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CONCEPT DESIGN AS KNOWLEDGE CONSTRUCTION – THE CASE OF USER-CENTERED DESIGN

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1. Introduction

After over forty years [Simon 1969] of empirical and theoretical studies of design, we are yet to develop a comprehensive cognitive theory of design. The progress in understanding creativity in design is similarly restricted. Several authors since have defended the notion that design is a distinct cognitive domain worthy of its own investigation [Goel 1995], but no universal theory of design psychology or cognition exists. Meanwhile design practice has developed particularly related to software design. Numerous new design methods, such as scenarios, probes, and personas, have emerged. However, recently Norman has argued for technology-driven development and criticized whether user-centered design (UCD) is good for design creativity [Norman 2010]. Because UCD has been viewed as a remedy for designer-centered technology, Norman's argument feels like a heresy. If we only better understood creativity in design, then maybe we could understand and learn from his provocative argument.

In this paper, we explore how "users" can influence the creativity of a professional, designer-driven product design process (cf. [Verganti 2008]). Unfortunately there is no design theory that could explicate the contribution of different design techniques to creativity. The existing theories are mostly founded upon the notion of design as problem solving (for instance [Goel 1995], [Simon 1969]). This approach has been insightful on some questions about design, but has turned out to be inadequate or inappropriate on many regards [Jonas 1993], [Thomas and Carroll 1979]. This seems to be the case with early design process, activity most unfit for problem solving framework.

Therefore we try to open up alternative perspectives for understanding creativity in the concept design of physical and software products. We do this by proposing a framework of design as *knowledge construction*; development of mental representations into external representations in a process influenced by explicit and implicit cognitive factors. The model tries to provide a common reference point, a cognitive framework, for different "creative" design techniques so they can be compared to one another. We see the present proposal as a first, heuristic step toward a building a cognitive design theory capable of explaining creativity better.

2. Background

This section reviews dominant models of design process with particular attention to the early stage, the "fuzzy front-end", starting from working definitions for key terms and proceeding to proposals of creativity in design.

2.1 Innovation and creativity

Creativity and innovation are among the most overloaded words in scientific and popular rhetorics. To study them, we need definitions for both. Along with the creativity research literature [Mayer 1999], we see that creativity is a label of *a designed artifact that is perceived both novel and valuable* (artifact as in [Simon 1969]). People capable of producing those designs could also be called creative, and the interest of this paper is in the production, which we call the *creative process*. We are promoting a process perspective which denies the existence of a clear creative component in the process. Instead we think that creativity emerges out of the collaboration of individuals facilitated by techniques and tools of design, and manifests in the design outputs. That is, the process channels the creative capacity of individuals into the creative design outputs.

The term innovation is similarly used for several purposes and can be ambiguous. We adopt the vocabulary found in a review of Garcia and Calantone [2002] and suggest that where as creativity can be attached to almost any object or act, innovation needs to be about some tangible and distributable product, service or behavior. An idea or even an invention (a proven idea) can be personally creative [Boden 2004], but is not yet an innovation. A creative idea may lead to an invention which we see plenty in design and research labs. But an invention at the back of our lab is not an innovation. If it spreads to all labs of our state or country, then it has become an innovation of some sort, historically creative act [Boden 2004]. Innovations require diffusion, adoption by endorsers. The ultimate proof is the market. In the design context, one could say that products are hypotheses about innovation, tested by their survival in the market. Here, we are interested only in the input design provides for the innovation process.

The innovation literature also describes the degree of change. Garcia and Calantone [2002] propose three categories of innovations: *incremental*, *really new,* and *radical*. Their typology is based on observing the magnitude of the effect created by some a technology on *micro* and *macro* levels, latter involving multiple micro levels. The effect is measured in worldwide diffusion, not in business profit as demonstrated by software world success stories of Linux or OpenSSL and others. As examples of radical innovation, [Garcia and Calantone 2002] they mention steam engine and WWW, really new innovations include laser printer and Sony Walkman, and supersonic planes and health foods fall into the category of incremental innovations.

2.2 The stages of the design process

We assume that different parts of the design process provide variable contributions to creativity. In the software engineering, prescriptive waterfall models have been commonly used to describe the ideal process. Typically stages such as *specification*, *design*, *implementation*, *testing*, and *maintenance* have been proposed [Sommerville 2001]. Similar stages can be identified in more recent models, which consider iterative, evolutionary, and agile development. In the product design literature, scholars too [Cagan et al. 2007], [Sommerville 2001], [Ulrich and Eppinger 2008] favor waterfall models, some of which are shown in Figure 1.

