Computational Explorations of Creativity and Innovation in Design

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According to the main assumptions of this work, ideas can be better understood when the creator is considered as part of the social group in which it operates and in relation to existing knowledge. In this vein, I wish to acknowledge the individuals and Institutions that have contributed to my doctoral studies.

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This thesis represents my highest personal academic achievement and, as such, I wish to dedicate it to all the people who are marginalised, excluded, and have no access to formal education and training. The world, and our understanding of it, would certainly be much better if opportunities were available to all.

Summary

This thesis addresses creativity in design as a property of systems rather than an attribute of isolated individuals. It focuses on the dynamics between generative and evaluative or ascriptive processes. This is in distinction to conventional approaches to the study of creativity which tend to concentrate on the isolated characteristics of person, process and product. Whilst previous research has advanced insights on potentially creative behaviour and on the general dynamics of innovation in groups, little is known about their interaction. A systems view of creativity in design is adopted in our work to broaden the focus of inquiry to incorporate the link between individual and collective change.

The work presented in this thesis investigates the relation between creativity and innovation in computational models of design as a social construct. The aim is to define and implement in computer simulations the different actors and components of a system and the rules that may determine their behaviour and interaction. This allows the systematic study of their likely characteristics and effects when the system is run over simulated time. By manipulating the experimental variables of the system at initial time the experimenter is able to extract patterns from the observed results over time and build an understanding of the different types of determinants of creative design. The experiments and findings presented in this thesis relate to artificial societies composed by software agents and the social structures that emerge from their interaction. Inasmuch as these systems aim to capture some aspects of design activity, understanding them is likely to contribute to the understanding of the target system.

The first part of this thesis formulates a series of initial computational explorations on cellular automata of social influence and change agency. This simple modelling framework illustrates a number of factors that facilitate change. The potential for a designer to trigger cycles of collective change is demonstrated to depend on the combination of individual and external or situational characteristics.

A more comprehensive simulation framework is then introduced to explore the link between designers and their societies based on a systems model of creativity that includes social and epistemological components. In this framework a number of independent variables are set for experimentation including characteristics of individuals, fields, and domains. The effects of these individual and situational parameters are observed in experimental settings. Aspects of relevance in the definition of creativity included in these studies comprise the role of

opinion leaders as gatekeepers of the domain, the effects of social organisation, the consequences of public and private access to domain knowledge by designers, and the relation between imitative behaviour and innovation.

A number of factors in a social system are identified that contribute to the emergence of phenomena that are normally associated to creativity and innovation in design. At the individual level the role of differences of abilities, persistence, opportunities, imitative behaviour, peer influence, and design strategies are discussed. At the field level determinants under inspection include group structure, social mobility and organisation, emergence of opinion leaders, established rules and norms, and distribution of adoption and quality assessments. Lastly, domain aspects that influence the interaction between designers and their social groups include the generation and access to knowledge, activities of gatekeeping, domain size and distribution, and artefact structure and representation. These insights are discussed in view of current findings and relevant modelling approaches in the literature. Whilst a number of assumptions and results are validated, others contribute to ongoing debates and suggest specific mechanisms and parameters for future experimentation.

The thesis concludes by characterising this approach to the study of creativity in design as an alternative ‘in silico’ method of inquiry that enables simulation with phenomena not amenable to direct manipulation. Lines of development for future work are advanced which promise to contribute to the experimental study of the social dimensions of design.

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Chapter 1

Introduction

This chapter presents an introduction to the area of inquiry and the problem addressed in this thesis. The aim, objectives and scope of this research are presented. The chapter ends with an outline of this thesis.

Design is an important social activity. Artefacts specified by designers respond to the needs and problems of social groups. Buildings are conceived for housing, objects and tools are developed for work and entertainment, and visual displays are created to support communication. Design practitioners are delegated by societies the fundamental task of transforming their environment. To that extent, design is seen as a social activity in which various stakeholders interact.

Designers may become change agents of their societies. They may propose new physical solutions or artefacts that trigger social transformations. The artefact specification is the immediate, tangible outcome of the design process. When artefacts are built and made available, their impact and ensuing consequences in a society are the final outcomes of design activity. Social and environmental changes are the ultimate products of design.

Creativity and innovation are possible outcomes of design. Design artefacts may be considered by social groups or by experts to address appropriate requirements in novel and unexpected ways. Certain artefacts may also influence the design of future solutions opening possibilities that were not available until then. When these types of conditions occur, both the artefact and the designer may be regarded as creative by their social group. The process by which a target group or population evaluates, adopts and adapts to creative solutions is considered the process of diffusion of an innovation. This research addresses some aspects of the fundamental relationship between individual generation and collective evaluation of design artefacts.

1.1 Research Problem

The fundamentals of creativity and its relation to innovation are not well understood (Runco 2004; Simon 2001). There is a clear gap in the current understanding of how individual action and social change integrate. An explanation for this divergence in the literature is that for the most part methods of inquiry tend to focus separately on individual or collective units of analysis without

considering their interaction within a system (Anderson 1972). The micro-macro link between individual action and collective change is an important interdisciplinary question today (Alexander et al. 1987; Sawyer 2001).

