Future Directions for Design Creativity Research

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Abstract. This paper commences with a brief overview of where the creativity may lie in the enterprise of designing artifacts. It puts forward the concept that design creativity is not a unitary concept and needs to be treated multi-dimensionally by stating that design creativity may be in multiple locations. The paper then proceeds to present a brief overview of what has been researched and how it is has been researched. It classifies what has been researched under: design processes, cognitive behavior and interactions. This is followed by the articulation of future directions for design creativity research in the areas of: design processes; cognitive behavior, social interaction; cognitive neuroscience; measuring design creativity and test suites of design tasks.

Keywords: creative design, users, social interaction, design processes, design computing, design cognition, future directions, cognitive neuroscience.

1 Introduction

Creativity is highly valued in Western society. Creative products and processes are thought to be the basis of transformations in economic value and of human values. Schumpeter introduced the term "creative destruction" to capture the concept of how creativity has the capacity to produce bifurcational changes while at the same time dramatically changing the value of what went before. Design creativity research focuses on developing an understanding of the creativity of designs as a precursor to improving the generation of designs that are deemed to be creative.

This position paper commences with a brief overview of where creativity may lie in the overall enterprise of designing. It proposes seven potential loci. This is followed by a brief overview of what has been studied by researchers in terms of design creativity. The methods used to study design creativity are listed. This leads to the final part that outlines a number of future directions for design creativity research and posits a set of research questions for each of the directions.

2 Where Can Design Creativity Be?

Where can the creativity be? Although this is an obvious question is surprisingly difficult to answer. There are seven hypotheses that are candidate answers to this question:

- in the design;
- in the assessor of the design;
- in the design process that produced the design;
- in the designer;
- in the interaction between the user and the design;
- in the society in which the design sits; and
- in the interaction amongst all of the above.

Given that are multiple hypotheses about where the creativity might be implies that design creativity is not a unitary concept and needs to be treated multi-dimensionally (Amabile 1983; Amabile 1996; Boden 1994; Boden 2004; Coyne et al 187; Csikszentmihalyi 1997; Dacey et al 1998; Dasgupta 1994; Feldman et al 1994; Gero and Maher 1993; Gloor 2006; Heilman 2005; Hofstadter 1995; Kaufman and Sternberg 2010; Partridge and Rowe 1994; Runco 2006; Runco and Albert 1990; Runco and Pritzker 1999; Sawyer 2006; Shirky 2010; Simonton 1984; Sternberg 1999; Weisberg 1993;).

2.1 Creativity is in the Design

The design itself would appear to be the most obvious place to locate design creativity. It is common to hear the phrase "that design is creative". A design can be assessed for its creativity against a set of criteria. Typically such assessment criteria include novelty, utility and surprise. This could lead to the conclusion that the creativity lies in the artifact. However, since the utterer is making the claim this supplies insufficient evidence to support the concept that all the

creativity lies in the design as it involves an assessor separate from the design. Since all cases of the assessment of creativity involve assessors it is may not possible to test whether the creativity lies in the design as some or all may lie with the assessor.

2.2 Creativity is in the Assessor of the Design

If creativity does not simply lie in the design itself it may be that creativity is an interpretation of a design by the assessor. The assessor may be a consumer of the design or a professional commentator and generally does not specify the criteria they use in their assessment. This turns creativity from an inherent property of the design to a property of the assessor of the design. The consequence of this is that different assessors would assess the creativity of a design differently. There is evidence for this assertion.

2.3 Creativity is in the Design Process that Produced the Design

Since designing is a process it can be suggested that there is some special process or processes – "creative processes" that result in creative designs. This a commonly held view. It has the attraction that is can be readily studied. Typical creative processes are: combination, analogy, induction, mutation, and first principles. The resulting designs still need to be assessed but are considered more likely to be assessed as creative.

2.4 Creativity is in the Designer

Many designers are recognized as being regularly and consistently able to produce creative designs. It may be that is the unique characteristics of those designers that make them consistently creative. That some designers are consistently creative is recognized socially when their names are used to promote the design itself.