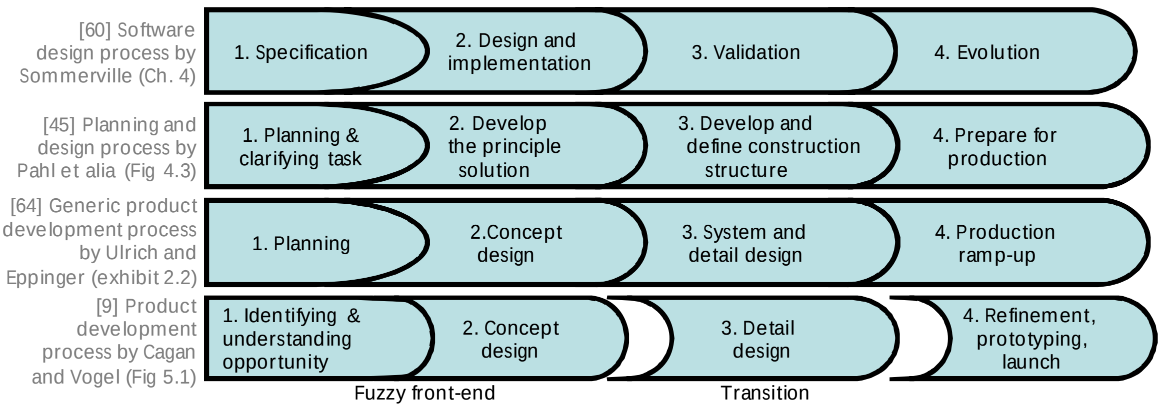

Figure 1. Models of early design process in software and product design from different authors

Concept design is an essential element of the process distinguished by two authors [Cagan and Vogel 2002] [Ulrich and Eppinger 2008]. This term is mostly popular in product design and automotive engineering fields. The goal of concept design is to create an approximation of the outcome of the design process – proof the idea and instruct further design implementation. In product design, this means product specifications or requirements, often complemented with or equaling to visualizations and prototypes. Concept cars are a prime example of this activity. With software, concept design is less commonly mentioned, but we believe that there are functionally equivalent activities. Instead of car mockups, software designers produce alpha releases, video demonstrators, and interactive prototypes of the emerging technology. In the cited process models (Figure 1), this would fall between specification and implementation.

Concept design has important influence on the whole design process. It largely defines *what will be designed* later on in the process. We claim that this commitment makes it the most important design phase for innovation, because the concept needs to already demonstrate how technical, user, and business constraints, together determining chances of success (according UCD proponents [Cooper 2004]), will be satisfied by the final design. Incremental innovation, on the other hand, seems to call for a change in detail, but not in the overall concept. While this paper is concerned with designing product concepts, it must be noted that there is room for innovation *related to products* also outside *product concept* design. Garcia and Calantone [Garcia and Calantone 2002] note how innovations can be based on marketing discontinuities. Similar point could be made for logistics, for instance. This would refer to *business process* concept design, not product concept design. Following the claim of generic design theory [Goel 1995], [Visser 2006], our thoughts should apply outside product design, although they are not discussed here.

Concept design involves many kinds of complementary activities. For Figure 2, we have gathered some necessary activity categories that are typical of concept design as it is currently practiced [Cagan and Vogel 2002], [Ulrich and Eppinger 2008]. Learning refers to the acquisition of new relevant knowledge, ideation to explicit attempts to come up with concept ideas, decision making to the selection of ideas, and implementation to the construction of external representations. These representations (sketches, videos, etc.) can become proofs-of-concept.

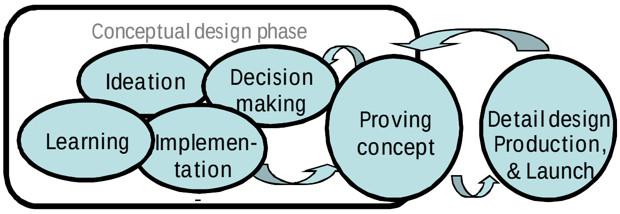

Figure 2. Model of typical contemporary concept design process, arrows illustrate knowledge transfer

