Elaboration d'une méthodologie Kansei à travers les interactions physiques et digitales

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T H È S E

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ELABORATION OF A KANSEI DESIGN METHODOLOGY THROUGH **PHYSICAL AND DIGITAL INTERACTIONS**

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This part is the only one where I will speak personally. My name is Théo, and I am a designer, with two master's degrees, one in Industrial Design and one in Innovation and Product's Conception. I am in love with right and memorable products that are able to touch a person's soul. All this magic that products convey while we are interacting with them is an amazing territory of study that I decided to approach through this Ph.D. My personal intention is to learn as much as I can from both the industrial and the academic side. Hopefully one day I will be the product designer that I long to be.

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TABLE OF CONTENT

-

ACKNOWLEDGMENTS 11

GLOSSARY 15

LIST OF ACRONYMS 17

SYNOPSIS 19

1 CONTEXT OF THE RESEARCH 23
1.1 Industrial Context 23
1.1.1 Toyota Motor Corporation (TMC) and Toyota Motor Europe (TME) 23
1.1.2 Toyota Motor Europe Kansei Design Division 24
1.1.3 Design Practices 25
1.2 Research Context 29
1.2.1 History of Design Research 29
1.2.2 Positioning this Dissertation within the Field of Research of LCPI Arts et Métiers ParisTech 31
1.3 Industrial and Research Collaboration History 37

2 LITERATURE REVIEW 41
2.1 Experiencing Designs 45
2.1.1 The Framework 45
2.1.2 Interaction 52
2.1.3 Experiential Interaction 58
2.1.4 A Metaphorical Approach to Physical and Digital Interactions 61
2.1.5 Summary of Experiencing Designs 66
-1- Model of Design Information (i) 66
-2- Three-Dimensional Taxonomy (d) 68
-3- Areas (a) 68

-4- Principles (p) 69
2.2 Designing Experiences **71**
2.2.1 Design Fields 71
2.2.2 Design Disciplines(di) 79
2.2.3 Design Processes 79
2.2.4 Design Levels(lev) 81
2.2.5 Design Information(i) 82
2.2.6 Designing Interactions through the Metaphorical Approach 83
2.2.7 Designing Experiences: Summary 85
5- Design Process 86
6- Design Levels (lev) 86
7- Design Disciplines (di) 86
2.3 State of the Art Summary and Statements **89**

3 RESEARCH QUESTION AND HYPOTHESES **93**
3.1 Research Question **93**
3.2 Hypotheses **97**
3.2.1 The Three Hypotheses 97
3.2.2 Hypotheses that Support Platforms Development 98

4 EXPERIMENTATIONS **103**
4.1 Introduction **103**
4.2 Experimentation 1 **107**
4.2.1 Objectives 107
4.2.2 Experimental Ground 107
4.2.3 Method 108
4.2.4 Results 116
4.2.5 Discussion 127
4.2.6 Conclusions and Perspectives 129
4.3 Experimentation 2 **133**
4.3.1 Objectives 133
4.3.2 Method 134
4.3.3 Results 140
4.3.4 Conclusions and Limitations 151
4.4 Experimentation 3 **155**
4.4.1 Objectives 155
4.4.2 Method 155
4.4.3 Protocol 156
4.4.4 Conclusion 177
4.5 Conclusion on Experiments **179**

5 CONTRIBUTIONS **183**
5.1 Academic Contributions **183**
5.1.1 Model of Design Information 183
5.1.2 Taxonomy of Interactive Products 186
5.1.3 Metaphorical Approach to the Design Process 186
5.1.4 A Set of Principles 188
5.1.5 Conclusion on Academic Contribution 189
5.2 Industrial Contributions **193**
5.2.1 Development of New Tools 193
5.2.3 Creation of New Methodologies 195
5.2.4 Uptake of the Industrial Contribution in Toyota Motor Europe Activities 198
5.3 Summary of the Contributions **201**

6 CONCLUSIONS AND PERSPECTIVES 205
6.1 Conclusions 205
6.2 Perspectives 209

ANNEXES 211
Annexes 211
A- Car's Evaluation (Evaluation Platform) 215
B- Kansei Kards (Creation Platform) 218
C- Kansei Kabin (Creation Platform) 220
D- Koncept Evaluation (Evaluation Platform) 221
E- Kansei Kabin (Evaluation Platform) 221
F- HMI Score (evaluation platform) 222
G- Kansei Evaluation Kit (evaluation platform) 223
H- Kansei Klassification (preliminary workshop) 224
I- Kansei Knob (Collaboration with Tue) (Creation Platform) 226
J-Superinteraction Tool (creation platform). 228
K-Scenario Kards (Creation Platform) 238

REFERENCES 241

LIST OF TABLES 257

LIST OF PICTURES 259

FRENCH VERSION 281

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I would also like to express my gratitude and appreciation to **the jury**. Thank you for your valuable perspective and feedbacks on the work.

All the **authors and researchers** upon whose shoulders I have stood have my eternal gratitude and they will find their names in the absurdly long list of references at the end. Hideyoshi Yanagisawa merits an individual mention for the great and inspiring discussions we had.

Thanks are due to **my friends** as well as **my colleagues** at the LCPI and

at Toyota Motor Europe, the environment that formed the foundation of my approach to interaction Design.

I would like to thank **my family** for their faith in me and their support all these years. Your 'ravioli' and 'andouilettes' have made me what I am today. And I hope that you are proud.

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Day of the final presentation at The LCPI of Arts et Métiers ParisTech.
Kenza Dracourt, my parents and myself.

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GLOSSARY

-

The following terms are of some of the key notions used in this research. The short definitions explain the way these notions are to be understood in the following pages.

User Experience: a dynamic phenomenon originating in user and artifact characteristics that interact in a specific context, involving personal user responses and perceived artifact attributes (more details about this notion in section 2.1.1)

Interaction: the action accomplished by the user or by the artifact on each other that influences or modifies the user's motor, perceptive, cognitive, and affective systems (more details about this notion in section 2.1.2)

Experiential Interaction: a sequence of unilateral and reciprocal interactions (more details about this notion in section 2.1.3)

Design Information: information regarding concepts discussed among a design team (more details about this notion in section 2.1.5)

Design Disciplines: the disciplines involved in the different design phases (more details about this notion in section 2.1.5)

Principle: consists of keywords mostly related to what the interactive product enables the user to do (more details about this notion in section 2.1.5)

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LIST OF ACRONYMS

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The following acronyms will be use in the text not as a way to abbreviate words, but as a way to reference to a higher notion.

(i): Design information from the theoretical model

(d): Dimensions from the taxonomy

(a): Areas highlighted by the taxonomy

(p): Pinciples to characterize Interactive products

(lev): Design Levels

(di): Design Disciplines

-

SYNOPSIS

-

What If Steering Wheels Were Digital?

Thanks to research and evolution, we can acknowledge that today technologies are unlimited. Potentially, every element we use to interact with could become digital. This is for instance exemplified by infotainment-related elements in a car. We used to interact physically with our components, as in this Maserati Boomerang of 1972 (see Picture 1 on the left). However, increasingly technologies allow us to transform interactions into something completely digital, through a simple screen. The 2015 Tesla Model X (Picture 1 on the right) is an example of this extreme digitalization trend.

Picture 1: Maserati Bomerang 1972 and Tesla model X 2015

Today manufacturers could digitalize almost everything in a car, including the steering wheel. Why do they retain a physical one? Why not use a screen with a digital circle that allows the driver to turn? From an objective point of view, choosing between physical or digital elements raises valuable questions regarding price, efficiency, time per task, and even standardization.

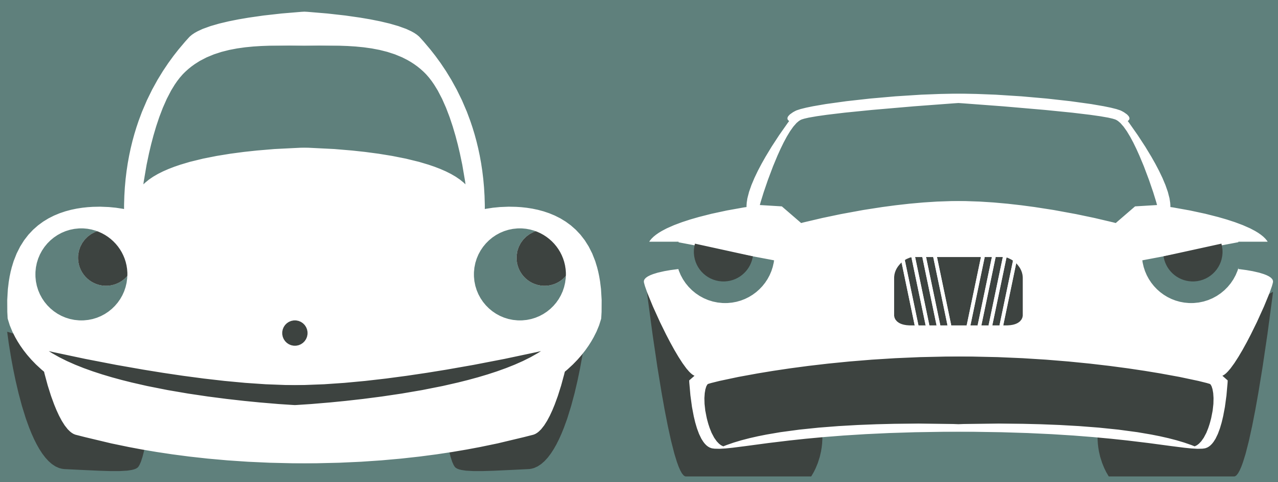
From a broader perspective, user experience can also be considered. This raises new questions such as "what will the user feel?", and "how will he or she perceive and enjoy the driving performance and interactions with the vehicle during the journey?" This is the kind of perspective that this research will employ. Thus, focusing on physical and digital interactions from these subjective ways of perceiving decisive notions such as trust, emotional impact, intuitive interaction and more broadly meaningful user experience leads us to consider **the way we can design it.**

What is very interesting when researching physical and digital interaction is the full range of interactions between the two options. For example, on the screen of the Tesla Model X, we can see digital buttons with a shadow. This shadow plays with the illusion of having physical buttons, but at the same time with an ability of infinite “screen changing”. This trend, known as “skeuomorphism”, is one example of the blurred boundary between physical and digital properties.

Our assumption is that the right user experience of a certain product might depend on the perfect balance between physical and digital interactions. Combining both dimensions could indeed permit taking advantage of both worlds.

In order to explore this point of view further, a research project was initiated with the LCPI Arts et Métiers ParisTech and the Kansei Design Division of Toyota Motor Europe.

Chapter 1 of this thesis presents the general context in which this research took place. The literature review in Chapter 2 explores both the relationship between a user and an artifact from a user experience point of view (experiencing design), and the relationship between the designer and the artifact (designing experiences). This exploration leads the research towards a central research question about the understanding of human-product interactions as a way to improve user experiences. Three hypotheses are suggested, and three experiments have been devised. The first formalizes the reciprocal impact between user experience and interaction. The second explores the impact of physical and digital properties on experiential interactions. The third experiment develops a tool for creating interactions based on the metaphorical approach. The research question and hypotheses are presented in Chapter 3, and the experimentations are discussed in Chapter 4. This research led to both academic and industrial contributions, resulting in an improved process for designing interactions based on the physical and digital paradigms. Lastly, the conclusion in Chapter 6 presents future perspectives on research.



«The car is the closest thing we will ever create
to something that is alive»
William Lyons

-

1 CONTEXT OF THE RESEARCH

-

1.1 Industrial Context

This chapter describes the industrial context, from the broader scope of Toyota Motor Europe to the smaller perspective of the design practices of the Kansei Design Division.

1.1.1 Toyota Motor Corporation (TMC) and Toyota Motor Europe (TME)

The research took place in the Kansei Design Division of Toyota Motor Europe (TME), the European subsidiary of the Japanese carmaker Toyota Motor Corporation. Toyota Motor Corporation (TMC) is a Japanese company designing, manufacturing and distributing automotive vehicles, predominantly to the consumer market. This company was founded by Sakichi Toyoda. His first commercial venture was an automatic loom, originally created for his mother. His aim was to develop robust, reliable and affordable products, with the user as a major concern.

Established in 1937, the company grew exponentially during the post-World War II economic boom in Japan. This growth, even in a propitious period, was also made possible by an innovative production system, the so-called Toyota Production System, a system that is based on lean manufacturing, continuous improvement and zero-defect principles. Expanding internationally, Toyota has over the past five years four times attained the position of top carmaker worldwide, in terms of vehicles produced. With 332,000 employees and a capital worth of ¥397 billion ($4,21 billion), TMC is also the world's most valuable automotive brand, according to Millward Brown (BrandzTM Top 100 Most Valuable Global Brands 2013). The company has maintained a strong corporate culture during its development, known today as the Toyota Way. This is a set of principles aimed at improving all company activities (Toyota Motor Corporation, 2001). This research project is located within this context of actual methodology improvement. TMC produces vehicles for its two different brands: Toyota and Lexus. The latter brand produces luxury cars, but this research will be conducted in the context of Toyota cars only.

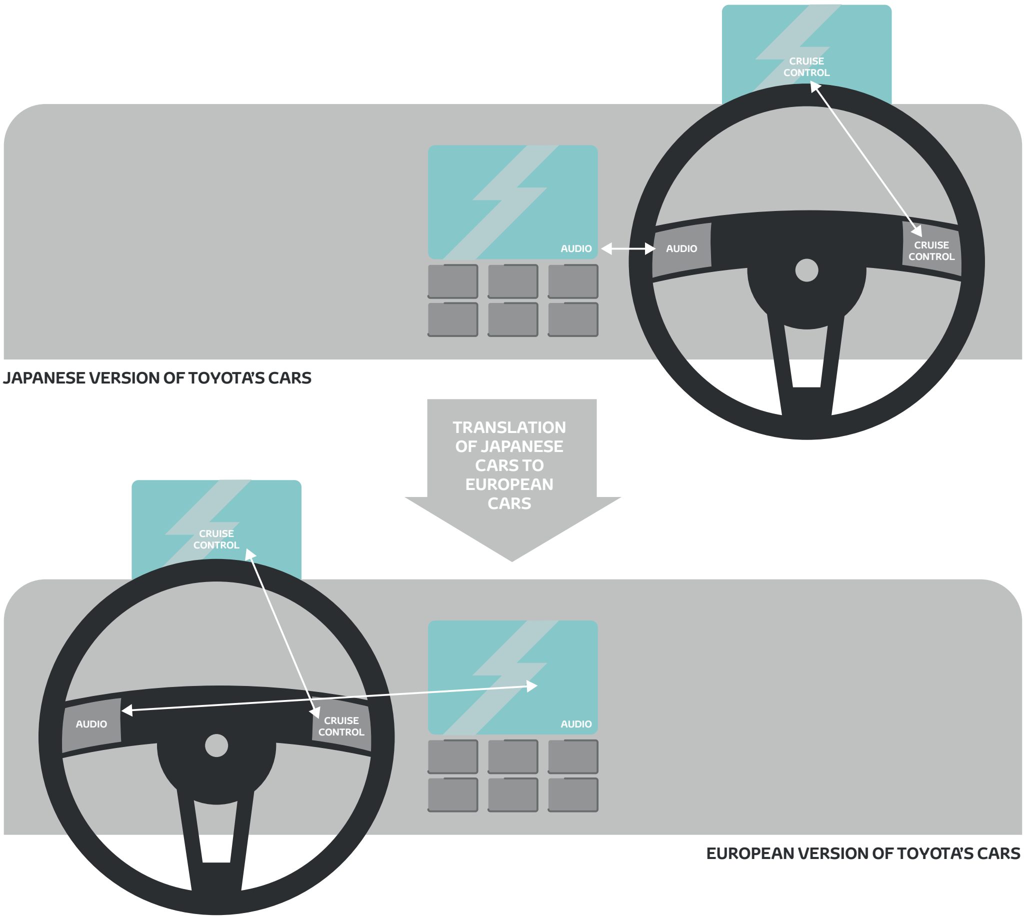


Figure 1: A car From Japon to Europe

1.1.2 Toyota Motor Europe Kansei Design Division

Toyota Motor Europe is the European subsidiary of TMC. Besides its standard role as a subsidiary (European research and development activities, manufacturing, sales, etc.), TME's role is to adapt vehicles developed in Japan to distinctive European features (from design tastes to morphological dimensions), in order to develop cars for the European market. For example, as can be seen in Figure 1, when a car is designed in Japan for the Japanese market, and is then sent to Europe, some adjustments need to be performed. In this simple example, it is clear that the steering wheel is on the right, and that the related functions are logically positioned: the audio that is on the left on the dashboard is also on the left on the steering wheel. However, when introduced in Europe, the steering wheel changes position, in accordance with the legislation of certain European countries, introducing some de facto inconsistencies in the cars.

As part of TME's research and development department, the Kansei Design Division aims to develop, implement, and use Kansei-related methodologies and tools to counter these inconsistencies. The Kansei Design Division is introduced step by step «as a new domain, re-exploring Japanese philosophy as an inspirational means to face current issues addressed by design research» (Levy 2013) and a new kind of interpretation, closer to user subjectivity, and its materialization through product design issues. The Kansei design approach is based on a «non-reductionist point of view, which can be used both to focus on, and to comprehend, the phenomena of perception and experience, inherently contextualized» (Levy 2013). The aims of the kansei design division is to find approaches that help to break with a standardized vision of the world, through a sensitive human-centered perspective. Studies at Toyota's Kansei Design Division are focused on the generation of greater energies for dynamism, and more opportunities for creativity. In terms of this philosophy, Kansei design at TME was initially described as a way to introduce Kansei engineering approaches into the scope of design thinking. The aim was to define the space for design (understanding), to create propositions fitting in this space (creating), and to assess propositions based on users' Kansei (assessing) (Gentner, 2014; Bouchard, 2009). Today, the approach of Kansei Design that TME developed aims at improving how the user experience way of thinking could be involved in the early phases of the design process.

1.1.3 Design Practices

The originality and particularity of TME's Kansei Design Division lies in the fact that it is based on user experience practices, as opposed to industrial design practices. Obviously, there is common ground between both: The design practices based on "design ambition", articulated by Henry Cole and Richard Redgrave in *The Journal of Design and Manufactures*, and developed by people such as Peter Behrens, who combines both industry and arts with a human-centered approach, to create what has recently been highlighted as the "design effects" (Kenya Hara).

If design practices can be acknowledged as the common philosophy between industrial design practices and user experience practices being advanced at Kansei Design Division, the three main distinctions between industrial design practices and user experience design practices can be summed up as the following: The methodologies, the tools, and the relational circle.

First of all, in terms of methodology, while industrial design practices create products that can elicit particular meaning to the user, user experience design practices focus on the user's reactions (meanings, feelings, etc.), that will be translated into products. Thus, the conceived products can be the same, but the scheme of conception, in terms of methodology, is different. The clearest example of this is certainly the design brief itself, which is functionally and materially oriented for industrial design practices, and emotionally, sensationally, or experientially oriented for user experience design practices.

Second, part of the originality of design practices is that it is a generalist profession (and passion) with broad application territories. Thus, surrounding a designer's practices with different specialists has always been necessary. Nevertheless, whereas industrial designers create their own relation with stylists, modelers and many more specialists depending on the mission they are working on. user experience practices lead to the development of a community of cognitive psychologists, affective computing experts, or even Kansei design researchers.

Third, when considering design practices, it is important to use tools and include design stages that allow for the creation of the final product. Indeed, designers' tools are what make the evolution of designers' practices possible. According to Bouchard (2003), the design information cycle is composed of various stages: Information, generation, evaluation and decision, and communication. These common design stages utilize proper tools and methodologies according to industrial or user experience design practices. Indeed, even if the final product is the common objective, the tools, methodologies, support, etc. are dependent on the practices.

Finally, we can acknowledge the strong common background of the **industrial design practices** and **user experience practices** employed by the Kansei Design team. Nevertheless, despite all of these common elements, some specificities allow one to distinguish between these practices, particularly as regards the methodology, the tools and the people the team work with. This is why the Kansei Design team adopted this maxim: **Since user experience design provides a valuable alternative and strong complementary design approach to industrial design practices in product conception, the community may adopt, create, and strengthen proper tools and methodologies for these new practices.**

Differentiating between **industrial design practices** and **user experience design practices**, it is interesting to highlight a particular typology of products. When looking at interactive design products, we can acknowledge two different visions for industrial design practices and user experience practices: Interaction design practices are based on the same common ground as design practices. Nevertheless, according to the above maxim, even if industrial design practices begin with the common and broad area of design practices, we can acknowledge a double vision of interaction design practices, corresponding respectively to industrial design practices and user experience design practices. Indeed, interaction design can be understood in terms of industrial design practices as a materialized product, interface, or something physically manipulable. Or, we can consider interaction design in terms of user experience practices, pointing out the approach for human-product interactions: An approach arising from cognitive psychology, Kansei design, artificial intelligence, and other fundamentals of user experience practices. The second group of practices is the focus of this thesis.

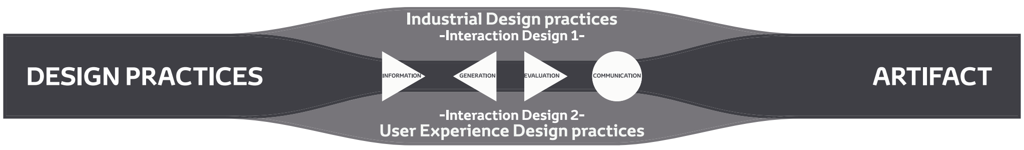
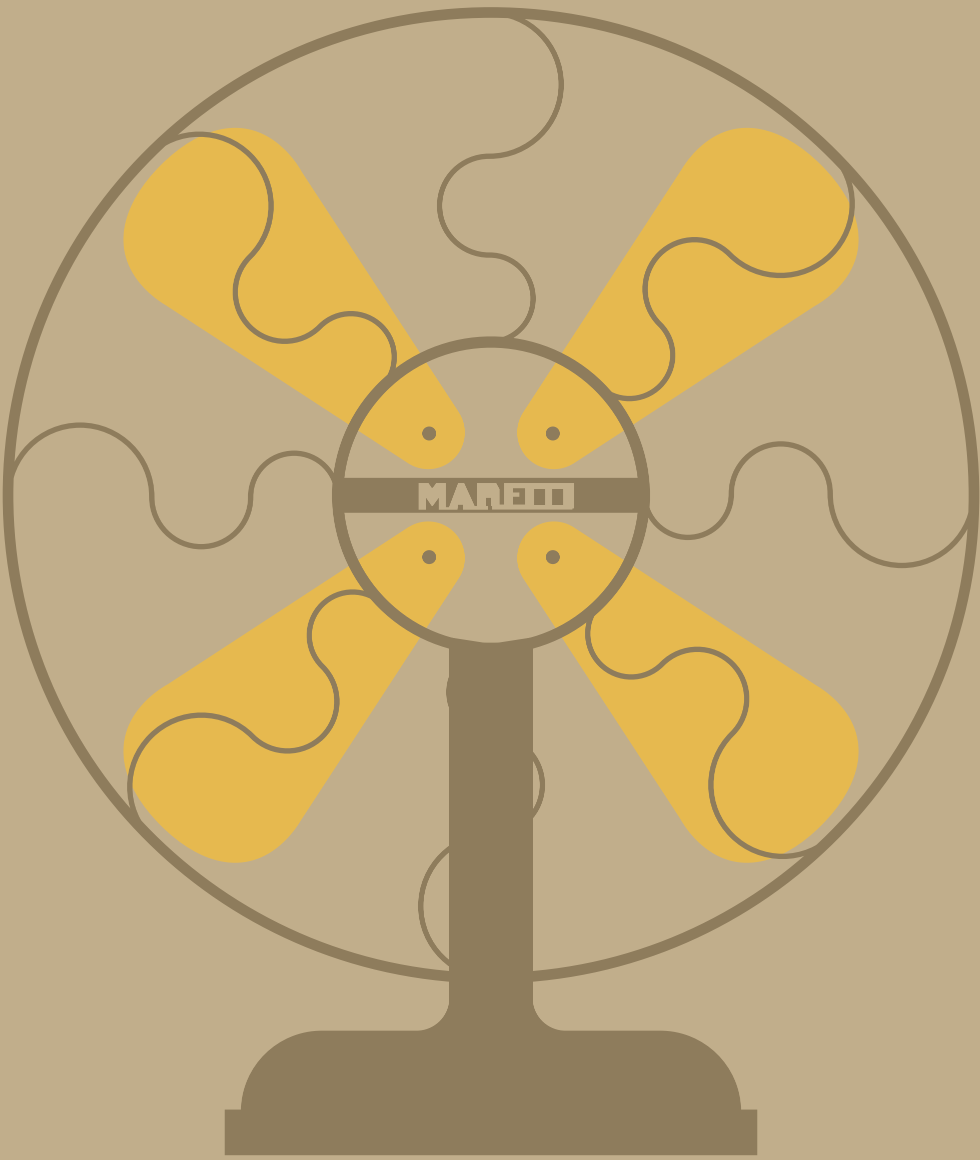


Figure 2: Design practices representation



«Experience wihout theory is blind,
but theory without experience is mere intellectual play»
Immanuel Kant

1.2 Research Context

This section describes the context in which this research takes place. First of all, the history of design research is presented. Then, this dissertation is positioned within the field of research conducted at the LCPI Arts et Métiers ParisTech.