Undoubtedly, the most important contribution of the last sixty years of research in this area has been the demystification of creativity (Simon 2001). An emerging consensus exists today that creativity is the property of a system where individual and environmental conditions interact (Feldman et al. 1994; Sawyer et al. 2003). It is characterised as an ascribed property that is not entirely contained within the person or artefact in isolation but takes place in the interaction between a person or artefact and a socio-cultural context (Csikszentmihalyi 1997). Under this view, there is a complementary relationship between generative and evaluative processes, i.e., how creative solutions are produced cannot be understood in isolation of how they are evaluated (Csikszentmihalyi and Epstein 1999). A possible approach to the study of creativity as a social construct (Amabile 1993; Saunders 2002) is to examine the role of the environment and its interpretation by individuals. These types of situational factors have been addressed across a number of disciplines (Argyle et al. 1981; Ross and Nisbett 1991; Sternberg and Vroom 2002). The underlying assumption is that factors that sit outside the individual may be important determinants of behaviour and emphasis is given to the understanding of behaviour as a result of the individual interacting with an environment (Clancey 1997).

Examples can be drawn to support the dominance of both person and situation-based accounts of creativity. However, there are no clear reasons to over-emphasise either. It seems more appropriate instead to explore the informative range between the two extremes.

Treating creativity as a product of complex human interaction, computational agent models are presented as a convenient method of inquiry (Gilbert and Doran 1994). Such approach provides means to implement and experiment with individual and situational components. Individual factors refer to the internal characteristics of subjects under study. Situational factors are defined as the combination of external conditions and their interpretation by individuals and groups of subjects. Examples of situational factors include time schedules, environmental conditions, emergent group effects and interaction rules with which social groups operate.

This thesis presents computational explorations into the twofold problem of creativity and innovation. Experimental frameworks are developed to support explorations of artificial systems that exhibit target phenomena (Simon 1995). Verbal statements regarding theoretical principles and hypotheses are extracted from these programs. The intent is therefore explorative rather than to model a particular theory in an area where theorisation is limited and evidence inconclusive (Mayer 1999; Runco and Albert 1990). The use of computers to this end seems appropriate since the outcome of a system is not necessarily deducible at initial time (Epstein and Axtell 1996). Computers can be appropriate laboratories where phenomena and structures of interest are ‘grown in silico’ with the aim to discover and understand resulting patterns and principles.

1.2 Aim and Objectives

The aim of this research is to develop an understanding of individual and situational factors in creativity and innovation in design. The approach is to present experimental evidence from computational simulations that demonstrate interaction principles behind phenomena associated to creative design. The following objectives are considered necessary to achieve this aim:

1) To identify a series of components and mechanisms at work in a systems view of creativity and innovation.
2) To develop an elementary model that captures key principles of interaction between these components.
3) To investigate change agency by studying the roles of individual behaviour and social influence in the emergence of group change.

4) To develop a more comprehensive model to address aspects of design as a social activity that includes the individual generation and social evaluation of design artefacts.
5) To define a range of computationally applicable parameters in this model that are likely to determine the interactions between system components.
6) To design experiments with these parameters focusing on individual and situational experimental conditions. In experimental systems one independent parameter at the time is manipulated and its effects over a period of time and over a number of cases are investigated.
7) To collect data and use statistical analysis to study the effects of these experimental parameters in determining patterns of group change.
8) To analyse insights from these studies in order to understand the mechanisms that determine the behaviour of the system.
9) To discuss results and implications in view of current related empirical evidence from the literature and to elaborate a future research program.

1.3 Overview

This thesis continues in Chapter 2 with background analysis. A general overview is presented of the current literature with special emphasis on approaches that shift the focus on creativity to a systems view (Csikszentmihalyi 1988; Rathunde 1999). The DIFI framework, Domain-Individual-Field Interaction (Feldman et al. 1994), is presented as a promising approach to the study of design as a social activity. Related work in the computational modelling of creativity and discovery is followed by a review of multi-agent simulation in social sciences. The background chapter concludes with an analysis of situated behaviour.

Chapter 3 presents an initial approach to the modelling of emergent structures of convergence and divergence in stochastic cellular automata (CA). This is presented as an introductory study of the relation between individual action and collective change. It illustrates some aspects of change agency at a general level. Several extensions to CA of diffusion are discussed including dissent, displacement, and individual differences. Limitations of this modelling approach are discussed and the case is made for a more comprehensive framework of computational agency to study patterns of design behaviour.

A computational framework of design as a social activity is introduced in Chapter 4. The conceptual model of a multi-agent system is described in detail. This approach is shown to support a rich interpretation of a design system including designer agents (i.e., individuals), populations of adopters and opinion leaders (i.e., field), and a design domain. Some of the mechanisms represented in this framework include processes of social influence, experts' evaluation, learning and imitative behaviour. The system is shown to simulate some aspects that have been related to the definition of creativity and innovation in the literature including: diffusion, gatekeeping, peer influence, prominence, popularity, productivity, and quality.

In Chapter 5 a number of individual and situational variables are selected for experimentation with the agent framework. These two classes of experimental designs are described and results are presented for each experiment. The relationships between variables and the significance of the patterns that emerge from this experimentation are discussed within the particular assumptions of this framework.

Chapter 6 presents discussion of our results and assumptions in view of current knowledge in the field. The aim of this discussion is to provide analyses of our insights that advance our understanding of the problem and serve to reformulate long-standing questions in the area. Published empirical and experimental evidence is used to validate our results. Comparisons with other models are also included in this discussion.

Lastly, conclusions from this approach to the study of creativity and innovation in design are presented in Chapter 7 with short and long term extensions to our inquiry. Responses to controversial issues of this type of research are advanced.