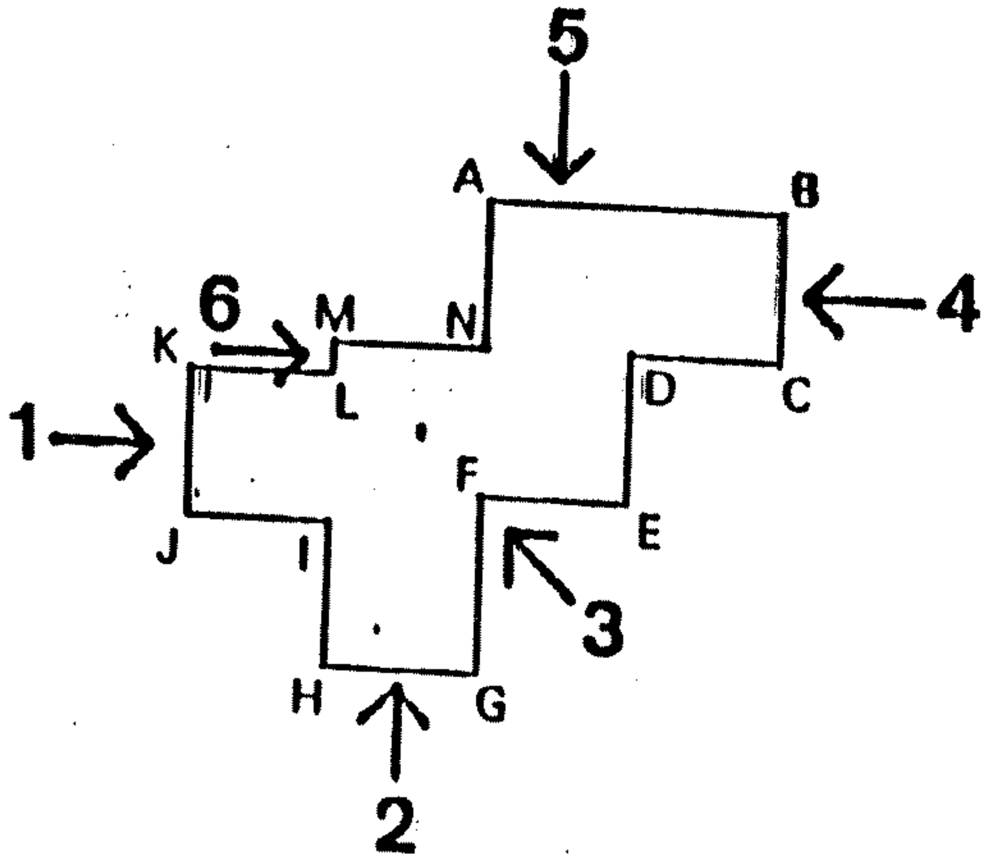

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