1.2.1 History of Design Research

This section will start by presenting the scope of design research, followed by a brief chronological review describing its almost 100 years of existence.

The word “design” is ambiguous, because it covers both the notion of planning (of products and systems), and of “form-giving” (Koskinen et al., 2013). Design is also an ambiguous term because it can be understood in terms of six different meanings in English alone. Considering “design” as a noun and not as a verb, it can mean, according to the wordnet database:

1- The act of working out the form of something;
2- An arrangement scheme;
3- A decorative or artistic work;
4- A preliminary sketch indicating the plan for something;
5- The creation of something in the mind; and
6- An anticipated outcome that is intended or that guides a person’s planned actions.

Deserti (2011) describes design in terms of four pillars: Future (visionary design); technical act (engineering design); present (situational design); and creative act (romantic design). These four pillars have been mapped along a horizontal axis from the creative act to the technical act (questions the notion of rationality in design), and along a vertical axis from future to present (dealing with an exploration of new opportunities or with the exploitation within the limits of a given context). It appears that it is not easy to identify the current boundaries of design.

The following section consists of a short overview of the history of design research. Two complementary fields are presented: The design thinking approach, which refers to a way of thinking and acting in terms of design; and the human-computer interaction (HCI) approach, which marks the birth of interaction-related research.

THE DESIGN THINKING APPROACH

Since the 1920s, scholars have set out to define design as a science, combining its artistic dimension with science and technology (Cross, 2007). A key input can be traced to 1919, with the creation of the Bauhaus school. This school sought to reconcile art and technology using a new set of practices, and is considered by many as the first modern design school.

In the 1960s, efforts were made to develop the field of design into a science, by applying scientific methodology and processes to understand how design operates. Cross (2001) describes the struggle that began to unfold in the early 1960s, when attempts were made to “make design a science”, and bring the field within the objective of the rational sciences. He highlights the reference by the radical technologist Buckminster Fuller to the “design science decade”.

In the 1970s, the notion of design as a “way of thinking” in the sciences arose. This approach can be traced to computer scientist and Nobel Prize laureate Herbert A. Simon’s (1969) book, The Sciences of the Artificial. A large portion of Simon’s work focused on the development of artificial intelligence, and whether human forms of thinking could be synthesized.

In the 1980s, Cross (1982) discussed the nature of problem-solving by designers. He compared designers’ problem-solving to the non-design-related problem solutions people develop in their everyday lives.

Over time “Design Thinking” as a subject progressed and made its journey through various fields of specialization, as thinkers in those fields explored the cognitive processes within their own fields, and eventually Design Thinking moved into a space of its own.

Since the 1990s the Design Thinking movement has rapidly gained ground, with pioneers such as IDEO and d.school formalizing a path for others to follow. Prestigious universities, business schools, and forward-thinking companies have adopted the methodology to varying degrees, sometimes reinterpreting it to suit their specific context or brand values.

In this research, the Design Thinking approach is used as a science for designing affective and cognitive reactions experienced by users. Various methodologies and tools support this way of including science in the design discipline.

THE HUMAN-COMPUTER INTERACTION APPROACH

“Human-computer interaction (HCI) is an area of research and practice that emerged in the early 1980s, initially as a specialty area in computer science embracing cognitive science and human factors engineering” (Carroll, 1996).
Historically, interaction design evolved in terms of goals and concerns.

Going back to the 50s, 60s, and 70s, interaction and interfaces were manipulated by operators, not users. Battleships, fighter jets, power plants, and early computers all had operators who had been trained. This changed radically with the development and popularization of personal computing in the later 1970s. It includes both personal software and personal computer platforms.

Thus, computers moved from laboratories into office workplaces. This phenomenon gave birth to the broad project of cognitive science. This project incorporated, artificial intelligence, cognitive psychology, cognitive anthropology, linguistics and the philosophy of mind, by the end of the 1970s. Among them, the program of cognitive science was to articulate “cognitive engineering”. HCI was one of the first examples of cognitive engineering, according to Foley (1982). In the 80s, computer graphics and information retrieval emerged very quickly (Carroll, 1996).

According to Carroll (1996), the original and abiding technical focus of HCI was and is the concept of usability, because usability is a way to approach the social practices of work. Usability was originally articulated somewhat naively in the slogan **“easy to learn, easy to use”**. This simple slogan gave an identity to the notion of usability in computing. However, inside HCI, the concept of usability has been re-articulated and reconstructed almost continually, and has become increasingly rich and intriguingly problematic. Usability now often subsumes qualities such as fun, wellbeing, collective efficacy, aesthetic tension, enhanced creativity, flow, support for human development, and others (Grudin, 2012).

Although Myers (1998) defined the original academic framework for HCI as computer science, and its original focus was on personal productivity applications, mainly text editing and spreadsheets, the field has constantly diversified and outgrown all boundaries (Myers, 1998). «It quickly expanded to encompass visualization, information systems, collaborative systems, the system development process, and many areas of design» (Myers, 1998).

When computers increasingly moved into the homes and other aspects of people's lives, there was an evolution of interface design into something broader: Interaction design. According to Mok (1996), "the biggest challenge designers face in working with the computing medium is not mastering the various technologies that are its constant companions, but introducing meaning and life into the products and services on the human side of the screen" (Mok, 1996, p. 4).

Nowadays, HCI is taught in many departments and faculties that address information technology, including design, communication studies, psychology cognitive science, information science, geographical sciences, management information systems, and industrial, manufacturing, and systems engineering. The research and practice that HCI encompass draw upon and integrate all of these scopes.

Finally, the HCI practices, compared to computer science itself, has grown to be larger, broader, and much more diverse. It has expanded from its initial focus on «individual and generic user behavior to include social and organizational computing, accessibility for the elderly, wellbeing, the cognitively and physically impaired, and interaction for all people, with environmental issues, and for the widest possible spectrum of human experiences and activities» (Carroll, 2004). HCI expanded from desktop office applications to include «games, learning and education, commerce, health and medical applications, emergency planning and response, and systems to support collaboration, community, and mobility» (Caroll, 2004) from a personal to a communal perspective. It expanded from simple graphical user interfaces to evolve into meaninful interaction techniques and devices, tangible interactions, tool support for model-based user interface specification, multi-modal interactions and a host of emerging ubiquitous, handheld, and context-aware interactions.

1.2.2 Positioning this Dissertation within the Field of Research of LCPI Arts et Métiers ParisTech

The first section describes what the LCPI is, in order, in the second section, to position the research within this scope. Finally, the last section positions this research in terms of related theses and research that has been conducted by others under the auspices of the LCPI.

What is the LCPI?

The LCPI – Laboratoire de Conception de Produits et Innovation can be translated as "Laboratory for Product Design and Innovation" – is a research laboratory located in Paris, France, and belonging to the Arts et Métiers ParisTech national engineering school. Research conducted by the LCPI aims at optimizing the product development process. Its long-term vision focuses on the digitalization of this process. Process optimization is based on two research axes: The first one is dedicated to **Formalization and Digitalization of Design Jobs**, the second one is related to the **Formalization and Digitalization of the Design Process**. These two axes feed and enrich one another.

The aim of the LCPI is to develop knowledge in order to improve design and innovation processes. This development leads to the building of theoretical models of design skills and design processes related to the activity of innovative products, systems, and services design. These models are evaluated in the operational context in order to validate knowledge, methodologies, and tools. Their integration contributes to both scientific and industrial progress. The results of this research are models and tools which enrich different levels:

The process model: Formalization of decisional or activities process.

Methodological models: Formalization of skills activities.

Design tools: Proposition of methodological and technological tools.

The LCPI scope of research belongs to the Industrial engineering and more specifically on the science of conception.

Positioning the Research within the LCPI Scope

The aim of the LCPI is to propose and develop a computational model of the innovative design process. This optimization is based on two complementary axes: The skills axis, focusing on enriching the design process through the integration of new knowledge and tools; and the process axis, focusing on the formalization of the general design process to better understand and optimize it. From these two axes, three points emerge:

1. Formalization, representation, and intelligent technologies: This point relates to the formalization and intelligent representation of disciplines' knowledge. It consists of formalizing knowledge on disciplines to create innovative theoretical formalization that supports the design of new tools for the design process. These tools focus on representation, simulation, and interaction. Virtual and physical prototyping systems are mostly used.

2. Managing and support in controlling. This second point is quite new in the laboratory and in the research community. It relates to the formalization of activities and experience feedbacks, in order to support decisions to support managing phases. It consists of identifying and formalizing parameters and indicators which have to be considered during innovative design processes.

3. Engineering of products, systems, and services design. The third point introduces an operational dimension, explaining why it is in between the two axes. It aims at supporting project managers in terms of methodologies and tools, to support the innovative process and enrich its quality, as much as

reducing the time for designing.
Thus these three points complement and enrich one another from three directions: operational design disciplines (point 1); operational design process (point 3); and decisional level (point 2). The following model formalizes this structure.

In terms of the scope of this research, this thesis can be positioned between two points: The first and the second. It relates to the first point (operational design disciplines) because this research also tackles a discipline knowledge perspective in order to formalize theoretical models that support the design of new tools and methodologies. It relates to the third point (operational design process) because the research also seeks to optimize the design process through methodologies and tools. Figure 3 illustrates how the research is positioned within the LCPI's scope of research.
Positioning the Research in terms of Related Research by Others from the LCPI

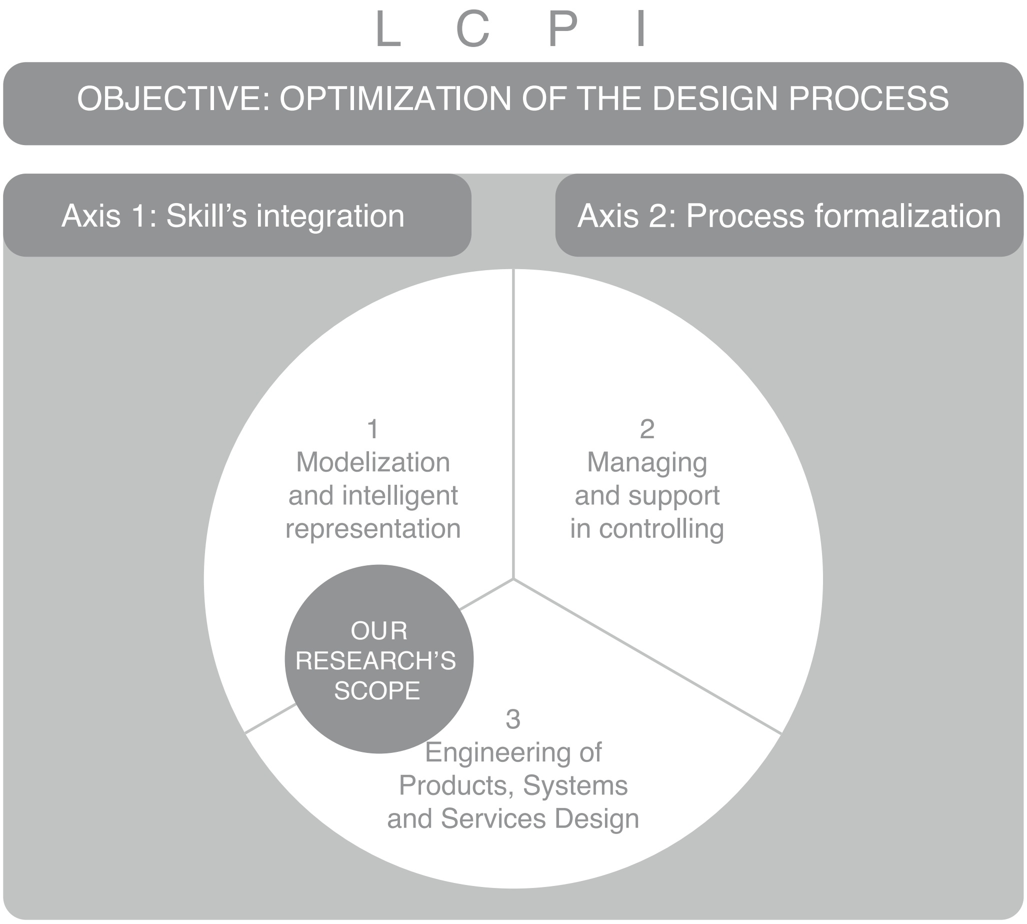


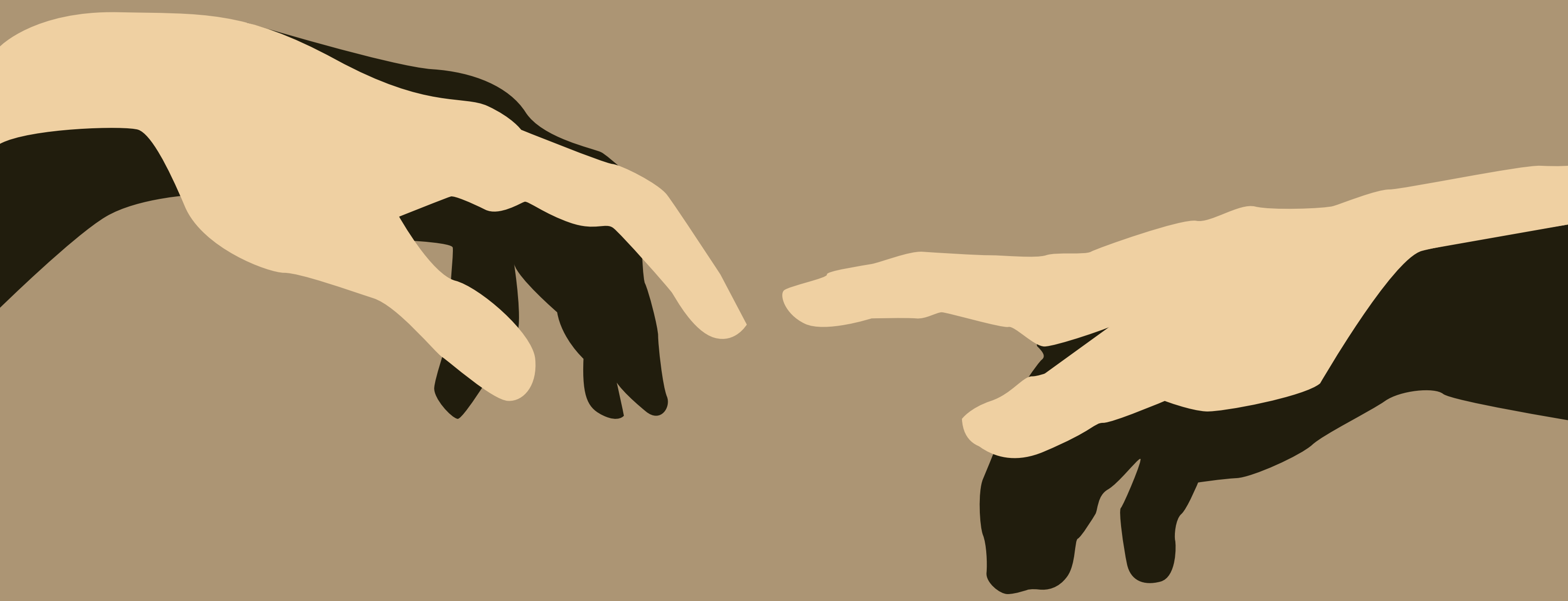
Figure 3: LCPI scope of research and postion of our research whitin this scope

This research can also be positioned within the research activities of the LCPI. This Ph.D. fits into a group of recent studies that investigate different ways to take into account users' Kansei process (i.e., affective-centered process occurring during an interaction with a product) in the design process. Notably, Bongard-Blanchy (2013) and Gentner (2014) were the first to tackle explicitly the notion of user experience.

This group of studies employ three types of measurements of the Kansei process: psychological measurements (questionnaires and interviews), physiological measurements, and behavioral (kinetic) measurements (see Table 1). The research presented in this dissertation mainly focuses on psychological measurements, but also touches on behavioral measurements. These measurements have the characteristics to involve participatory design sessions with users, to include multi-sensory samples, and to evaluate users' reactions when interacting with products.

Psychological	**Physiological**	**Behavioral**
Mantelet 2006 Mougenot 2008 Bongard-Blanchy 2013 Gentner 2014	Kim, 2012	Rieuf 2013

Table 1: LCPI thesis also tackling Kansei related studies



«I do not believe in things,
I only believe in their connection»
George Braque

1.3 Industrial and Research Collaboration History

The Kansei Design Division of TME has been working in collaboration with the LCPI of Arts et Métier ParisTech for the past 10 years.
The collaboration started when Carole Bouchard, professor in the CPI laboratory, and Carole Favart, general manager of TME's Kansei Design Department, met. This meeting resulted in a long-term partnership based on strong foundations, powered over 10 years by 10 master's students and two Ph.D. students, as presented in Figure 4.

The present research is the second LCPI Ph.D. study being undertaken in TME's Kansei Design Division. The first was the research by Alexandre Gentner (2014), who worked on user experience, and more especially a model of Kansei-related design information among design teams, highlighting the added value of early multi-sensory representation resulting from experience-centered design activities. Gentner's work will be discussed later in this thesis.

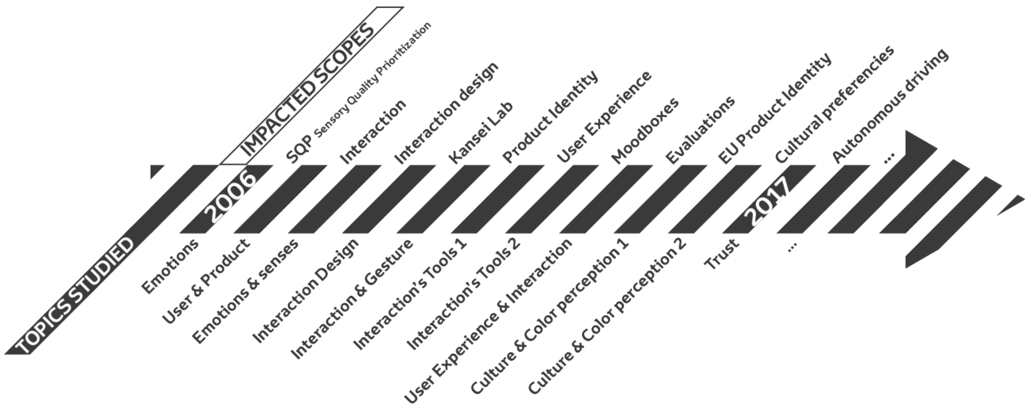
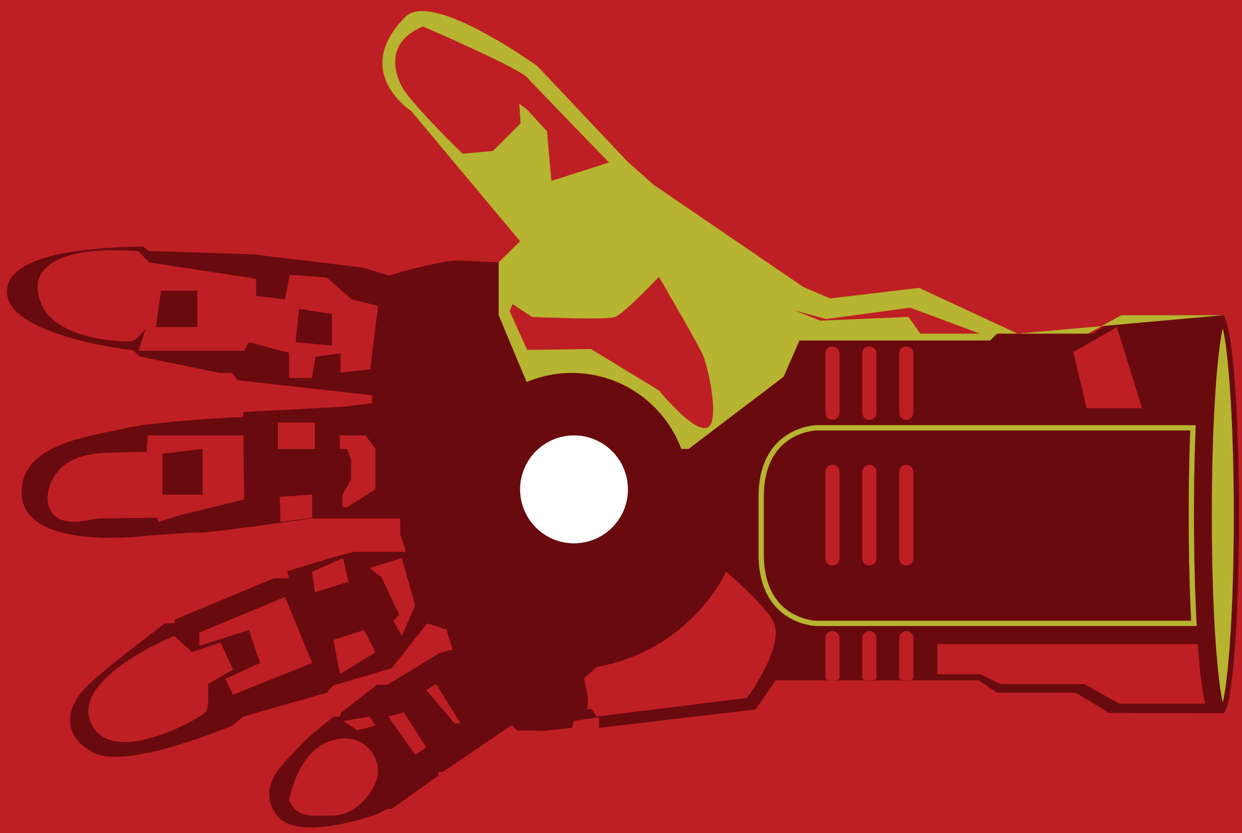


Figure 4: Past project between TME-KD and LCPI

To trace the story of this collaboration, one has to go back to 2006, when the first master's student initiated the collaboration. It started with a study on emotions, and on what would be named, a few years later, sensory quality prioritization (SQP). The second master's student investigated the notion of interaction between the user and the product, leading a year later to a study on senses to link emotions and interactions. This milestone in the collaboration brought the name of the Kansei laboratory to the division. In 2010, four years later, a study started on the association between the emotional and interaction design visions. This study focused on the concept of identity territory, including, for the first time, collaboration on the notion of product experience. This study led to the materialization of different tools, such as MoodBoxes. The following three studies, over the following three years, focused on interaction, including a study on gesture, and two on applications and tools for interactive design. In 2014, a study was conducted on the link between what has previously been presented as user experience and interaction design, leading to improving theoretical models on which the division is working. The following two studies focused on the impact of cultural influences on interaction, and more specifically on color perception and preferences. Thus, the collaboration started with emotions and SQP; magnified toward Kansei Design; then developed to the full notion of user experience; and finally focused on the heart of user experience, the scope of interaction. Recently, studies have focused on particular pillars of interaction, such as culture and perception. Following this collaboration progress, the next study will pursue another aspect of interaction and user experience, namely the notion of trust in autonomous driving.

As part of this collaboration, two Ph.D. candidates studied user experience and interaction design with the Kansei Design Division. The first is Gentner (2014), whose work will be described later in this research. The second is the current author. Gentner is still working on the development and integration of tools and methodologies for both evaluation and creation of user experiences and interactions in early phases.



«I guess I would say that interaction design is making technology fit people».

