CAN ABDUCTION RESEARCH ENHANCE UNDERSTANDING OF DESIGN PROCESSES ACCOUNTED FOR BY C-K THEORY?

Kroll, Ehud (1);
Koskela, Lauri (2)

1: Braude College of Engineering;
2: University of Huddersfield

ABSTRACT

Design process descriptions in the literature in general and those using C-K theory in particular lack some useful cognitive information that may affect the credibility of the process. Notions from abduction research are presented and proposed for enhancing such descriptions. Specifically, it is important to distinguish between design activities that are intuitive and those that result from deliberation; a topic that has long been discussed by philosophers of science and design scholars. The focus of the paper is on the ubiquitous design moves of proposing an idea and selecting among ideas, and on their execution by expert and novice designers.

Keywords: Abduction, Design cognition, C-K theory, Design process, Design theory

Contact:
Kroll, Ehud
Braude College of Engineering
Israel
kroll@braude.ac.il

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1 INTRODUCTION

The relatively modern C-K (Concept-Knowledge) theory of design is capable of accounting for many design-related phenomena, such as innovation and generativity (Le Masson et al., 2017), but at the same time seems to avoid dealing with many cognitive aspects. Even when explaining fixation (e.g., Agogué et al., (2014)), it mostly looks at the structure of K-space but leaves out other cognitive issues. We know that expansions in C-space are driven by knowledge in K (and vice versa), but there seem to be aspects of the design process that are not fully elaborated by the theory, such as the origin of ideas and the mental mechanism of making selections among alternatives. To demonstrate some interesting and mostly unanswered aspects of design processes, let us consider the following imaginary, albeit realistic, scenario (so far, unrelated to C-K theory):

> You are an expert designer with significant experience. Your company asked that you sit in a design review of a project by another team of engineers. The presenter elaborates the proposed solution; let us call it *Alternative1*. Your first question to him is whether they have also considered *Alternative2*, *Alternative3* (different solutions), etc. What is it that you would like to know by asking that question? You probably wish to know if *Alternative1* has been chosen over other solutions by deliberation, because it was investigated and proven to be better, or perhaps this was an intuitive choice of the first solution that came to mind. In the case of deliberation, you would like to know what the criteria used to select among the alternative solutions were, and this is especially important if you, as an expert designer, intuitively favor another solution. In the case of an intuitive choice, you would like to know whether the designer is a novice or expert. If novice, you might have doubts regarding the quality of the intuitive selection and possibly suspect a cognitive fixation. However, if the designer is an expert so that his/her intuition is based on considerable experience, the results of the design process are probably more credible.

This scenario deals with two common activities in design: generating a solution and choosing among several alternative potential solutions, and offers two main explanatory mechanisms for them: intuition and deliberation. Attempting to characterize these aspects requires better understanding of the designer's thought process, which is the domain of the cognitive branch of design research. Simon's (1969) bounded rationality (albeit its limitations as a theory of problem solving) emphasizes heuristics, while Schön's (1983) reflective practice uses the notion of framing. Some more recent works with a cognitive focus are by Badke-Schaub and Eris (2014), dealing with the role of intuition in design decision-making, Taura and Nagai (2017), addressing intuition in creative design processes, and Kannengiesser and Gero (2019), who modify and use their FBS framework to accommodate system 1 design moves *à la* Kahneman's fast and slow thinking with system 1 and system 2. These authors sometimes differ in their views, but all make use of notions expressed through such terms as intuition, guessing, gut feeling, insight and instinct.

We propose in this paper to use ideas from research into abduction, both in science and in design, to shed light on unanswered aspects of design process descriptions that follow C-K theory. In the following we briefly describe C-K theory and list those aspects and issues that seem to be described by it relatively weakly or not at all. Next, some research into design abduction is depicted, and the controversy regarding the definition of abduction is used to adopt a unified view on its meaning. Finally, we examine possible abduction-derived answers to the questions raised earlier and offer some suggestions on enhancing design process descriptions with the abduction notions to create a richer representation and deeper understanding of design process accounts.