2.3 Descriptive models of the creative design process

There are several process models that highlight the actions leading creative output. Warr and O'Neill have reviewed different accounts of design creativity [Warr and O'Neill 2005]. They propose a definition creativity, which we endorse: "*Creativity is the generation of ideas, which are a combination of two or more matrices of thought, which are considered unusual or new to the mind in which the ideas arose and are appropriate to the characteristics of a desired solution defined during the* ***problem definition and preparation*** *stage of the creative process.*" ([Warr and O'Neill 2005] p. 122; original emphasis) They relate the design process to general models of creativity and present important points for design creativity as a social process. They provide a nice overview of creativity models including [Amabile 1996], [Osborn 1957], [Wallas 1926] illustrated in Figure 3. Their meta-model (Figure 3) aligns several previous models among three stages: *problem analysis*, *generation of ideas*, and *evaluation of ideas.* The correspondence of these stages to the model of conceptual design in Figure 2 is clear, making concept design an exemplar model of creative process and grounding our claim of the importance concept design for creativity.

Author	Analysis	Synthesis	Evaluation
Wallas	Preparation	Incubation Illumination	Verification
Osborn	Fact-finding	Idea-finding	Evaluation
Amabile	Problem/task presentation Preparation	Response generation	Response validation
Shneiderman	Collect	Create	

Figure 3. General models of the creative process, adapted from Warr and O'Neill

2.4 Cognitive theories of design

2.4.1 Design as problem solving

Turning to psychological theories of creativity, we find a family of related proposals, all associated with what Fallman [2003] identified as the conservative account. Psychologically-oriented design researchers have repeatedly described design as *problem solving* (e.g. [Goel 1995], [Jonas 1993]). These proposals originate from early cognitive science which tried to duplicate human performance in a variety of task environments using computational models [Simon 1969]. The basic idea was to model a step-wise process of advancing from a defined initial state to a goal state operating with a set of legal moves chosen based on different search mechanisms. This was called searching the problem space. The approach succeeded very well in areas such as logic and simple games, but the application did not on all intellectual areas, for example in design tasks. Because design did not behave as a "real" problem, it was classified as an "ill-defined" problem [Reitman 1965]. The issues with this decision were already articulated in 1967 when Rittel analyzed the poor fit of problem solving theory to social policy design [Rittel and Webber 1973].

Since then, many have noted the troubles in relationship of design and the problem solving theory [Liikkanen and Perttula 2009], [Lloyd and Scott 1994]. The careful review of Visser [Visser 2006] finds several aspects why design does not meet the criteria for a problem. Design problems are ill-defined, fulfilling their requirements is a matter of satisficing multiple solutions rather than optimizing one solution, search in the "solution space" is opportunistic, problems are semantically rich, and they involve generative constraints. Solving these "problems" is complex because they are not simply decomposable [Visser 2006], but rather become decomposed implicitly in the knowledge-intensive interpretation process [Liikkanen and Perttula 2009]. As an outcome, design challenge can turn out to be trivial (routine) or too complex to be a problem [Visser 2006]. Also the attempts to characterize design excellence in terms of procedural knowledge, design problem solving techniques, has not been very fruitful (cf. [Stein 2004]).

Despite these issues, problem solving has persisted as the dominant paradigm in design psychology. This body of research has given us some insights (e.g. [Akin 1986], [Goel 1995]) to design, but there is an increasing number of results incompatible with this view (e.g. [Jansson and Smith 1991], [Purcell and Gero 1998]), particular related to concept design. Our view is that problem-solving metaphor is misleading and its continued use hampers the development of understanding of creativity in design. We claim that this is a fallacy similar to the one made by a person holding a hammer who tends to see everything as nails. If an object resists nailing it would be called an ill-behaving nail – not excluded from the category of nails, and the futile hammering persists.

2.4.2 Alternative approaches

Alternative accounts of design cognition are scarce. The majority of "deviant" theories include a divergence in a form of a shifting the emphasis away from problem solving and search paradigms. Visser [2006] holds a view that design is primarily about constructing representations. Her book focuses on external representations as objects of design, rather than mental structures underlying the process to a disappointment of traditional cognitive theorists. Hatchuel and associates [Hatchuel and Weil 2009] have proposed a C-K theory that uses similar concepts, creativity and knowledge. However, their focus of the C-K theory is formalizing generic descriptions of knowledge and concepts (i.e. design ideas), how they interact and expand. It does not attempt to provide a psychological description of design, but a new formalism, not void of old concepts, such as searching a space.