David Kelley

-

2 LITERATURE REVIEW

-

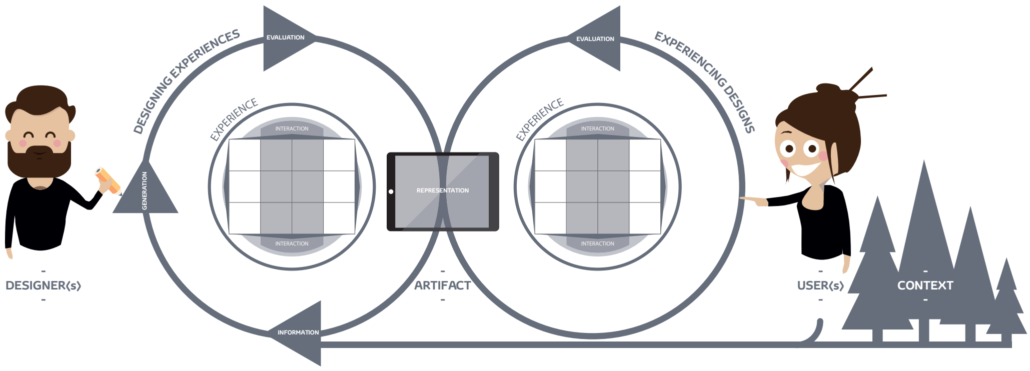


Figure 5: Model of Litterature review scope

The literature review explores and describes two loops where both User Experience and Interaction are involved, as presented in Figure 5

The first loop, **Experiencing Designs**, deals with the links between the user and the artifact. It introduces a general framework for the user experience that is applied to all interactive responses that can be experienced. This state of the art presents user experience as a multifaceted phenomenon that involves subjective feelings (change in core affect) (Mugge, Schifferstein & Schoormans, 2010), and behavioral, expressive, and physiological reactions (Desmet & Hekkert, 2007). These factors are direct consequences of attachment, and highlight the relationship that exists between a user and an artifact. Furthermore, the authors emphasize that the user experience is determined by different elements interacting with one another in complex ways. According to these authors, four elements make up user experience: The user, the artifact, the context, and the interaction that occurs.

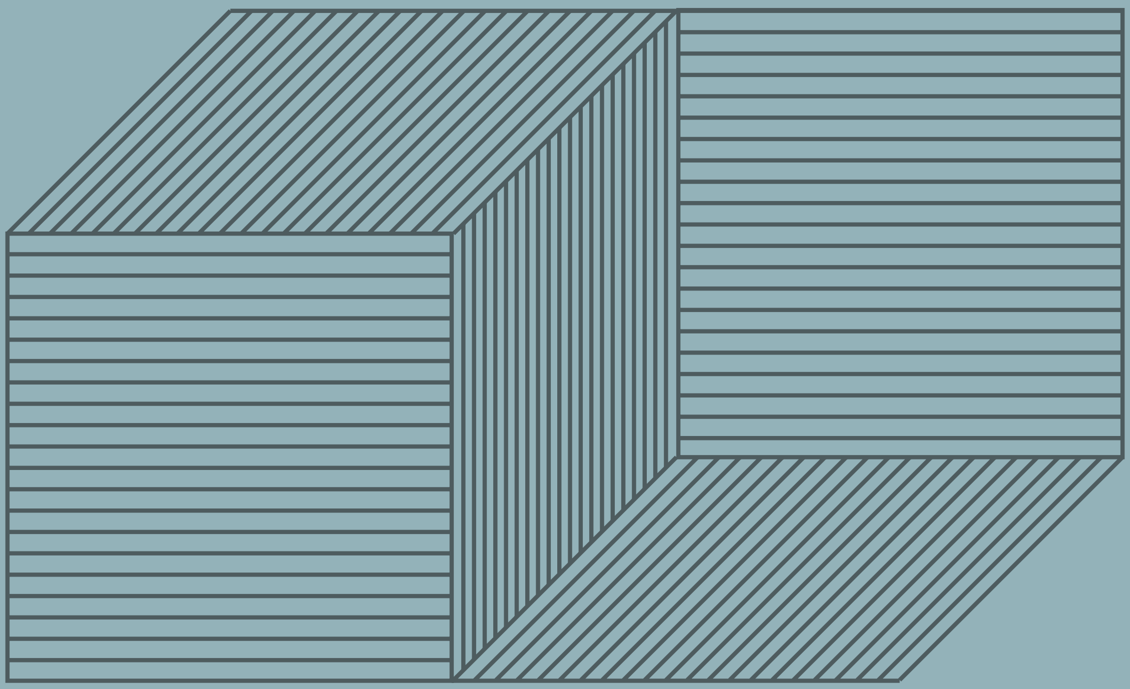
Thus, the first loop of **Experiencing Design** (Figure 5) , proposes to describe, understand, and focus on the parameters of user experience in order to highlight a new understanding of interaction in user experience. It spans the parameters from the largest vision (experience) to the smallest one (interaction). By so doing, this loop covers and investigates the different components of user experience from the user perspective, in order to highlight and formalize the relationship between these elements. Thus, this loop presents consecutively through different chapters the notion of user experience (2.1.1) through sections on the user, the context and the artifact; the notion of interaction (2.1.2) through its major pillars; the link between user experience and interaction name experiential interactions (2.1.3); and finally the physical and digital paradigm through the metaphorical approach (2.1.4).

This loop on **Experiencing Design** allows the conclusion and summary of findings through four elements: A model of design information (i); a three-dimensional taxonomy (d); eight areas of Interactive products (a); and principles (p) to describe them.

The second loop, **Designing Experiences**, relates to the designer and the artifact. It describes practices of designing, the design process, design disciplines, and the design levels in terms of tools and methodologies. Designing Experiences follows Hassenzahl and Tractinsky (2006), who defined the objective of interaction design as a contribution to the quality of life by designing for pleasure rather than for the absence of pain. Thus, this research on user experience and interaction leads to a deeper consideration of designing for subjective perception, rather than for the objective dimensions of artifacts. This point of view has been broadly covered by research on experience design (Gentner, 2014), human perception (Saussure & Pierce), and more recently on metaphors (Hekkert & Cila, 2015). This separation between objective properties and subjective areas led us to consider the link between physical and digital interactions when designing interactive artifacts. Thus, this loop explores, describes, and structures the act of designing, through fields (2.2.1); disciplines (2.2.2); processes (2.2.3); design levels (2.2.4); and design information (2.2.5). Additionally, this loop explores the way we can design interactions through the metaphorical approach (2.2.6). It presents and explores the physical and digital paradigm, and the metaphorical approach as tools and methodologies for designing interactive artifacts.

This loop is summarized through three key notions: The positioning of this research within the design process; the different design levels(lev); and the design disciplines(di) involved in the design process.

Finally, we summarized the two loops of **Experiencing Design** and **Designing Experiences** in a final part named Summary and Statement (2.3). It lists and summarizes the seven key elements that will be used during the experimentations.



«People perceive reality through the lens of their mind»
Carbonell, Sanchez-Esguevillas, Carro 2015

2.1 Experiencing Designs

This section explores and presents the framework in which Experiencing Design takes place (2.1.1), encompassing the notion of user experience. Then, the notion of interaction will be described, first of all independently from user experience (2.1.2), and then as part of the scope of user experience (2.1.3). Finally, this part of the state of the art will cover the link between physical and digital interactions through the metaphorical understanding (2.1.4). A last section will be presented to summarize the findings that will be used in this research (2.1.5).

2.1.1 The Framework

The aim of this section is to understand what a user experience is, and what it is composed of. To achieve this, definitions of the two first elements of an experience are suggested, as proposed by Ortiz and Aurisicchio (2011): the user and the context. The user is acknowledged as the one living the experience. Desmet and Hekkert (2007) note that an experience is not a property of an artifact, but an outcome associated with the user, pointing out that even without an artifact we can approach the notion of experience. Second, the research community acknowledges the relevance of context to experience. In fact, Parrish's work (2008) emphasizes that an experience is highly contextual. These two elements are therefore suggested to be the key components of an experience. The research then addresses the notion of an artifact in order to shift from an experience to what the field refers to as user experience. This loop of Experiencing Designs and its major components are represented in Figure 6.

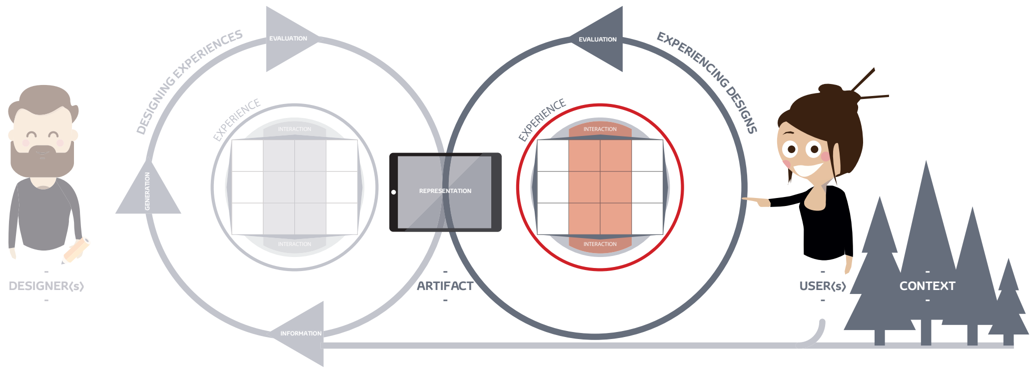


Figure 6: Model of Experiencing Designs scope

2.1.1.1 User

The human-centered approach described in several fields of research attaches strong importance to the user side of user experience for two reasons: First, products are designed for users; second, the user is the reason the user experience is such a difficult and broad research field, because of the implications of subjective notions associated with the user's ability to feel emotions, sensations, etc. In order to explain user reactions and how they impact the concept of user experience in the research community, we propose to develop an understanding of the user as a set of characteristics involving personal responses when stimulated.

The user can be described as possessing a set of characteristics that affect his or her relationship with the world, according to Juan Carlos Ortiz Nicolàs and Marcos Aurisicchio. These characteristics are: Senses (Fenko, Schifferstein & Hekkert, 2010; Dong et al., 2016); motor skills (Overbeeke, Djajadiningrat, Hummels & Wensveen, 2002); values (Nurkka, 2008); expectations (Wright, Wallace & McCarthy, 2008); needs (Hassenzahl, Diefenbach & Göritz, 2010); personality traits (Govers & Mugge, 2004); an individualized sense of fun (Carroll & Thomas, 1988); and attachment (Mugge, Schifferstein & Schoormans, 2010). User characteristics are more generally described by Gentner (2014) as "personal characteristics" that structure the understanding of the user: Culture; values and personality; mindset; and memory. All of these characteristics are described as inherent to the user, how the user interacts with something and can experience the world.

Starting from these characteristics, the research community pointed out the notion of process that creates responses according to many models, especially those based on appraisal theory (Demir, Desmet & Hekkert, 2006). Helander and Khalid's research (2006) is interesting for our research, because they presented a vision of the user that is very close to how we can describe a machine: The user composed of two processes, the affective and cognitive processes, where both processes are undivided, that allow him or her to create responses when stimulated. The affective process relies on cognition, and vice versa. They present the affective process as a fast, intuitive and experiential user's way of being, mainly responsive for the emotions, feelings, and attitudes of the user, while the cognitive process is slower and based on the user's analytical and rational side, including user knowledge, meaning and beliefs. Viller (1999) presented the cognitive process as decisive. Indeed, he presented it as responsive for human errors when interacting, because it relies on social, cultural, and skills-based learning.

The community, through different names, defends what these affective and cognitive processes imply for the user: Responses (Helander & Khalid, 2006); cognitive, behavioral or physiological changes (Gil, 2009); or reactions (Ortiz Nicolàs & Aurisicchio, 2011). These responses are important for our research, because they greatly influence perceptions, according to Izard (1993) and Forlizzi and Battarbee (2004), and decisions, according to Damasio (1994). More specifically, Forlizzi and Battarbee (2004) argue that a part of these responses, the emotions, influence how we intend to use an artifact and how we interact with it, as well as our perception of it before, during and after use. Consequently, emotions are increasingly considered in the research fields, to increase, improve, and manage their impact. Some research has focused on negative emotions and their impact on users' trust, cooperation, and good faith (Picard & Klein, 2002). The emotional design, the affective computing, and Kansei engineering and design are those fields of research tackling this emotionally centered design approach.

To conclude on our understanding of user experience, we highlight that the user can be considered as a set of personal characteristics (including sensory inputs) that allow creating responses (psychological, physiological, or behavioral responses). The translation of user characteristics to user responses is made possible by affective and cognitive processes. Relying on previous models and researches that describe how stimuli are analyzed by the user's system, and how they impact internal responses, we propose the following definition: A user can be described as a set of characteristics involving responses through affective and cognitive processes when stimulated.

2.1.1.2 Contextual Experience

It is important to highlight the major role played by context in the field of experience, as stated by various researchers (Forlizzi, 2007; Brown, 2000). According to these authors, context affects the user's experience. In her research, Forlizzi (2004) defined "context" as a dynamic process (Susi & Ziemke, 2001; Forlizzi, 2007) composed of four factors: Social, historical, cultural, and institutional. More recently, several authors have described context as involving five general factors: Physical (location where the interaction occurs), social (social interaction), cultural (values, languages, and norms), situational (judgments), and temporal (Schmidt, Rich, & Makris, 2000; Hassenzahl, Kekez & Burmester, 2002). This recent view of context is used in our research, because it adds the dimension of time to Forlizzi's analysis. It certainly seems that time affects our past, present, and future experiences. This notion can be summarized as follows: Context is defined as a dynamic process involving physical, social, cultural, contextual, and temporal properties that impact an experience.

2.1.1.3 Experience

According to Roto (2006), Hekkert (2008), Schifferstein (2007), and even Parrish (2008), an experience can be described in terms of its subjective, situational, temporal, and intended aspects.

The subjective side of an experience: According to Overbeeke (1995), an experience is based on several senses. Furthermore, he has characterized experience as holistic. Indeed, all of those ways to identify stimuli are ways to provoke a user's reactions (Helander & Khalid, 2006). Thus, the reactions of the user in the face of a stimulus create specific behavioral, cognitive, and physiological changes, according to Gil (2009) What these authors highlight, is how people can react differently to a stimulus. Indeed, it affects the internal state of the user, so it can be lived differently by different people, according to Hekkert & Schifferstein (2008). How we all respond differently to the same stimulus is all about subjectivity. For example, emotions are some of those unpredictable reactions specific to a particular user.

The situational impact of an experience is mainly argued by Parrish (2008). He defends experience as a situation taking place in the physical world that affords or constrains engagement, including one's own body (Parrish, 2008). Other people are also a key part of the situation according to Parrish (2008), as are social and cultural qualities. So the situational part of an experience is mainly influenced by the contextual component of an experience (Virpi Roto, 2006; Schifferstein & Hekkert, 2008), and by social and cultural qualities taking place in the situational part of this experience.

The temporal part of an experience: According to several authors, an experience is temporal. This temporality greatly impacts how the user is going to live his or her experience, is living his or her experience, and has lived his or her experience. These three temporalities are called by various appellations by different authors (Parrish, 2008; Krippendorff, 2006; Poole & Folger, 1988).

Hassenzahl divides the notion of time with regard to user experience into three steps: Micro (corresponding to an hour of usage); meso (a few weeks of usage); and macro (years of usage). Other researchers such as Roto (2006) highlight four types of user experience in terms of time: The anticipated user experience (before usage); the momentary user experience (during usage); the episodic user experience (after usage); and the cumulative user experience (multiple periods of usage over time). We consider this understanding as complementary to Hassenzahl's approach.

Finally, the notion of temporality highlights three distinctive phases. The observing phase can correspond to all visual interaction with something. The interfacing phase can be associated with the physical relation with the same thing. Finally, the anticipating phase can be associated with the way the user relates his or her experience, or can be associated with the designer's works.

The intended side of the experience is presented in research as the leveled, structured or effective part of an experience. This thesis points out how authors consider experience as a product: Experience has goals, it is supposed to impact the user's perception of a situation. So an experience can be defined as more or less effective, just like a product is. Patrick Parrish (2008) approaches these levels through the following terms: No experience; mindless routine; scattered/incomplete activity; pleasant routine; challenging endeavors; and aesthetic experience (Parrish, 2008).

Following the presentation of these two main components, the user and the context, we can define an experience as the alchemy of the user within a specific context. Indeed, according to previous authors, experience is felt, not just observed as a passive exterior entity. Parrish (2008) defended that «an individual's relationship with a situation at a given moment, before rational analysis and when affective influences hold at least equal sway to cognition, is a critical factor in the ultimate value attached to it». The meaningfulness of the felt experience can affects and impacts all other aspects, determining the entire experience. Thus, we can highlight experience as subjective and temporal, involving the entire set of user and contextual parameters, such as culture, habits, skills, values, personality, etc.

We can therefore define experience as a subjective, temporal, intended, and situational phenomenon, lived by the user in a particular context.

In the following section, we shall discuss experiences if we add an artifact. Indeed, by considering an artifact as the designer's creation, the "narrative temporality" really makes sense.

2.1.1.4 Artifact

If an experience is created when a user is in a specific context, a user experience implies an artifact. This is why the following part focuses on the artifact. We previously presented the user as a set of characteristics that led to responses according to affective and cognitive processes. Here we present the artifact as part of the user-artifact system: The artifact can be defined as a set of characteristics that lead to the artifact's perception.

The design of artifacts without reference to user interpretation (artifact characteristics), has been widely tackled by the research community and called by different names: Hassenzahl (2004), and more recently Minge (2013), call these objective characteristics of the artifact the "instrumental" or "pragmatic" qualities, which include only pure performance and usability. Ortiz Nicolàs and Aurisicchio (2011), and Crilly (2004) named it the "technical" side of the artifact. Finally, Dias (2009; 2013) refers to the "physical attributes" of the artifact. Included among these are the form, scale, volume, color, material, texture, brightness, sound, smell, and other objective elements of the artifact. Bouchard (2009) notes that an artifact's characteristics can involve the design of both concrete and abstract dimensions. More recently, Gentner (2014) proposed a model crossing abstract and concrete dimensions with the user-artifact system. When looking at the work of Amic G. Ho (2014) on emotional design, we note that he addresses and tentatively explains such abstract conception as the "emotionalized design". All of these works convey one central notion which defines a part of the artifact through characteristics, including objective design information, such as color, shape, form, and scale, and also more abstract design information, such as style, function, and object sector that are designed.

According to Gibson (1983), and more recently Vial (2014), we should not only consider the physicality of a product, but also how the user perceives it. This view is also supported by "Sign Theory", a major theory of product perception proposed by authors Saussure (1916) and Peirce (1978) (see Figure 7). Sign Theory argues that an artifact is a material sign, composed of forms, scales, and objective properties (as we just described it). However, there is a second state of the product, not related to its objective reality, but to its reality from the user's perspective, through the meanings he or she perceives. In the literature several researchers highlight this "perceived artifact". Hassenzahl (2004) and Minge (2013) defend the notion of "non-instrumental" to refer to the hedonic qualities such as beauty and visual aesthetic, whereas Ortiz Nicolàs and Aurisicchio (2011) refer to the "non-technical", i.e. the social and aesthetic. Dias (2013) proposes an understanding of the perceived artifact in terms of three simple notions: Practical attributes, symbolic attributes and aesthetic attributes, which make sense in terms of our understanding of an artifact composed of both characteristics, and perceived attributes or meanings.

So far, this paper has noted that artifacts can be considered as both a set of characteristics and perceived attributes. The designed artifact, added to the experience, brings our research to the notion of user experience.

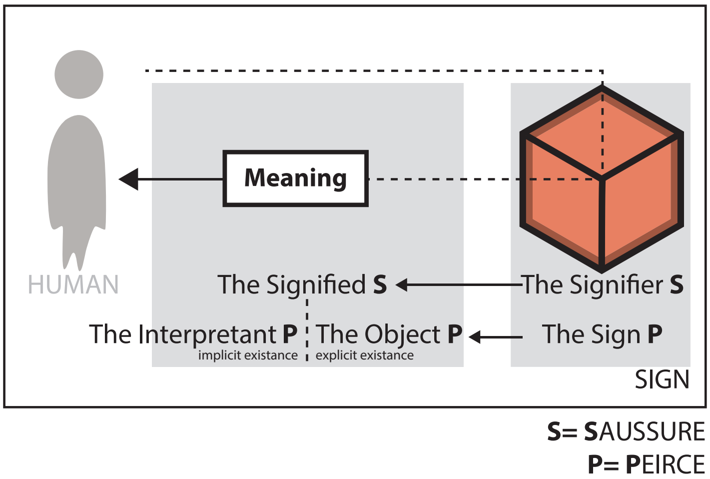


Figure 7: Representation of Sign Theory according to Saussure & Pierce

2.1.1.5 User Experience Understanding

The two models that will support the experiments are those proposed by Ortiz Nicolàs and Aurisicchio (2011), and Gentner (2014). They offer a broad view of the essential elements previously presented, wherein user experience is determined by four elements interacting with one another in complex ways:

-The user's internal state;
-The characteristics of the designed system
-The context; and
-The interaction occurring in the context (Gentner, 2014).

These elements are what create a user experience. It can be defined using the words of Desmet and Hekkert (2007): "User experience is a change in core affect that is attributed to human-product interaction" (Desmet & Hekkert, 2007). Nevertheless, it remains unclear whether a user experience involves action, interaction or interface. Thus, using various authors' definitions, we attempt to identify the elements of the user experience, summarized in Table 2. The table highlights that a user experience involves a user, an artifact, a context, actions, and interactions. We acknowledge, according to the table of definitions, that we can talk about user experience without the notion of interface (see Table 2).

To conclude, user experience can be defined as follows:

Experience is a dynamic phenomenon originating in user and artifact characteristics that interact in a specific context, involving personal user responses and perceived artifact attributes.

This definition has been greatly influenced by the authors in bold in Table 2. The full notion of artifact in early design, within the context of user experience and interaction studies, can be enriched by Kansei studies.

AUTHORS	DEFINITION OF USER EXPERIENCE	INVOLVE AN ACTION	INVOLVE AN INTERACTION	INVOLVE AN INTERFACE
Desmet and Hekkert 2007 p58-59	A change in core affect that is attributed to human product interaction	yes	yes	not necessarily
Roto 2006	Involve a product or a service	yes	yes (feedbacks)	not necessarily
Hassenzahl 2011 p4	UX is a consequence of a user's internal state, the characteristics of the designed system and the context, within the interaction occurs	yes	yes	not necessarily
Ortis Nicolas & Aurisicchio 2011	The overall appraisal, judgment or evaluation of the subjective and conscious encounter that the user has with an artifact through interaction, occurring in a particular context and time	yes	yes	not necessarily
Hassenzahl & Tractinsky 2006	User internal states plus characteristics of the designed system	yes	not necessarily	not necessarily
Mäkelä& Fulton Suri 2001	A result of motivated action in a certain context	yes	not necessarily	not necessarily
Gentner 2014	Subjective and affective outcome of a situation in which a user interacts with a product or service in a defined environment	yes	yes	not necessarily
Norman 2004	User experience encompasses all aspects of the end-user's interaction with the company, its services, and its products.	yes	not necessarily	not necessarily
Law & al 2009	User experience focuses on the interaction between a person and something that has a user interface	yes	yes	yes
Forlizzi and Battarbe 2004 p261	User experience focuses on the interaction between people and products, and the experience that results.	yes	yes	not necessarily
Desmet and Hekkert 2007	Product experience is used to refer to all possible affective experience involved in human-product interaction	yes	yes	not necessarily
Alben 1996	All the aspects of how people use an interactive product: the way it feels in their hands, how well they understand how it works, how they feel about it while they're using it, how well it serves their purposes, and how well it fits into the entire context in which they are using it	yes	yes	yes
Shedroff 2006	The overall experience, in general or specifics, a user, customer, or audience member has with a product, service, or event	yes	not necessarily	not necessarily
UPA 2006	Every aspect of the user's interaction with a product, service, or company that make up the user's perceptions of the whole	yes	yes	not necessarily
Wikipedia, online	The overall experience and satisfaction a user has when using a product or system	yes	not necessarily	not necessarily
Hekkert and Schifferstein, 2008 p2	An experience is subjective. It depends of psychological effects elicited by the interaction with the product.	yes	yes	not necessarily
Krippendorff & Butter 2008	We experience artifacts by interacting with them.	yes	yes	yes

Table 2: Definition of User Experience according to the litterature

2.1.2 Interaction

Some recent works have made concrete links between user experience and interaction (Gentner, 2014; Hassenzahl, 2011). However, the relationship between user experience and interaction is still difficult to identify, because of its youth. So how to define interaction in order to maintain the right balance between user experience and interaction?

Interaction is the action accomplished by the user or by the artifact on each other that influences or modifies the user's motor, perceptive, cognitive, and affective systems (Gil, 2009). Interaction can be physical (driving a car), or non-physical (contemplating a car) (Hassenzahl & Tractinsky, 2006). Interaction binds the user, the artifact and even the context (Gentner, 2014; Thompson, 1992). Furthermore, according to Desmet and Hekkert, interaction refers to instrumental interaction (function), but also to non-instrumental interaction (no function), and even to non-physical interaction (no touch), because each of these consequences can generate physiological, motivational, or motor responses (Norman, 2004; Bongard-Blanchy, 2013). So, we consider interaction as a dialogue between user and product (or service or system), in a particular context. This dialogue is not specifically based on the use of advanced technology. Interaction surrounds the design process, which creates a way to make it an easily usable, useful, desirable, and profitable relationship with a product. During the early stages of design, designers try to respond to a given design brief, and find a good conception. This is because the product plays a critical role as a precursor to consumers' cognitive and affective responses (Crilly, Moultrie & Clarkson, 2004).