2 C-K THEORY AND QUESTIONS RELATED TO ITS DESCRIPTIONS

In C-K theory (Hatchuel and Weil, 2003; 2009; Le Masson et al., 2017), design is modeled as an interaction between two spaces, the space of knowledge (K), composed of propositions that have a logical status (true or false), and the space of concepts (C), where propositions are undecidable with respect to the existing knowledge. Concepts are of the form "C_i = *there exists a class of objects X for which a group of properties* $p_1, p_2, \ldots, p_n$ *is true in K*". A design process starts with an initial concept C_0, and the theory formalizes how this undecidable proposition becomes a decidable one. This is realized by two mechanisms, *expansions* in K (new propositions are added to K by deduction, learning, experimentation, etc.) that can continue until a decidable definition for the initial concept is obtained, and *partitions* in C (adding properties, known in K space, to the concept in C to promote its

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decidability). Partitions are called *restrictive* when they rely on properties usually associated with the class of objects *X* in K, and *expansive* when the properties are not normally associated with *X*.

Consider now the following occurrences and accompanying issues and questions that are typical of C-K descriptions, all using a hypothetical example of designing a smart road. Many C-K theory examples start with a definition of a relatively vague, sometimes described as ill-structured, concept C_0, as opposed to a better-defined design task. For example, Le Masson et al. (2017, p. 175) demonstrate the design of a "smart shopping cart"; quite an equivocal initial concept.

Question 1: Where do the properties, which are added through a K→C operator, come from? Obviously, the property comes from the K space, but how does it emerge in the designer's mind? Is it intuition or deliberation? Suppose, for example, that the property being added is "charging electric vehicles", meaning that the smart road is capable of charging cars while they move on it (see Figure 1). How was this idea conceived in the designer's mind?

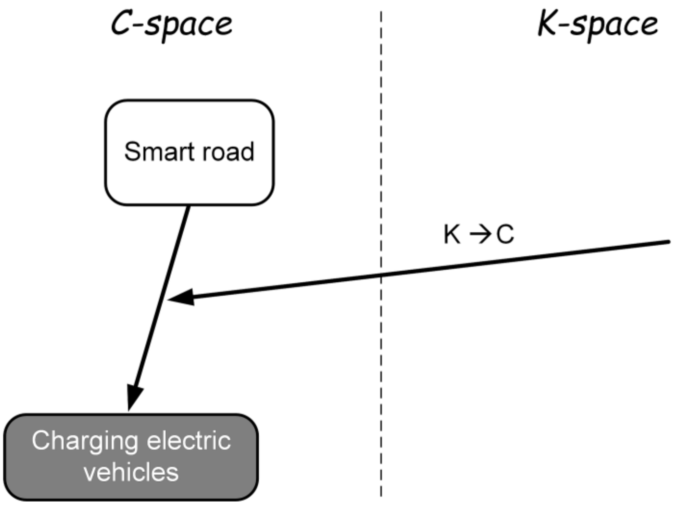

Figure 1: A K→C operator adds a property to the initial concept as described by C-K theory

Question 2: Why this particular property and not another? Was the property selected among several available ones or was it the only one thought of? Here is another property that can be added to the smart road concept: "adapting to varying traffic volume", perhaps aiming at changing the number of lanes in each direction during the day. But how to choose between adding the property "charging electric vehicles" and "adapting to varying traffic volume"? Was the latter property even taken into consideration when the former was chosen?

Question 3: Why are there usually just a few candidate properties to consider and not many, with some of them being 'crazy' and 'wild'? The number of properties to be considered for addition to the current concept is usually quite limited: Le Masson et al. (2017, p. 137) show that a C_0 of a "cheaper and lighter camping chair" resulted in only six different paths based on the number of legs, and they demonstrate (p. 154) how C_0 of "micro-mobility services" led to considering only three properties: neighborhood bus line, no vehicle, and no bus (other vehicles). Similarly, in the smart road example, we may have "charging electric vehicles", "adapting to traffic conditions", perhaps also "display speed recommendations", "warn of road hazards", "provide location-relevant entertainment/information", and a few more. But we usually do not see hundreds of candidate properties being mentioned, and certainly not farfetched ones such as "cook food" or "knit a sweater".

Question 4: If a certain property is selected for further development of the concept (i.e., this particular property is the one being added to C_0), and this selection is made among several candidate properties that are all present in K, how is the selection carried out? Is it by intuition or deliberation? If deliberation, what are the selection criteria?

