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An Introduction to Innovative Design

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Elements and Applications of C-K Theory

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Foreword

This book offers an introduction to C-K theory and some of its main practical lessons for the innovative design of products and services for organizations looking to enhance on their existing innovation capabilities. C-K theory has been the subject of numerous publications and is taught in various academic institutions; moreover its value in industrial contexts is well-established. Still, there was no available overview of its principles and current practices. This book specifically aims to fill this gap and who could better do it than post-doc researchers who extended the theory and developed applications in several contexts?

C-K theory was conceptualized in the Engineering Design and Management Curriculum, which was organized within the Center for Management Science[1] at Mines ParisTech[2]. Created in 1994, this curriculum provided engineering students with courses on modern design theories and methods. The purpose of this course was to better manage innovative projects or to re-align the R&D departments through collaborative research with industrial partners. Soon, the main design approaches and traditions were studied and questioned. Clearly, there was a lack of an integrated approach articulating both research and creativity, within a design framework. Indeed, it seemed difficult to model within a unique framework these different types of reasoning. However, such integration was also strongly advocated by firms coping with global competition through innovation.

These challenges were the point of inception of C-K theory. In 1996, Armand Hatchuel sketched its main principles. It was further consolidated by Benoit Weil, Pascal Le Masson, Akin Kazakçi, Blanche Segrestin from Mines Paristech, along with contributions from Yoram Reich, Offer Shai, Jean-François Boujut, Chris McMahon and Ade Mabogunje, from other universities, who played a major role in bringing design theory to its present

1 Translation of: Centre de Gestion Scientifique

2 Former, Ecole des Mines of Paris.

state and revitalizing a design theory community of research. In 2008, the Design Society asked Armand Hatchuel and Yoram Reich to create the Special Interest Group on Design Theory, now an active community in the field. Since 2009, large companies[3] have supported the creation of the Design Theory and Methods for Innovation chair at Mines ParisTech. It aims to further develop the research on C-K theory and other advances in design theory.

In some ways, C-K theory is paradoxical: it requires some technical background for those who want to get into its mathematical foundations, and yet from a practical perspective, such a detour isn't necessary to handle it, as it can be taught easily. There are strong reasons for the technical principles of C-K theory. Innovative design is a venture in the unknown which strange rationality could be captured only with unprecedented theoretical means. Surprising results and similarities were found between C-K theory and the Forcing technique of Paul Cohen in set theory: a fascinating tool which introduces the design of new sets at the heart of mathematics. It was also amazing to find striking similarities with the teachings of Johannes Itten and Paul Klee, great masters at the famous Bauhaus school. Such fascinating developments only unveil further the strong roots of the C-K theory. Fortunately, their study is not necessary to understand its principles and utility and they cannot be treated in this introduction.

On the other hand, the KCP method is the most widely known application of C-K theory. In more than thirty field experiments with our partners, the KCP method has shown and proved that it can be helpful to develop innovative projects and to generate disruptive concepts, while a company adopts a participatory and collaborative approach. It is worth mentioning that the KCP method builds on opposite principles than those of classic brainstorming, as the latter ignores research and tends to isolate creative groups when they should learn from others.

3 Dassault Systems, RATP, Renault, SNCF, Thales, ST-Microelectronics, and Vallourec.

Today, C-K theory is taught in engineering and management departments as well as in industrial design schools, fostering a common language between different design professions. Presenting all existing research about C-K theory would require a huge book. Partners and friends urged for a more accessible introduction. Our post-doc colleagues accepted the challenge. We express to them our warm gratitude and thank the Presses des Mines for publishing their text. We hope that readers will find this book a useful introduction of C-K theory for a wider audience.

Armand Hatchuel & Benoit Weil,
November 2013

Acknowledgements

In 2011, Carl Trémoureux, a manager of the French Armaments Council, asked us to present a state of the art paper on research and innovative design: more specifically on C-K theory. This demand accounted for a growing interest of an audience unfamiliar with these issues. The success of this first introduction on innovative design encouraged us to continue our effort by writing a first book in French, presenting the innovative design theory and C-K theory for an audience beyond the academic sphere. The present book is an enriched English version of the first book.

We would like to thank Carl Trémoureux, who has provided the impetus that led us to write this book and who kindly agreed to also write the afterword of this book. We would like to thank Georges Amar as well for the second afterword of our book and also for shedding an industrial insider light on the research presented in these pages. We take the opportunity to also thank Armand Hatchuel and Benoit Weil who highlight the first steps of C-K theory in their foreword, and this book only covers part of the developments from their work.

We also thank the industrial sponsors from the Chair on Design Theory and Methods for Innovation-DTMI (Dassault Systems, RATP, Renault, SNCF, STMicroelectronics, Thales and Vallourec) for their support both for our research on theoretical and practical issues related to innovative design and their participation in numerous research programs, playing a decisive role in the development of theoretical and practical elements described in this book.