Maybe the most complete diversion comes from general psychology rather than design studies. Finke, Ward, and Smith [1992] have introduced the concept of "preinventive structures" for describing the creative process as creation specific mental representations. They have collected all elements of the creative process to an extensive model of creativity called GenePlore, which is compatible with design. In this model, preinventive structures are first separately explored and ideas are consecutively constructed from them. They name several cognitive processes that can produce the structures [Finke et al. 1992]. We accept the notion of creating mental representations, but find the separate generation and exploration of these constructs dubious. Thus we see it necessary to propose a knowledge construction view that steps even further from design (or scientific discovery) as problem solving views.

3. Design as knowledge construction

Our proposal is to think about the design as a process of individual and collaborative knowledge production, loosely inspired by the product design research literature [Jonas 1993]; [Visser 2006]. Our framework is describes building, sharing, and committing to knowledge. The notion of knowledge refers to generally things we know and that maybe incorrect and incoherent, not to the traditional sense of knowledge as justified, true beliefs. The process involves constructing mental representations and external artifacts that reflect them. Designers are mutually constructing a non-existing entity, the design. They are collaboratively adding bits of knowledge to the representations that defines the design. This is a transformation process from how each design team member perceives the concept to a shared view expressed by prototypes, demonstrators, or documentation, etc. As a disclaimer, our proposal does not consider the development or transfer of procedural knowledge (the tacit skills), only declarative knowledge regardless of its format [Paivio 1986]. This is because we think that differences in construction skills, although necessary, (see next page) are less important for creativity than conceptual (declarative) knowledge. Design, unlike use, is foremost not based on perceived affordances in the world [Norman 1988]. In the following, we describe our view of knowledge construction process in conceptual desing. An example application of this view can be found in other sources ([Liikkanen and Holmquist 2011]).

3.1 The format of knowing

What are the bits of knowledge we were referring to? The concept we have chosen to describe knowledge structures is mental representation. Mental representation is a necessary explanatory concept (or a category of concepts) in most theories of mind that tries to understand how our mind can relate us to the world [Paivio 1986], essential in symbolic theories of cognition. According to several theorists, we recreate the world in our mind using mental representations. This is known as indirect realism in philosophy. The representations reflect both the regularities of external world (referents) but also make possible to extend it through imagery that generates new representations. The notion of mental representation seems suitable descriptor for concept design because it reminds how design emerges exclusively from and through designers' minds. Our proposal is inspired by a generic cognitive theory and leaves the details of knowledge representation for future research.

Literature includes some alternative concepts in cognitive science to describe knowledge representations [Anderson 1983], [Paivio 1986]. Mental models have been extensively investigated as a particular category of representations [Johnson-Laird 1980]. Mental models are considered as in some ways analogous (morphological homogeneity) to the represented external entity (a geographic or functional configuration). They have also been used in design to describe user mental models, that is how non-designers understand artifacts [Norman 1988], but not for describing designers' representations of design. In addition to mental models, scripts, frames, schemata, and propositions are explanatory concepts used in representational theories. They target some specific information processing requirements underlying behavior [Paivio 1986]. The problem is that none of these concepts fits design task characteristics very well. Also, there is no established psychological theory of the structures of knowledge representation in design, when the problem space is excluded. The previous psychological descriptions of knowledge structures in design [Hatchuel and Weil 2009], [Lawson 2004] are primarily about acquiring knowledge and becoming an expert designer. We know from that experts are distinguished by their ability to draw on huge amounts of domain knowledge. For instance, chess masters can play multiple games in parallel, presumably because they can easily relate to games situations based on what they've learned earlier [Chi et al. 1988]. We believe that similar expertise effects exist also in design based on [Cross 2004], [Liikkanen and Perttula 2009], [Stein 2004].

3.2 From mental representations to design artifacts

We are proposing few organizational principles for mental representations that are needed to account for design knowledge. The selection of principles is based on the needs to understand design thinking. In other contexts of psychological theory, additional principles are likely needed to exlain thinking. The main arguments will be described in detail in the following paragraphs, they are listed here:

- **Mental representations are configurations of associated constituents**
- **Design requires constraints to filter constituents**
- **Designs involves both explicit and implicit constituents and constraints**
- **Constituents are positively distinctive features**
- **Mental representations are incomplete**

Constituents are the pieces of knowledge that are vehicles for what we know and what we can think of. Constituents capture information necessary to represent design: including at least propositional and visual information, but not necessarily limited to them (e.g. emotions can be important for design). Ideas are particular configurations of constituents. For a mental representation (an idea), constituents must be organized. Organization is associative and hierarchical (categorical) (cf. semantic networks in [Anderson 1983]). For each representation, there is a configuration of associated constituents. Our mind effectively categorizes almost anything and forms connections we are unaware of, showing up in stubborn stereotypical thinking, especially about other people [Greenwald et al. 1998].