Question 5: In case there are multiple branches when partitioning a concept, how is a particular branch selected for further development? Intuition or deliberation? If deliberation, what are the criteria? Consider, for example, the situation depicted in Figure 2, where the smart road initial concept branches to "creates value for driver" and "creates value for road owner", and these in turn branch further. "Creates value for driver" is the first selection, "safer" is the second, and so on. But how are these choices made?

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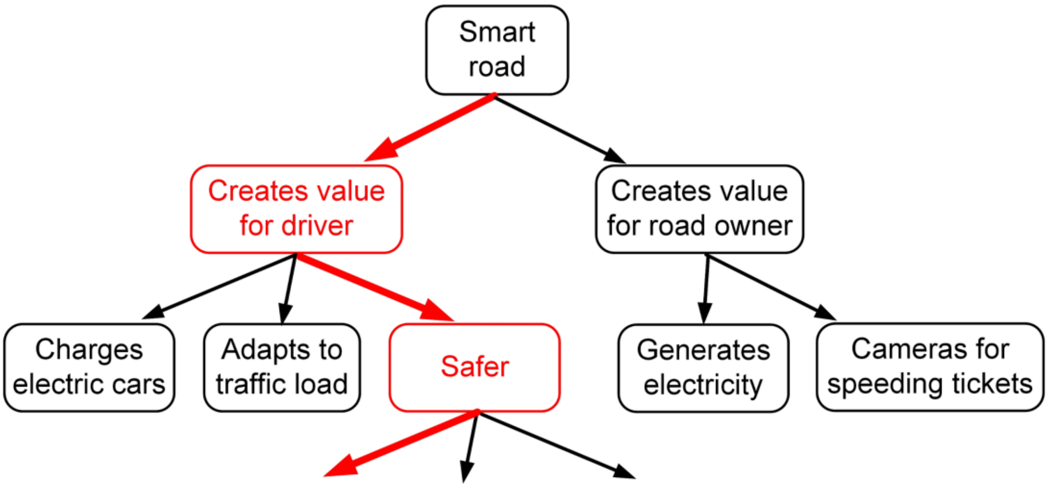

Figure 2: Multiple selections among branches lead to creating a design path in a typical C-space diagram

The abovementioned questions can be summarized as follows. Some are related to the generation of new concepts through C-K's partitions (that is, adding properties to concepts) in C, and more specifically, these questions are concerned with identifying the origin of the evolving ideas (the added properties) with an emphasis on whether it is deliberation or intuition. Some other questions focus on selection activities, where choices are made, and the interesting aspect is again, whether deliberation or intuition are used. In case it is deliberation, we would like to know whether the selection criteria are generic or problem dependent, and whether easier-to-implement, easier-to-test or more promising branches are preferred. As shown in the next section, research on abduction attempts to address the same or very similar questions.

3 BACKGROUND ON DESIGN ABDUCTION

One of the first treatments of abduction in relation to design is by March (1976), who claims that it is the key mode of reasoning in design, but also that it differs considerably from science. The goal of science, according to March, is to establish general laws, while design is concerned with realizing a particular outcome. March proposes the following pattern of abduction: from certain characteristics that are sought, and on the basis of previous knowledge and models of possibilities, a design proposal is put forward.

March's work has been followed by several design researchers, some of them inspired by treatments of abduction in philosophy of science, who attempted to analyze the design process and associated reasoning in terms of abduction. A well-known contribution can be found in Roozenburg's (1993) discussion of whether the reasoning towards a tentative description of a design follows the conventional view on abduction. He argues that the common view of abduction as "explanatory" is not applicable to design, and that the core of design reasoning follows another type of abduction, which he calls "innovative abduction" or "innoduction" (Roozenburg and Eekels, 1995). In fact, says Roozenburg (1993), Habermas (1978) distinguished between *explanatory* abduction and *innovative* abduction, and it was March who did not make that distinction. Roozenburg says that in the case of innovative abduction, one starts from a surprising, not yet explainable fact (the result), and tries to conceive of a new rule (a principle, law, or theory) that allows inferring the cause (the case). Therefore, the rule itself is not yet assumed to be true. He further explains that the conclusion of this inference is a hypothesis that still needs to be tested by deduction and induction before it becomes a new rule. The abovementioned patterns of explanatory and innovative abductions are shown in Figure 3.