Three major characteristics of interaction in the field of user experience are presented in the following parts. It proposes to approach interaction through the notions of **temporality, artificial intelligence**, and **tasks**.

2.1.2.1 Temporality

Krippendorff's model of interaction (2006) (Figure 8) describes a product interface as a step-by-step sequence of actions, followed by product feedbacks. In this protocol, users catch product meanings preliminarily according to specific clues offered by appearance and external conditions. He pointed out that products could be treated as being constructed to comply with a collection of triplets:

1 - Sensing the present state(s t);
2 - Acting as the input(a t); and
3 - Sensing the next state(s (t+1).

"At any moment of this interaction protocol, the meaning of a product is the range of imaginable actions and senses that the user could anticipate" (Krippendoff, 2006, p. 83).

When looking at the field of interaction, easy parallels to story-telling could be drawn. The way we sequence an interaction is close to the way we create and tell stories. This vision of interaction as stories, is also supported by Lin and Chen

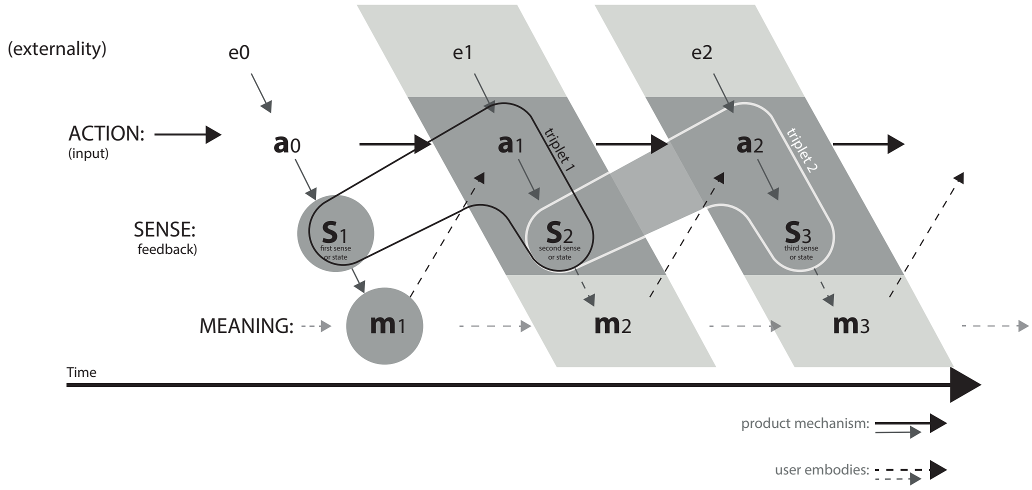


Figure 8: Temporal representation, reproduced from Krippenforff 2006

(2011). In their work, they link the dimensions of sequential interactions from Krippendorff (2006) to Todorov's (1981) narrative model. Krippendorff already highlighted that narratives place artifacts in grammatical constructions that provide the linguistic context of the noun object (Krippendoff, 2006, p. 54), and artifacts should be designed so that their interfaces are narratable (Krippendoff, 2006, p. 174). Through this statement, Lin and Cheng (2011) use the understanding of Tadorov's works to theorize about interactions. According to Hawkes (2003), characters can be treated as nouns, their attributes as adjectives, and actions as verbs. Tadorov focuses on an ideal five-step construction of stories, where he describes "a stable original situation", "a perturbing force", "disequilibrium", "a force in a converse direction", and "a re-established equilibrium". It is from this model and this ideal five-step construction that Lin and Chen (2011) create a link to the recurrent sequence of actor-action-target suggested by Krippendoff (2006).

Thus, according to previous authors, temporality seems to be a key dimension of interaction. Furthermore, different notions of temporality can be found in the literature.

If Torodov introduces many interesting points on interaction, we can acknowledge that his levels are a micro-vision of interaction. Other models can characterize larger scope and focus of interaction through another temporal point of view. For example, a larger view of interaction and temporality can be defended by the research of Maes. She proposed using products according to three steps:

1. The learning phase: Interactions to learn and understand the product and how to use it. This could be interaction such as just looking at something, or touching, to discover.

2. The set-up phase: Interactions we perform to set up the parameters of the product. How we will use it, changing the size, or temperature of the product.

3. The operate phase: Interactions to use the product. For example, with a pen, it corresponds to interactions we perform to write something.

What is very interesting with these steps is the understanding of phases as sets of several interactions. Indeed, if Torodov's model approaches the "action scope", Maes's understanding is closer to the product scope.

The work of Hassenzahl highlights another scope of temporality; he proposed a view of use based on three levels:

1. The micro level (corresponding to hours of use);
2. The 'meso' level (corresponding to weeks of use); and
3. The macro level (corresponding to years of use).

Thus, even if these authors present a view of interaction in terms of temporality, they present different scopes that can be differentiated according to their level of focus. Figure 9 illustrates these three views on a focused axis.

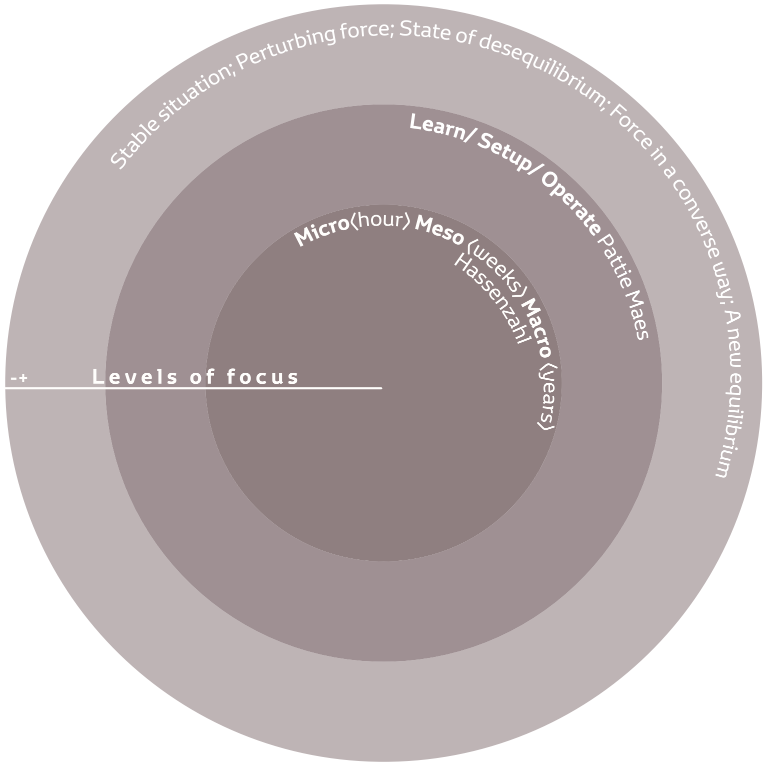


Figure 9: Temporal representation in Interaction

2.1.2.2 Artificial Intelligence

Another characteristic of interaction that this thesis highlights is proposed by the Multimodal Integration for Advanced Multimedia Interfaces (MIAMI) developed by Schomaker et al. (1995), which has its origins in the European Strategic Program on Research in Information Technology (ESPRIT) project (see Figure 10). The MIAMI model considers both the human and the computing system explicitly, and proposes a number of layers or levels of abstraction in HCI. The model assumes that both a user and a computing system are involved in an interaction. The model clearly points out the cognitive dimension in interaction, but not only from the user's side (What Schomaker et al. call "natural cognition"), as we do in the user characteristics description, but also from the artifact (computer) point of view. Indeed, Schomaker et al. (1995) argue that intelligent artifacts, as computers are, have an artificial cognition that allows communication at a certain level.

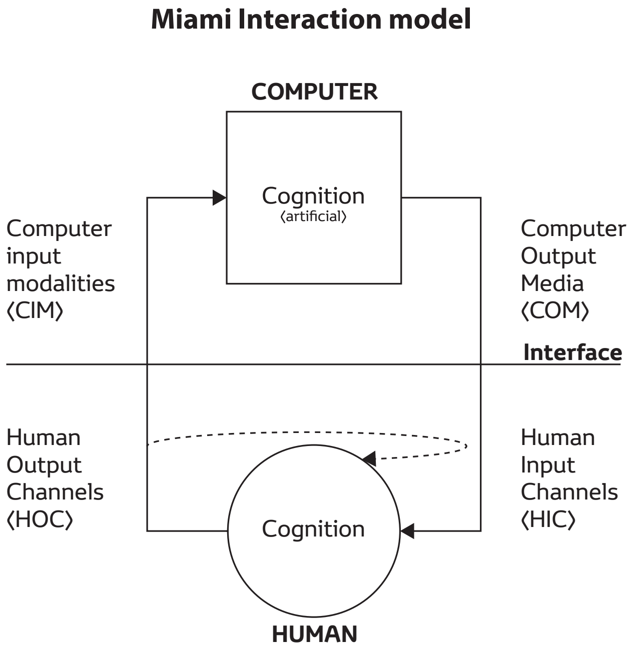


Figure 10: Miami model of Interaction reproduced from Schomaker et al 1995

2.1.2.3 Performing a Task

The last model of interaction this thesis focuses on, is the notion of action in the scope of interaction, and more especially in the scope of HCI. This model is Norman's interaction model (1998) (see Figure 11). In his works, Norman defends that problems in the use of objects and interfaces can be explained as the gaps between user's intention and the system's available actions (gulf of execution), and the differencies between the system's physical representation and the user's expectation and intentions (gulf of evaluation). In order to focus on these problems, he proposes a seven-stage model of actions to explain,

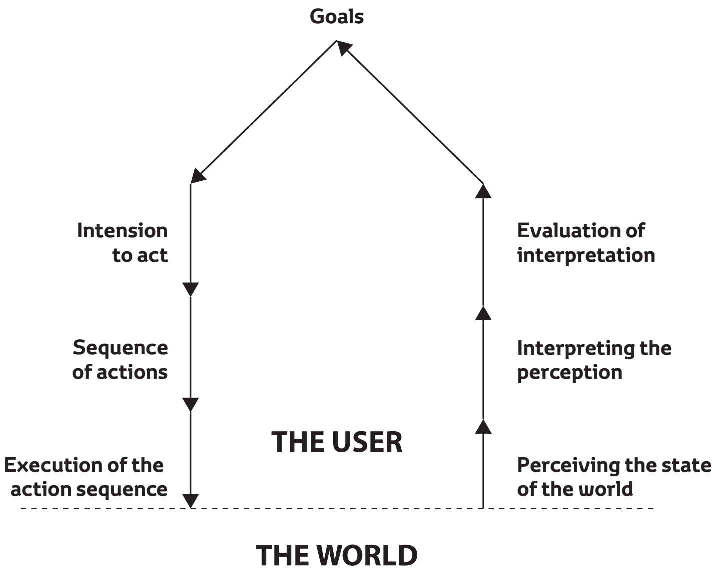


Figure 11: Norman's model of interaction

from a general perspective, how people perform tasks. Through his model, he assumes that people have to establish a goal. To reach this goal, people have to execute actions. These actions have two distinct aspects: first of all they have to be executed, and secondly their result has to be evaluated. This sequence leads Norman (1998) to formalize the seven stages of action. The stages of execution (intentions, action sequence, and execution) are coupled to the stages of evaluation (perception, interpretation, and evaluation). These stages are not intended as discrete entities, and all stages need not always be traversed sequentially. What Norman (1998) considers as actions and activities, seems to fall mainly in the class of discrete actions. So the system regards change only as a result of human actions. The model does not consider the sequential action intended by the artifact.

2.1.2.4 Conclusion on Interaction

The main principles of interaction defined above are summarized in Table 3, The Interaction Table.

AUTHORS	DEFINITIONS	RESEARCH ADVANCES
Krippendorff (2006)	Interaction= form, functional and 'meaning' values. Model of interaction as sequences of actions followed by feedbacks.	The narrative dimension of Interaction. Indeed, according to previous authors, temporality seems to be a key dimension of interaction.
Torodov (1981)	Link between Interaction and story telling	
Lin and Cheng (2011)		
Coelho & Maes (2009)	Three steps vision: learning, set up, operating	
Schomaker et al (1995)	The MIAMI group points out the cognitive dimension in interaction from the user's side ('natural cognition') and also from the artifact side ('artificial cognition')	A reciprocal understanding of User and Artifact intelligence and an ability to capture and react to any kind of stimuli.
Norman (1998)	Seven-stage model of actions to explain how people perform tasks	It brings to our understanding of interaction the notion of actions and processes when interacting.

Table 3: Main principles of Interactions summarized

Based on this table, a definition of interaction will be proposed according to the following statements:

1- Core of the user experience: Authors who make statements about interaction in the context of user experience research always acknowledge a strong relationship between both. For example, Hekkert and Schiferstein (2008) recognize that "experience and interaction are fully intertwined". Furthermore, some authors consider interaction as the core of the user experience (Ortiz Nicolàs & Marcos Aurisicchio, 2011; Gentner, 2014).

2- Multisensory: The research community presents interaction in the user experience field as multidimensional. Hassenzahl (2004), Dias (2009; 2013), and Desmet and Hekkert (2007) define interaction as a multidimensional phenomenon, involving both abstract and concrete dimensions. Furthermore, the MIAMI interaction model also acknowledges that interaction is composed of several layers of abstraction. More recently, Gentner (2014) proposed a vision of interaction that covers each level of design information defined by Bouchard (Bouchard, 1997, 2003; Kim, 2011). According to these authors, an interaction can be a multidimensional phenomenon composed of both abstract and concrete design information.

3- Subjectivity: We previously noted that an interaction in the field of user experience is defined by various components: The user, the artifact, the context, and the interaction. Because interaction depends partly on the user, it is holistic and subjective (Overbeeke, 1995). Furthermore, human beings are subjective beings (Picard & Klein, 2002), due to their reliance on affective and cognitive systems (Helander & Khalid, 2006). Therefore, since the user is a subjective being and a major component of interaction, we consider interaction in the user experience field as a subjective and holistic phenomenon.

4- Process: Interaction is often presented as a “dialogue”. However, Saffer (2010), and Lowgren and Stolterman (2004) use the concept of “process” to define interaction. The idea of process suggests a time-dependent phenomenon and dynamic system. According to Parrish (2008), Krippendorff (2006), and Lin and Cheng (2011), in reference to Todorov’s Narrative Theory, temporality is a decisive characteristic of interaction. Indeed, temporality supports the understanding of each step of the process that allows users to interact with an artifact (control, action, decision-making). These stages support the significance of temporality in interaction.

5- Designing: The notions of meaning and semantic are crucial in interaction (Krippendorff, 2006). For designers and design tasks, the key to interaction is to understand how the user and the product affect one another (user response, perceived artifact), producing a specific effect on each of them (Desmet & Hekkert, 2007). Furthermore, to paraphrase Kenya Hara (2007), interaction design is not about “things that are”, but about “things that happen”. Thus, the goal of the interaction designer is not to create products, but to create effects and affects.

6- Feedbacks: Several researchers, including Roto (2006), define interaction through an objective understanding of feedback. According to these authors, there is no interaction without physical feedback. Other authors, such as Hassenzahl and Tractinsky (2006), note that interaction can be either physical or non-physical. Moreover, Desmet and Hekkert characterize interaction as instrumental (function), non-instrumental (no function), and non-physical (no touch). Indeed, just looking at something can cause behavioral, psychological, or physiological changes (Gil, 2009): Watching a spider can have a strong impact and affect change, as described by Gil. So we consider that interaction can be instrumental, non-instrumental, and even non-physical, as long as there is feedback (change in the user or change in the product).

By defining interaction through the user experience scope, we pointed out the activities of designing and taking a decision in product development and manufacturing. This process of designing interactions in the human-artifact system can be defined as the interactive approach. It encompasses the different activities of the design process (previously presented by the 2003 Bouchard model), based on a human-centered approach. This interactive approach uses tools and methodologies for designing products by focusing on human affective and cognitive responses.

2.1.3 Experiential Interaction

This section focuses on a notion between the user experience and the interaction field, namely experiential interaction (see Figure 12).

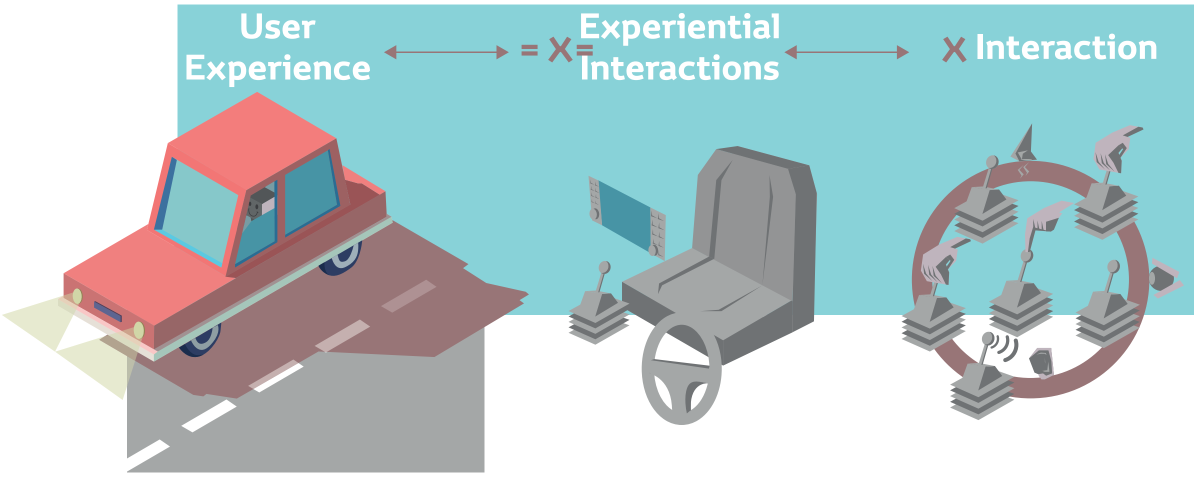


Figure 12: Representation of the link between User Experience and Interaction

Authors' definitions discussed above suggest that interaction is an internal process, influencing the user and the artifact. Indeed, our previous investigations already highlight that a user experience is composed of several actors, according to Ortiz Nicolàs and Aurisicchio (2011): The user, the artifact, the context and the interaction. Furthermore, cognitive psychology, the theory of sign, and the consideration of system/response by Helander and Khalid (2006) contribute a strong understanding of the agents of the user experience.

To build a bridge between user experience and interaction, this section suggests a new notion, that of "experiential interaction". Indeed, if the user experience field encompasses many situations dedicated to this dynamic phenomenon, such as the driving experience, a simple interaction is far more focused on the micro level, for example, the way we touch, hear, smell, and see. Each of these elements is considered as interaction. So, how to consider the set of meaningful interactions that an element can provide? We consider in our work that the user experience, such as driving a car, depends on the way we experience a simple interaction. However, if an interaction deeply impacts the user experience, we can acknowledge that a **sequence of interactions** is even more decisive for our user experience. This is the reason we characterize a sequence of interactions as **an experiential interaction**. For example, a seat, a steering wheel, and a gearbox are products. However, if we consider them in terms of their impact on the user experience, we focus on the experiential interaction impacts.

The notion of experiential interaction is a way to focus not only on an interaction, but also to understand and design sequences and transitions between interactions. Working on what we call experiential interaction, might provide a suitable solution for understanding the entire scope of features that the user experience includes, pointing to a direct link between interaction and user experience.

This understanding of experiential interaction leads the research to take a position on the understating of interaction: The following two sections highlight our views on unilateral interaction and reciprocal interaction.

2.1.3.1 Unilateral Interaction

Can we consider a simple emotion as an interaction? The emotional design field acknowledges the fact that an emotion is a response to an interaction. A stimulus impacts internal and external cognitive processes, according to the community (Mandler, 1982; Forlizzi & Battarbee, 2004). It affects the dominance (Mehrabian, 1980), and the activation, and positive and negative affects of the user (Bales, 2001; Desmet, 2002; Van Gorp, 2006; Russel, 1980). These kinds of reactions to the stimulus imply what Gil (2009) characterizes as changes in the user. These changes are user feedbacks, even if there is no product state modification. This thesis proposes to call these responses the "unilateral response". It refers to responses that do not affect the state of the product.
For example, Norman (2004) highlights the visceral relation to a product, where interactions are mainly focused on the ability to see, hear, or even touch and feel.

These kinds of unilateral responses that affect feedback are close to what Hommel and Prinz (1997) consider as automatic responses in interaction. If an interaction is a link between the user and the artifact, characterized by feedbacks, we can acknowledge that looking at something is an interaction, because the stimulus (for example, a blue carpet) involves the user system through his or her sensory process (mainly based, in this case, on the ability to see). It produces feedbacks in the form of changes in the user state, not only from user to artifact, but also from artifact to user: The way an artifact captures information through the user's sensors impacts his or her responses. Therefore unilateral interactions can be experienced by the user or the artifact.

More recently, Krippendorff (2006, 2008) submitted what he calls the "observing phase". This is described as the "experienced phase" by Poole and Folger (1988). Krippendorff defines this phase as the set of meanings of the artifact perceived through observation. What this thesis understands under unilateral perception, encompasses the entire sensory spectrum of a human being, not only the ability to see and hear, but also to touch. Something can be considered as a unilateral interaction if there are no functional intentions. Thus, these changes do not imply one state's modification of the other, such as "automatic interaction" (Hommel & Prinz, 1997). Unilateral interactions affect the way the user or the artifact is perceived or affected by the other (the artifact or the user).

Unilateral interaction is therefore a process where the user characteristics identify a stimulus and respond to this stimulus through the steps of response selection, followed by response execution (or automatic response). Unilateral response impacts the user, and produces change or feedback. Finally, it affects the way one perceives the other (interchangeably, depending on who is capturing the stimuli, the user or the artifact). This entire process is called unilateral interaction in this thesis, in contrast to "reciprocal interaction", described in the next section.

2.1.3.2 Reciprocal Interaction

The second kind of interaction implies a reciprocal response. Indeed, while unilateral interactions do not imply a functional reaction through a state's evolution from the user (unilateral interaction), reciprocal interactions do. The physical response of the user (or the artifact) is a typical choice reaction task in which each stimulus is assigned to a unique physical response. The main particularity of this reciprocal response is that it shifts the conditions of the other, i.e. the user or the artifact.

According to Proctor and Van Zandt (1994), interaction is defined in terms of response selection and response execution; the execution could be dependent on motor responses. Thus, the way a user responds to a stimulus can also be a response based on user motor capacity. This means that interaction could be a reciprocal system, where the user interacts physically to a stimulus.

Kemp, Krygier, and Harmon-Jones (2014) describe this understanding of reciprocal reactions to a stimulus as "motor programming". This refers to the specification of the physical response to be made. This reciprocal response is an additional perception of the product, through manipulation. This way of perceiving the product is described as "temporal capacities" by Mousette (2012). It encompasses how the user encloses, touches, grasps, presses, etc. the artifact. Furthermore, we can link reciprocal interactions to what Krippendorff (2008) calls the "interfacing phase" (based on the "experiencing phase" of Poole and Foger, 1988). This phase is also close to Gibson's understanding of "direct perception" (Gibson, 1983), which is about the manipulation, exploration, and action of the user with regard to the artifact, and vice versa.

Reciprocal interaction is therefore a process where the user characteristics identify a stimulus and respond to this stimulus with the steps of response selection and response execution. This is a reciprocal response, and impacts both the user's and the artifact's status, and produces change in, or feedback from, the user and the artifact. This reciprocal response finally impacts the perception of the other (the user or the artifact). This entire process is called reciprocal interaction.

2.1.3.3 Conclusion on Experiential Interaction

This thesis describes a sequence of unilateral and reciprocal interactions that can be regrouped as an experiential interaction. For example, the user experience of driving is composed of several experiential interactions, such as interactions with the seat, interactions with the steering wheel, and interactions with the GPS. Each of these experiential interactions can be seen as a number of unilateral and reciprocal interactions. For example, watching the seat, touching the seat, smelling the seat leather are unilateral interactions, and adjusting the seat, being on the seat, and moving the seat are reciprocal interactions.

This thesis highlights, through an understanding of experiential interaction, a solution for understanding the entire scope of features included in the user experience, and points out the notion of sequential interactions, called experiential interaction, as a direct link between user experience and interaction.

2.1.4 A Metaphorical Approach to Physical and Digital Interactions

Interaction in user experience is approached as a field materialized through interfaces and opportunities to capture our senses. Interface is a surface, a frontier between two bodies, according to Vial (2014). Even if this expression is global, it is often used in computer science to define the junction between two systems. This device determines concrete conditions of this interaction between human and machine (human-computer interaction, or HCI). It refers to the exact place where two systems are sharing information, communicating, and so interacting. These conditions include physical elements (screen, mouse, joystick) and digital elements (programs, application, operating system). The relation between hardware (physical) and software (digital) is transcribed through interfaces (graphic user interfaces) (Vial, 2014).