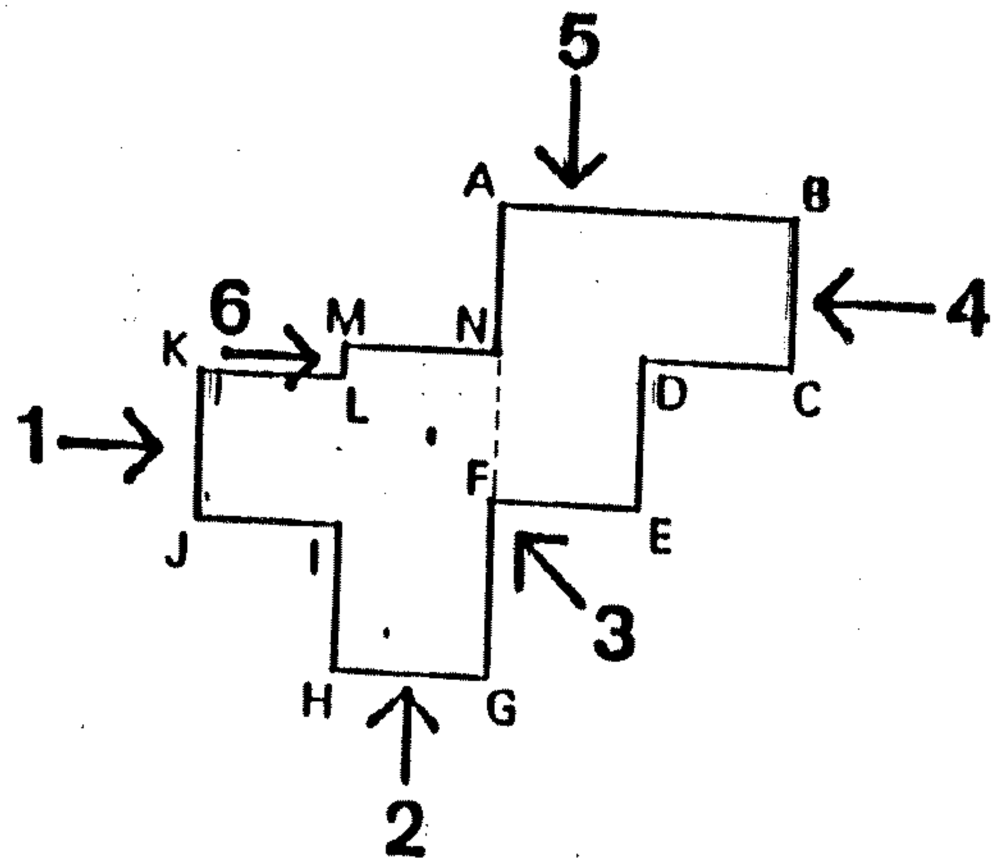

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