Roozenburg even claims that this pattern is Peirce's original intention, using the well-known argument that the *p* cannot be part of the premise and needs to be part of the conclusion of the inference. This means that both $p \rightarrow q$ and *p* "present" themselves together, at the same moment. Roozenburg's innovative abduction is claimed to represent the kernel of the design process. The desired result is the *function* to be satisfied, his rule looks like "if *form* + *way of use* then *function*", and the conclusion is *form* + *way of use*.

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Explanatory abduction:

$p \rightarrow q$	(a given rule, IF p THEN q)
q	(q is a given fact, a result)
p	(p is the conclusion, the case or cause)

Innovative abduction:

q	(q is a given fact, a desired result)
$p \rightarrow q$	(a rule to be inferred first, IF p THEN q)
p	(p is the conclusion, the cause, that immediately follows)

Figure 3: Explanatory abduction vs innovative abduction after Habermas (1968) and Roozenburg (1993)

Dorst (2011) offers another view on design abduction that uses the following formula:

what (the artifact) + *how* (the working principle) → *value* (aspired)

in which the aspired *value* is always given and is the starting point for design. If the *how* is also given, then the *what* is generated by a so-called *abduction-1*, which is precisely "explanatory" abduction. Dorst calls this case "conventional ('closed') problem-solving that designers often do". However, if the *how* is not given, then we have a more 'open' problem in which we need to decide on both the working principle and the artifact. This is accomplished by *abduction-2*, which is the same as Roozenburg's innovative abduction. *Abduction-2* is carried out by first developing or adopting a "frame" (after Schön, 1983), which is a "general implication that by applying a certain working principle we will create a specific value", and takes place according to the pattern of Figure 4.

q	(q is a given desired *value*)
$p \rightarrow q$	(IF *how* THEN *value*, the first conclusion)
p	(*how*, the second conclusion)

Figure 4: Abduction-2 after Dorst (2011)

In addition, Dorst says that when a possible or promising frame has been proposed and the *how* is known, *abduction-1* can take place to design the *what*, the artifact.

Kroll and Koskela (2016) build upon the works of Roozenburg and Dorst and present their own version of the kernel of design: the mechanism of design reasoning from function to form is suggested to consist of a two-step inference of the innovative abduction type. First is an inference from a desired functional aspect to an idea, concept, or solution principle to satisfy the function, and this is followed by a second innovative abduction, from the latest concept to form, structure, or mechanism.

4 THE CONTROVERSY IN DEFINING ABDUCTION

The few studies into design abduction described so far hint at the variety of interpretations that exist and the lack of a unified picture of the subject. Koskela et al. (2018), for example, ask whether abduction should be understood as a type of inference or as a property of an inference. This, of course, is also related to the ongoing controversy among philosophers of science regarding Peirce's original (but changing over time) intentions and the debate between interpreting abduction as the generation of novel explanatory hypotheses (Peircean abduction) and the selection of the most promising

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hypothetical explanation among several for further testing, usually considered to be inference to the best explanation, or IBE (McAuliffe, 2015).

Each interpretation raises some objections and counter-arguments, as summarized by Mohammadian (2019a), who proposes a unified interpretation of abduction and IBE whereby abduction has two phases: (1) hypotheses-generation, a creative, ampliative phase governed by insight, to generate a few plausible explanatory hypotheses, and (2) hypotheses-ranking, wherein relative "pursuitworthiness" is determined based on economic considerations in a rule-based, deliberate and self-controlled manner. Selecting the highest-ranking hypothesis follows.

