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CAN THERE BE SCIENTIFIC THEORIES OF DESIGN THAT DO NOT SCIENTIZE DESIGN?

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ABSTRACT

This paper asks, Can there be scientific theories of design that do not scientize design? And it answers in the affirmative. Not only can there be scientific theories of design that do not scientize design but also that a scientific lens can potentially reveal important aspects of the design process. We apply Karl Popper's criteria for the scientific status of a theory to four seminal theories of the design process: Bounded Rationality, FBS Framework, Figural Complexity, and C-K Theory. We demonstrate that (1) some theories about design can be construed as scientific in Popper's terms, and that (2) these theories do not "scientize" the design process.

Keywords: Design Theory, Falsification, Science of Design, Philosophy of Science

1 INTRODUCTION

Design and science can be seen as two major approaches of inquiry and action that humans have developed over time. While science has strong philosophical and theoretical foundations, design is not as well developed. This has led to a dialectical exploration of the differences, strengths, and weaknesses of one in terms of the other. Designers and design researchers seem to be grappling with an ontological dilemma, which Karl Popper described for science as the "problem of demarcation" (Popper, 1963). What is it that makes designing what it is? What makes it design and not science? What is its nature and core? Can that core be theorized? Popper was interested in similar questions for science, and he generated answers in the form of criteria that could be used to demarcate *scientific* theories from other kinds.

There have been attempts to develop similar criteria for design theory, in some cases by seemingly translating Popper's criteria (Jones and Gregor, 2007). Other attempts start with what they see as the core of design. They argue that theories about design should not only describe design but also incorporate and manifest its unique characteristics (Chakrabarti and Blessing, 2014; Hatchuel et al., 2011). This sort of theorizing makes sense if a key aspect of the agenda of design as a discipline is to understand and study design on its own terms within its own culture (Cross, 2001; Nelson and Stolterman, 2012). But this should not mean that we cease in our attempts to understand design from other perspectives, such as that of science.

We propose that if we wish to articulate the fundamental nature of designing, then we should examine the possibility of theoretical lenses that (1) answer to scientific criteria while (2) respecting the unique nature of designing. This paper engages in a philosophical study of design theories. It asks, Can there be scientific theories of designing that do not also scientize designing?

We argue that there can be scientific theories of design that do not "scientize" design and that a scientific lens can potentially reveal important aspects of designing that may be less visible if designing is understood from within, i.e., through a designerly lens.

There exist many theoretical accounts of designing. *Most* of these theories are designerly in nature, that is, they are theories that are *themselves* designed and are intended to be *useful* to designers rather than scientifically correct and verified. In most cases, these theories make claims about being useful but do not make any scientific claims. But we suggest that there are theories about designing that make stronger knowledge claims by providing a scientific account of designing. We do not see designerly theories of designing as less valuable, but in this work they are not our primary objects of study.

To investigate our assumptions, we apply Karl Popper's criteria for the scientific status of a theory to four seminal theories of designing: Bounded Rationality (Simon, 1969), the FBS framework (Gero and Kannengiesser, 2014), Figural Complexity (Schön, 1990), and C-K Theory (Hatchuel et al., 2011; Hatchuel and Weil, 2009, 2003). Through our analysis we aim to demonstrate that (1) these four theories can be construed as scientific in Popper's terms, and that (2) they do not scientize designing. Given our findings we end with a discussion about the offerings and potential implications of scientific theories about designing.

2 THE PROBLEM OF DEMARCATION IN SCIENCE AND DESIGN

Karl Popper (1963) began grappling with "the problem of demarcation" as a student. What distinguishes science from other approaches and what distinguishes scientific theories from other types? The latter question is highly relevant in design research, where researchers engage in theorizing partly as a means of establishing disciplinary boundaries. In parallel with Popper's question about science we can ask, What is design? What is a proper design theory?