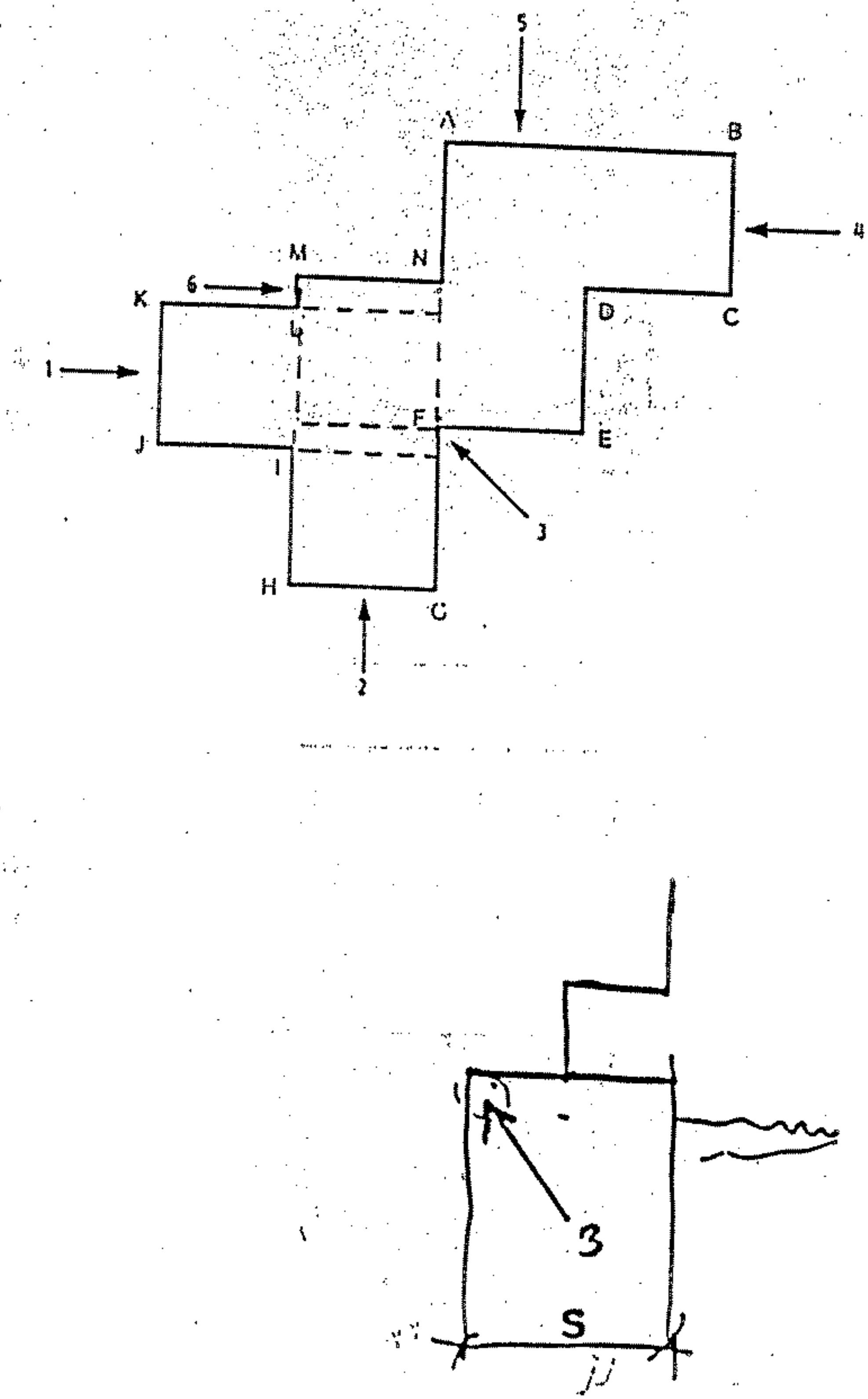

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