Peirce said that the generative phase 1 is carried out in an instinctive way, through the mental faculty of guessing, which he called insight (Peirce, CP 6.531, 1901; 7.46, 1907), and which has two functions: inventive and restrictive. The latter is a tendency to conjecture rightly or towards preferring truthful hypotheses, so only reasonable hypotheses are generated. In contrast, phase 2, where it is decided which of several hypotheses is the worthiest one for further testing, is a calculated and rule-governed procedure, so it is self-controlled and deliberate. Assuming all candidate hypotheses are equally capable (to explain), they need to be ranked based on economy and the highest-ranking one picked (Peirce, CP 6.525, 1901). Economic criteria are cost of testing, testability, intelligibility, consistency with well-confirmed beliefs, refutability (falsifiability), broad scope, fruitfulness or ability for continuation of inquiry, simplicity and accuracy. Cost of testing is of the highest importance to Peirce, while all the other criteria are called “theoretical virtues” or “epistemic values”. For Peirce, having a higher rank does not make an explanation closer to truth; it only means that its testing requires less expenditure of time, money, energy, etc. in comparison with lower-ranking hypotheses.

Mohammadian (2019b) says that philosophers who claim that Peircean abduction and IBE are the same, or that they are completely different, are all wrong, as there are some similarities and some differences. For Peirce, says Mohammadian, abduction is understood as the first stage of scientific inquiry and not a merely formal inference. Abduction should be interpreted as unification of hypotheses-generation and hypotheses-ranking. Some researchers say that in IBE, one explanation is chosen because it is better than the others. But some say that the chosen explanation should be good by itself, not only by comparison. If only one explanation is found, it is probably true.

McAuliffe (2015) claims that Peirce’s abduction is the process of generating and selecting hypotheses to test: “Peirce’s notion of abduction does not address how to choose one theory over others given a body of evidence. Rather, abduction is best interpreted as a method for arriving at hypotheses and selecting a hypothesis to test. Put another way, inference to the best explanation is supposed to be the *last* stage of inquiry, whereas abduction corresponds to the *first* stage of inquiry.” Quoting Peirce, McAuliffe further says that abduction is the “process of forming an explanatory hypothesis. It is the only logical operation which introduces any new idea”. However, in Peirce's later work he also talks about abduction as “the process of choosing a hypothesis”, saying that choosing well can help find the truth faster than chance guessing or investigating dead ends. He proposes criteria for selecting which hypothesis to test, which are necessary conditions for worthiness of consideration (Peirce, CP 7.220, 1901): the hypothesis should be experimentally verifiable, and it should explain the facts in question. There are also economic considerations that increase the likelihood of finding the truth faster:

1. Time and money should be conserved: if a hypothesis is unlikely but can be refuted quickly or inexpensively if false, then it should be tested first.
2. The value of the thing proposed, in itself: look for signs that the hypothesis is true. Two kinds of signs are possible: (a) instinctive (come naturally, insight), (b) reasoned (have supporting background evidence). However, Peirce warns against “likelihood” and prefers “uberty”, the productivity of a process and its ability to bring about undiscovered truths.
3. Relation to other possible investigations: prefer first to test hypotheses that are relevant to a wide range of phenomena, are easily interpretable, and whose falsification would rule out entire classes of hypotheses to which they belong.

So, McAuliffe's conclusion is that abduction is both hypotheses generation and selection for testing: “hypothesis generation is not purely instinctual, at least if that implies that the hypothesis was formed on no rational grounds. Rather, abduction is principled—hypotheses are formed in such a way that they meet certain criteria”. Then, the hypothesis is evaluated to see if it is testable, economical to test relative to rival hypotheses, highly likely, etc. If not, then the process repeats. The relative speediness of this process is underwritten by humans’ innate ability to generate plausible hypotheses.

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5 POSSIBLE ANSWERS FROM ABDUCTION RESEARCH TO THE C-K THEORY RELATED QUESTIONS

The many discussions on abduction in science contribute insights that can be used in design research. If design abduction is broadly defined in such a way that it encompasses generating plausible concepts *and* choosing one among them for further development, then perhaps advances in understanding design can take place. In particular, it may be useful to distinguish between design activities that are the result of insight and intuition, and those that are governed by reasoning and deliberation, and to examine the nature of the criteria used in making selections among alternatives. The questions from Section 2 are now addressed with attempts to answer them.

