Is Design Theory Possible? *

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Abstract

Because design is a practice, a theory of design is not possible in the same sense as a theory of chemistry is. Socio-psychological theories of what designers do are not design theories. Knowledge of how to design cannot be reduced to theory, for reasons that grow out of the philosophy of science. But a practice like design can be supported or aided by theories. Most of these are from other sciences, but some may be design theories in the sense that they use a style of analysis that is particularly suited to design. It is not obvious what this style is, but it might involve incomplete description or teleological explanation, key features of design.

1 Introduction

The notion of a theory of design is problematic because design, like medicine or management, is a practice. Whereas chemistry or physics is defined by a set of phenomena it is assigned to study, design is defined by a task it assigned to do. Chemical theory is clearly possible because one can organize one's knowledge of chemical phenomena in a systematic way. But it is not obvious that one can reduce knowledge of design practice to theory.

I will argue that it is impossible to do this, for reasons that derive from a body of thought in the philosophy of science. I do not dispute that one can theorize about design practice in the sense that one can theoretically understand the socio-psychological phenomenon of design. But this, I will argue,

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does not issue in design theory. My claim is that one cannot theoretically organize one's knowledge of how to design.

Despite this negative conclusion, I will identify a sense in which design theory is possible. Practical arts like design, medicine, and engineering are typically assisted by supporting theories that provide techniques and a basic understanding of the phenomenon one is trying to influence. These theories are generally part of other sciences. But a supporting theory may investigate a phenomenon, or employ a level or style of analysis, that is unique to the practice in question. At an extreme, one could say that even chemical theory is a supporting theory uniquely suited to the practice of chemistry, albeit one that does not reduce to theory all the knowledge required to practice chemistry.

The possibility of design theory, then, turns on whether there are theoretical styles or subject matters that support design practice and are uniquely associated with it. I will suggest that there are. But on this understanding, design theory is in its infancy, and my rumination about what it might become must be treated as speculation.

I begin below with a brief discussion of what is meant by "theory." After an even briefer definition of "design," I argue that a socio-psychological understanding of the design process is important but is not design theory. I then argue at some length that one cannot reduce practical design knowledge to theory. But this leaves open the possibility that there are supporting theories unique to design, and I suggest ways in which these can arise from the need to understand the behavior of incompletely described objects, which are characteristic of design. In particular, I discuss the potential for design theory in computational models, design representations, optimization models, and empirical investigations. I also point out that since part of what it means to design is to concoct a functional or teleological explanation of the resulting artifact, teleological theories can play a special role in design. I defend the notion of teleological explanation and suggest how it might lead to design theories.

I make no attempt to survey systematically the literature that might be relevant to design theory. Useful surveys can be found in [2, 5, 6, 10, 18, 20].

2 What Is Theory?

A theory is an explanatory account of the way things are. This means that a theory is not number of things it is commonly taken to be.

2.1 What Theory Is Not

A theory is not (necessarily) unsubstantiated. We colloquially contrast "theory" and "fact," as though a theory is speculative and a fact is established. This is wrong on several levels. First, it makes a category mistake, since it confuses a description with what is described. A theory is an account of the way things are, whereas a fact is the way things are. Second, a fact need not be established. If there are sixteen inhabited planets in the galaxy, then this is a fact whether we know about it or not. Third, a theory (i.e., its truth) may be quite firmly established, as is Maxwell's theory of electromagnetism.

A theory is not a conceptual framework (even though it uses one), because a theory makes claims about the way things are. The Linnaeus system of species, genera, etc., is not a theory, because it makes no claims. Rather, one uses it to make claims, as for instance, "Homo australopithecus is extinct." A framework or "tool" developed for an artificial intelligence system, such as a semantic net or a graph grammar, is not a theory, because it is neither true nor false. This is not to deny that a conceptual framework develops hand-in-hand with theory. We use the Linnaeus system because animals and plants actually come in species, and because evolutionary theories at least partially explain their occurrence. One's choice of conceptual framework is heavily theory-laden, because the way we divide up the world is intimately related to our understanding of what the world is like. But to propound a theory is not only to choose a framework but to say things within the framework as well.