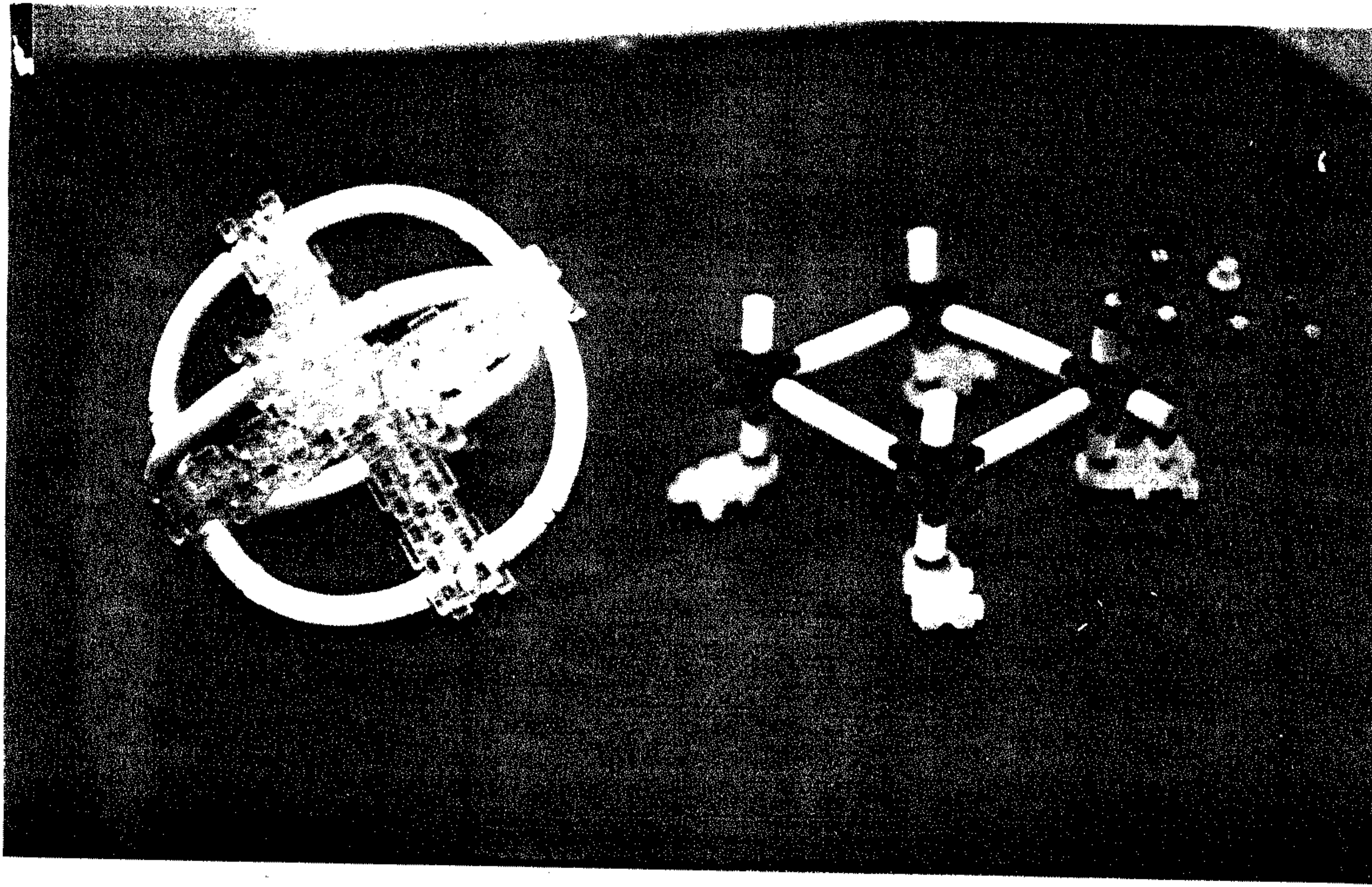
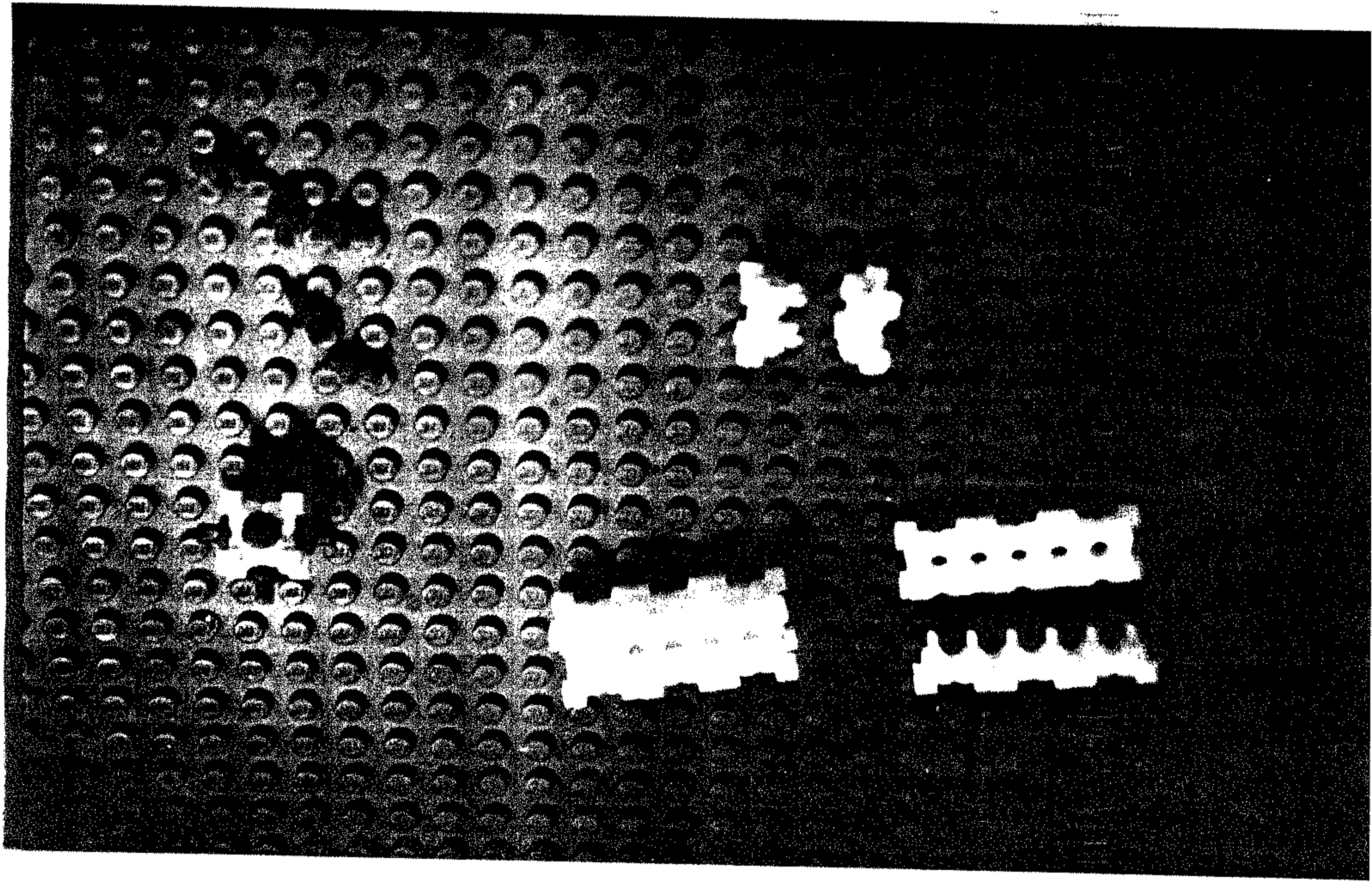