Question 1: Abduction research offers two possible answers to the question of where properties come from. They may come from a conscious, controlled process of deliberation, and this would probably be the conventional way for engineers, for example, to design. But abduction research also tells us that intuition, gut feeling and knowing by instinct, without thinking, are possible sources for the new properties. Peirce himself, while clearly concerned with scientific inquiry and not design, brings the following *design* example of intuitive abduction taking place (Peirce, CP 7.498, 1898):

> Suppose I have long been puzzling over some problem, — say how to construct a really good typewriter. Now there are *several ideas* dimly in my mind from time, none of which taken by itself has any particular analogy with my grand problem. But someday these ideas, all present in *consciousness* together but yet all very dim deep in the depths of *subconscious* thought, chance to get joined together in a particular way such that the combination does present a close analogy to my difficulty. That combination almost instantly *flashes out* into vividness. Now it cannot be contiguity; *for the combination is altogether a new idea.* It never occurred to me before; and consequently, cannot be subject to any acquired habit. It must be, as it appears to be, its analogy, or resemblance in form, to the nodus of my problem which brings it into vividness. Now what can that be but pure fundamental association by resemblance?

In modern terms we would probably refer to this description as a period of incubation followed by an "aha" flash of insight or "eureka moment".

Question 2: Abduction may also offer an explanation to why a particular property is chosen over another property to be added to a concept. The ongoing debate about the meaning of abduction (Section 4) clearly shows two possibilities: if abduction is all about *generating* a hypothesis, then the chosen property is the only one that presented itself; if abduction is about *selecting* a hypothesis among several, then the chosen property may have been compared to other properties before its final selection. In the latter situation, a deliberate comparative process is hinted at, although we cannot rule out some sort of an intuitive choosing step. In the former situation we may also want to distinguish between two cases: (a) the chosen property is the only one that *intuitively* comes to the designer's mind, in which case we might suspect a fixation effect, or (b) the chosen property is the only one that *deliberately and consciously* comes to mind because the design problem is very difficult, in which case we are happy to be able to think of even one solution.

Question 3: To explain why there are usually just a few candidate properties to consider and not many, with some of them being 'crazy' and 'wild', we should look at what Peirce wrote about this issue (Peirce, CP 5.172, 1903): "trillions of trillions of hypotheses might be made … [but] after two or three or at the very most a dozen guesses, the physicist hits pretty nearly on the correct hypothesis". Peirce attributed this phenomenon to the human tendency to guess correctly (Peirce, CP 7.679, 1903), and generate only reasonable hypotheses (Peirce, CP 7.680, 1903). We might wonder whether humans have the mental capacity to guess rightly also in design. Have humans evolved to be good at designing, or design problem-solving, in addition to making good guesses regarding laws of nature? In this context we should remember that animals too can respond to nature through instinct, building nests and shelters, which seems to be a sort of design. It may also be that we try to be economical, or efficient, or we are just lazy: we stop with a few candidate properties (especially if we feel that they are good), unless we are forced somehow to map a large solution space (e.g., a brainstorming session).

Another explanation for why only a few hypotheses are generated may be the subjectively felt certainty connected to the outcome of abductive processes (Peirce, CP 5.181, 1903). In design this sense of certainty may express itself as a lack of inclination to do further reasoning and look for additional solutions after several of those have been generated.

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The reason for not normally generating many crazy, wild, unrelated hypotheses too is that our guessing instinct is good at restricting us to conjecture rightly in general, as Peirce thought, but also that we may prefer preservative generativity, that is, generating new hypotheses that do not contradict existing knowledge, thus avoiding unnecessary and costly knowledge reordering, where existing rules and theories should be abandoned (Kroll et al., 2022). Yet, we also should recognize that sometimes crazy and wild hypotheses are necessary for disruptive design innovations.

Questions 4 and 5: Selecting a property to be added among several available ones or selecting a particular branch of a concept tree for further development are both design activities that can be related to the notion of inference to the best explanation (IBE), or hypothesis ranking and selection. In both cases we are interested in knowing whether intuition or deliberation is used, and if deliberation, what are the selection criteria. The "pursuitworthiness" interpretation by Mohammadian (2019a) and others emphasizes that this phase is rule-based, deliberate and controlled. In design we seem to prefer such deliberate processes when evaluating alternatives, but we cannot rule out intuitive action here. The focus of interest should be the expertise level of the designer: If the selection is intuitive, how reliable is it? Does the designer have enough experience and expertise to base his/her intuitive selection solidly, even in retrospect (i.e., to explain, at a later time, why that choice was better beyond saying that it was his/her gut feeling)? If the designer is a novice, an intuitive selection may seem unreliable, and we expect to see a deliberate process instead. Lawson and Dorst (2009, p. 99) explain this difference in reasoning: "A novice will consider the objective features of a situation, as they are given by the experts, and will follow strict rules to deal with the problem. [...] The expert responds to a specific situation intuitively and performs the appropriate action straightaway. There is no problem solving and reasoning that can be distinguished at this level of working."