2.5 Creativity is in the Interaction between the User and the Design

It may be that creativity is an affordance (in the Gibsonian sense) between the user and the design and as a consequence is the result of an interaction between the user and the design. This means that the creativity is in neither the design nor the user but is a consequence of the interaction of the user with the design. That interaction could take many forms. It could be a derivation by the user of the behavior of the design. It could be an ascription by the user to the design. It could be a mixture of both of these.

2.6 Creativity is in the Society in which the Design Exists

It may that creativity is a construction that is an outcome of social interactions between members of a society. For example a person need not own and use a product in order to comment on it. As a consequence it comes primarily from the society based on some interaction with the design.

2.7 Creativity is in the Interaction between the Design, the Users/Assessors and Society

It may that creativity lies in the interactions between users, assessors and the design within a society. The consequence of this is that creativity becomes a situated, constructive act. Situated means that the social interactions of individuals depend on their view of the world at that time and this guides their interactions. Constructive means that any assessment is not simply a recall of past assessments but is generated based on the past and the current situation to meet expectations that come from the situation.

This last notion of design creativity subsumes the notions of the creativity being in the assessor, creativity being in the designer, creativity being in the interaction between the user and the design and creativity being in the society within which the design exists. What it does not cover directly is the notion that creativity is in the process.

3 What Has Been Researched

All seven of these hypotheses for the location of creativity in design creativity have been studied at various levels of intensity and detail (Bonnardel 2000; Christiaans 1992; Dorst & Cross 2001; Gero 1996; Gero 2000; Gero and Maher 1993; Liu 2000; Saunders and Gero 2002; Sosa & Gero 2005; Sosa et al 2009; Suwa et al 2000; Tang and Gero 2002). However, in terms of scientific studies the primary focus has been on the following, although the other loci has been investigated often using a humanities paradigm:

- design processes;
- cognitive behavior; and
- interactions.

3.1 Studying Design Processes

The study of creative design processes has been a major research area in design science. It has taken four paths depending on the source of the idea being modeled:

- models simulating conjectures based on perceived human creative design processes;
- models simulating results from empirical studies of human creative design processes;
- models simulating conjectures based on purely abstract constructs; and
- models of human creative design processes based on empirical results.

3.1.1 Models simulating conjectures based on perceived human creative design processes

There is considerable anecdotal evidence that designers use a variety of defined processes as they produce designs that are deemed in some way to creative. This anecdotal evidence is not necessarily founded on empirical results. The conjecture is based on an agreed perception of human behavior. The model aims to produce results that bear some relation to those that might be produced by a human designer within a highly limited situation. For example, it is not known how designers combine design concepts to form a new design concept that is not simply a union of the two initial concepts. However, a number of processes have been postulated and implemented to study this conjecture.

3.1.2 Models simulating results from empirical studies of human creative design processes

Here the focus is on producing results of the kind that humans have been shown to produce. An example area is visual emergence, where the aim is to be able to produce the same visual emergence that humans are capable of producing within a specified domain.

3.1.3 Models simulating conjectures based on purely computational constructs

Here the focus is on processes drawn from computational constructs that bear no relation to human cognition or behavior. Examples of computational constructs that are not modeled on human behavior include evolutionary systems and simulated annealing.

3.1.4 Models of human creative design processes based on empirical studies

Here the focus is on modeling human cognitive behavior. The most well developed example is that of analogy, which is considered one of the basic human creative processes.

3.2 Studying Cognitive Behavior

Studies of human cognitive behavior have been directed at trying to understand what are the parameters that play a role in producing or impeding creative behavior. There have been studies on analogy, combination of ideas and incubation as well as on fixation, amongst others. These have built on studies of cognitive characteristics and cognitive styles of the designers.

The results of such cognitive studies have not yet produced results that allow an unequivocal connection to be made between unique parameters and creativity, although there is increasing empirical evidence for the roles that some specific parameters do play.

3.3 Studying interactions

Interactions between designers and their tools and the interactions between designers as they collaborate are two streams of interaction research.

Studies of the interactions between designers and their tools focus on the change in cognition when using a tool, the change behavior and the change in the results produced. Most of the studies have been at a foundational level rather than focusing specifically on design creativity.

Few studies of designers collaborating have focused on creativity although team behavior has been studied from a creativity viewpoint, where the team members were not designers in the traditional sense.