Computers are the most complex machines ever created. Their complexity is so huge because humans created an interface able to interact with them. Thus, screens have been created because of our inability to interact directly with a computer. How do we see the future of the screen? Recent progress in hardware technology has demonstrated that computers can be small enough to be carried or even worn. These new computers, however, preclude traditional user interface techniques such as graphical user interface or desktop metaphor (Rekimoto, 1996).

"How sad that our connection to computers is 'sensory deprived and physically limited'. Visual displays are gradually improving, but our sense of touch is limited most of the time to the feel of the keyboard and mouse […] Can we go beyond x, y and z and make more use of the time dimension?" (Moggridge, 2006).

Recent research has looked into new ways of interacting through our senses. For example, Mousette (2012) proposes haptic interfaces; recent MIT research defined a new sound desktop; smell research has already been conducted into user experience and marketing. New ways of feeling and experiencing are even developed through our back sensors (Eagleman, 2015).

2.1.4.1 The Physical and Digital Paradigm

This research aims to focus on the physical and digital paradigm in human-product interaction, to propose a taxonomy that classifies interactions from the user-experience approach, based on different dimensions. Developments in material science, fabrication processes, and electronic miniaturization have dramatically altered the types of objects and environments we can construct (Coelho, 2007), and interact with: Augmented reality products, virtual environments, tangible interfaces, mixed reality, and immersion.

Developing a taxonomy ("interactive taxonomy") could therefore strengthen our understanding of these interactive products. The originality of this research lies in the fact that this taxonomy is centered on user experience. Thus, it is not only focused on the objective reality of the product, but also on the perception of the user between the two notions of physical and digital attributes when interacting, according to cognitive science researchers. Some taxonomies of interactive products already exist (Pine, 2009; Milgram & Colquhoun, 1999; Jacob, 2008; Benford et al., 1998). However, even if they provide a great understanding of interactive products, they do not include the subjective perception of an artifact by a user. It already appears that two elements can be extracted from the literature to feed our taxonomy. Following Milgram and Colquhoun (1999), we acknowledge the relevance of "environment" when considering such a taxonomy. In their work, they propose an understanding of the environment that spans the real to the virtual environment. Furthermore, following Pine (2009), we acknowledge the product properties he defines of "matter" (atom) and "no matter» (bits). What Pine (2009) proposes is an objective understanding of product properties. Following our state of the art on user experience and cognitive psychologies, we can also define this axis from the user perception point of view. Following sign theory, a major theory of product perception proposed by Saussure (1857-1913) and Pierce (1839-1914), we ackowledge the notion of "perceived product properties".

Thus, the user can perceive physical properties (atom) or digital properties (bits) when interacting. This objective understanding of what a product is versus what the user perceives when interacting, led us to consider another major field of research, that of the metaphor in product design. Indeed, before closing the state of the art of the three axes highlighted previously (environment, objective properties, and perceived properties), we should consider the metaphor in research, which proposes an understanding of target and source that can be linked to our objective and perceived properties.

2.1.4.2 The Metaphorical Approach

This section will seek to understand and define "metaphor" in terms of interaction. The first section explains the concept of "metaphor", from a linguistic approach to a product perspective on metaphor. The second section describes how metaphors can be used in everyday human-product interactions. The last section focuses on metaphor in terms of both physical and digital paradigms, resulting in a definition of metaphor in human-product interaction, and a formalization of metaphor through the axes of target, source, and environment.

What Are Metaphors?

A central definition of "metaphor" has been proposed by Lakoff and Johnson (1980). In their work on linguistics, they define metaphors as "understanding and experiencing one kind of thing regarding another". While Lakoff and Johnson define the notion of metaphors from the linguistic approach, the literature has increasingly extended the metaphorical approach to other fields, including Gibbs (1994) in cognitive psychology, Forceville (2008) in advertising, Cienki and Muller (2008) and Chung (2015) in gestures, and Hekkert and Cila (2015) in design science. In these fields of research where metaphors are increasingly used, a common understanding is shared: A metaphor is an association of a target and a source (see Figure 13). The definition of metaphor and its constituents (target and source) might slightly change according to the fields where it is used. When focusing on the most recent definition of metaphor, in the closest field of interaction design, we find the definition proposed by Hekkert and Cila (2015), who define metaphor as "any kind of product whose design intentionally references the physical properties of another entity for precise, expressive purposes". They describe the target as the product, whose shape alludes to a more or less disparate entity, and define the source as the remote entity whose characteristics are associated with the target to assign a particular meaning to it.

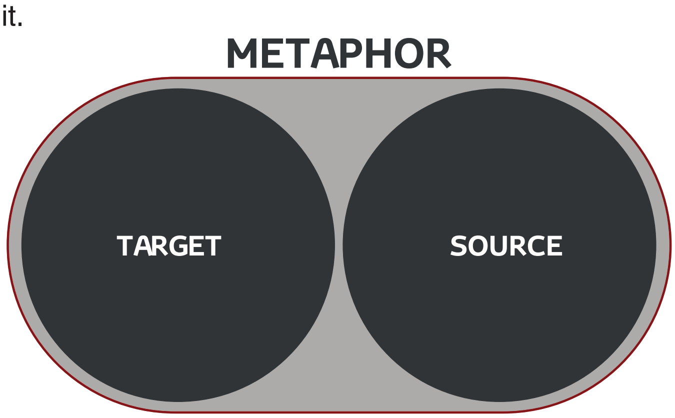


Figure 13: Representation of metaphor

Even though studies have been conducted on interaction design and metaphor, research that proposes a definition of metaphor and interaction within the scope of user experience is still lacking. Thus we propose the following definition, as a draft, based on the definitions of product design and metaphor (Hekkert & Cila, 2015):

«Interaction metaphor relates to any kind of artifact, whose interactive perception intentionally references another entity, to increase meaningful interaction and user experience.»

The interaction metaphor also refers to an "association" between two entities: A target (artifact properties whose design alludes to a more or less disparate entity), and a source (the remote entity whose perceived characteristics are associated with the target to assign new and more meaningful experiences). The right association of a target and a source should increase meaningful interactions and user experiences. This meaningfulness can be defined as "the qualitative and quantitative impact of affective and cognitive responses users can experience".

Metaphors in Everyday Interactions

Looking at the definition of metaphor in the literature allowed us to understand what metaphors are used for. Several authors argue that metaphors underlie how people think, reason, and imagine in everyday life (Gibbs, 1994; Lakoff & Johnson, 1980; Sweetser, 1990; Turner, 1998). Furthermore, metaphors can help to create a map from familiar to unfamiliar knowledge, and can help users reflect on and learn new domains based on their previous experiences, according to Neale and Carroll (1997). Using the metaphorical approach from an interaction perspective leads to easily understandable "use cues" or "affordance" (Hurtienne & Blessing, 2007). It can also facilitate active learning (Carroll & Mark, 1985), because it bridges perception, action, and higher verbal and non-verbal representations (Hurtienne, 2009). Hurtienne (2009) has demonstrated that these representations that increase metaphorical interaction in the human cognitive system operate automatically and beneath conscious awareness. Hekkert and Cila (2015) showed recently that metaphorical thinking is an innate capability we all possess. These natural links enable the selection and application of existing models of familiar objects and experiences to comprehend novel situations or artifacts (Alty, Knott, Anderson & Smyth, 1999). Thus, metaphors are present in every human-product interaction, consciously perceived by the user or not. These metaphorical schemas can be useful for different reasons: For helping to approach new technologies through familiar interactions (through clues, for examples), or by contrast, metaphors can be used to break with too familiar and too predictable products, linked to the notion of contrast in perceptual expectations (Yanagisawa, 2016).

Finally, the notion of target is very close to the understanding of objective properties, and the source can be related to perceived properties. By using terms from research on metaphor rather than from existing models and taxonomy (Pine, 2009), we construct a taxonomy based on a more experiential approach, closer to sign theory and other theories of perception. What an understanding of target(d) and source(d) bring to our research, is therefore a strong interdependency, summarized by a single word, metaphor.

2.1.4.3 Metaphors and the Physical and Digital Paradigms: a Three-Dimensional View

Following the previous understanding of both metaphor and the physical and digital paradigms, we regrouped product properties and perceived product properties in terms of "target" and "source". Additionally, we use the notion of environment proposed by Pine (2009). These terms (environment, target, and source) structure the taxonomy as three dimensions, which will be described in greater details below.

In this research document, we will use the clue (d) when **referencing one of the three dimensions** described in this chapter. It will be referenced as follows: environment(d); target(d) or source(d).

The Environment(d)

Several research studies regarding the term "environment" were accessed.

Wang and Schnabel (2006) define the notion of environment in terms of “reality”, defining the real and physical world as a realm of elements within the world that exists. According to Wang and Schnabel (2006), reality offers high sensory engagement, because of the factual existence of the elements. However, in the real environment, only a low level of abstraction can be experienced. In contrast to the virtual environment, a strictly real world environment is constrained by the laws of physics (gravity, time, and material properties) according to Milgram (1994). Several researchers have presented the virtual environment as an entirely computer-simulated environment. The commonly held view of a virtual environment is one in which the participant observer is totally immersed in an entirely synthetic world, which more or less mimics the properties of the real world environment, either existing or fictional. The virtual environment may also exceed the bounds of physical reality, by creating a world in which physical laws govern gravity, time, and material properties (Wang & Schnabel, 2006; Milgram, 1994; Anders, 2003).

Based on the definitions of the above authors, we decided to use the term environment(d), as defended by Pine (2009), from real to virtual, as advocated by Wang and Schnabel (2006).

The Target(d)

The term “target” encompasses physical and digital properties, as advocated by various authors (Djajadiningrat, 2004; Ishii, 2012; Poupyrev, 2007). This definition of target is similar to the properties of an artifact in terms of the user interaction system.

The Source(d)

The term “source” has been chosen to define the perceived characteristics associated with the target, increasing meaningful experience. The term “source” is borrowed from the metaphor field, and builds on a strong influence from sign theory research. One fundamental problem in defining the source is choosing an adequate form of reference (physical or digital). Thus, physical sources are not limited to physical targets, but when the interface references physical notions, it is already a physical source for the user. For example, the Disney research device is a screen with an electro-vibration system. With this product, one interacts with a digital target (the data); the user can perceive a physical source because the electro-vibration system reproduces the feeling of different textures through the screen. Thus, this digital target uses a physical source.

On the other hand, the source may also reference digital principles. According to the community, a source is digital when it breaks with physical properties (Kamaruddin, 2006), in terms of directness of effort, locality of effort, visibility of state, or when it uses computational language, such as windows, menus, or icons, materialized through graphical user interfaces based on the Xerox 8010 Star System (1982). This breaking with physical properties is characterized as “the fluidity of Bits” by Ishii (Ishii et al., 2012). Examples of sources that reference the digital world in interaction are interacting with a shape that changes its structure and reacts like pixels (Ishii, 2012), or a chirurgical intervention across the world.

The research community acknowledges another perspective that can be used for a better understanding of metaphors, namely the image schema vocabulary, briefly presented in the understanding of metaphor. It is used as a metalanguage for designing interfaces (Hurtienne, 2007), and began with Johnson (1987) from the philosophical perspective. Image schemas can be useful as a list that can be used for an empirical study. However, according to Johnson (1987), one danger of such inventories of image schemas is that they are never complete. Applied to the interaction design scope, we can say that “principle that is more related to “action enablement”, in terms of what the product allows the user to do. Thus, this user experience approach of image-schema leads us to use the word “principle” in this research.

2.1.5 Summary of Experiencing Designs

In the first part of the literature review, we focused on the loop between the user and the artifact, as presented in Figure 14.

Four elements are highlighted to summarize the state of the art:

1- a model of **design information(i)**;
2- a **three-dimensional taxonomy(d)** of interactive products through the metaphorical approach;
3- the **eight areas(a)** that emerge from this taxonomy; and
4- the different **principles(p)** that we can use to describe interactive products.

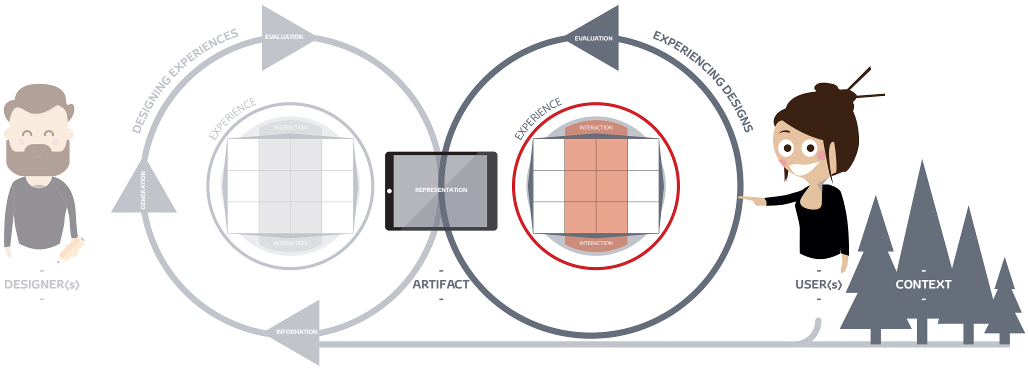


Figure 14: Model of Experiencing Designs scope

-1- Model of Design Information (i)

According to the definitions of Ortiz Nicolàs and Aurisicchio (2011) and Gentner (2014), we can state that a user experience is composed of a user, an artifact, a context, and the interaction that occurs. The user creates responses (or feedbacks) through affective and cognitive processes (Rasmussen, 1980; Atkinson & Shiffrin, 1968; Helander & Kahlid, 2006) when stimulated. We showed that the artifact is composed of specific characteristics (e.g. form, color, size) that are perceived and interpreted by the user (sensory input), not objectively but through “meanings”.

Artifacts can therefore be understood in terms of both their objective characteristics and their meaning to the user. In addition, user experience is sequential and temporal (Krippendorff, 2006); narrative (Lin & Cheng, 2011; Torodov, 1981; Hassenzahl, 2011); subjective and holistic (Norman, 1998; Overbeeke, 2002); instrumental, non-instrumental and even non-physical (Desmet & Hekkert, 2007); and something producing changes, called feedbacks (Gil, 2009), highlighting that simple emotion is an interaction because it produces emotional feedback, for example.

The state of the art led us to create a model to summarize our literature review, the design information model (see Figure 15). We constructed a vision of interaction from the user experience field. The model attempts to map all elements: The user, the artifact, and the environment. The model is based on two axes: The vertical axis separates the design information into abstract design information (top) and concrete design information (bottom). The horizontal axis traces the user-artifact system, highlighted in the state of the art. At the core of the user experience, we can see the interaction space (dotted). The user, through his or her characteristics (such as personality, senses, etc.) may perceive stimuli and react to them, according to affective and cognitive processes. These reactions affect the perception of the artifact by creating artifact meaning.

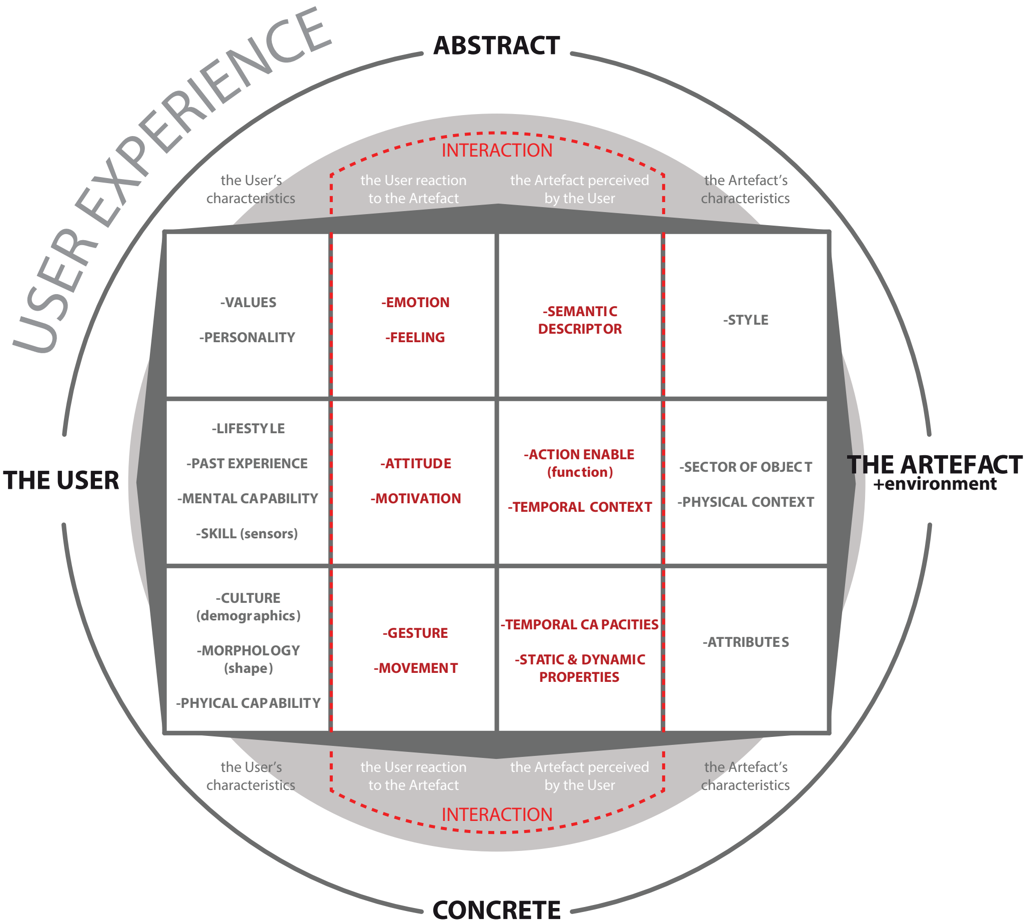


Figure 15: Model of User Experience scope

Finally, this model maps the different components of the user experience, highlighting the area of interaction, and points out all the design information that we have to consider in the interactive approach of designing and evaluating user experiences and interactions in the early phases. This model simply helps to understand all the design information related to user experience and interaction, from a human-centered approach.

By using this model, designers can choose between considering the listed design information when designing during the early phases, or assess products by measuring their impact on both the interactive and user experience scopes. In this research document, we use the letter (i) to reference the design information(i) in this theoretical model.

-2- Three-Dimensional Taxonomy (d)

Above we used a three-dimensional perspective to distinguish the physical and digital paradigms of interactive products in terms of the user experience. These three dimensions are the environment(d); the target(d) and the source(d). Each of these dimensions can be considered as an axis from physical to digital properties. Thus, we can describe an environment(d) from real to virtual; and a target(d) and source(d) from physical to digital properties. Figure 16 illustrates this three-dimensional(d) perspective.

-3- Areas (a)

The third element ensues from the three-dimensional representation(d). It consists of eight areas(a) where interactive artifacts can be displayed according to the different dimensions(d) (see Figure 16).
As dimensions are referenced with the letter (d), and design information with the letter (i), the notion of area is referenced with the letter (a), for ease of reading. Thus, the three dimensions(d) highlight eight areas(a). This principle of interactive taxonomy could strengthen the understanding of interactive products, and improves the design process when merged with design methods. The following are the eight areas:

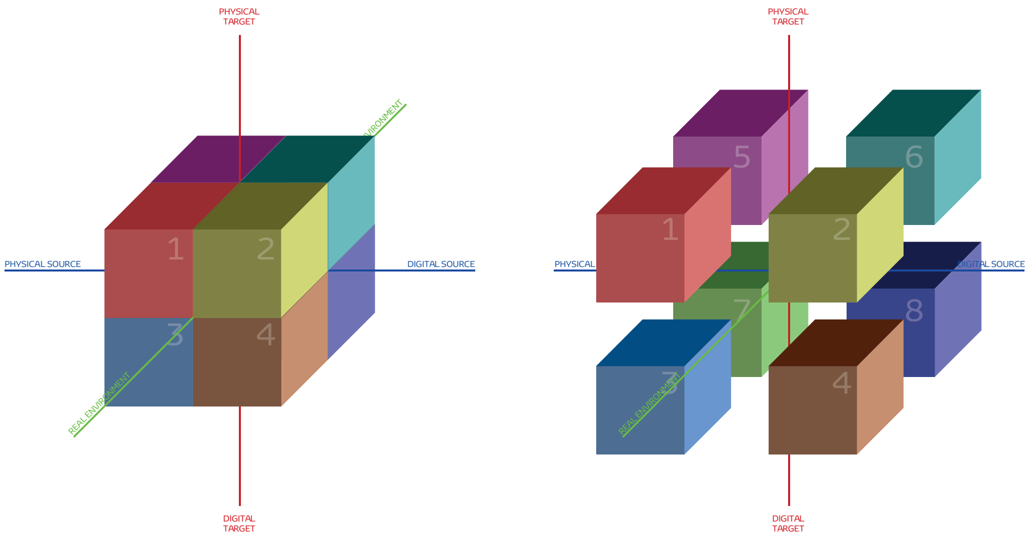
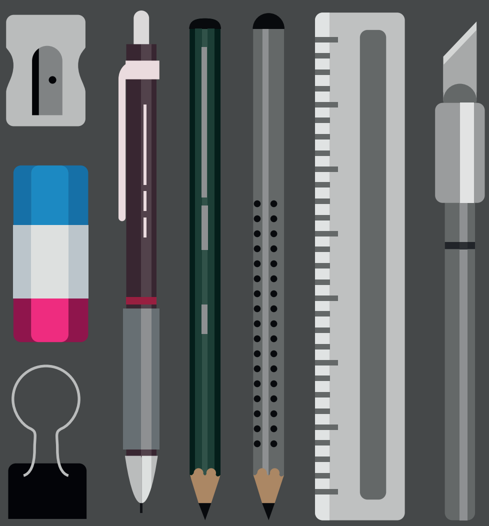


Figure 16: Three dimensional taxonomy

1- Real environment; Physical target; Physical sources;
2- Real environment; Physical target; Digital sources;
3- Real environment; Digital target; Physical sources;
4- Real environment; Digital target; Digital sources;
5- Virtual environment; Physical target; Physical sources;
6- Virtual environment; Physical target; Digital sources;
7- Virtual environment; Digital target; Physical sources;
8- Virtual environment; Digital target; Digital sources.

-4- Principles (p)

The fourth element is the notion of principles that can be used to better define and understand users' perception of interactive products. We use the letter (p) to reference the notion of principle(p) in this document. The notion of principle(p) is extracted from the "image scale vocabulary" previously described, and encompasses what the interaction allows the user to do.



«We shape our tools,
and our tools shape us»
Marshall Maluhar

2.2 Designing Experiences

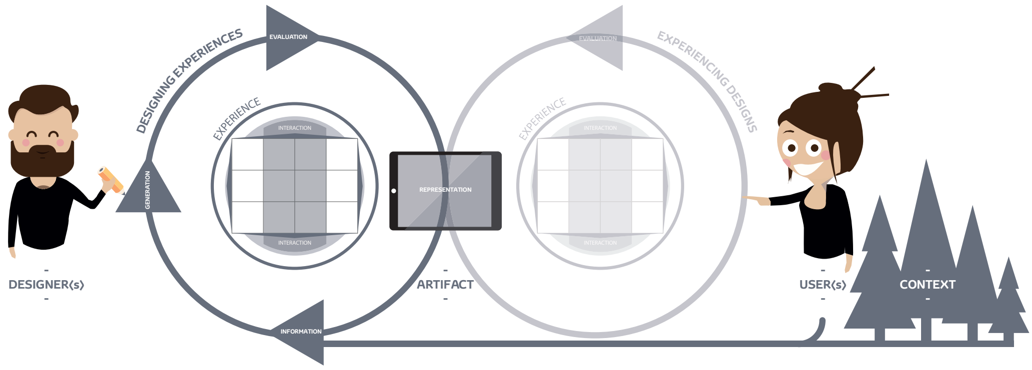


Figure 17: Model of Designing Experiences scope

In the first part on the state of the art, we explored the loop between the user and the artifact from a user experience point of view (experiencing designs). This second part explores the second loop, **the link between the designer and the artifact (designing experiences)** (see Figure 17).

We will explore notions such as the different design fields (2.2.1); the different design disciplines (2.2.2); the design process (2.2.3); the design levels (2.2.4); and finally, the design information (2.2.5).

2.2.1 Design Fields

In this section, we explore both the Kansei understanding of design (the context of this research), and alternative fields that are relevant for the scope of this research, namely emotional design and affective computing.