In *Science: Conjectures and Refutations*, Popper (1963) summarized his thinking about what demarcates a scientific theory from other types with the term(s) "falsifiability, refutability, or testability." Popper argued that Freud's psychoanalytic theories *do not* fulfill his criteria. Nor do Marx's economic theories. Neither (set of) theory is falsifiable. In Popper's words, "Once your eyes were thus opened [to these theories] you saw [only] confirming instances everywhere… whatever happened always confirmed [them]" (Popper, 1963). As a counterpoint, Popper described Einstein's theory of relativity as an exemplar scientific theory.

From Einstein's theory, one could deduce that "stars close to the sun would look as though they had moved a little away from the sun, and from one another" (Popper, 1963). It is risky in the sense that it is "incompatible with certain possible [empirical] results—in fact [it is incompatible] with results that everyone before Einstein would have expected" (Popper, 1963). It diverges from well-established scientific theory. The consequences of its right*ness* were profound. Finally, it is falsifiable both logically and empirically. This latter point signals our alignment with Popper's notion of *methodological* falsification as opposed to naïve falsification (Kuhn, 1970; Lakatos, 1970) or sophisticated falsification (Lakatos, 1970). When we reference falsification throughout this paper, we are referencing methodological falsification and not one of its "relatives." And when we ask whether theories about designing can be construed as falsifiable, we are asking whether they can be construed as *methodologically* falsifiable.

Popper's work is not sacrosanct. Thomas Kuhn (1970) famously authored a substantive critique in which he presents three main criticisms against Popper. First, he argues that Popper missteps in selecting Einstein's theory as an exemplar scientific theory. For Kuhn, such "revolutionary" theories are anomalous and therefore misrepresentative of science writ large. Normal science and its theories attempt to solve more mundane "puzzles" with the purpose of filling small gaps in existing theory. Second, Kuhn argues that *non*scientific theories, such as the astrological ones that Popper decries as "pseudo-scientific," are falsifiable. If nonscientific theories can be falsifiable, then falsifiability cannot be the demarcating feature of scientific theories. Finally, Kuhn points out that just as "conclusive proof" of scientific theories is illusory, so too is "conclusive disproof." In other words, disproof is no more plausible than proof as a distinguishing feature of scientific theory.

There are others who have critiqued Popper, such as Lakatos (1970). However, we see these criticisms as signifiers that Popper's theory is interesting and worth taking seriously—not as "conclusive disproof" of its validity. Our decision to use Popper's work should not be taken as an endorsement of his theory as the best, consummate theory of science. But few others have equaled or outmatched the impact Popper's theory has had both on the theoretical and empirical scientific communities. Consequently, we see his theory as a useful tool for addressing the problem of demarcation when it comes to design.

3 THEORIES ABOUT DESIGNING

We selected four theories to analyze in terms of their scientific*ness*: C-K Theory, FBS framework, Figural Complexity, and Bounded Rationality. We will describe each theory below. However, since each one is well developed, it is quite impossible to make fair descriptions in a few paragraphs. Therefore, our descriptions should be seen as indications of what the theory is like as a way for the reader to understand our work and not as comprehensive explanations.

— Hatchuel and Weil (2009; 2003) put forth **C-K Theory** in response to what they deemed a lack of design theories accounting for the generation of novel concepts. Their theory describes designing as an interaction between two interdependent spaces: a concept space (C-space) and a knowledge space (K-space). The C-space is filled with partly unknown design concepts. "Partly unknown" indicates the incompleteness of designers' knowledge about a concept in the C-space. We can think of concepts as logical propositions that are neither true nor false. To "prove or disprove" these propositions, designers venture into the K-space to explicate and "test" their propositions. The output of activity in the K-space is knowledge, which the designer takes into the C-space. Armed with this new knowledge, a designer might abandon a concept (if it is shown to be "false" by the K-space), partition a concept (if it remains unknown even after working in the K-space), or earmark a concept as a potential design candidate (if it is shown to be true in the K-space). There are no time constraints put on the interaction between the C and K spaces. Nor are there any strictly prescribed methods of "concepting" or "knowledge-generating." The C-K Theory has been presented in the following writings (Agogué and Kazakçi, 2014; Hatchuel and Weil, 2007, 2002; Hatchuel et al., 2004).