Finally, we express our gratitude to the entire research team from the DTMI Chair, as well as Akin Kazakçi, Thomas Gillier and Yacine Felk to have contributed to the richness of the work presented here. We also wish to thank all our colleagues in France and in foreign universities: high-quality discussions contribute significantly to the deepening of the research presented in this book. Especially, we are grateful to Karen

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Introduction

Theoretical and practical implications of innovative design

In this day and age, when the identities of common objects are constantly evolving, when business models are becoming more and more innovative, when new entrants are surprisingly changing the rules of the game, and unknown technologies are appearing in uncertain markets, it is quite apparent that companies are being faced with situations of disruptive innovation, which in turn are destabilizing established models of their products or services as well as their organizations *per se*.

In this context, incremental innovation is appearing as an insufficient lever to support major changes disrupting our economy, especially since they occur very frequently.

Historically, studies on design activities have fostered various theories that have allowed firms to adapt to rule-based design approaches, *e.g.* through the organization of R&D departments. But these structures and their associated theories are now struggling to account for situations of intensive innovation and change, where the identity of the products or services is constantly challenged.

An industrial illustration

In 2010, the Chief Operating Officer (COO) of Renault asked the engineering departments to develop "re-insuring[4] technologies and services" to support the entry of the firm's range of Electric Vehicles (EV) to the market. Given that engineers were convinced that EVs could embed fears and anxiety for consumers, a "re-insuring technology" presented a collective dilemma. Was it a new Human Machine Interface? New acoustic technologies? New sales services? All of these combined? No one knew… "Re-insuring" was an explorative concept for the automotive firm, a potential field of innovation which could enhance not only the competitiveness of Renault's EVs, but also enhance the attractiveness of its thermic range. Across all hierarchical levels of the firm, managers faced critical questions. How to start the exploration? How to select the design paths? How should the funding be done? Who could be the potential partners? Who should be the person in charge of implementing a smooth coordination amongst all the stakeholders? Overall, the managers were facing classical issues raised by dealing with innovation.

The current COO appointed the manager of the Creativity and Vision unit of the R&D department to address the "Re-insuring" challenge. The Creativity and Vision unit had often partnered with a famous school of engineering, and especially with a research group that had developed a strangely named design theory, called C-K theory. The promoters of this theory tended to criticize standard brainstorming approaches. And this time, the internal stakeholders of the "Re-insuring technologies" had adopted a similar point of view, in particular the manager in charge of proposing a strategy for overcoming the challenge. Initial brainstorming sessions had not been of much help and had actually increased the Creativity and Vision unit leader's anxiety. Ideas which emerged were

4 The word " Re-insurance" is a technical term from Insurance Industry, that refers to an insurance purchased by an insurance firm to one or more other insurance companies as a means of risk management. The COO of Renault knew this technical word as he was engaged in this particular process with Renault's insurance for Electric Vehicle business model but nobody in the Engineering department knew it. Consequently, it has been mostly interpreted as "reassurance".

disorderly. They were often interconnected and appeared to, in fact, be variants of the same idea; and as such, lacked novelty. Analogies and metaphors could be multiplied endlessly without any concrete outcome. Moreover, the leader of the Creativity and Vision unit has led many internal interviews with the experts of the departments of Marketing, Customer Intelligence and Industrial Design but she felt that experts stood silent, waiting for some clear orientations before intervening. Most of all, she was convinced that the team lacked crucial competences and needed a change of perspective. Could this strange C-K theory help her?

With her team, she decided to further explore the understanding of the concept of "Re-insuring". They wanted to be able to identify firms outside the automotive industry which used the concept in innovative products or services, and to be able to explain clearly the differences or convergences between various approaches of the concept. While interacting with Sophie Hooge from Mines ParisTech, the manager used the C-K modeling for different goals:

- First, missing knowledge on the polysemic meanings of the word "Re-insuring" had been identified. The team carried out many learning activities with specialists of "re-insuring" (in particular, they involved a semiotician and a philosopher in order to understand this concept, rarely used in the business arena);
- Second, outputs from several brainstorming sessions were sorted and hierarchically organized. These had initially given an overview of the conceptual space embedded in the Re-insuring concept. The team members took part in systematic documentation of linked knowledge in order to identify industrial players that were involved in different design paths;
- Third, the leader worked on conceptual formulations and reformulations, through tests and trials of C-K diagrams, which supported a guided elicitation of a concept manipulated in several industries. This, in turn, enabled positioning of innovative products and services from various industries in the conceptual field.

At the end of the process, the manager of the Creativity and Vision unit was confident in the robustness of the work given by her team. This process had allowed her and her team to cope with massive influx of data, and to structure the argument on industrial applications of the "Re-insuring" concept. The final modeling of the conceptual space and the related knowledge with a synthetic C-K diagram led them to distinguish four types of markets mobilizing the concept (objects or services to reassure the individual of the exposure to a threat to the physical integrity, emotional stability, ability to overcome obstacles, and cognitive ability to act in situations of potential threat).

The work carried out had opened up a new potential for efficient innovative design, with appropriate operational guidance along with research activities conducted by the R&D department. More importantly, the process had encouraged managers towards building and disseminating a robust argument in order to coordinate diverse activities of the company under "Re-insuring technologies". C-K theory was proven to be adaptable to situations requiring innovation where usual methods were encountered difficulties.