We have extensive mental representations that are adaptive to the environment we are living in. At the top level, constituents create a mental representation of the world we are living, a (somewhat) coherent world view. This emphasizes that the constituents are only meaningful as a part of a larger whole, when they can be traced back to other constituents. This reminds of the fact that the knowledge we communicate must be similarly referable to recipients' knowledge network. Another consequence is that we possess massive amounts information we never disclose and usually remain unaware of, unless trying to teach a blank slate. This is here called implicit knowledge and it is manifested in the way we complete our everyday communications. The existing knowledge is controversially both necessary and problematic for design, because the designs must be based on the world as it is now, but they should also go beyond. This means they are going to be in opposition to the existing configurations constituents. The results regarding "structured" imagination [Ward 1994], the re-use of common prototypes in knowledge are here considered to reflect the influence of implicit constituents on creative cognition.

The second concept used here is called constraints. Constraints are exclusive constituents that explicitly limit the possible configurations of constituent. They can be considered as filters of constituents, they are inflexible in associating to other constituents. Constraints define the design task, it is impossible without them, and research has shown that constraints can increase creativity [Finke et al. 1992]. Constraints match only some constituents and allow those to become parts of the mental representation for design. The subsequent list names two classes and six categories of constraints important for the design process:

<u>Human constraints:</u>

- **User-of-artifact** (needs, ecology) and **Designer-as-human** (culture, style, expertise, sex)

<u>Environmental constraints:</u>

- **Technology** (affordances, limitations) and **Infrastructure** (organization)
- **Design** (previous design decisions) and **Business** (economical viability)

The human constraints are inherent to everyone's position as a member of culture, gender, and a profession but also users of technology. These tend to be so utterly over-learned that they are often implicit [Greenwald et al. 1998], we act according to them unknowingly. Environmental constraints reflect the dynamics of the constructed world and a domain in which designers consciously are

learning from thus these constraints are more likely explicit. The list of possible constraints cannot be exhaustive. When it comes to design, it impossible to say a priori what knowledge is irrelevant, before strict constraints have been imposed.
A “creative” capacity of the human mind is that of being able to create new constituent associations. For instance, in addition to listing the “natural” and distinctive features of your dog, you could describe what it is not about (driving car, producing electricity, or designing watches). We can produce an endless number of this kind of associations, leading to a philosophical dilemma called frame problem. The implication is that we need to focus on the distinctive constituents of mental representations. Finally, one characteristic of mental representations is that they are incomplete (cf. user mental models in [Norman 1988]). This is natural because they concern a new design before the “thing” has been defined. The incompleteness is revealed when models are communicated or realized as an artifact.

3.3 Design activities behind constituents and constraints

Design does not happen just in our minds, it must turn into behaviors. Next we present a set of activity categories in design process. In contrast to the descriptive model in Figure 2, this categorization tries to capture necessary steps for an activity of called design based on distinct cognitive capacities. These actions must be implemented by the designer, the team, or the whole organization, not necessarily by one agent. In our view, the iconic design activities of concept design include the following:

- **Research →** produces knowledge
- **Construction →** produces prototypes and sketches
- **Decision making →** produces design decisions