2.2.1.1 The Kansei Design Field

This section is dedicated to an understanding of Kansei design. It focuses on a global definition of Kansei, mainly derived from the work of Harada (2003), Nagamachi (2001), and Levy (2013). It then continues by describing the three domains of Kansei, namely Kansei engineering, Kansei science, and Kansei design (Levy, 2013). The research proposes to define Kansei as a leveled informational system, from abstract to concrete information (Bouchard, 2009), involving affective and cognitive processes (Kim, 2011). Moreover, the research considers Gentner's work (2014) as a major pillar of our state of the art, because we consider his research as the first link between Kansei, user experience, and interaction dimensions, based on his use of the abstract-to-concrete axis in the user-artifact system.

General Kansei

As mentioned previously, user experience and interaction suggest specific subjective and emotional responses in the user. In order to better understand the process of user responses from a design point of view, this section focuses on the understanding and definition of Kansei.

Kansei refers to making artifacts that relate to people's subjective and emotional needs. The definition of Kansei is rooted in Japanese philosophy and culture, and is difficult to package in a single sentence (Gentner, 2014; Schütte, 2005). However, the Japanese word can be translated, as it has been by several researchers, as various terms such as "feeling", "emotion", "semantics", and "affectivity", in relation to a product (Ishihara & Nagamachi, 1997; Kiyoki & Chen, 2009; Nagamashi, 2011; Harada, 2003). It can be understood as a multidimensional outcome of perception, based on the meaning and value of an artifact. Lévy, Lee and Yamanaka (2007) describe three main elements for comprehending Kansei: Kansei process, Kansei means, and Kansei results.

- "Kansei process regroups functions related to emotions, sensitivity, feelings, experience, and intuition, including the interactions between them." (Lévy 2007)
- "Kansei means are all the senses (sight, hearing, taste, smell, touch, balance, recognition…) and—probably—other 'internal factors' (such as personality, mood, experience…)." (Lévy 2007)
- "Kansei result is the fruit of Kansei process (i.e., of these function processes and of their interactions). It appears to be a unified perception providing a qualitative meaning and value of one's direct environment. In other words, Kansei result is how one perceives qualitatively one's environment. Therefore, Kansei is a synthesis of sensory qualities." (Lévy 2007)

These three aspects of Kansei can easily be linked to our previous understanding of the user experience. "Kansei means" can be seen as the "user system", "Kansei process" is a way to consider "user responses", and finally, "Kansei result" is how the artifact is perceived ("perceived attributes").

Part of the originality of this research is that it attempts to combine the notions of Kansei and interaction in the context of user experience. Before linking these ideas, each of the three fields of Kansei engineering, science and design are described in the following sections.

Kansei Engineering

"Feel faster than it is, but it doesn't have to be fast in absolute terms." This sentence is how the Mazda Miata was conceived, thanks to the Kansei engineering method. Nagamachi, a professor at Hiroshima University, is considered to be the father of Kansei engineering. The term "Kansei engineering" was used for the first time in 1986 by Yamamoto (1986). Today, the Kansei engineering method aims at translating user feelings into concrete product parameters. Schütte et al. (Schütte, Eklund, Axelsson, & Nagamachi, 2004) argue that although Kansei engineering did not originally aim to correlate user Kansei with design details, it establishes a correlation between users' expressed impressions and design details.

Kansei Science

Harada works during the same period on Kansei science. According to Lévy (2013), Kansei science represents a meeting point between Kansei and cognitive science. Harada aims to describe users' cognitive processes related to preferences and product choice from a holistic perspective (Harada, 2003). Kansei science aims to characterize and evaluate emotional experiences and creativity to contribute to a better understanding of the mind-based knowledge derived from physiological and psychological perspectives (Lévy et al., 2011). Kansei science is often used in the automotive industry for appreciation and visual aspect preferences (Kim, Cho, Niki & Yamanaka, 2012), and driving comfort (Zhang, Lei, Harada & Yamanaka, 2006). All these research projects share a common understanding of human perception and behavior. While Kansei engineering is associated with affective engineering, Kansei science can be associated with sensory science (e.g., Bakalar, 2012).

Kansei Design

The Kansei design discipline is considered as the discipline that creates artifacts as outputs. In his work, Levy (2013) considers that Kansei design projects can be split into two groups based on their main foci: Physical materiality, related to intrinsic properties and the evaluation of preference by the user; and interactive materiality, related to the qualities of the artifact in interaction. This understanding can easily be linked to the sign theory presented previously. Gentner (2014) links both Kansei design and the user experience perspective to build a summary of the "Kansei experience framework". He proposes a model of this relationship, presented in Figure 1. The framework presents the Kansei process, and the result of this process, namely perceived Kansei qualities. They correspond to direct Kansei consequences (Lévy et al., 2007), including user responses such as pleasure, meaning elaboration, primary and secondary emotions (Colombo, 2012).

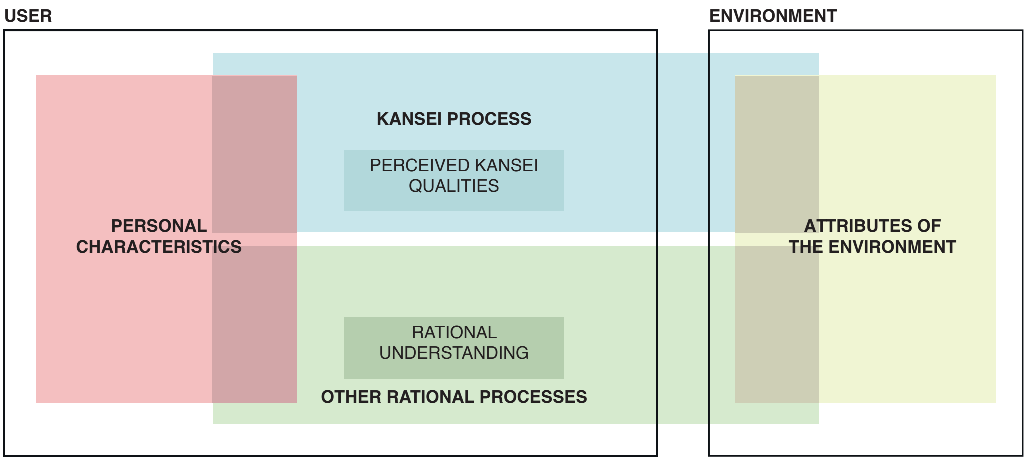


Figure 18: Kansei Experience framework reproduced from Gentner 2014

Finally, Kansei design has been described as the subjective consideration of a product's perception. Levy (2013) enriches the definition of Kansei engineering by developing the Kansei design field. More recently, Gentner (2014) brings to the Kansei design vision a direct implementation in the user experience field. In terms of this understanding, Kansei design can be defined as a blend of Gentner's and Levy's definitions (Lévy, 2013; Gentner, 2014), as a psycho-cognitive process occurring during an interaction in a user experience. It results from sensory-perceived attributes, and covers the notions of sensibility, sensitivity, and feeling.

While Kansei has been explored in this section through the work of Harada, Nagamachi, Levy, Gentner, and Bouchard (the European and Asian visions), we did not approach the way the rest of Europe and America perceive this field. This is because the subjective dimension of product design is not approached through the Kansei side, but through the emotional design field (Europe) and the affective computing field (America). In order to extend our vision of the subjective side of product design, the next sections briefly describe what is meant by the emotional design field and the affective computing field.

2.2.1.2 Emotion Design Field

Defining emotional phenomena is a complex task, because many fields of research define this notion. According to Arnold (1945) and Schachter (1959), a cognitive process is required to evaluate a stimulus in order to give rise to emotion. Mandler (1982), Desmet (2007), and Scherer (2005) argue that the cognitive process is based on both the internal and external processes of the user. The external component corresponds to the stimulus' features, whereas the internal component refers to the individual's past experiences and expectations. These elements prepare the user for his or her reaction. Two dimensions of the emotional process are discussed in the research field, namely affect and activation (Bales, 2001; Desmet, 2007; Mehrabian, 1981; Russell, 1980; Van Gorp, 2006). The affect side refers to whether the emotion is lived as positive or negative. The activation side refers to how much energy or stimulation the emotion causes. Scherer (2005) proposes to differentiate two kinds of emotion: "Utilitarian emotion" (such as anger, fear, joy, disgust), and "aesthetic emotion" (such as admiration, ecstasy, fascination).

From a design point of view, emotion can contribute to create products intuitively and efficiently, and thereby improve the ease of use. This feeling is supported by many design scholars. Desmet and Hekkert (2007) also suggest that the influence of emotion on design could be integrated into the product development process and in the roles of designers. It can affect how humans treat information, and manage creativity and other factors (Skinner, 1994), influencing the designer's ability, effectivity, and manipulation of the design process (Desmet & Hekkert, 2007). Inspired by the research of Norman (2004) and Desmet and Hekkert (2007), Lo (2007) defined emotional design as design that focuses on users' needs and experience, emphasizing that emotional concerns can improve the function, form, and usability of design outcomes, and thus enrich users' experience.

The emotional design field works on this link between emotion and design, focusing on the relationship between the user and a product from the emotional point of view. It has been widely adopted in recent years by the research field. Hummels (2009) illustrates the growing tendency to include emotional concerns in interactive design products, and proposes that it reflects the development of technological complexity. At the same time, Cupchik (1999) offers a valuable theoretical insight into how products elicit emotions, and asserts that this insight has helped designers enhance the emotional impact of their designs.

More recently, Desmet and Hekkert (2002) have seen consumers' appraisals as key factors in determining how a design outcome evokes an emotion and which emotion is evoked. They propose the "model of product emotions", in which the emotions associated with products are classified into five classes: Surprise emotions, instrumental emotions, aesthetic emotions, social emotions, and interest emotions. Their study reveals that products can elicit several emotions and that users' emotional responses are complex and personal. Other design authors have conducted further research on how pleasurable experiences enable designers to meet the needs and demands of users. Choi (2006) concludes that emotional design can create a strong and positive mental attachment (i.e., emotional concerns in design) between the user and the product that strengthens the usability of the design.

Based on these authors and studies, this research acknowledges that "emotional design" focuses on the needs and experience of users. Moreover, according to Ho (2010), emotional design is used to create products that elicit emotion. Specific criteria and conditions related to emotional design can be highlighted: First of all, even if emotions are universally based on design outcome, each user's emotional response is complex and personal. Indeed, emotional design is subjective. This subjectivity is due to the relation between the conceived product (function, form, and usability) and the user's personal needs, demands, and interpretation.

To conclude this part dedicated to emotions, and more specifically to emotional design, this research proposes to consider emotional design as a way to impact the subjective perception of the product in a user experience, involving reactions of behavioral, cognitive, and physiological changes. Those reactions are stimulated by the product, impacting the internal and external cognitive process.

2.2.1.3 Affective Computing Field

This section describes the affective computing field, in order to highlight how the American research field (in contrast to the European field dedicated to emotional design, and to the Asian one dedicated to Kansei design) works on the "subjective conception".

Affective computing is a multidisciplinary field encompassing computer science, engineering, psychology, education, neuroscience, and many other disciplines. The affective computing field is indeed diverse. According to Rafael et al., in The Oxford Handbook of Affective Computing (2014), theories on how affective factors influence interactions between humans and technology may be organized. It affects sensing, generation techniques, design and evaluation of systems that intricately involve affect at their core. Affective computing impacts various domains such as learning, human-computer interaction, perceptual information retrieval, creative arts and entertainment, human health, and machine intelligence.

Picard (1995, 2014) presents affective computing as follows: "Computing that relates to, arises from, or deliberately influences emotions". He points out that emotions play a decisive role in affective computing.

One of the main characteristics of affective computing is that it is directly linked to technological products exclusively (computers, wearable technologies, smart devices). Another specificity of affective computing is how it is worked. The understanding of affective computing is split into two schools of thought. The first considers emotion as embodied cognition. This is a consideration of the body as the main factor in emotion, motivation, and cognition (Price, Peterson & Harmon-Jones, 2011). The second movement advocates that brain connectivity is a necessary development in the neuroscientific understanding of the emotions (Damasio, 1994; Porges, 1995, 2011; Reimann & Bechara, 2010; Thayer & Lane, 2000, 2009).

Particularly relevant are the two generally opposing treatments of emotions in the literature: Emotions as cognition, and emotions as a physiological response (Picard, 2014). The two complementary movements of affective computing have different views on the ability to recognize, express, and model affect (Picard, 2014), based on the head, and the heart. For the head, emotions are a fundamental process that exists across species (and human cultures); a phenomenon that is discovered, not created, by the human mind (Panksepp & Watt, 2011; Vytal & Hamann, 2010). For the heart, emotions are themselves constructed from activation relating to more basic building blocks, such as core dimensions like valence (positive vs. negative affect), and arousal (deactivation to activation). One of the problems here is that the terms "emotion" and "feeling" are used interchangeably, and this has led to the use of common language "feeling" words such as fear, anger, love, and sadness, to guide the scientific study of emotion, rather than focusing on specific phenomena of interest (LeDoux, 2012).

Recent neurological evidence indicates that emotions are decisive and necessary. They not only help to regulate important processes such as memory acquisition, attention, and engagement, but also help to achieve successful social interactions, irrational human thinking, and decision-making. "Decision making without emotion can be just as impaired as decision making with too much emotion" (Picard, 1995). Emotions affect our way of living.

According to the affective computing field, both cognitive and physiological events can contribute to emotion, and vice versa, perhaps because the mere fact of thinking is both a cognitive and a physiological event, although the mind-body separation can be considered as the separation of objective and subjective understanding.

Finally, the affective computing field argues that humans almost always respond with emotion to highly emotional stimuli. As a consequence, an intelligent computer needs to be capable of recognizing emotion and providing affective responses. The implications are also significant for computers. If they are to be truly effective at decision-making, they will need to have emotional mechanisms, working in concert with their rule-based systems. But how could computers translate emotions? Obviously, current computers do not have the equivalent of a limbic brain and a cortical brain, or the biochemical washes that connect these regions, and so forth. However, computers have bodies – they are currently not affective – so they are able to express emotions.

If computers will ever interact naturally and intelligently with humans, then they need the ability to at least recognize and express affect (Picard, 2014). Affective computing is a new area of research, with recent results primarily in the recognition and synthesis of facial expression and the synthesis of voice inflection. In order to create more natural and human-like interactions, researchers have focused their work on the creation of user interfaces that can measure and adapt themselves to human emotions (Picard, 2014).
With developments in technology, more sophisticated modeling, and growing knowledge about the neuroanatomical and physiological correlates of emotion, the future of affective computing seems bright, with better understanding of the neuroscientific basis of emotion (Picard, 2014; Kemp, 2014). Affective computing focuses on objective information from the brain and body (e.g., facial expressions, brain electrical activity, sweat response, heart rate, and respiration), in order to better manipulate subjective and affective experiences. Affective computing will allow designers to better understand and define the future of interaction design.

2.2.1.4 Conclusion on the Three Fields

The above sections describing Kansei design, emotional design, and affective computing are summarized in Table 4. This table highlights useful points for this research. Some of them allow us to regroup the Kansei design, emotional design and affective computing schools of thought (columns in gray). However, there are also some points where these schools of thought are not compatible (columns in red).

	GOAL	FIELD OF RESEARCH	LINKED TO	AFFECTING WHAT	PROCESS INPUT	CHARACTE-RISTICS	LEVEL OF INFORMA-TION
KANSEI DESIGN	Discipline that creates products	User Expe-rience	User and Artifact	User and Product perception	Kansei Pro-cess (feeling, emotions, affectivity...)	Objective and Subjective dimensions	From hight to low levels of informations
EMOTIONAL DESIGN	Discipline that creates products	User Experience & Emotional Experience	User and Artifact	User and Product perception	Emotional Process (emotions)	Subjective dimensions	Only high level of infor-mation
AFFECTIVE COMPUTING	Discipline that creates technological products	Interaction Design, Human Intel-ligence and Perception	User and Technological products	User and Product perception	Emotional and cognitive process (emotion, cognition)	Objective and Subjective dimensions	From high to low levels of informations

Table 4: The three fields: Kansei Design/ Emotional Design and Affective computing

Commonalities

According to Table 4, several characteristics seams identical: The three processes of Kansei design, emotional design, and affective computing are dedicated to the creation of products in the field of user experience. They are all focused on the link between the user and the artifact, impacting both the user and the perception of the product. The final products that are created by the Kansei design process, emotional design and affective computing could be the same, even if we can see different ways of conceiving the product. Indeed, the following sections describe different notions of conceiving the three processes.

Distinctions
Figure 19 demonstrates the differences between the way we consider Kansei design, emotional design and affective computing in the field of interaction design research. If the three fields are in the scope of "user and product perception", we could compare fields from two axes, respectively named the "level of information" (vertical axis) and the "set of products" (horizontal axis).

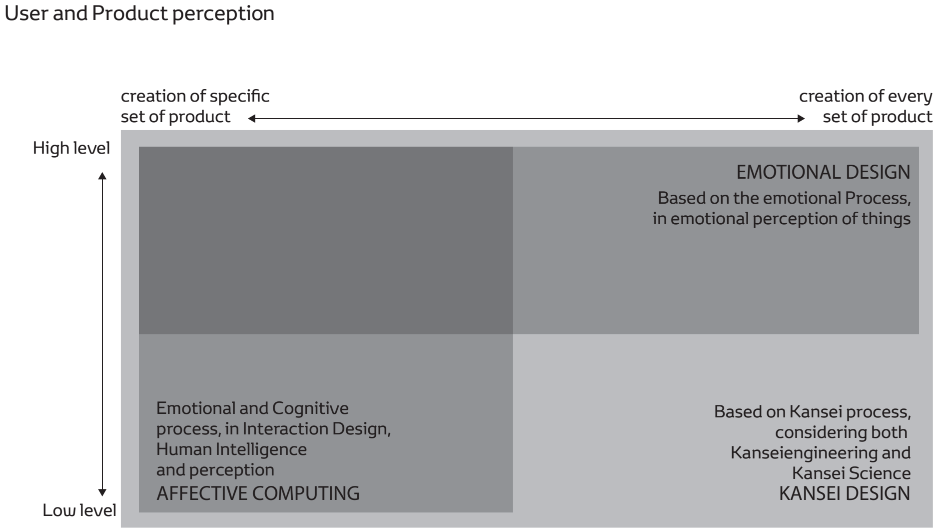


Figure 19: The three fields from the User and Artifact perception

Set of Products
If we consider the angle of the set of products, we can easily distinguish the Kansei design and emotional design processes from the affective computing process. Indeed, the affective computing process considers only technological products, whereas the Kansei design and emotional design processes admit the entire scope of products. It includes technological and computer products (obviously), and even products such as textures, simple materials, and so on.

Levels of Information
If we only consider the angle of "levels of information" (Bouchard, 2009), from high level (abstract notions such as feelings, meanings, style, notions that are subjectively considered dependent on the interlocutor) to low level (concrete dimensions, based on the objective view of things, such as materials, colors, gestures and so on), we could bring Kansei design and affective computing into opposition with emotional design. Indeed, whereas Kansei design and affective computing consider every level of information as an input to the process of conception, emotional design only considers high levels of information as input. The emotions that are perceived are the subjective consideration of emotional design conception.

Finally, because we consider the three approaches as processes of conception, we can highlight that the only thing that is not similar in those fields are the inputs. Indeed, the inputs of the three processes are different. Nevertheless, the outcome could be the same, as presented in Figure 20. It is about a product, in the user experience perspective, based on objective and subjective parameters.

2.2.2 Design Disciplines(di)

In order to be able to describe what kind of people are involved in the design phases at TME, we focused on a way to differentiate them. Moggridge (2006) developed the quadrant of human and subjective/physical design disciplines, which distinguishes four types of design discipline, presented below.

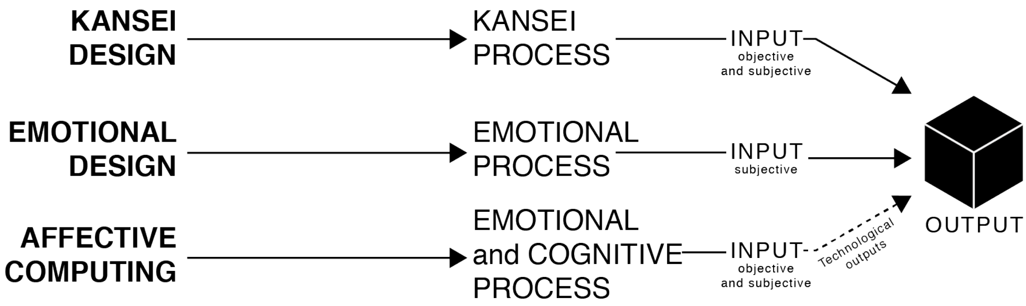


Figure 20: The three fields representation

1. Design disciplines (industrial design, graphic design, web design, interaction design). "Design is what links creativity and innovation. It shapes ideas to become practical and attractive propositions for users or customers. Design may be described as creativity deployed to a specific end" (Cox, 2005).

2. Human science disciplines (physical ergonomic, human-computer interaction). "Human science studies the biological, social and cultural aspects of human life. Human sciences aims to expand our understanding of the human world through a broad interdisciplinary approach" (Oxford, 2017).

3. Engineering disciplines (mechanical, production, hardware, software engineering). "The application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems" (Apa, 2007).

4. Technical science disciplines (physical sciences, computer sciences). "Scientific and practical approach to computation. For example: Computer programming."

2.2.3 Design Processes

Following the understanding of Kansei design, we can focus on the design part as the discipline to create user reaction and perception. According to Mok (1996), everything around us is designed, and our role is to introduce meaning and life into artifacts, a reflection of the approach referred to as "experience design" or "user experience goal-driven design" (e.g., Karvonen et al., 2012; Koskinen et al., 2013), which suggests that "user experience goals" should be defined at the very beginning of the design process. In other words, designers should, in principle, first choose what kind of activity or emotion is to be supported by the design, and then generate the artifact-related design ideas (Wahlström, Karvonen, Kaasinen & Mannonen, 2014).

When addressing the concept of the artifact in user experience, it is important to take into consideration the Kansei design discipline: The term "artifact" was previously presented and defended as a final product. However, our Kansei design approach (designing user's responses rather than artifact properties) leads us to consider the affective and cognitive processes as the real outputs we should design. The characteristics of the artifact are just a way to support what the user will live (feel, perceive, etc.). This is what the Kansei designer should focus on.

We propose hereafter a brief overview of how a simple idea can grow until a final artifact in early design. According to Bouchard (2003), designers' cognitive processes during early stages can be represented as cycles consisting of four design activities in early design: The information level (dedicated to knowledge, focusing on the various pieces of information a designer can gather); the generation level (generation of new ideas and new concepts); the evaluation and decision level (assessing the proposed ideas and concepts); and finally, the communication level (sharing previous results with representation adapted, depending on the interlocutor). These activities are presented in Table 5, Bouchard (2003) Model of Design Activities Augmented with References.

This model has the particularity of being fractal, as it can describe information processes at different levels. At a micro level, it can be used to describe the reflexive conversations between the designer's mental representations and externalized representations. In this case, the "seeing–drawing–seeing" cycle described by Schön and Wiggins (1992) can be superposed with the "information–generation–evaluation" cycle. The timespan of such a cycle typically lasts seconds or minutes. At a more macro level, used also to discuss the tools and methodologies, it can be used to represent early-phase design activities, typically leading to 2D or 3D visualization of a product concept, or to guidelines related to design strategy (i.e., idea/concept representations, character/differentiation strategy). In the latter case, the design informational cycle's timespan is usually weeks or months (Bouchard, 2003).

There are three intermediary representations of artifact's states that are important for this research. The first representation is a simple idea, proposed by Khalaj and Pedgley (2014) as the preconception. For this state, no artifact exists, only an idea. Evaluation is based on expectations and anticipation. The evolution of the idea into something greater and more precise is the concept state. This level can be linked to the "pre-use" level of Khalaj and Pedgley (2014). It can be divided into three categories: The visual appraisal of artifact representations (e.g., photo, image, website, catalogue); visual appraisal of a physical artifact (hands-off); and multi-sensory appraisal of an artifact (hands-on). Finally, the materialization of this concept can be called the prototype state. Utilitarian concerns such as usability, comfort, performance, efficiency, and compatibility become strong influences on product experience, and can thus cause revisions to initial product impressions. Different design activities represent interactive prototypes. For example, the Wizard of Oz is a research experiment in which participants interact with a computer system that subjects believe to be autonomous, but is actually operated or partially operated by an

MODEL OF DESIGN ACTIVITIES BOUCHARD (2003)	INFORMATION	GENERATION	EVALUATION	INTERMEDIATE REPRESENTATION
DEFINITION	The information focuses on the various information a designer can gather in order to increase his knowledge on the content he is working on. This activity consists in questioning the initial need form different perspectives (Intended user, political, economical, environmental, brand) by collecting and organizing data.	The generation level focuses on new ideas and new concepts. Designers can use the collected date, mental images and other kinds of information. Different types of representation can be involved in the process. Physical and digital representations are both relevant, depending on several parameters (price, time, needs…)	The evaluation and decision level is dedicated to the activity of assessing the proposed concepts and ranks each concept on order to keep the more relevant one. Many criteria can be used through methodologies and tools.	Finally, the communication level is about sharing previous result to other design members, to stakeholders or even more people. The type of representation is often adapted depending on the interlocutor.
TOOLS TO SUPPORT ACTIVITIES	Bargas-Avilas & Hornbaek, 2011 Bongard-Blanchy, 2013 Ideo, 2003 Interview/ Focus group Diary/ journal Potes Personas Questionnaires User Observation …	Bongard-Blanchy, 2013 Nagamashi, 2011 Schutte 2005 Creativity tools, Co-creation Quick prototyping Innovation Tool Material libraries Tools from ergonomics Kansei engineering systems …	Rieuf, 2013 Chen 2016 Objective measurements: Brain area reading Movement tracking Heart rate Subjective measurement: Position my state/ vision Discussions Cards sorting …	Papadimitriou, 2007 Ruiz-Dominguez, 2008 Hisarciklilar, 2009 Paper idea Video Quick prototyping Arduino Wizard of Oz ...