A scientific effort to understand innovative design

In 1994, Prof. Armand Hatchuel and Prof. Benoit Weil of the Center for Management Science (CGS) of MINES ParisTech launched a research program on *Innovative Design* based on a double ambition: (1) an attempt to rationalize R&D type of activities in these new disruptive innovation situations, and (2) the pursuit of a scientific foundation for design sciences, which could overcome the limitations of existing theories. This research program has yielded results both in theory and in practice. At a theoretical level, the main contribution has been in the form of a continuous definition of C-K theory (Concept-Knowledge) as a theory of innovative design, first by Prof. Armand Hatchuel and Prof. Benoit Weil, then by Prof. Armand Hatchuel, Prof. Benoit Weil and Prof. Pascal Le Masson. To reiterate, C-K theory aims at modeling activities and notions associated with innovative design, *e.g.* the intensive creation of new knowledge, or notions such as *creativity* or *identity of an object*. The notion of the identity of the object is

core to the work on C-K theory. It has to be understood as the set of attributes that define an object, including the functional description of the object, the technologies that are used, the value for the customer and the business model[5]. In practical terms, the theory has triggered an empirical research by providing both researchers and designers a unified language to describe and discuss the design reasoning implemented in organizations. Moreover, C-K theory gave birth to a set of methods, guidelines and tools to help designers deal with new issues raised by innovation-intensive systems. It is these different results, stemming from more than twenty years of collaborative research at the Center for Management Science, which are presented in this book. Today, the collective efforts of research on these issues are regrouped within an academic chair called "*Design Theory and Methods for Innovation*."

This book starts by positionning theoretical advances on innovative design in a longer history of successive research on the formalization of design activities (Chapter 1). After describing the limitations of existing theories and the requirements of a theory adapted to the challenges of intensive innovation, we present a unified design theory (C-K theory), first conceptually and then through a more concrete example (Chapter 2). Then, we situate C-K theory within the landscape of formal design theories (Chapter 3). Next, we present the main industrial mobilisations of the theoretical work, namely the methods and tools developed jointly by the researchers and their industrial partners (Chapter 4), with a dedicated focus on the KCP method (Chapter 5). Afterwards, research perspective sin design theory are presented followed by caveats and limitations, thus concluding the book. Four appendicies are proposed for the reader who is curious to deepen their understanding.

5 This notion is described further in Chapter 1.

Chapter 1

From rule-based design to innovative design

A brief history of design activities

First attempts to the rationalization of design activities

Historical accounts of design activity rationalizations mainly retain the tradition of rule-based design, that emerged at the same time as the figure of the engineer appeared during the early nineteenth century. However, we can trace the oldest attempts of formalization of design, and find the first evidence of such a rationalization in the architectural treaty of Vitruvius, written in the first century BC. In the early chapters of his work, Vitruvius describes his design activity detailing the reasoning of an architect based on a vast body of knowledge that comes from the science of architecture. He aims at characterizing the reasoning that helps structure this vast knowledge for the purpose of an architect. He develops his theory based on major functions of the object to be designed, which must meet a set of five criteria: order, arrangement, eurhythmy or proportion, coherence and economy. This characterization of the work of an architect highlights the need to rationalize the reasoning among a wide range of knowledge that is both available and relevant to the design activity.

It is only later, in the early nineteenth century, that further efforts were undertaken in order to pursue this rationalization, embodied by the very first Research and Development (R&D) departments. Indeed, the first industrial revolution in England stimulated the emergence of many new industries, including Arkwrigt's mechanized mills, steam engines designed by Watt and Boulton and later the birth of the railway industry. These new industries

triggered a vast diversification of products as well as skills, which were much solicited for their design. Firms gradually developed organizational capabilities in order to structure their rule-based design activities, *i.e.* design activities based on the collective use of rules for continuous improvement and increased variety of products. Thus large R&D departments emerged and became responsible for thinking out of box and designing the products as well as the parts to produce; whereas Organization and Methods (O&M) departments took charge of the development of production lines, as well as assembly and test protocols. Since the late nineteenth century, R&D departments were made to represent the organization of design activities in large industrial firms. The model of a typical R&D division is based on a design rationale through the application of a system of rules that provides designers the ability to effectively generate a variety of objects of a certain type. A logical organization of bureaucracy is aligned with this logical organization of design activities. The organization of bureaucracy is related to the structuring of knowledge to determine the design rules, and allows therefore an adequate division of design-related work.

Along with the emergence of R&D and O&M departments, a model of design activities also emerged, as theorized by two German professors, Gerhard Pahl and Wolfgang Beitz, in their book *Konstruktionslehre* written in 1977. This design theory was called Systematic Design and it divided the design activity into four stages:

- A functional definition phase detailing the features that must be completed and in accordance to which the functional requirements must be modeled;
- A conceptual design phase characterizing the physical principles that are used to fulfil the functional requirements of the previous stage;
- A phase of physical and morphological definition specifying the natural and organic elements that are required to achieve the physical principles used;
- And finally a detailed definition phase describing interactions between the different parts of the designed object and their production processes.