4 How Design Creativity Has Been Researched

Three methodological approaches have been used to research design creativity:

- computational modeling
- input-output experiments with human designers
- protocol studies of human designers

4.1 Computational Modeling

Computational modeling is the basis of the field labeled design computing. Computational modeling provides the opportunity both to test specific ideas and, more generally, to build a laboratory within which to test a range of ideas.

4.1.1 Computational modeling of creative design processes

This has been the most fruitful methods of design creativity research. Computational models of conjectured human creative processes have provided researchers with insight into how such processes might be utilized to produce designs, although always in a highly circumscribed environment. Computational

models of results from empirical studies of human creative design processes are much fewer largely because there are very few such studies. Computational models of processes based on computational constructs only have a widespread currency. Computational models of human creative design processes based on empirical studies have proven to be very successful where the results of such studies have been robust.

4.1.2 Computational laboratories for creative design research
This is a relatively new modeling area that is the outgrowth of the use of multiple, social agents, where agents are computational constructs with a degree of autonomy. Agents can be used to model players in a system. Their interactions produce system-level behaviors both intentional and extensional. Such a system can act as a laboratory for the investigation of the effect of parameters and their variations without directly programming the output behaviors.

4.2 Cognitive Modeling

4.2.1 Input-output experiments with human designers
Input-output experiments take the designer as a black box and examine the effects they produce in the output when the input is changed. An example of such an approach is the studies on design fixation, where fixation inhibits creativity.

4.2.2 Protocol studies of human designers
Protocol studies in design cognition involve having designers verbalize as they design and converting their verbalization into semantic symbols. These symbols can then be analyzed in multiple ways to inform the cognition of creative designing. Protocol studies have proven to be a popular research method in the study of the cognition of human designers.

5 Future Directions for Design Creativity Research

Designing is not a unitary act. It involves multiple fields of knowledge and multiple classes of processes and is practiced in multiple disciplines in what may appear to be in different ways. As a consequence it is difficult to have a widely accepted agreement on its definition. Similarly, creativity is not a unitary concept and this may explain the difficulty in producing a universally agreed definition of it. However, it is claimed that contributing to the notion of design creativity are the issues of:

- design processes;
- cognitive behavior;
- social interaction;
- cognitive neuroscience;
- measuring design creativity; and
- test suites of design tasks.

Although the first three of these classes of issues, have already been the focus of previous study, they provide the basis for future directions for design creativity research. The fourth is a novel dimension.

5.1 Design Processes

Design processes continue to be fruitful research direction for design creativity. Sources for design processes will include empirical results from studying humans and nature. Future research questions for design processes for design creativity include:

- what are the human creative design processes?
- can design by analogy be made more generally useful?
- what can be generalized from design by analogy with nature – biomimetic design?
- what are collaborative creative design processes?
- what are team creative design processes?
- what are collective design processes?
- what are the differences between a user designing and a designer designing?

5.1.1 Human creative design processes
The current knowledge of human creative design processes is limited. Determining the set of these processes still remains a research question. How designers use these processes is not well understood. Future research questions related to creative design processes include:

- what is the set of processes used during creative designing?
- are there unique configurations of processes that contribute to creative designing?
- what is the effect of education these processes on performance and outcomes?
- what is the effect of experience of using these processes on performance and outcomes?

5.1.2 Design by analogy
Analogy is well-developed process utilized in creative designing. Current approaches to design by analogy make use of concept from structure mapping, which assumes that the representation of the source and target are congruent and hence the matching process is directly applicable. Future research questions in design by analogy include:

- how can representations of potential sources be constructed to match the target's representation?
- can the representation of the target be constructed to match that of the potential source?
- does context change the process used for locating potential sources?
- what is the effect of context on matching in potential sources?
- does experience change the process used for locating potential sources?
- what is the effect of context on matching in potential sources?

5.1.3 Biomimetic design

Biomimetic design is a specialization of design by analogy where the sources come from natural biology. Future research questions in biomimetic design include:

- can the biological processes that produce desired behaviors be generalized?
- can different biological processes that produce the same behavior be identified?
- can a set of biological processes be accessed through intended behaviors?
- is there a base set of biological processes involved in the production of most of the behaviors?