— The **FBS framework** is derivative of the FBS ontology, which describes designed artifacts in terms of what they are for (function), what they do (behavior), and what they are made of (structure). The FBS framework builds on the ontology to "represent the process of designing as a set of transformations between function, behavior and structure. The most basic view of designing consists of transformations from function to behavior, and from behavior to structure" (Gero and Kannengiesser, 2014).The authors argue for eight fundamental transformations constitutive of any discipline-agnostic design process: formulation, synthesis, analysis, evaluation, documentation, reformulation type 1(RT1), reformulation type 2 (RT2), and reformulation type 3 (RT3). The authors prescribe no concrete processes or methods to "force" transformations to happen. The FBS framework has been covered in the following writings (Cascini et al., 2013; Gero and Kannengiesser, 2004; Gero, 1998; Vermaas and Dorst, 2007).

— **Figural Complexity** plays a central role in Donald Schön's critique of Herbert Simon's theory of designing. Schön (1990) argues that Simon's understanding of designing falls short in three important ways, one of which is learning. Designers are constantly learning things that engender changes to design situations, structures, representations, and design proposals. Changes in one area necessitate changes in others; this is the essence of *figural complexity*. Schön illustrates this concept with examples from music composition and fine art. He does not suggest that music and art are design, but rather that we can see how figurally complex artifacts change *as wholes* when changes are made to their parts. For example, adding a single note to a melody changes the whole melody and adding a new color to a canvas changes the whole composition. The theory of figural complexity has serious logical implications for the nature of, and relationships between, design problems, design solutions and the design process that, according to Schön, are unique to designing and distinct from scientific rational processes.

— **Bounded Rationality** is Herbert Simon's (1969) conception of the design process as a special case of decision-making. Simon theorizes the design process as a series of decisions from finite lists of options. For instance, clients might select from a list of design requirements to impose on the designer. The designer would then generate a list of possible functions in order to meet the clients' needs. From this finite list of functions, a designer would select the "satisficing" option, which is one that both satisfies and suffices (Simon, 1969). In other words, through an analytical process, a designer evaluates lists of options and moves through the design process. According to this theory, designing is a process of exploring and searching a space of existing solutions and, through rational decision-making, choosing a "satisficing" solution.

We argue that each of these theories claims to say something about the true nature of designing, but this alone does not imply scientific*ness*. Freud claimed to say something about the true nature of the mind, but according to Popper, Freud's theory was pseudo-science at best and the substance of myth at worst. In the following section, we make the case that C-K theory, the FBS framework, Figural Complexity, and Bounded Rationality can be understood as scientific theories in Popper's terms.

4 A POPPERIAN ANALYSIS

In this section, we focus on an explication of each theory in terms of its falsifiability. One way to initiate this task is by considering each theory in light of those that Popper describes as non-scientific (e.g. Freudian psychoanalytic theories or Marxist theories of history). Our point of departure can be a question asked by Popper, but revised for our current purposes: What makes Marx's theory of history or Freud's theory of psychoanalysis different from our chosen theories of designing? They are unfalsifiable, and unfalsifiable theories can only ever yield confirmations.

Think of a proposition as simple as "All men are mortal." It is *un*falsifiable. As with Marx and Freud's theories, everywhere we look we can find confirming evidence of its "truth." No factual propositions exist that clash with it. We define factual propositions as those propositions with high truth-values, where truth-values are functions of empirical observations and mutual consensus within a community. Newtonian mechanics, for instance, had centuries of empiricism and consensus within the scientific community. And so when Einstein proffered his theory of relativity, it clashed with established (antithetical) factual propositions about the way the world worked—all derivatives of Newtonian theories. In addition, unlike Marx and Freud's theories, Einstein's was empirically viable—it could be falsified by empirical observation. There are two lines along which we must consider our theories, then. First, we must consider potentially antithetical factual propositions. Second, we must consider empirical viability.

Antithetical factual propositions presuppose factual propositions. So, the question then becomes, What factual propositions about designing might we infer from C-K theory, the FBS framework, Figural Complexity, and Bounded Rationality that would point towards empirical viability?