Research is the most extensive activity category and the source of knowledge produced in design. This “design research” neither implies scientific research nor design-for-research [Fallman 2003], but gathering knowledge about the domain of design for being able to design. We propose two forms for it: research within and outside. Each designer provides their own expertise which can be intentionally exploited by accessing, combining, and sharing knowledge; this is research within. Explicit attempts in idea generation exemplify this, they are dependent on accessing appropriate knowledge in one’s permanent memory. In addition to access, the constituents must be combined or transformed to achieve novel configurations; seeds for creativity. Several mental operations have been associated with this part [Finke et al. 1992]. Most thoroughly explored cognitive functions are analogical thinking [Hummel and Holyoak 1997] and related conceptual combinations [Costello and Keane 2000]. But the knowledge possessed by designers is not usually enough for creating new designs, outside research is required. This type of design research can involve consulting colleagues and experts, interviews with stakeholders, reviews of literature, searching Internet, getting inspired by examples, or even scientific studies and technology development (cf. [Verganti 2008]). Relevant for both types of research, design teams must first individually, then collectively generate and bring together constituents and constraints. Communication is thus essential for maximizing the probability of successfully combining the constituents, i.e. colliding distant “matrices of thought” [Warr and O'Neill 2005], because mental representations cannot be directly replicated or transferred from a person to another. This is a challenge because group thinking involves various phenomena that hamper ideation [Diehl and Stroebe 1987].
Construction refers to all activities in which presentations external to the designers are created. This transfer of mental representations to external is never “perfect” and often details (future features) are left out. It requires application of some skill to transform the mental representation to an artifact. This skill (procedural knowledge) is the traditional design capacity and makes construction a distinct activity from research. Construction is tightly related to research as the artifacts will be used for communication and decision making. Construction can also serve the function of research as mental representations may change due to construction. External representations, sketches and prototypes, may evoke surprises as designers experience new aspects of the design that did not exist in their mental representation but have now appeared in the external representation [Schön 1995]. This is because the mental model has not anticipated (represented) all features of the design that have become visible through construction. Surprises force the designers to complement their mental representation

based on their experiences (typical learning from research). This might explain why construction is in the nature of design.

Decision making brings in a "stopping rule" for the design process. Research and construction typically produce much more ideas than can be taken further. While designers probably have a feeling how good their ideas are, it is unlikely that after communicating them, all team members would immediately agree on the best design(s). Thus group decision making involves persuasion, argumentation, and emotional conflicts unlike anything encountered in research or construction phases. Decision making consolidates the mental representation of each designer by fixing constraints and constituents of the design. At least the following decisions are required: What to design (selection of constituents), How to implement (preparation of the artifact)?, (If) How to test?

4. Conclusion

In this paper we have presented a cognitive framework to conceptualize concept design as knowledge. We did this to propose an alternative to prevalent psychological descriptions of design as problem solving which we saw misleading and ill-suited particularly for understanding the creative design phase of concept design. As disclaimer for the argument, we do not insist that design process is void of problem solving. However, problem solving happens only once decisions about the product have been put forward and are likely to arise during the implementation of the concept, rather than in concept design. Design might be more comparable to *problem finding*, an activity that has been shown correlate with success in the context of scientific inquiry [Jay and Perkins 1997]. As a cognitive theory, we admit that our proposal is very sketchy. However, we believe it makes a contribution and stands out from the other knowledge-centered theories. An example of how it might benefit the analysis of a design process can be found in previous literature [Liikkanen and Holmquist 2011]. Most prominently, a clear difference to C-K theory is that we do not think that a psychological theory benefits from the assumption of two complementary representations (C and K spaces). We also find little value in strict adherence to the truth value embedded in knowledge of K space.

In detail, we described here a process of constructing mental representations and transforming them into external artifacts through decisions and construction from and within a design team. Mental representations are constructed in part from the knowledge held by the designers, but mostly from knowledge acquired through design research activities during the design process. We emphasized how the construction process is subject to numerous implicit constituents. Designs are created not only to match constraints and constituents the designers exchange easily, but also those they hold implicitly and which are normally undisputed. This means that the "secret" of design creativity is on individual level the retrieval, acquisition, and exploitation of knowledge, on team level the effective communication of knowledge. But this is useless without the right decisions and high quality construction. The main question of this paper was that can user data help designers to get things right? What is the relation of user-centered design to creativity?

Design methods and techniques can facilitate breaking away from the constraints of existing knowledge. The design and creativity research literature includes examples on how to improve efficiency in design activities such as idea generation [Liikkanen and Perttula 2010], which may help to develop design practices to be more creative. Or it may fail if the fit of techniques vs. individual differences turns out be idiosyncratic and creativity solely determined by personal qualifications in research. Even in this case, our framework makes it understandable why some forms of UCD might be considered useless or even harmful for creativity [Norman 2010]. This is because they can add constraints to the process and can thus make the overall concept unnecessarily compromised if the user input is adopted inflexibly. Additional constraints may also lead to less good constituent combinations (ideas) in concept design if cognitive resources such as working memory capacity are taxed [Liikkanen and Perttula 2010]. When adopting a UCD approach, designers must realize that not all "problems" reported by users translate into actionable constraints of design. Instead, designers need to interpret what the problem with the user (or the client) really is, keeping UCD designer-driven [Verganti 2008].

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