5.1.4 Collaborative design processes

Collaborative design occurs when two or more designers work on producing a design through their interactions. The designers do not make a team, where a team involves the development of a continuing common ground of understanding the behaviors of others members of the team. Collaborative design occurs when two or more designers, who have not worked together previously and there is no expectation that they will work together again, are brought together for the production of a single design over a relatively short period. Future research questions for collaborative design processes for design creativity include:

- what are the effects of synchronous compared to asynchronous collaboration?
- what are the effects of co-location compared to remote location?
- what are the effects of the use of tools?
- what are the effects of asymmetry in the decision-making roles of the collaborators?

5.1.5 Team design processes

Teams are groups of designers who are formally constituted and who develop a continuing common ground with each other. Future research questions for team design processes for design creativity include:

- how do team mental models develop?
- what are the process and outcome effects of changing team membership?
- what are the process and outcome effects of structured versus unstructured teams?
- how does team expertise develop?
- what are the process and outcome effects of having team members work as members of other teams asynchronously with the current team?

5.1.6 Collective design processes

Collective design distinguishes itself from both collaborative design and team design in that the designers who form a collective primarily interact with each other through the emerging design. Such designers do not need to know each and therefore they are only judged by their performance not by their demography. Future research questions for collective design processes for design creativity include:

- what motivates people to join collective design?
- how do collective designers partition design tasks?
- how do collective designers reach a consensus?

5.1.7 User design processes

Many product suppliers offer the opportunity to the user to design or customize some aspects of their product. Future research questions for user design processes for design creativity include:

- do users customize differently to designers?
- do users customize "better" designs than designers?
- does user customization improve user satisfaction?

5.2 Cognitive Behavior

Current studies of the cognitive behavior of the creative designing have produced results that have not been sufficiently robust (in the sense of controlled experiments), not generalizable (since many were case studies), have been too narrow in scope, and not transferable (since different dimensions were used to collect and analyze the results) to generate adequate conclusions. Future research into the cognitive

behavior of design creativity must first address the following procedural issues.

5.2.1 Robustness
Robustness implies improved experimental design through better use of controls and reductions of confounding variables. Many published results from the design cognition literature are not reproducible because of a lack of attention to the issues.

5.2.2 Statistical reliability
Statistical reliability implies the need to move from individual case studies to populations of subjects, the reasons for case studies have included the cost of carrying out reliable studies so better tools are required to reduce these costs.

5.2.3 Scope
The scope of many studies has been limited to single variables. These are case studies from which general conclusions cannot be drawn. Studies of single designers do not allow for either lateral or longitudinal studies, which limits the applicability of any results.

5.2.4 Generalizability
Generalizability implies one or more generally used coding schemes when using protocol studies and a set of commonly used measurements to allow to comparisons across studies. A lack of such commonly used approaches has limited the utility of any results produced.

5.2.5 Future research questions in cognitive behavior
Once these issues have been addressed cognitive behavior of the creative design can be explored more fully. Future research questions in cognitive behavior of design creativity include:

- are there unique cognitive processes that contribute to design creativity?
- are there unique combinations of ordinary processes that contribute to design creativity?
- what is the effect of tool use on the cognitive behavior involved in design creativity?
- what is the effect of interactions with other designers on the cognitive behavior involved in design creativity?
- what is the effect of interactions with the evolving design on the cognitive behavior involved in design creativity?
- what is the effect of interactions with the users of the design on the cognitive behavior involved in design creativity?
- what is the effect of education on the cognitive behavior involved in design creativity?
- what is the effect of experience on the cognitive behavior involved in design creativity?
- what are the cognitive behavior differences between a single designer and a designer working within a team?
- what are the cognitive behavior differences between having incubation breaks and continuous design sessions?
- how can the cognition of collective design be measured?
- what is the empirical support for the situated cognition view of creative design?

5.3 Social Interaction

Creative designing is the consequence of a variety of social interactions, where social interactions means that the interaction occurs in not programmed and has the capacity to change value systems of the interactees: social interactions between designers; social interactions between designers and consumers; social interactions between designers and the society in which they sit. Future research questions in studying the social interactions in design creativity include:

- what are metrics for social interactions?
- what value changes occur as a result of social interactions?
- what is the cognition of social interaction?
- what is the effect of differing channels of social interaction on design creativity?