2.2 What Theory Is

Theory represents our efforts to make the world intelligible. It must not only tell us how things are, but why things are as they are. Engineers, for example, use a number of empirical formulas that predict the resistance to flow through a pipe. These formulas do not represent a theory because they do not explain why resistance varies with flow rate as it does. On the other hand, the D'Arcy-Weisbach formula, which states that the resistance varies with the square of the flow rate, reflects a theoretical understanding of Newtonian fluids.

A closely related property of theories is that their claims have a lawlike (or "nomic") character. Nelson Goodman's famous "grue" example illustrates this [8]. Let something be "grue" if it is green until the year 2010 and blue thereafter. If I observe the color of grass in 2003, I can conclude that grass is green but not that it is grue. The reason is that we do not consider "grass is grue" a nomic statement, whereas "grass is green" is connected with the order of nature. Lawlikeness is closely connected with the notion of explanation because, ultimately, the way we tell whether a statement is nomic is by whether it fits into a system of statements that can help make the world intelligible.

My examples so far deal with empirical theories, but similar points apply ton mathematical theories. Euclid's Elements might be characterized as a theory of geometry because it elucidates geometrical ideas, showing how they relate to each other. It is important to note, however, that it is not the theorem- proof format of Euclid's work that makes it a theory. In fact there seems to be a prevalent idea that theorizing consists of axiomatizing a field and proving theorems. One can certainly deduce the consequences of statements in a theory, and to this extent one can in a sense "prove theorems" in any theory. But Euclid proved theorems in order to elucidate the structure of geometry, and it is the elucidation, not the theorem-proving, that makes it a theory.

3 What Is Design?

Design is a passage from a functional description to a physical description of an artifact. That is, when the one begins with a description of what a thing is supposed to do and produces a physical description of a thing that does it, then he is designing.

The term "physical description" is a bit too narrow, since one can design such nonphysical things as software, organizations, information systems, and even theories. But I think it good practice to let the design of physical artifacts stand as the paradigmatic case of design, so that other types of design are design insofar as they resemble the design of physical objects.

4 What Is Design Theory?

A fundamental fact about design that complicates theoretical treatment is that design is a practice. Design theory must therefore organize our knowledge of design practice. But "knowledge of design practice" has two very different senses that seem often to be confused. It can refer to knowledge about the socio-psychological phenomenon of designing, or knowledge one must have in order to practice design.

4.1 What Design Theory Is Not

When the phrase "design theory" is mentioned, what seems often to be meant is a socio-psychological theory of the designing phenomenon. This in turn can be either of two basic types.

One type investigates the process by which people actually generate designs. What steps do designers generally follow? How did they learn their craft? When several people produce a design, how do they interact? There is no reason one cannot build a theory around these questions, at least to the extent that one can build psychological and sociological theories of any kind. A good deal of effort has already been exerted in this direction, much of it based on analysis of "protocols," or records of what designers say when they talk to each other or are asked to "think aloud" [4].

One can also ask what would happen if people designed differently—a research program described by John Dixon in [3]. In particular, one would like to know what factors lead to good designs, where the criterion of "goodness" is defined in advance (efficiency, cost, robustness, or whatever). I take efforts to formulate "design procedure" or "steps to follow when designing" to be part of this research program.

Socio-psychological theories of these kinds are legitimate and important and can help one know how to design. But they are not the *same* as knowledge of how to design. One can know much about how to design while knowing very little about how designers (other than oneself) actually behave. Conversely, one can know much about what designers do and little about how to design, particularly if other designers know equally little!

There is a significant sense in which the socio-psychological theories are not theories of design at all. They are like theories of how chemists practice their science, or what would happen if they practiced it differently. One could study how chemists behave in the laboratory, how they keep records, how they design experiments, how they train their apprentices, and so on. In other words, one can treat the practice of chemistry as a phenomenon to be studied, one that is quite distinct from the chemical phenomena studied by chemistry. One can also ask how chemistry should be practiced, and chemists have in fact evolved certain practices that seem to work.

The practice of chemistry is actually served by several supporting sciences, of which chemistry itself is only one. A chemist uses mass spectrometers, for instance, whose operation relies on optics and quantum physics. Computer science and discrete mathematics are helpful in the identification of isomers, and so on. A socio-psychological theory of chemical practice could be viewed as one of these supporting theories. By helping us to understand how chemists think and how they interact with each other, it could improve the practice of chemistry. But it would not be a theory of chemistry.