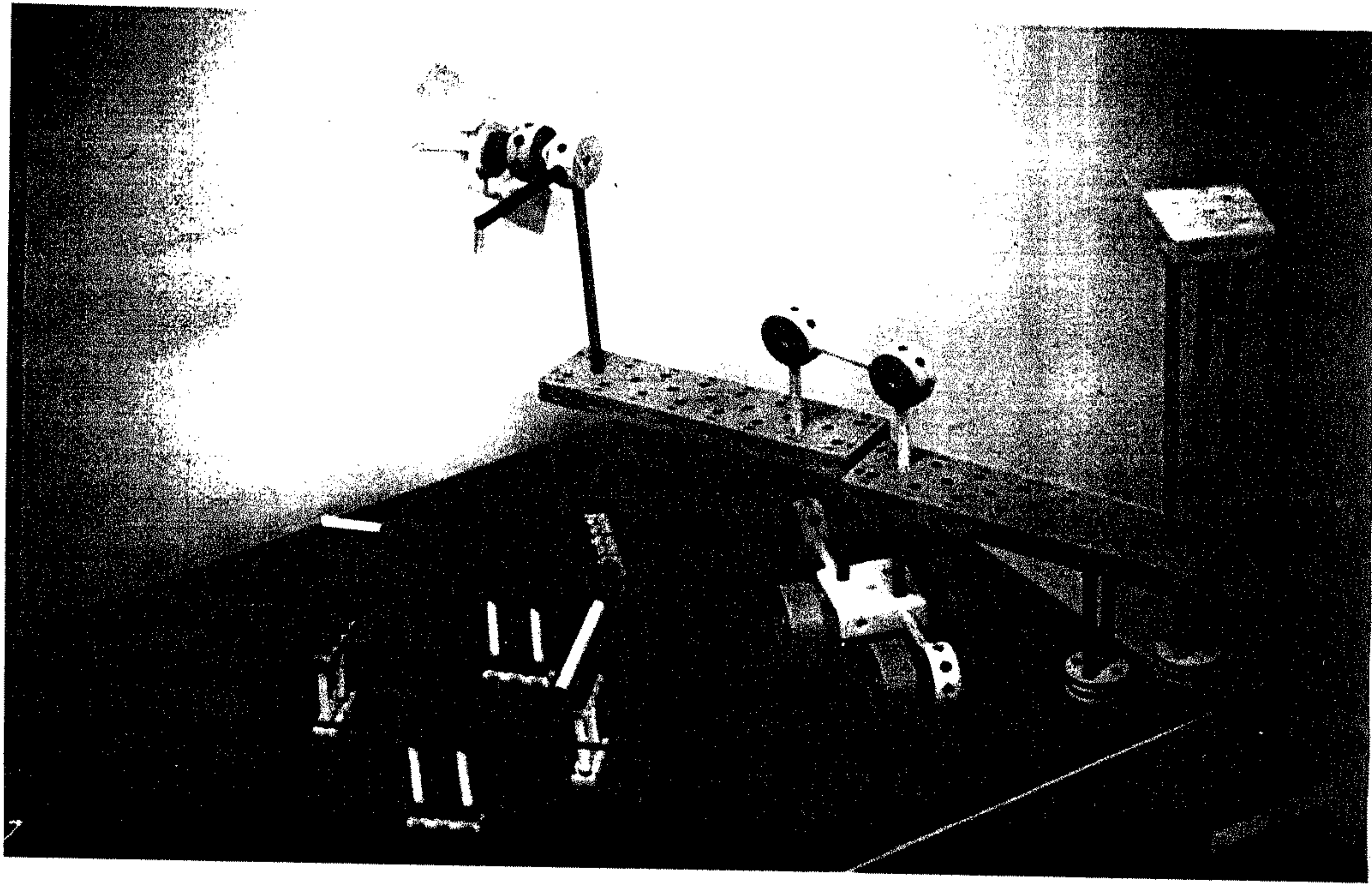


Figure 5

Figure 6





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