5.4 Cognitive Neuroscience

Cognitive neuroscience is that part of brain science that studies the brain while it is carrying out cognitive acts and attempts to correlate brain behavior with that cognition. The cognitive neuroscience of design creativity is an open research field and is the fourth future direction for design creativity research. Future research questions in studying the cognitive neuroscience of design creativity include:

- are there unique structures involved in design creativity?
- assuming there are unique structures involved in design creativity, are they the same in different design disciplines?
- assuming there are unique structures involved in design creativity do they change with education?
- assuming there are unique structures involved in design creativity do they change with experience?

- assuming there are unique structures involved in design creativity are they different in novices and experts?
- are there unique neural pathways involved in design creativity?
- assuming there are unique neural pathways involved in design creativity, are they different in different disciplines?
- assuming there are unique neural pathways involved in design creativity, do they change with education?
- assuming there are unique neural pathways involved in design creativity, do they change with experience?
- assuming there are unique neural pathways involved in design creativity, are they different in novices and experts?
- if there are no unique structures nor unique pathways associated with design creativity, are there significant differences in either structure or neural pathways to ordinary design?
- if there are no unique structures nor unique pathways associated with design creativity, are there significant differences in either structure or neural pathways between novices and experts?
- if there are no unique structures nor unique pathways associated with design creativity, are there significant differences in either structure or neural pathways as education proceeds?
- if there are no unique structures nor unique pathways associated with design creativity, are there significant differences in either structure or neural pathways between designers in different disciplines?

5.5 Measuring Design Creativity

There are inadequate measures of design creativity. Since the claim is made that design creativity is a multidimensional set of concepts it is appropriate to consider the measurement of design creativity from a multidimensional view. The most common measures relate to the product and are often qualitative measures of novelty, utility and sometimes surprise. Future research on measuring the creativity of designs needs to quantify these measures in a coherent manner.

Design creativity changes the values of the users and even observers. There is insufficient research on this aspect of creativity. Future research questions in measuring design creativity include:

- what are design creativity measurement metrics for designed artifacts?
- what are design creativity measurement metrics for design processes?
- what are design creativity measurement metrics for users?
- what are design creativity measurement metrics for societal creativity?

5.6 Test Suites of Design Tasks

Studying designing is different to studying many other human activities because when each designer is given the same set of design requirements the results of each designer is and is expected to be different. A different paradigmatic view is required if comparisons of designing are to be made. It is common to have a suite of problems to which a solution method can be applied and a set of metrics that are used to measure the performance of the method. Typical metrics include: how close to the correct solution the method reaches, how long it takes and how much resources are consumed in reaching its solution. In designing there is no correct solution. The time taken to complete a design is largely a function of the resources available rather than a characteristic of the requirements. Similarly the resources expended are largely a function of the resources available rather than a characteristic of the requirements of even of the design produced.

However, it is still appropriate to have test suites of design tasks but to utilize different measurement metrics to measure design creativity of the process, the product and the changes produced in the user, the designer and in society generally. Future research questions in determining test suites of design tasks for design creativity include:

- what are appropriate metrics for design tasks?
- what is an appropriate ontology of design tasks?
- what makes for appropriate design tasks at the function level?
- what makes for appropriate design tasks at the behavior level?
- what makes for appropriate design tasks at the structure level?

6 Conclusions

Design creativity remains a relatively under-researched area, as a consequence there are numerous research questions to be raised and answered to develop an understanding of design creativity. The results of this research will lead not only to an understanding of design creativity but will provide the foundations for the development of tools to support design creativity and potentially to augment it.

Designing is one of the value adding activities in a society. It has the potential to improve the economic

condition as well as the human condition and make lives better. Research into design creativity is a lever that magnifies design. Research into the following areas will produce benefits:

- design processes;
- cognitive behavior;
- social interaction;
- cognitive neuroscience;
- measuring design creativity; and
- test suites of design tasks.

There continues to be a lack of qualified researchers in this field. The field needs to attract more researchers and they need to come from disparate fields to progress.

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