Regarding the selection criteria used, Peirce talks about cost of testing as the most important criterion (see Section 4): The highest-ranking hypothesis has the lowest cost of testing but is not necessarily closest to the truth. In design we may sometimes develop a less-promising branch, but one whose development cost is lower, just to eliminate it (see an example of such reasoning in Kroll and Koskela, 2017). But what does more (or less) promising mean? Some of Peirce's economic criteria were mentioned before, and they all seem generic and problem-independent. In design, however, we usually have a mix of evaluation criteria, with some being general (e.g., robustness, simplicity, intrinsic safety) and some specifically addressing the design requirements at hand (e.g., the ease with which low weight can be obtained, availability of spare parts), as can be found in many textbooks using Pugh's concept selection method (Pugh, 1991).

6 DISCUSSION AND CONCLUSION

In this paper we intentionally chose to refer to C-K theory's descriptions of designing because they clearly show the two aspects of design processes that we wished to address: (a) developing a concept in C-space by adding properties to it that come from K-space, and (b) selecting among alternatives, both competing properties in K and competing branches in C for the next step in evolving the design. The scenario in Section 1 of questions raised during a design review was hypothetical. Yet, this imaginary description should look realistic and familiar to anyone involved in design. The example of designing a smart road in Section 2 was also made-up but helped demonstrate the major subjects of this paper: intuition vs. deliberation and selection criteria. It was also a purposeful decision to focus on just intuition and deliberation, and not investigate possible other taxonomies of reasoning.

Abduction research makes a clear distinction between the activity of generating hypotheses and selecting among them the most promising one for further exploration. This is analogous to the ubiquitous design activities of proposing a hypothetical (that is, not yet proven) solution and selecting among design alternatives. The usefulness of this analogy is in applying the dichotomy of intuition vs. deliberation, as used in abduction research, and the nature of selection criteria also in design.

Intuition, insight, guesses are all discussed by Peirce as opposed to conscious deliberation. In design, we tend to think that deliberate reasoning prevails, but it seems that intuition is also present. We may even want to distinguish between three sources of ideas: serendipity (being a wild guess), intuition (an educated guess) and deliberation. As we showed in this article, it is not always easy to tell which of these sources is or should be used, but there are significant consequences to whether the designer is a novice or expert.

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The ongoing controversy among philosophers of science as to the exact nature of abduction and their attempts to explain Peirce's intentions constitute a rich foundation for adopting notions that are relevant also to design. Yet, we propose an understanding of abduction in design that is beyond Peirce's formulation. We do not wish to reconcile or participate in the ongoing argument about what Peirce really meant, just offer a new perspective on designing that is based on abduction research, and whose foundation is the unified interpretation of abduction, covering both generating hypotheses and selecting among them.

The abduction literature is somewhat vague on one aspect of IBE: it is unclear whether the selection is made among explicitly given alternatives, or it can also take place when the choices are implicit, in which case the unselected alternatives never emerge into consciousness. Lawson and Dorst (2009) and many other researchers believe that expert designers work intuitively and directly retrieve a solution idea from their memory without going through all other solution ideas, so they remain implicit. Inexperienced designers, on the other hand, should follow a more structured process wherein alternatives are made explicit.

A practical result from the present study is that design process descriptions may benefit from adding information regarding the thought mechanisms and the criteria used to propose ideas and to choose among them. This, together with recognizing the level of expertise of the designer, can inform us as to the extent of trust we can have in a particular design. For example, a C-K-style description of designing, which often consists of a diagram of the spaces and operators, could be supplemented with accounts of whether deliberation or intuition was used in the reasoning and what were the criteria used in making selections. In this sense, the proposed enhancements to the process descriptions constitute contributions to capturing the design rationale, which is a much-desired outcome.

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