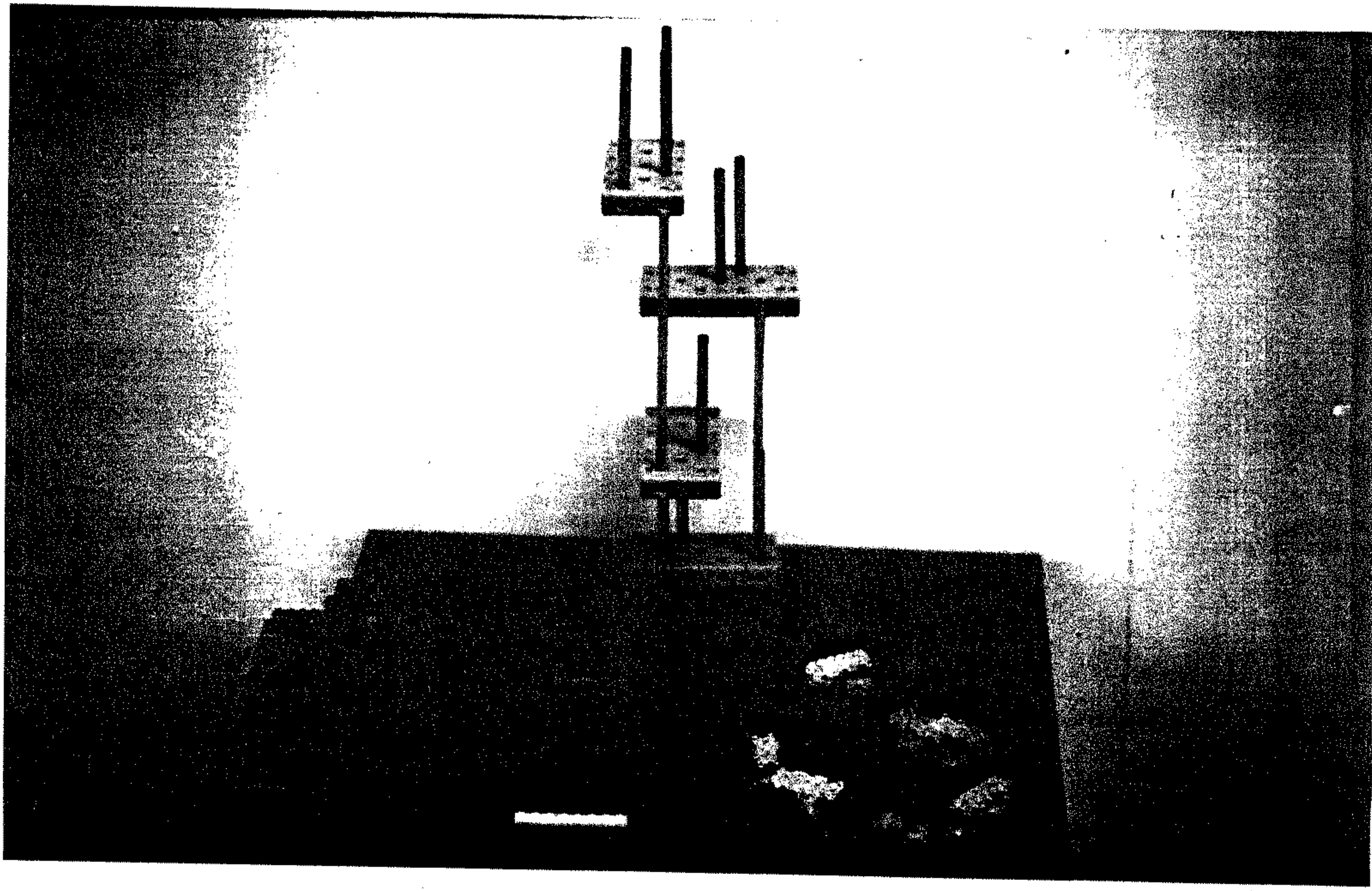