In a similar sense the practice of design can have supporting sciences. In engineering design, for instance, one appeals to physics and materials science to determine whether a proposed bridge will fall down. Socio-psychological theories of the design process can comprise another supporting science. But again, they are not theories of design.

4.2 What Design Theory Is

I now seem to have reached an impasse. I distinguished design theory from socio-psychological theories of design practice. But since design is a practice, a theory of design must be a theory of design practice, and it is unclear how one can have a theory of a practice except in a socio-psychological sense. Chemistry is free of this difficulty, because it is associated with a set of phenomena (i.e., chemical phenomena) distinct from the phenomenon of chemical practice. But design seems to have no such set of associated phenomena.

One can attempt either of two escapes from this impasse. One is to insist that it is possible to understand a practice theoretically in a way that does not reduce to socio-psychological theories. That is, one can develop a theoretical ordering of practical knowledge. Another is to show that design, like chemistry, has its own subject matter after all—even if it is not so obvious what it is.

I will argue below that the first avenue of escape is blocked by considerations put forward by philosophers of science.

The second possible avenue of escape in effect claims that design practice calls for supporting theories that are peculiar to design. The theory of chemistry is not only a "supporting theory" for the practice of chemistry, but one that is uniquely tied to that practice. In other words, among the theories useful for chemical practice are those whose subject matter is particularly associated with chemical practice (i.e., chemical theories), or whose type of analysis or level of abstraction is uniquely suited to chemical practice. The claim here is that the same is true for design practice.

5 Irreducibility of Practical Knowledge to Theory

The issue as to whether one can understand a practice theoretically is one of the central questions addressed by a school of philosophy developed in the 1970s and 1980s by Jürgen Habermas [9], Hans Georg Gadamer [7], Richard

Rorty [17], Richard Bernstein [1], and others (see [1] for a discussion of this literature). These thinkers argue at length that practical knowledge is logically prior to theoretical knowledge, and that it makes no sense to speak of understanding practice theoretically. I cannot convey here the full scope of this body of thought, of which social criticism is an important component. But I can say something about its reasons for denying that practice can be theoretically understood.

I begin with a distinction, originally drawn by the ancient Greeks (notably Aristotle), between three types of knowledge: *techne*, *episteme* and *phronesis*. Techne is technical know-how, and episteme is theoretical knowledge. Phronesis might best be translated as judgment, or the ability to apply techne and episteme to a practical problem.

Suppose a physician encounters a patient who appears to have appendicitis. The physician knows how to examine the patient, which tests to order, and how to remove the appendix if necessary. This is techne. The physician is also well schooled in anatomy, pathology, and histology, and knows the etiology of the disease and its effect on bodily systems. This is episteme. But determining whether the patient really has appendicitis is another matter. The patient may not have all the symptoms, the laboratory tests could be borderline, and the patient's own account uncertain or even self-contradictory. There may be no time to obtain more definitive tests before the organ ruptures. At this point the physician must exercise judgment. This is phronesis.

Phronesis, then, is the ability to use one's theoretical knowledge (episteme) to determine which technique (techne) to use. It is where theory and practice meet. Good judgment generally takes much longer to acquire than theoretical knowledge or technical know-how, perhaps the better part of a lifetime. Apparently it cannot be taught, but obtained only by experience, preferably under the supervision of an expert.

Phronesis clearly relies on techne and episteme. Judgment without technical know-how is impotent (a surgeon without a scalpel). Judgment without theory may be ineffective, as is some folk medicine, and judgment with bad theory can be even worse. (Think of bloodletting, for which patients once traveled long distances to find a skilled and experienced practitioner). But even though phronesis relies on techne and episteme, it is reducible to neither.

I first dispose of two bad arguments for the irreducibility of phronesis. One argument draws the distinction between knowing that and knowing how. "Knowing that" is propositional knowledge; that is, knowing that something is true. "Knowing how" is a skill; that is, knowing how to do something. One might maintain that phronesis involves knowing how, whereas episteme does not. For instance, phronesis involves observational skills (ability to assimilate details and distinguish the ones that matter), and the ability to reasoning clearly under the pressure of the moment. Thus phronesis is irreducible to episteme.