From C-K theory, we might infer that designing involves "expanding" concepts by moving between (C) and (K). Within (C), designers develop and partition concepts. Within (K), designers acquire and generate knowledge, which fuels expansion of (C). However, (C) and (K) are conceptual spaces. We cannot observe them when we observe designing, but they are useful ways to frame the process of concept expansion, which, arguably, might be an observable phenomenon. If we make the claim that concept expansion is an observable phenomenon in designing, then we also make claims about what designing is not. In other words, like Einstein's theory, C-K theory forbids certain observable states from occurring. For example, it bars concepts (and knowledge) from static states. If a process is a true design process then, according to CK theory, concepts and knowledge *must* expand. Concept expansion might entail iterating existing concepts into different, novel ones. Knowledge expansion might manifest in learning or the application of learning through iterating. The absence of such phenomena could be a potential falsifier of the theory.

Factual propositions about designing might look different if we turn to the FBS framework. For example, based on the theory we might predict that designing will entail a series of transformations of functions, behaviours, and structures. In fact, Gero has provided a model that communicates the kinds of transformations that are observable in designing. In the case of the FBS framework, while we would agree that it does not capture the whole complexity of designing, it does capture one aspect of designing that, if taken away, leaves us with an approach that is not designing. We should be able to look at designing and "see" evidence of transformations. In the absence of such evidence, we should reconsider the theory and scrutinize our means of looking at/for the predicted phenomena.

Figural Complexity provides yet another perspective from which to look at and make predictions about designing. Unlike C-K theory and the FBS framework, Figural Complexity theorizes the nature of designing from the perspective of the design proposal. If you look at design proposals (with their inherent figural complexity), and if you see changes to parts of those proposals, then your appreciation of (and hence approach toward) the whole design changes. Perhaps this motivates the following prediction: during designing, designers perpetually redefine their understanding of the design situation, and their approach towards the object of their activity. Redefining an approach could mean redefining requirements, realigning values, or setting a new "problem" in need of a solution. Schön himself has suggested that if we were to observe designing, among other things, we should always see "kinds of learning where, in the process of designing, the designer comes to see the situation, design trials, and criteria of fit in new ways" (Schön, 1990). Schön's theory can yield concrete testable claims, verifiable through empirical observation.

Bounded Rationality provides a fourth perspective from which to look at and make predictions about designing. Coming from an antithetical perspective to that of C-K theory, Herbert Simon's theory frames designing as a special case of decision-making whereby designing proceeds from a set of fixed requirements in a known (knowable) situation. Designing involves selecting (representations, functions, behaviours, etc.) from finite lists using well-defined, decision-making heuristics. Designing, then, is a series of decisions motivated by a static set of requirements. *Not* designing, therefore, might be a series of guesses or moments of random inspiration, motivated by a set of unknown or malleable requirements.

In this section, we have suggested that each of our four theories asserts *non-trivial* factual propositions about designing, which, we believe, are subject to disproof through empirical observation. These factual propositions also forbid certain observational states. For example, C-K theory forbids designing from concept "stasis" or "contraction." The FBS framework forbids designing that does not include transformations of functions, behaviours, or structures. Figural Complexity forbids designing from excluding types of learning whereby the designer reframes the requirements, trials, or criteria of fit.

Given the scientific status we have attempted to confer upon these theories, we now must turn our attention to the notion that these theories do not "scientize" design. Instead, as we will argue, they respect the integrity of designing as an approach distinct from science.

5 DISCUSSION

We argue that scientific theories of designing do not necessarily scientize design—they do not necessarily turn designing into a scientific process. By "scientific process," we mean an "organized, [objective,] rational, and wholly systematic approach…" (Cross, 2001). Of our four theories, it is perhaps apparent that Bounded Rationality skews closest to a scientific process. It has even been described as the "culmination" of the "design science decade," (Cross, 2001) during which many design theorists and practitioners sought to develop the design equivalent of the scientific method. Maybe Bounded Rationality does not provide an understanding of designing as an approach distinct from science whereas our other three theories do. If this is the case, then what kind of understanding of designing do C-K theory, the FBS framework, and Figural Complexity provide us with? We will suggest that these theories provide us with an understanding of designing as having three distinct characteristics: no given problem, no given process, and no given solution.