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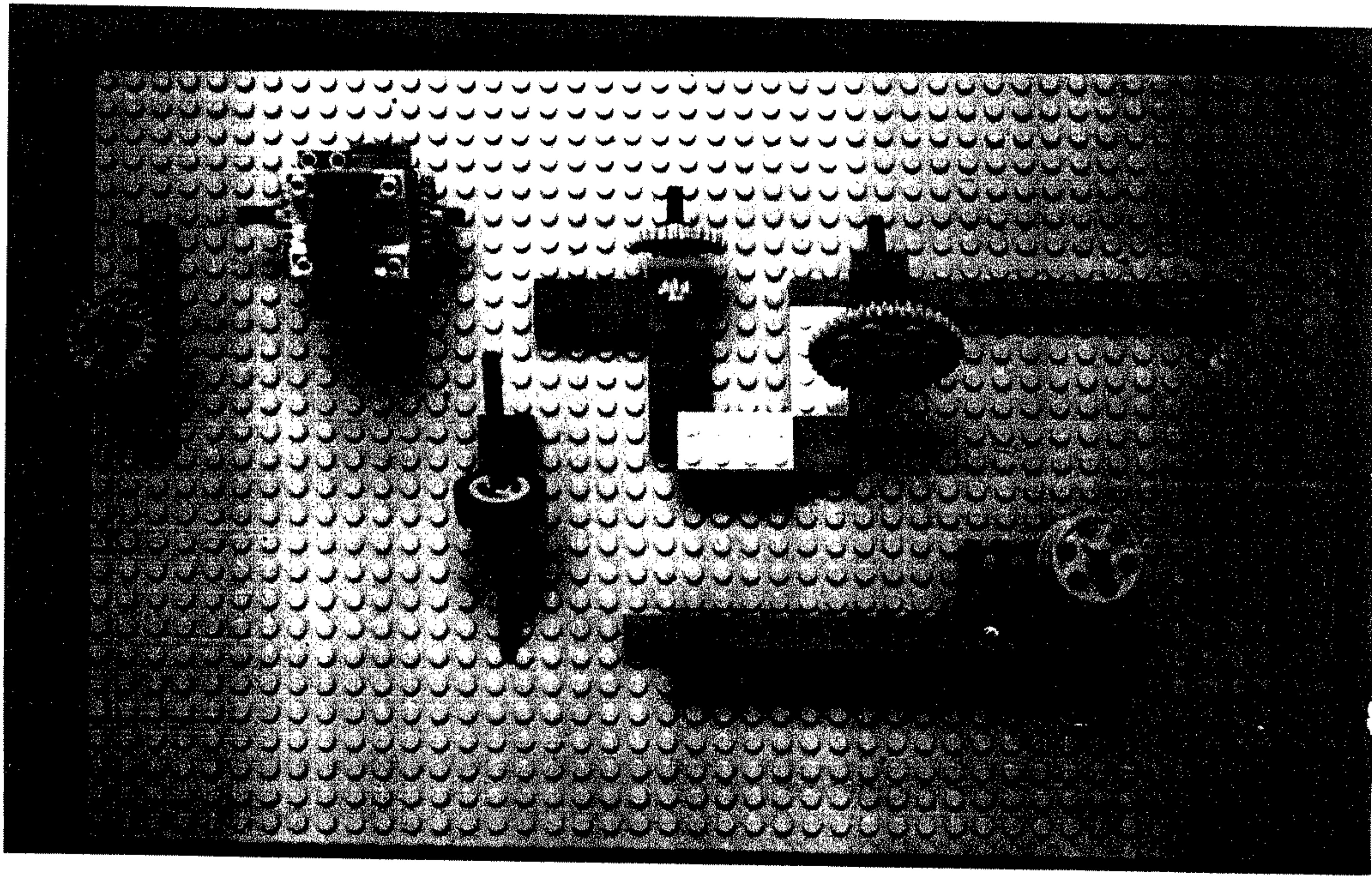

Figure 9