But the irreducibility of phronesis does not concern the irreducibility of "knowing how" to "knowing that." If this is what Habermas and company have in mind, their claim is trivial and uninteresting. They claim, rather, that the propositional component of phronesis is irreducible to the propositional component of episteme. In fact, they maintain that it is on phronesis that all propositional knowledge is ultimately based.

Another bad argument for the irreducibility of phronesis is that people who know the theory and have the "how to" skills sometimes do not know what to do in a concrete situation. So there must be more to phronesis than theoretical knowledge. But one can explain this inability without supposing the phronesis is irreducible. For instance, the theory may be incomplete. If blood tests do not determine whether the patient has appendicitis, it may be because we are not fully aware of the effect of appendicitis on blood chemistry. Alternatively, the "boundary conditions" may not be fully known. Given enough information about the patient's symptoms, theory predicts reliably whether he or she has appendicitis, but perhaps the patient does not report all symptoms, or perhaps the blood tests were not carefully done.

The philosophical arguments for irreducibility go deeper than these. One of them springs from the observation that while scientific worldviews come and go, much of everyday, common-sense discourse stays the same. Scientists themselves dwell in this "life world" of everyday knowledge while they work on their theories. Everyday discourse is therefore pretheoretical, the source from which scientific theories spring.

This theme was echoed by such "postmodern" thinkers as Wittgenstein [21], Quine [14, 15, 16], Habermas, Rorty, and Gadamer. It is best known from Thomas Kuhn's argument [12] that science undergoes "paradigm shifts" so radical that theories before the shift are in some sense incommensurable with theories after the shift. One way in which they are incommensurable is that a theoretical statement, such as "light travels in straight lines," may assume a new meaning in the new paradigm; in this case, euclidean straight lines became noneuclidean straight lines (geodesics). This alone is not upsetting, but (to seize on Quine's way of putting it) there may be no translation from the old language into the new. There may be no way to pick a claim in the old paradigm, translate it into the new language, and check whether it remains true in the new paradigm. This is because a statement in the old paradigm receives its meaning from the role it plays in the scientific discourse of that paradigm, where by "discourse" I mean not only linguistic behavior but how it interacts with other types of behavior.

Yet there is a sense in which all of the theories talk about many of the same things, namely the things in our everyday experience that they attempt to explain. They talk about light and darkness, heat and cold, the sun and the moon. This is possible only if these words receive their meanings from some overarching discourse (or "form of life," to use Wittgenstein's phrase) that endures through changes in scientific worldview. This is the everyday discourse that embodies our common-sense understanding of the world, the practical knowledge that gets us through the day. It is the *praxis* that provides the foundation for *theoria*.

The irreducibility of practical knowledge to theory explains our intuition that medicine or design is an "art" as well as a "science." To build medical science or design science one must develop scientific knowledge that *supports* the practice of medicine or design, and is uniquely associated with it, but does not transform the practice itself into a science.

6 Toward Theories of Design

I now turn to the task of identifying a set of problem areas whose systematic study could yield theories uniquely associated with design practice. Again, the problem of understanding the socio-psychological phenomenon of design is not one of them, since it is most appropriately treated as part of sociology, psychology, cognitive science, or some combination of these. But I will discuss three subject areas, or types of theoretical analysis, that could lead to sciences of design. These are computational models of design, understanding the properties of incompletely specified objects, and teleological explanation.

6.1 Computational Models

If the study of the concrete designing phenomenon is not peculiarly a design science because it focuses on the behavior and interaction of human beings, perhaps one can obtain a design science by removing the human element. That is, rather than ask what happens when humans follow certain design procedures, one can ask what happens when computers do. When one specifies procedures for humans to follow, it remains unclear what will happen when humans in fact follow them. This calls for empirical investigation of human beings. But when one specifies what procedures computers are to follow, then one need not study the machines that carry out the procedures. One need only study the procedures themselves. Perhaps one can develop theories that explain and predict what sort of designs will issue from certain types of procedures. Dixon [3] refers to these as "computational models" of design.