It is clear that our theories all have concerns with the terms, problem, process, and solution. For instance, Hatchuel has suggested that "problem" is an ill suited term for designing (Hatchuel, 2001). And, as we will argue, according to our three theories, design outcomes do not "solve" problems. As Gero has said, designing "does not produce solutions… it produces representations of things that might work" (Gero, 2013) given changeable sets of functional requirements. We might therefore recast "problems" as "existing situations," which can be construed as problems or not. Similarly "preferred situations" could be understood as "solutions" or design outcomes.

A fuller explication of a *lingua franca* of design would certainly be interesting and useful for design as a discipline. But in the absence of a common language of designing—even amongst our theories—we construe of our terms as useful conceptual bridges. There may not be problems, processes, or solutions in designing, but perhaps there are analogous concepts for which these terms might act as useful proxies in the following discussion.

Designing has no given problem. By "no given problem" we mean that "design briefs," "specifications," or "requirements" even if clearly stated are not fully known at the outset. Hatchuel and Weil, Gero, and Schön abide by this proposition. Hatchuel and Weil (2009) claim that "ambiguity, ill-defined issues, and poor project wording are not problems or weaknesses in design, they are necessary!" Gero (1990) acknowledges the vagueness of design problems when he asks, "How is it that designers can begin designing with incomplete information and before all the relevant information is available?" And one of Schön's (1990) critiques of Simon's theory is its failure to account for the "ill-formed problems" characteristic of the "early phases" of designing. For Schön (1990), it is only as designing progresses that problems become "well-formed… after a basic design structure has stabilized." Moreover, we can see how these claims inform each model of designing.

C-K theory models designing as a process of expansion, and its starting point is an "incomplete, even ambiguous" concept in the C-space. Once this concept has been established, the designer moves into the K-space to "prove" the concept. "No given problem" can be viewed in C-K theory as a *prerequisite* for designing since ambiguity is apparently a driving force behind the expansion of the C and K spaces. In the same way that the first concept in C-K theory "triggers" expansion, the formulation of initial "functional requirements" in the FBS framework triggers transformations. The initial set of functional requirements is the output of the first type of transformation, which Gero and Kannengiesser (2014) call "formulation." *Formulation* describes the move from requirements, which can be "given to the designer by external specification," to functions. But this initial set of functions is iteratively transformed throughout the design process. Iterative transformation is perhaps analogous to the expansion occurring in C-K theory. Finally, Schön proposes the concept of generative metaphor as the first step in designing. Generative metaphors "[frame] the problem of the problematic situation and thereby set directions in which solutions lie and [provide] a schema for exploring them" (Schön, 1990). Generative metaphors "give direction to inquiry" (Schön, 1990). This direction can be understood as a response to the innate ambiguity of "design briefs," "specifications," or "requirements." Designing proceeds from ambiguity towards clarity, yet the nature of its procession is just as ambiguous as its starting point.

Designing has no given process. By "no given process" we mean that the design process cannot be clearly stated or known *a priori* or *in medias res*. It may seem as though each of our theories articulates "given" processes. C-K theory models designing as a continuous interplay between the C-space and the K-space whereby concepts and knowledge "expand" until a design is produced. The FBS framework models designing as a series of transformations between functions, behaviors, and structures. And Figural Complexity models designing as the perpetual reframing of the "situation, design trials, and criteria of fit." (Schön, 1990). But these "processes" are abstract. As John Gero (2013) has said, "[The FBS framework] is not how design happens," by which he means it does not account for the singular twists and turns indicative of "situated" instances of designing. So perhaps we should refine our claim to the following: designing has no given, *particular* processes, where a particular process is a stated or known set of detailed steps taken to achieve (an) outcome. In contrast, it is clear that science has given, particular processes, by which we mean that scientific processes can be (or at least should be) clearly stated or known *a priori*.