Table 5: Model of design activities, defintion and tools

unseen human being (Bella, 2012).
There are two ways of considering such an understanding of design activities: By focusing on user or artifact characteristics (color, shape, texture), or by focusing on the relationships inside the user-artifact system, the user's affect and perception of the artifact. This is how the Kansei design discipline considers this model of activities, and this is how we position this research within design development. The early phases are decisive when designing user experiences and interactions. Indeed, according to Bouchard (2003), early design is a key point, because it is a wide scope that conveys both abstract and concrete design information.

2.2.4 Design Levels(lev)

Parallel to the four activities presented by Bouchard (2003), Hassenzahl (2010) defines three levels in user experience design when interacting with an artifact. He calls them the "Why", the "What", and the "How" levels (Hassenzahl, 2010).

The Why underlies needs, emotions, and associated practices; the What addresses the things people can do through an interactive product; and the How addresses acting with regard to an object at an operational, sensory-motor level (turn a button, play on an interface), and makes given functionality accessible in an aesthetically pleasing way.

Thus, a direct link can be found between the four activities from Bouchard (2003), and the three levels of design conception from Hassenzahl (2010). Indeed, the three levels (Why, What, and How) can be considered as direct design levels of each activity proposed by Bouchard.

2.2.5 Design Information(i)

Gentner (2014) has proposed a model of design information that can be used to convey user-experience-related intentions (see Figure 21). Indeed, he argues that one of the characteristics of Kansei representations is that they communicate design information related to an extended picture of user experience. What he calls the picture, includes much information that is useful for early conception (Gentner, 2014). The following model lists this information. His works, and especially his models, can be considered as the first step to link Kansei with design information dedicated to early user experience. The simple fact of listing this kind of information conveys many decisive clues for our research.

Furthermore, Gentner (2014) has developed his model through three levels that can be easily linked to Bouchard "levels of abstraction": The "mental level" defended by Gentner can be associated with the "abstract level" of

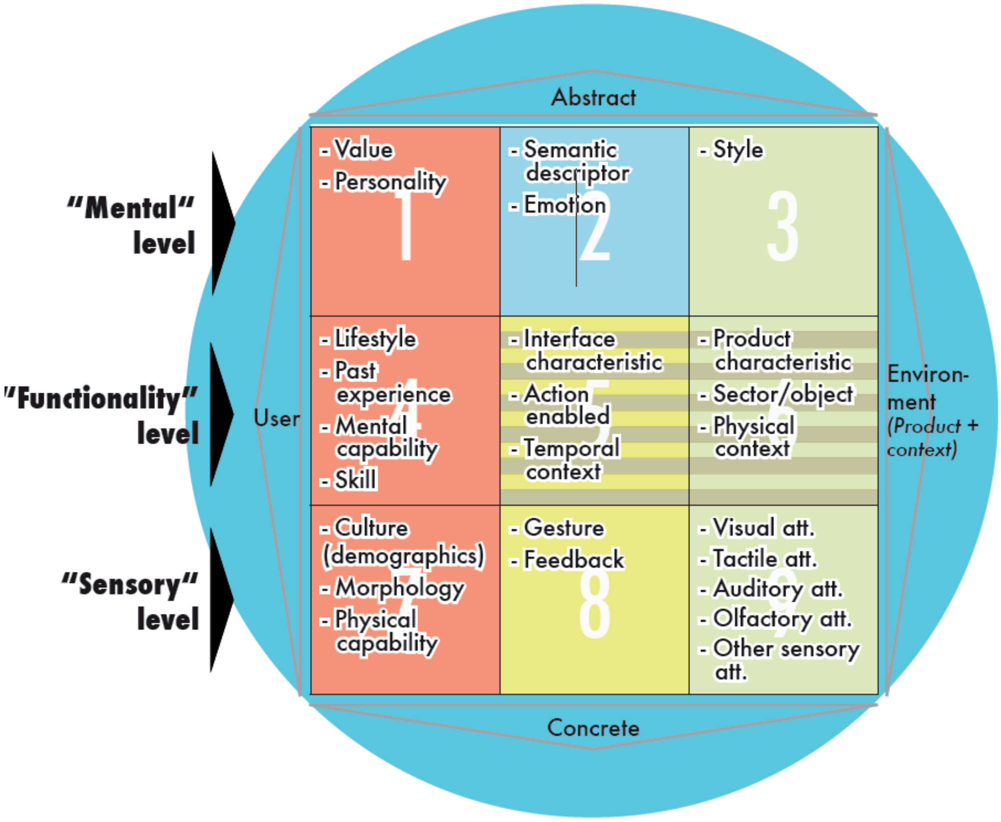


Figure 21: Model of Design information reproduced from Gentner 2014

Bouchard (2003), and so on for the sensory level (called the “concrete” in one of Bouchard’s works). What he brings to Bouchard’s work, is the intermediary dimension called the “functionality level”, conveying information such as skills, past experience, interface characteristics, and physical context.

Through these three models, this research acknowledges a direct link between design information (Gentner, 2014), levels of abstraction (Bouchard, 2003), and levels of conception (Hassenzahl, 2010).

Indeed, Gentner (2014) proposes a set of information that is conveyed in early conception, based on Bouchard’s abstract and concrete dimensions (2003), and on the other hand, Bouchard has proposed a model of design activity structured through “information”, “generation”, “evaluation”, and “communication”. What is interesting, is that each level proposed by Bouchard (2003) can be associated with a model of design information proposed by Gentner (2014). Thus, one approach has been created, where each step of design activity is linked to a model of design information (see Figure 22). Furthermore, a second approach can be added to this understanding, based on Hassenzahl’s works: An axis of design information that we are working on, composed of Why, What and How levels.

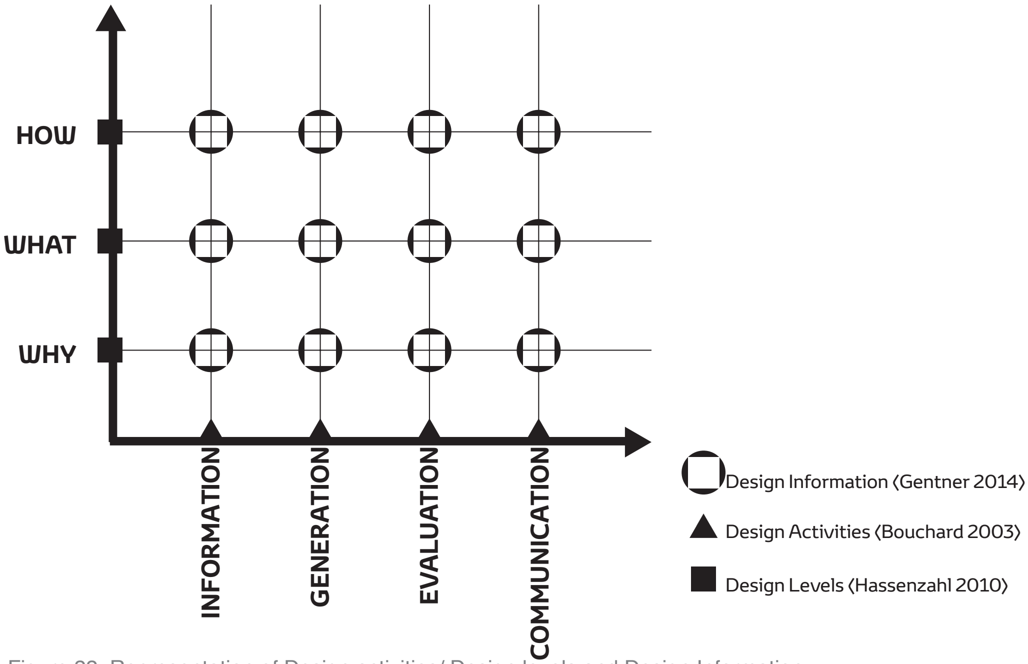


Figure 22: Representation of Design activities/ Design levels and Design Information

2.2.6 Designing Interactions through the Metaphorical Approach

This section describes the concept of metaphor from the design angle. This section is divided into three parts. The first describes how metaphors can be considered as useful for interaction design, the second defines a scope for interaction design through metaphors within the design process, and the third describes metaphor as a tool for interaction design.

2.2.6.1 The value of Designing Metaphors

According to Forceville (2008), metaphor can be used in product design. Recently, fields of design and engineering have incorporated this notion of metaphor (Forceville, 2008; Chung, 2015; Hekkert & Cila, 2015). By doing so, they highlight the link between linguistics (language) and form (design). Hence, a designer has control over how a product's form conveys a metaphorical message. Designers are responsible for making the physical manifestation of the features they wish to map. According to Forceville, "Designers shape the target in such a way that it evokes the experience of the source without violating the identity of the target" (Forceville, 2008). Furthermore, Chung (2015) points out that the target and the source should share some common attributes in order to be consistent. This view is also shared by Krippendorff (2006): "The effective use of metaphors presupposes the two domains to have some structural resemblances." This dialogue between the target and the source in the activity of designing aims at learning about a particular object by relating it to another. Thus, designers may employ a metaphor in order to promote other kinds of user experiences, according to Rompay (2008). The activity of designing metaphor therefore has to be considered, following the assumption by Hekkert and Cila (2015). Metaphors can be actively generated, experienced, and studied. This metaphorical approach when designing products and interactions has the strength to convey abstract meaning in user interfaces and interactions (Hurtienne, 2009).

Considering metaphors in the interaction field leads to exploring the notion of temporality in metaphor. Indeed, as argued previously, the notion of temporality underlies the difference between product design and interaction design. Temporality implies ideas of "step by step", of sequence, story, and narration in the everyday uses of products. Because temporality is decisive in interaction, and because metaphor is a good way to link narrative process to design, according to Krippendorff (2006), using the metaphorical approach for designing interactions could be valuable. Indeed, using metaphors not only for product design, but within the interaction design scope, could help facilitate user learning, by supporting the transformation of existing knowledge to improve the comprehension of novel situations, as suggested by Alty, Knott, Anderson and Smyth (1999).

2.2.6.2 Metaphors as a Tool

Metaphors can be used as a tool for designing products and interactions. For example, Ahmed et al. (2014) worked on the "superhumans" metaphor, as a conceptual character-driven approach aiming to enrich the design of virtual environments and experiences. Also, Van Rompay (2005), and Van Rompay and Hekkert (2008), conducted exploratory design exercises and workshops to show that embodied expression (metaphors) are practical insights for designers, facilitating the transition from abstract idea to form. Averbukh (2008) extended the idea of magic metaphors to magic fairy tales as source of inspiration for interface metaphors. Alty, Knott, Anderson and Smyth (1999) worked on metaphor as a conceptual tool for facilitating consideration of implementation issues. Thus, this research aims to use metaphors as a tool during creative sessions with designers.

2.2.6.3 Metaphors in the Design Process

According to the community, there are three major reasons why using metaphors could be beneficial when implemented in the design process. The first is that metaphors help to identify, frame and solve design problems (Casakin, 2012; Hey, Linsey, Agogino & Wood, 2008; Schön, 1979). The second is that metaphors help to break away from the limitations imposed by problem constraints (Casakin, 2011). Finally, metaphors help to justify design decisions (Madsen, 1994). The first two arguments focus on designing, whereas the last one focuses on evaluating metaphors. The evaluation of metaphors has also been improved by Alty, Knott, Anderson and Smyth (1999). They proposed six steps to assess the suitability of a metaphor (in situ), and hence provide feedback for improved design. However, in this part of the research, we will focus on designing interaction through the notion of metaphor. Indeed, as for "analogy" often compared and considered as the family where "metaphor" belongs (Chung, 2015), metaphor is a powerful tool in the generation phases. According to Beck (2004, p. 168), "the question is not whether you will think metaphorically or not, the question is whether you will become aware of your metaphors and choose them consciously".

2.2.7 Designing Experiences: Summary

In the second part of the state of the art, we focused on the loop between the designer and the artifact (see Figure 23). The first summary of the state of the art, focusing on experiencing designs highlighted four elements:

1. Model of design information (i);
2. Three-dimensional taxonomy (d);
3. Areas (a); and
4. Principles (p).

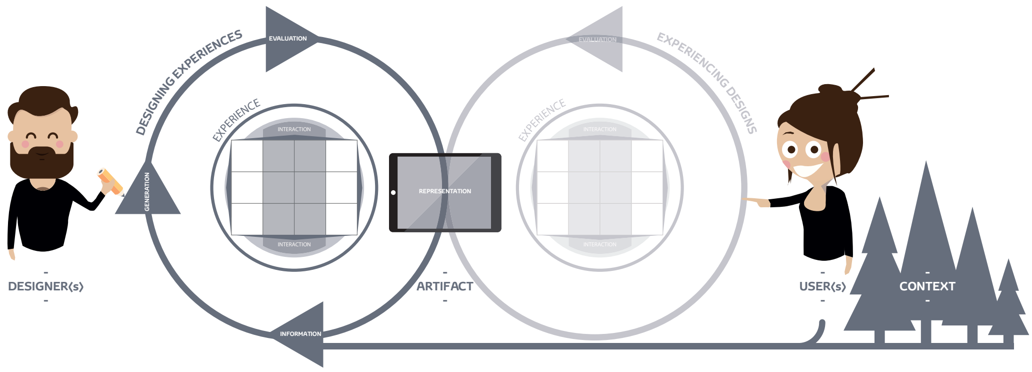


Figure 23: Model of Designing Experiences scope

From the second part on designing experiences, three elements can be highlighted, and added to the list of the four already mentioned:

5. The design process within which the research is positioned;
6. The different design levels(lev) that have been highlighted; and
7. The different design disciplines(di) that are involved in the design process.

5- Design Process

The fifth element has been defined by Bouchard (2003), and presents the different design activities in a specific design process. As has been mentioned, this process is based on four points: Information, generation, evaluation, and communication. It focuses on the loop between the designer and the artifact. By considering this design process, we assume that different activities are punctuating the design process: Information, generation, evaluation, and representation. Many loops can be performed between the activities themselves, and many loops can also be performed from the first representation (such as a simple sketch) to the final prototype. In this research we will mainly focus on the two design activities of **generation and evaluations.**

6- Design Levels (lev)

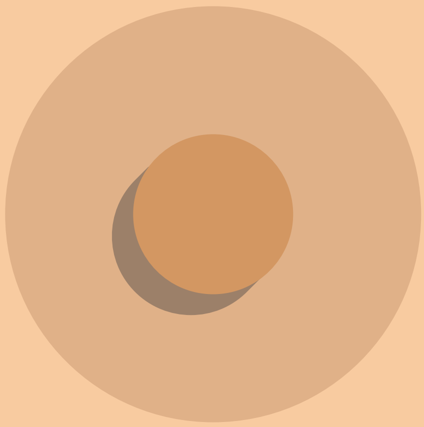
The state of the art describes three design levels (Hassenzahl, 2010) to be considered during every design activity, presented previously with reference to the notion of process (Bouchard, 2003), i.e., the Why, What and How. In this document, we will use the letters (lev) when referring to one of the design levels(lev). To facilitate an understanding of the three design levels, we use the following names:

Why = **Theorization(lev)**
What = **Characterization(lev)**
How = **Materialization(lev)**

These terms are easier in the industrial context, less theoretical and more process oriented.

7- Design Disciplines (di)

The seventh element concerns the different design disciplines. We will use the letters (di) to easily distinguish design disciplines from the other elements. As we saw previously, four disciplines can be distinguised: Design disciplines(di), human science disciplines(di), engineering disciplines(di), and technical science disciplines(di). These disciplines are involved in some or all design activities during the design process.



«The only intuitive interface is the nipple.
Everything after is learned»
Wilson Miner

2.3 State of the Art Summary and Statements

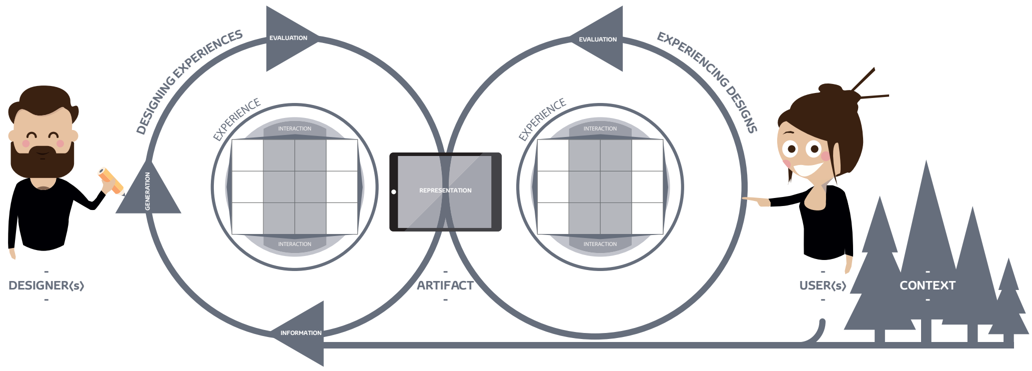


Figure 24: Model of Litterature Review scope

As stated previously, two loops have been defined (see Figure24). The first loop, **Experiencing Designs**, focuses on the experience between the user and the artifact within a specific context. The second loop, **Designing Experiences**, focuses on the links between the designer and the artifact. The state of the art highlighted seven elements that will be used during this research. These elements are summarized in Table 24.

The state of the art presented and mapped the different components of the user experience, highlighting the area of interaction, and pointing out all the different aspects of design information(i) that we have to consider in the interactive process of designing and evaluating user experiences and interactions in the early phases. It also covered some studies that have been conducted on interaction design and metaphor. We argued that metaphors can be used as a tool for designing products and interactions.

Based on this state of the art, **seven insights have been proposed** and are presented in the conclusions of each loop:

1. The first insight is an understanding of interaction as the core of user experience. This approach proposes to focus on the interactive design information(i) (affective and cognitive responses) (e.g., Figure 15), rather than on the product materiality when evaluating or designing user experiences.

2. The second insight corresponds to the three dimensions(d) proposed by the taxonomy of interactive products.

3. In terms of our experiential approach to the physical and digital paradigms, the three dimensions of environment(d), target(d), and source(d) have been highlighted as a way to differentiate and distinguish interactive products. This three-dimensional(d) approach allows us to set up the third insight: the eight areas(a) that compose the taxonomy. These areas(a) are the different typologies of interactive products described by the three-dimensional(d) representation.

4. The fourth insight is the principle-based approach(p). It describes and characterizes what the interactive product enables the user to do.

5. The fifth insight is the different activities proposed by Bouchard (2003) for the early design phase.

6. The sixth insight arises from this design process. It consists of the three design levels(lev) proposed by Hassenzahl (2010) that we can consider during every design activity (Bouchard, 2003).

7. Finally, the last insight concerns the different design disciplines(di). As we saw previously, four disciplines can be identified when describing the design process: Design disciplines(di), human science disciplines(di), engineering disciplines(di), and technical science disciplines(di).

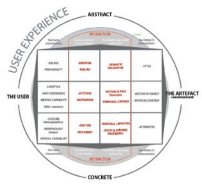
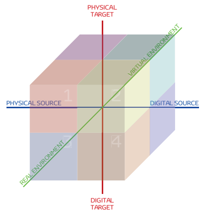
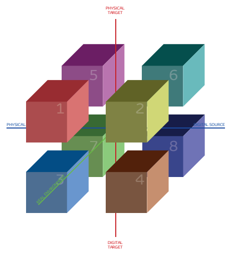
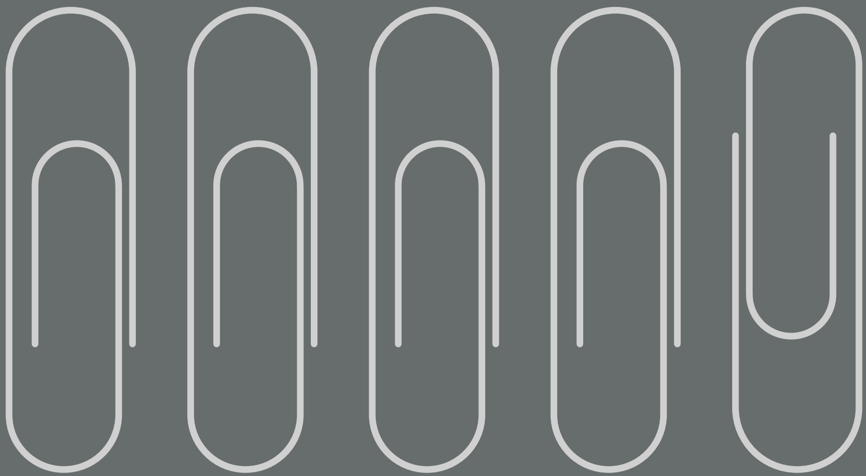
Name	Understanding	Related figure	Reference in the text
DESIGN INFORMATION	The different design information highlighted by the theoretical model		(i)
3 DIMENSIONS	The three dimensions highlighted in the state of the art: environment; target; source (represented as axis)		(d)
8 AREAS	The eight areas highlighted by the three dimensions' representation		(a)
PRINCIPLES	Product principles consisting of keywords mostly related to what the interactive product enables the user to do	ø (not yet)	(p)
DESIGN ACTIVITIES	The different activities related to the design process (proposed by Bouchard 2003)		ø
DESIGN LEVELS	The different design levels initially proposed by Hassenzahl (2011).	Theorize/ Characterize/ Materialize	(lev)
DESIGN DISCIPLINES	Disciplines involved in the design process. Defined by Moggridge (2006)	Design Disciplines; Engineering Disciplines; Human Science Disciplines; Technical Science Disciplines	(di)

Table 6: Summarized litterature review



«Creativity is to discover a question that
has never been asked. If one brings up an idiosyncratic question,
the answer he gives will necessarily be unique as well»
Kenya Hara

-

3 RESEARCH QUESTION AND HYPOTHESES

-

This chapter deals with the central question raised by the state of the art. This question is then proposed to be answered by investigating three hypotheses.

3.1 Research Question

1. Even if the model of design information(i) clearly shows that interaction is the core of the user experience, there is no formalized understanding of the impact of user experience on interaction (or of interaction on user experience). This lack of knowledge on the relationship between interaction and user experience, on their influence on each other, leads us to pose the following question:

How should the reciprocal relationship between user experience and interaction be formalized and enriched?

2. Even though the state of the art outlined a model of design information(i) and three dimensions(d), structured into eight areas(a), we could not find knowledge on the impact of such dimensions(d) on the user's affective and cognitive responses (interaction-related design information(i)) in the research community. This lack of information leads us to the following question:

How do the three dimensions(d) (environment, target and source) influence the design information(i) of the model (users' affective and cognitive responses) when a user interacts with an artifact?

3. While the state of the art argued that the metaphorical approach can be a powerful tool, and could be used in early design, we could not find knowledge on the link between the metaphorical approach and the design process in the research community. This lack of information leads to the following question:

Which design level(lev) is best suited to support the generation of interaction by using the metaphorical approach in early design?

These three questions are summarized in the following central question:

-

How can an understanding of human-product interaction improve early user experience design?

-

This question has been designed in order to highlight three issues, namely the direct link between interaction and user experience; the notion of design and conception of interaction in the user experience field; and the creation of tools and methodologies to succeed.