This maneuver, however, only postpones the question of what design science is. Presumably when one studies design algorithms, one does not study them *qua* algorithms, as a computer scientist would. One is not primarily interested in the finiteness or complexity of the algorithms. One is interested in the "content" of the algorithms, namely what they reveal about the nature of design. But what is this content?

There is a sense in which one can theoretically understand a class of algorithms in a content-specific way. This is the project of formalist mathematics, as characterized by David Hilbert, which studies number theory, for instance, by investigating how its theorems follow from the Peano axioms. Thus computational design theory might be viewed as a branch of formalist mathematics. (There is, incidentally, a branch of mathematics called "design theory," but it is a very specialized branch of geometry that only peripherally relates to our interests here.) Yet the appeal of the computational model may derive precisely from an assumption that it is *not* to be regarded as formalist mathematics. Hilbert notwithstanding, there is a sense in which Euclid not only studied the formal syntactic properties of a geometric proof system (if at all) but studied *geometry.* He studied the properties of objects in a certain kind of space. I am presupposing a certain kind of Platonism here, but I think it is this same presupposition that makes computational models for design attractive. What one hopes to understand by studying computational models is not the formal structure of design algorithms, but design. This assumes, of course, that there is an underlying subject matter that a study of design algorithms might organize in the way that Euclid's axiomatic treatment organized geometry. It is yet to be determined what this underlying subject matter is.

6.2 New Levels of Description

A characteristic and remarkable trait of design is that it deals with incompletely described objects. An architect, for instance, may work with schematic representations of a building and leave the smaller details to engineers and construction firms. This suggests a type of theory that may be unique to design. Whereas science normally studies real, concrete objects, design science would study the properties and behavior of incompletely described objects.

This proposal requires careful analysis. To begin with, all science abstracts certain features of an object and more or less ignores the rest. In fact, the sciences are defined and distinguished partially by the level and type of abstraction they employ. So, if the proposal is that design science focus on only certain features of an object—namely, those belonging to the designer's incomplete description of it—then it would seem to be no different in principle from any other sort of science.

But design practice may well call for different levels or types of abstraction than the other sciences. In this way it can inspire theories that are uniquely suited to design.

6.2.1 Theories Arising from Design Representations

A design science can be strongly influenced by the way that designs are represented, since the choice of representation determines what aspects of the artifact are considered. Some recent developments in design representations may in fact embody some nascent design theories, although it must always be remembered that a representation alone, or any kind of conceptual framework alone, does not comprise a theory.

A graph grammar or shape grammar, for instance, pays attention to certain geometrical properties of an object. One could conceivably build a geometrical theory that understands the structure of objects at this level of abstraction, much as topologists have investigated the properties of objects that are considered the same whenever one is a continuous deformation of the other. Since graph and shape grammars focus on computation—that is, the generation of geometrical objects—the resulting theory could be a computational model with a subject matter. That is, it would be more than a "grammar" (a purely syntactic notion) but a theory of what the grammar is "about," just as topology (on a nonformalist interpretation) is a theory about topological spaces. Finger and Dixon [5, 6] survey some other design representations that might allow theoretical treatment, such as representations that study basic mechanical functions, how objects fit together, and so on.

6.2.2 Empirical Theories of Design

The design theories so far suggested have the character of mathematical theories, but design could give rise to new empirical theories as well. Suppose, for instance, that a new state sets out to design its economic system.

Existing economies are generally studied by investigating equilibrium conditions. But a designed economy may be so heavily driven by tax incentives, regulations, and social psychology that equilibrium is no longer a useful idea, and new methods must be developed. Predicting the behavior of an incompletely described economy may require a level of analysis unique to economic planning.

6.3 Teleological Theories

Another important characteristic of design is that it begins with a functional description of what is to be designed. In fact the functional description may become more detailed as the design progresses. One may begin by specifying that an automobile is to serve certain purposes (commutation to work, long-distance travel, off-road exploration, etc.) and continue to develop the design by specifying that part W will propel the car, part E will power part W, part F will supply energy to part E, and so on. This of course eventually evolves to a physical description of the wheels, engine, fuel system, and so on.

I have already said that since the physical description of the artifact remains incomplete through most of the design process, it may be useful to develop theories of incompletely described objects. But if the artifact is also described functionally through much of the process, it may be equally useful to develop theories of functionally described objects.