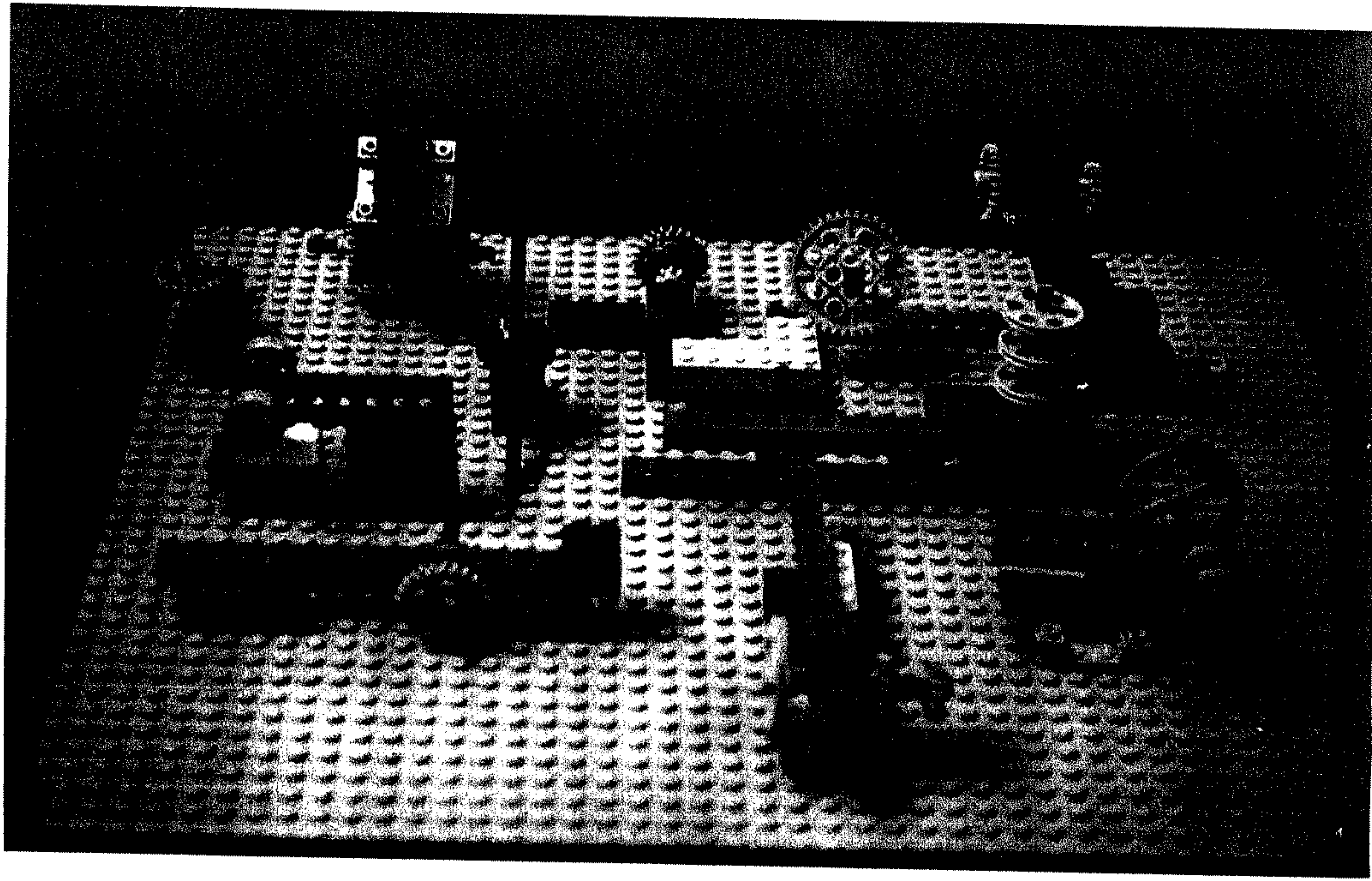

Figure 10

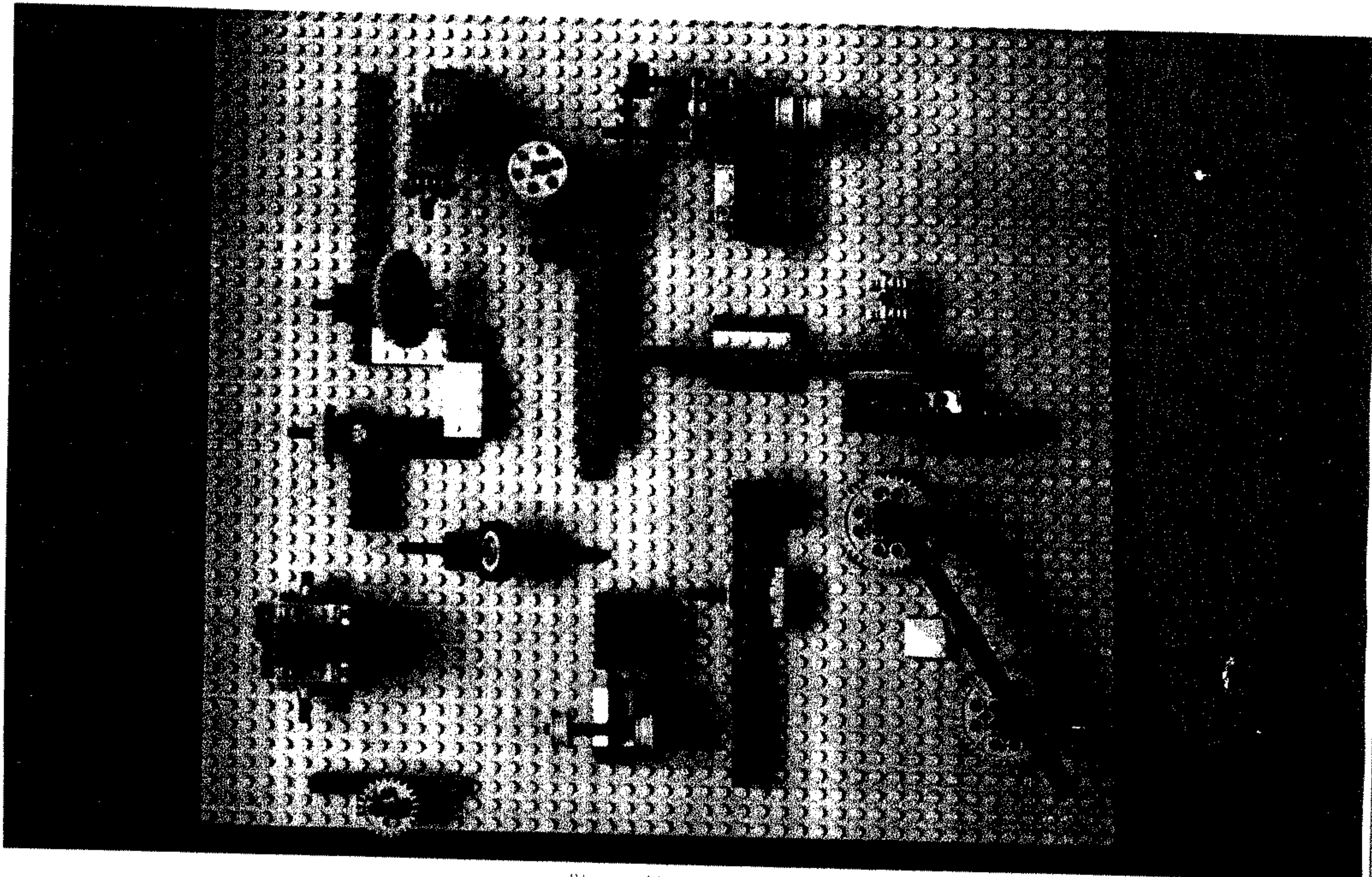

Figure 11