Empirical science concerns itself with modeling and predicting how the natural world works. Implicit in this concern is a disavowal of practitioner subjectivity. It is important that empirical science is replicable since replicability is a factor in determining truth. The truth of an observation of a phenomenon relies on the principle of multiple access. Different scientists observing the same phenomenon (using the same process) should "see" the same thing. They should come to the same "conclusion" about the theory or hypothesis under examination. Importantly, conclusions to empirical scientific processes can be articulated *a priori*. In the case of the eclipse expedition, either the stars would be in the same location in the sky in both photographs or they would be in different locations. We do not mean to suggest that there are no anomalies in science. There are. But in discussing the empirical scientific process, it seems reasonable to claim that there exists a finite list of known, possible outcomes, specifiable *before* observation. This is perhaps because there is a kind of causal relationship between the problem, process, and solution in empirical science. The nature of the problem determines the testable claim, which determines the empirical method(s). While the problem and process do not necessarily "cause" the empirical outcome in science, it seems reasonable to suggest that they cause the generation of a finite list of *potential* outcomes. The same cannot be true of designing because the problems, processes, and solutions are infinite and unknowable *a priori*.

Designing has no given solution. By "no given solution" we do not mean that solutions remain ambiguous throughout designing. As Schön (1990) acknowledged, possible solutions emerge from "well-formed problems" in the later stages of designing *after* a "basic design structure has stabilized." Hatchuel and Weil (2009) echo Schön when they claim "design faces situations where it is not possible to define even an infinite list of known design candidates...” Design candidates shift over time through the act of expansion by way of “a group of partitions that could not be activated at the beginning of the process” (Hatchuel and Weil, 2009). Designers simply lack the knowledge at the outset of designing to infer the nature of final design candidate(s). Finally, Gero (1990) captures the nature of the “solution” as an emergent quality of the process when he says, “… what is relevant [to the solution] only manifests itself as the design [process] proceeds and varies with the decisions taken.”

There seems to be a nontrivial relationship between process and solution inherent in each theory. At some (unspecifiable) juncture in designing, possible solutions emerge in response to a burgeoning sense of what constitutes the problem. But we must be cautious. While each theory describes a “stabilization” wherein the problem becomes “well-formed” enough for the emergence of proposals, candidates, or descriptions, this does not mean that the relationship between problem and solution—or for that matter *process* and solution—in design is in any way deterministic as it is in science. In design, it is perhaps more apt to suggest, as Schön (1990) and others have stated, that well-formed problems do not exist until there is a solution—a final design. Even with strict framing and fixed boundaries around a possible design space, limitless solutions might still emerge until a decision is made about what is an appropriate design.

In this section, we have explored the possibility that C-K theory, the FBS framework, and Figural Complexity communicate an understanding of designing as having no given problem, no given process, and no given solution. We claimed that designing (as understood by these three theories) is necessarily distinct from science. Science strives towards establishing clear problems, clear processes, and definite solutions, which relate to each other in nontrivial ways. We suggested that there is a causal relationship between problems, processes, and solutions in science—a relationship that is wholly absent in designing. Problems do not determine the process, and neither the problem nor the process determines (a) solution.

With this perspective, we believe that we are better positioned to scrutinize different activities in order to determine whether they truly are instantiations of designing. This means that the question of demarcation could at least partially be answered.

6 CONCLUSIONS

In this paper, we set out to answer one question. Can there be scientific theories of design that do not scientize design? We adopted Karl Popper’s criterion for demarcating scientific theories from others: falsification, refutation, or testability. Simply put, if a theory is falsifiable—if from the theory one can deduce antithetical factual propositions that refute its explanatory hypotheses—then it is scientific. Armed with this criterion, we analysed four seminal theories of designing: CK theory, the FBS framework, Figural Complexity, and Bounded Rationality. We concluded that these four theories of designing *can* be framed as scientific theories. Furthermore, we concluded that at least three of these theories do not scientize design—they do not turn design into a scientific activity. They respect the integrity of design as its own approach. We suggest that these theories subscribe to a common theoretical core when it comes to the nature of designing.

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