6.3.1 The Nature of Teleological Theory

Teleological explanation may seem an odd idea, due to the fact that "explanation" has meant finding the "efficient cause" since the advent of the modern era. We explain something by telling what caused it, and the paradigm case is that of one billiard ball hitting another. But David Hume pointed out long ago that there is no way in principle to tell whether a billiard ball's motion is caused by its impact with another or simply coincides with the impact. No amount of observation can detect a cosmic glue that joins cause and effect. What we call "causation" is actually an ordering of our experience that helps make it intelligible.

There are modes of explanation other than efficient causation that are equally useful for making the world intelligible and therefore should be regarded as equally legitimate. Aristotle recognized three others: material, formal and teleological explanation. The last is most relevant to design. Teleological explanation orders experience by assigning a purpose or function to its components. Imagine for instance that someone is shown drawings of human anatomy for the first time. The complexity would be bewildering. But if it is explained that this organ pumps a fluid that supplies nutrients to the body, and this organ converts food into those nutrients, and so on, then the complexity quickly begins to make sense. In fact, this is how we all first come to understand human anatomy. Our grammar school teachers tell us about the functions of the organs, not about chains of chemical reactions that explain the body in terms of efficient causes.

Teleological theories also make testable predictions. If we theorize that the function of a certain gland is to regulate growth, we can remove it and see if growth rate is affected. This in fact illustrates how teleology supports medicine. Medicine relies on a number of supporting sciences, but the one that seems uniquely associated with medicine is a teleological science of the human body. It is a science that tells us what the body is supposed to do and how to fix it when things go wrong. It rests on such nonteleological sciences as endocrinology and molecular biology but goes beyond these to assign systemic roles to glands and molecules. If the supporting science uniquely associated with medicine is teleological in nature, we might expect the same of a uniquely supporting science for design.

Teleological explanation is in fact foundational for design but for a different reason: since design moves from a functional description to a physical description, and refines the functional description as it proceeds, *the very act of design produces a teleological explanation of the artifact.* In many cases the explanation is on a common sense level and requires no refined scientific treatment. But complex functionalities may call for something more. We have in fact a dual situation parallel to that of theories of incompletely described objects. On the one hand, modes of functional representation may give rise to mathematical or computational theories that investigate the structure of "functional space" at a different level of abstraction than required by the study of existing objects. On the other hand, design may require empirical theories in a teleological mode that again call for a different level of abstraction than the investigation of existing systems.

6.3.2 Teleological Theories Arising from Functional Representations

As for functional representations, several systems have been proposed, at least in the area of mechanical engineering. They classify mechanical operations and to some extent study how they interact. Suh, for instance, proposed an "axiomatic treatment" of functionality [19, 20]. His treatment seems aimed at making recommendations for design, such as that of keeping functions independent, but similar axiomatic treatments could explore the structural properties of functional representations.

6.3.3 Empirical Teleological Theories

An empirical theory along teleological lines would be useful in the design of complex systems, such as an ecological system, an economy, or a community. Successful system design may require teleological theories that were never developed to study existing systems. To design an ecosystem, for instance, one might put a forest in one spot in order to provide habitat for certain species, which is needed to control other species, which must be limited to protect certain vegetation, and so forth, so that by the time the design is complete, every significant feature of the landscape has a set of functions. We now need to know whether an ecosystem with these interlocking functionalities can really exist. Existing ecological science tells us something about the function of different elements of an existing system, but can it evaluate the possibility of an imaginary configuration of functions? This may require a systematic teleological science that does not now exist.

7 Conclusion

There cannot be a science of design in the same sense that there is a science of chemistry, because design is a practice, much as medicine is a practice. *Praxis* cannot be reduced to *theoria*. Socio-psychological theories of the design process can be useful but are not design theories. The only sense in which design theory or medical theory is possible is as a supporting science uniquely associated with design or medicine.

I suggest two ways in which a supporting science might be peculiarly suited for design: (a) it explains and predicts the behavior of incompletely described objects, or (b) it is teleological in the sense that it explains and predicts the behavior of functionally described objects. The latter is already exemplified by medicine, since the supporting science uniquely associated with medicine is arguably teleological in nature. Only small and tentative steps have been taken, however, toward an analogous science of design.

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