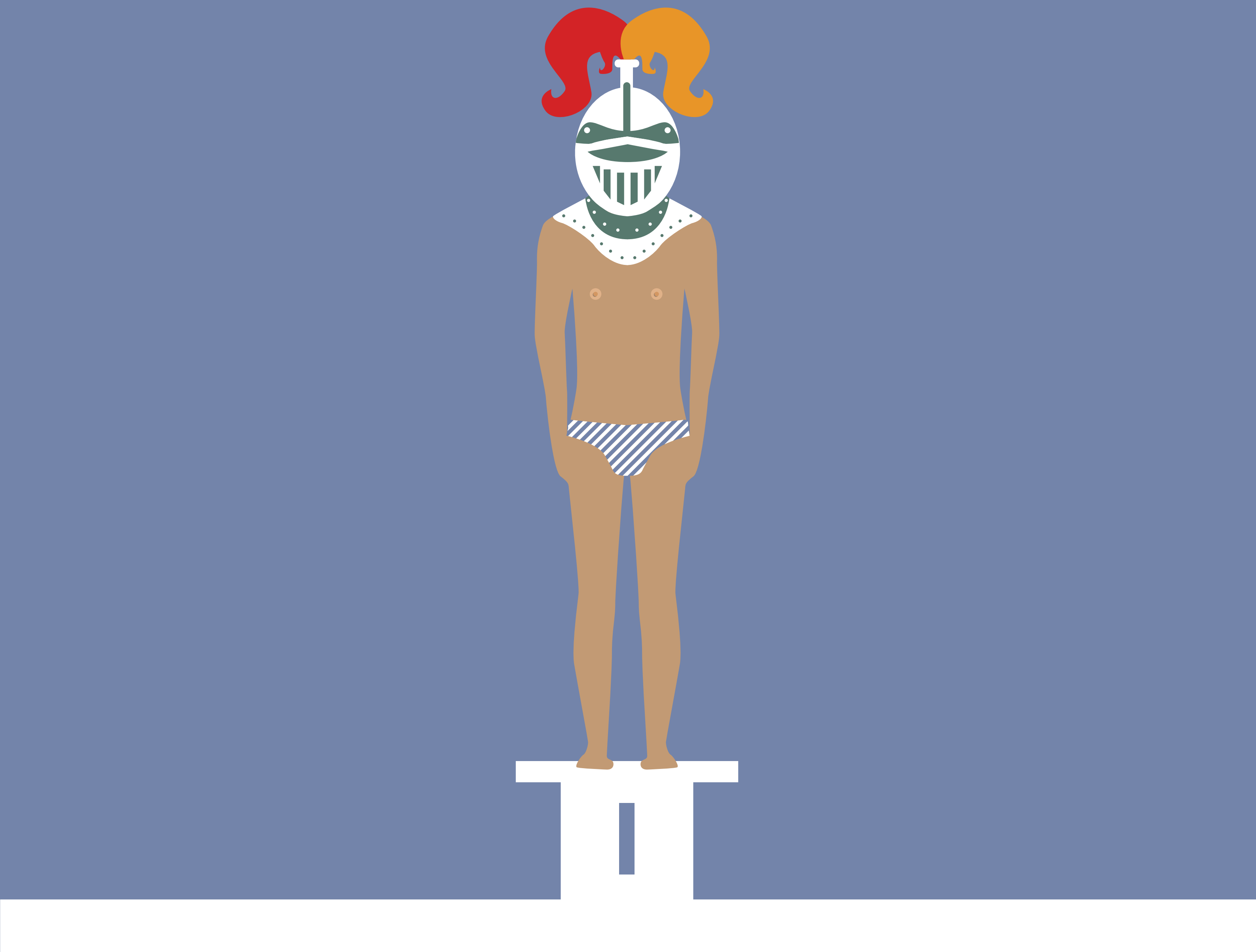
The goal of our research is to provide a better understanding of the relationship between user experience and interaction, in order to support early design phases, both design and evaluation of interactions and user experiences.

-

How can an understanding of human-product interaction improve early user experience design?

-

?



«Recognizing the need
is the primary condition for design»
Charles Eames

3.2 Hypotheses

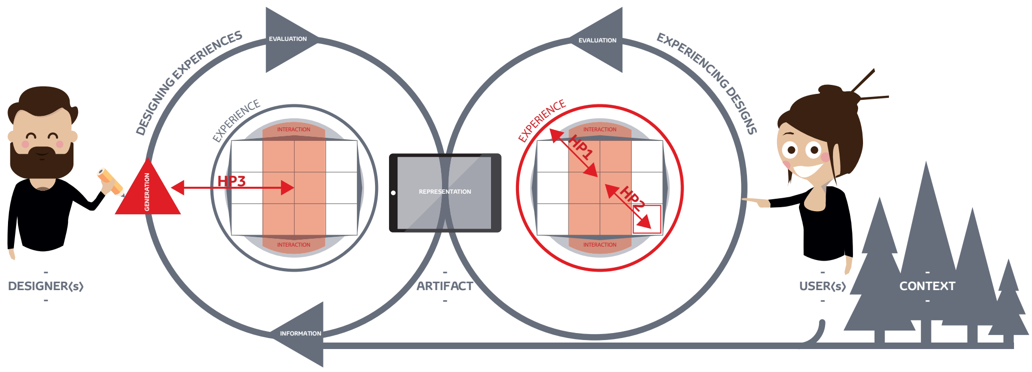


Figure 25: Hypotheses representation

The research question raises three hypotheses, set out in 3.2.1, and in Figure 25 as HP1 (hypothesis 1), HP2 (hypothesis 2), and HP3 (hypothesis 3). These hypotheses could support the way we design and evaluate interactions and user experience, discussed in section 3.2.2.

3.2.1 The Three Hypotheses

This section presents the three hypotheses arising from the research question.

1

The formalization of, and connection between, user experience and interaction could improve and enrich the design process.

-

To make the reciprocal relationship between interaction and user experience intelligible, so as to enrich the design process, we should understand and formalize the successive exchanges of design information between interaction and user experience.

-

Because interaction is at the core of the user experience, the way we experience an interaction should impact the entire user experience. We also make the assumption that user experience and interaction are both emotional and meaningful. So, how should we consider the impact of interaction on user experience in terms of emotions and meaning? And how should we consider the impact of user experience on interaction? Is there a reciprocal link between the two?

2

How we experience an interaction with an artefact is affected by the physical/digital paradigm.

-

A better understanding of the impact of the three dimensions(d) of interactive design information(i) could improve the way we design interaction from a user experience perspective.

-

If a simple interaction impacts the user experience, understanding how an interaction takes place and affects the user is decisive. Furthermore, this research highlights that the artifact is one of the pillars of the user experience, and, more specifically, of the interaction itself. This hypothesis therefore suggests that linking user experience and the physical and digital paradigms can improve the methodologies and knowledge for designing interactions in the early phases.

3

The metaphorical approach can be used to improve the way we design interactions in the physical/digital paradigm.

-

A better understanding and formalization of the terms of design information(i), and the metaphorical approach's impact on design levels(lev) and design disciplines(di), can improve the way we design interaction and organize creative sessions.

-

This approach proposes to focus on the design process in order to better understand and formalize the way we use the metaphorical approach for designing experiential interaction. By doing so, we can formalize what design information is tackled and which disciplines could use this approach.

3.2.2 Hypotheses that Support Platforms Development

As we just saw, the three hypotheses could bring answers and solutions for improving both the way we **EVALUATE interactions and user experience, and the way we DESIGN them.**

Indeed, this research could lead to developing and establishing several tools and methodologies that focus on the two questions mapped in Figure 26.

The first question, "How to evaluate interactions and user experiences?" could focus on evaluation activities. Both users' and designers' evaluations of artifacts are considered by this question. We call the framework for the evaluation tools and methodologies "the evaluation platform" (see Figure 26).

The second question, "How to create interaction and user experiences?" could focus on the design development activities of designers during early design. These activities focus on information and the generation of new interaction and user experience. We call this "the generation platform" (see Figure 26).

Hereafter, we propose the first understanding of these two platforms.

-Evaluating Interactions and User Experiences

The aim of the evaluation platform is to assess both existing and new concepts of interaction in the scope of user experience. The goal is to translate how the user feels, or how he or she perceives the interaction or the user experience

itself, into a common scale or language with both objective and subjective measurement methods.
Many tools, methodologies, and sensors can be used to assess both the user experience and interactions. Tables 30, 31, and 32 in the Annexes summarize some activities that can be used, and how these activities can support the assessment of specific criteria. Tools and methodologies are listed according to each kind of activity. These evaluation criteria, with the entire set of tools and measurement methods that they convey, are only relevant to user experience and interaction if they are combined, compared, and gathered. Indeed, the only way to accurately evaluate interaction is to use as many criteria as possible, and to combine all the collected data to highlight specific features.

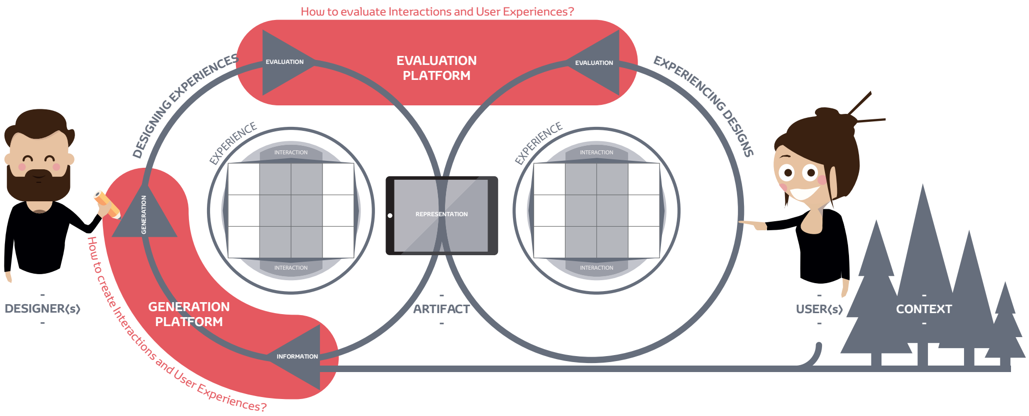


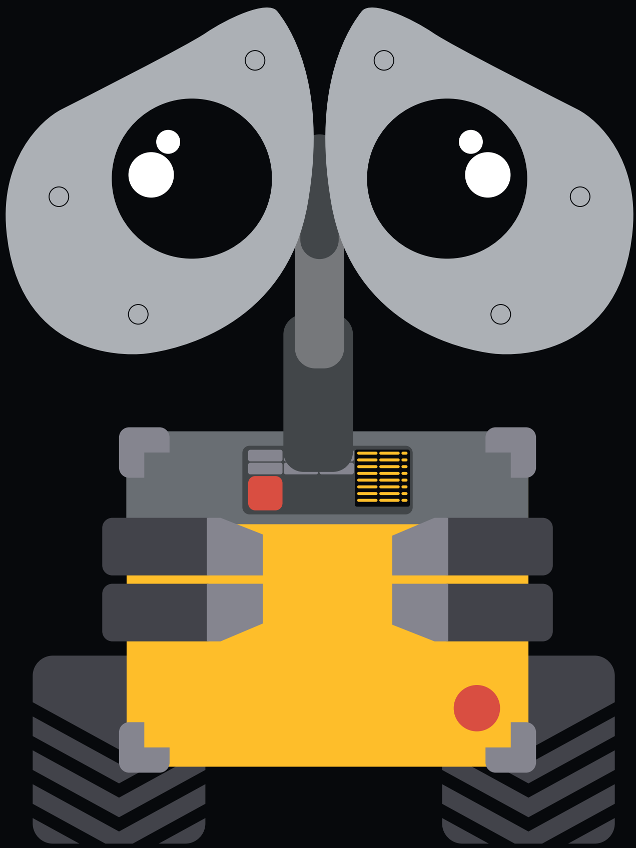
Figure 26: Representation of the Evaluation and the Generation platforms according to model of litterature Review

-Creating Interactions and User Experiences

This category of tools might enable the designing of great user experiences, focusing on interactions. In order to explore new interactions, body storming, and role-playing (Larssen et al., 2007) are commonly used by Kansei design team members. These tools allow exploring and exchanging new solution spaces in groups during ideation sessions.
Scenarios are used for all interaction design projects. These narrative approaches allow the design team to better explore and convey its views about new experiences (Sanders, 2006). They allow the validation of designers' hypotheses (regarding the way users act, think, and experience) during the information activities (Fulton Suri, 2003). The identified user journey narration is then often transcribed on storyboards (Chung & Gerber, 2010). A series of drawings in a cartoon style allows for quicker and more immersive understanding by the design team members. In the case of scenarios involving an ecosystem of stakeholders (typically the case in service design projects), blueprints are used (Kalakota & Robinson, 2004). These display the different stages of the scenario on a horizontal flowchart above and below the line of visibility to the user. The user experience touch points and functions are placed above the line of visibility, and the backstage processes and related stakeholders corresponding to the different user experience stages are organized accordingly below the line of visibility.

Besides these mentioned above, many other tools are used in generation activities.

In this research, we will see how the three experimentations migh support the creation of tools for **evaluating and designing interaction and user experiences.**



«It is not enouth that we build products that function,
that are understandable and usable, we also need
to build products that bring joy and excitement, pleasure
and fun, and, yes, beauty to people's lives»
Don Norman

-

4 EXPERIMENTATIONS

-

4.1 Introduction

This research is based on three experimentations that ensue from the initial research question. The experimental flow will start from the broader scope, the reciprocal connection between user experience and interaction in Experimentation 1 (4.2), and lead to the narrower scope of Experimentation 3 (4.4), about the way we can design interaction and user experience using the metaphorical approach. This increasing focus of the research will lead to the development of tools and methodologies for both evaluating and designing interactions and user experiences in early design phases.

The tools and methodologies are fully described in the Annexes, for ease of reading. The developed tools and methodologies are summarized in the section on the industrial contribution (5.2)

The three experimentations and their flow are described in the following sections.

Experimentation 1: Reciprocal Connection between User Experience and Interaction

This experimentation addresses the first hypothesis, on the connection between interactions and user experience. The aim of the first experimentation is to prove that there is a reciprocal link between interactions and user experience, by looking at the design information conveyed by the interaction level, and the user experience level. With this experimentation, we will collect data from both levels that will help us to understand the values, semantics, and emotions of each level, and how they evolve from a simple interaction level to a full user experience level. These results will help to enrich the design process by formalizing a theoretical model of interaction and user experience, based on their reciprocal impact.

We will assess a user experience and its more memorable interaction by using different criteria. Based on the collected data, we will analyze the results of each level to find specific clues supporting our first hypothesis, and formalizing the link between interaction and user experience.

Experimentation 2: Formalization of the Impact of the Physical and Digital Paradigm on the Design Information

The second experimentation addresses the second hypothesis, on artifacts' characteristics. This experimentation will attempt to show how the physical or digital characteristics we choose for a product impact the way we experience an interaction. Thus, we will conduct an experimentation based on evaluations of different interactive products. Based on evaluations of the design information(i) of the theoretical model (see Figure 15), we will highlight and formalize the impact of every dimension(d) (see Figure 16) on the user's affective and cognitive responses(i).

The results can lead to a better understanding of designing interfaces and interactions from a user experience point of view, by highlighting the positive and negative features of each dimension(d). Furthermore, this understanding could bring valuable opportunities for understanding, defining, positioning and designing the tangible interface, fluid interface, peripheral interactions, and even haptic interactions from the physical and digital features point of view.

Experimentation 3: Formalization of the Metaphorical Approach for Designing Interaction

The third experimentation addresses the last hypothesis, namely how to design experiential interactions using the metaphorical approach. This experimentation aims to formalize a tool for designing interaction using the metaphorical approach, and to position this tool within the design process and the design disciplines(di). By so doing, this experimentation will provide a tool and a methodology to enable design interaction in the early design phases, based on three design levels(lev).

«People react positively when things are clear and understandable»
Dieter Rams

4.2 Experimentation 1

The objective of the experimentation is to test the first hypothesis, “The formalization of, and connection between, user experience and interaction could improve and enrich the design process.” It is composed of three parts: The first part (4.2.1) presents an understanding of our objectives, the second part (4.2.2) defines a method for success, and the third part (4.2.3) presents the results.

4.2.1 Objectives

The experimentation addresses the reciprocal relationship between interaction and user experience, in order to formalize the interdependency between the user’s perception of interaction and user’s perception of experience and to enrich our understanding of interaction within the user experience scope. By so doing, we highlight what kind of design information(i) is impacted, and how it is influenced. This can improve the way we design interactions and user experiences in early design phases.

4.2.2 Experimental Ground

To explore the hypothesis and the objectives that ensue from it, this research proposes an experimental ground where participants evaluate their perception of different user experiences and interactive products developed during a design process. This experimentation tests the results of this design process, as presented in Figure 27.

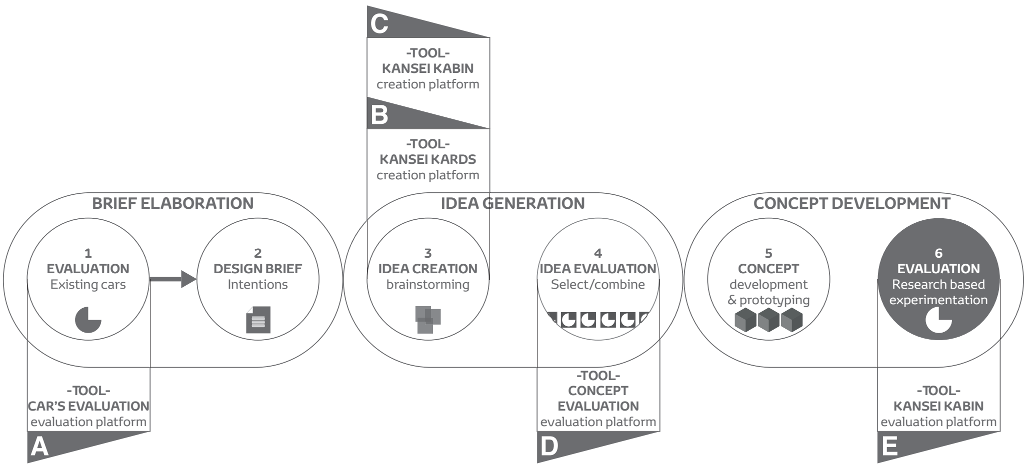


Figure 27: Concept development process

The experimental ground is based on the creation and development of a heating, ventilation and air conditioning system (HVAC) in cars. The goal is to provide thermal comfort and acceptable indoor air quality. The simplicity and the “hand-sized” property of this interactive product led us to choose it as the experimental ground. The development project involved six steps, as presented in Figure 27. Various tools were created or improved in order to support the design activities.

The first step consists of evaluating different cars in order to highlight design opportunities and design challenges. The methodology used for evaluating cars, Tool A, is presented in the annex. The collected design challenges were used to build the design brief in Step 2. Based on this brief, we generated ideas in Step 3. Two tools were developed to support the generation activity. Tool B, which consists of different cards of creativity focused on interaction purposes, and Tool C, an architecture for supporting, contextualizing and recording the creation of ideas, are detailed in the annex. The evaluation of the collected ideas in Step 4 was supported by a proposed methodology, called D and presented in the annex. Finally, the selected ideas were improved as a concept in Step 5. Step 6 consists of evaluating the generated concepts. This is what was used for the experimentation.

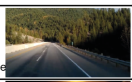
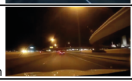
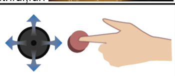
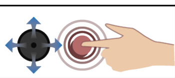
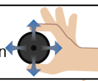
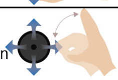
4.2.3 Method

The method used in this experimentation consisted of testing and assessing one user experience (UX) with one interactive prototype (ID). We tested the same UX with different IDs in order to observe how the user experience evaluations (perception of UX = Pux) were impacted by the different interactive prototypes. The experimentation was then performed in reverse: an interactive product was evaluated (perception of ID = Pid) by different UXs in order to observe how user experiences affect the evaluations of an Pid.

Two loops were organized (loop A and B in Table 7) to support this method.

Loop A aims to observe if an interaction influences user experience according to the following assumption: **≠ID => ≠Pux, literally, "different interactions imply different perception of the user experiences"**. Thus, Loop A tests how Pux1 is affected when we change the interactive prototype: ID1, ID2, ID3, and ID4.

Loop B is organized the other way round. The aim is to observe whether a user experience can (also) influence how an interaction is perceived. It is based on the following assumption: **≠UX => ≠Pid, literally, "different user experiences imply different perception of interactions". Thus loop B tests how Pid1 is affected when using UX1 and UX2**.

	Name	Type	Functions	Concept description	Materialisation properties
A	UX1 'Inner Harmony'	User Expe-rience	Immerse the participant in a simulated User Experience	Behavioral values: harmony; transcendence; disciplined Emotions: serene; peaceful; fulfilled Meanings:elemental;timeless;pure 	-A cabin -Video projection (road+landscape from user pov) -Music system (Erik Satie : 'Gymnopédie No.1' + Clint Mansell: 'The Last Man')
	UX2 'Playful Behavior'			Behavioral values: enjoyment; excitement; cheeky Emotions: engaging; amused; enthusiastic Meanings: cheerful;youthful;fun 	-A cain (car simulator) -Video projection(road+landscape from user pov) -Music system (les Pascals: 'Nohara' +Pascal Comelade 'the blank Invasion of Schizofonics Bikinis').
B	ID1 'Knob'	Interaction	-Turn ON or turn OFF -Increase or decrease the amount of air -Increase or decrease the temperature -Adapt the direction of the air flow.	based on simple knobs 	Laser cutting (wood) +arduino (sensors, light, motor...) -1mn Video presentation of the concept
	ID2 Augmented knob			based on augmented knobs 	Laser cutting (wood) +arduino (sensors, light, motor...) -1mn Video presentation of the concept
	ID3 'Manipulation'			based on direct manipulation 	3D printing (plastic) +arduino (sensors, light, motor...) -1mn Video presentation of the concept
	ID4 'Gesture'			based on gesture recognition 	ø (gesture=no materiality) +arduino (sensors, light, motor...) -1mn Video presentation of the concept

A Loop A: focus on one User Experience's evaluation when interacting with each interactive prototype
B Loop B: focus on one interactive prototype's evaluation when lived during each User Experience

Table 7: Two User Experiences and four Interactive products

To perform these two loops, we created different interactions and user experiences, as presented in the protocol (4.2.3.1). Then, based on a specific procedure (4.2.3.2), we tested and evaluated them. Finally, our processing of the data is presented in the last section (4.2.3.3).

4.2.3.1 Protocol

In this section, we present the established protocol. The following table (table 8), summarize the different elements that will be presented.

The first part, related to the first colomn, presents the Input Data consisting of two user experiences and four interactive products that will be evaluated during this experimentation.

The second part (related to the second colomn) presents the different values participants will use to evaluate their perception of both User Experiences and Interactive products.

Finally, the last part, and last colomn, present the scales and questions we will display during the experimentation.

Additionnally, the table 8 presents also the different sequences of evaluation in the Input data colomn. It consists in 8 associations of User Experiences and interactive products, that will be used to describe the procedure of evaluation.

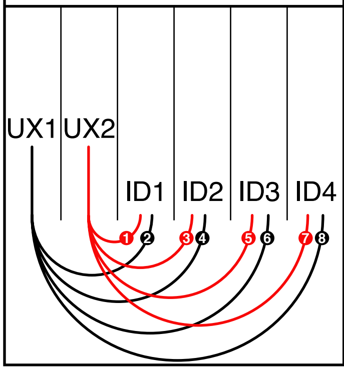
Input Data	The cards	Scales			
	Sensory (6 cards)	"Was this sensory card very useful, somewhat useful, or not at all useful?"	-1	0	1
	Emotional (40 cards)	"Are you in agreement, unsure of, or in disagreement with this card's description of your emotional state?"			
	Semantic (23 cards)	"Can you say that one of these words has significant value, or are they both neutral?"			

Table 8: Table of evaluated elements

The Input Data

The protocol involved a short design project during which both evaluation and generation of ideas, concepts and prototypes were organized (see Picture 2). By doing so, 2 user Experiences and 4 interactive products were generated:

User experiences: In order to propose two different user experiences, we used the "experience framework boards" conceived and developed by the Kansei design team of TME. This is a strategic tool for user experience orientation at the concept stage. Thirty boards are characterized by three kinds of information: Behavioral values, emotions, and meanings. Two of these were selected to conduct the experimentation. The first board we chose presented a solitary, reserved user experience, characterized by behavioral values,


Picture 2: Workshops during design project. Generation of ideas

emotions, and meanings (called “inner harmony”) (see Table 7). The second board presented a more easygoing, carefree user experience (called “playful behavior”) (see Table 7). Using words corresponding to the two user experiences, we involved a French-language expert in sound design (Clos, 2010), who chose two musical pieces related to these experiences. For each experience, we chose a video of driving along a road from the driver’s “point of view”. For the first user experience (UX1), we used a very contemplative road, very straight and without traffic. The road selected was surrounded by a wonderful landscape on a sunny day. The video corresponding to the second user experience was selected to be the opposite of UX1, a video from the same driver’s point of view, but occurring at night, with four-lane circulation and many other cars, as well as illuminated buildings all around. The selected videos made the user experience more dynamic and active. These two user experiences are presented in Table 7 (UX1; UX2).

Interactive prototypes: To conduct the experimentation, we chose not to use an existing product, but to create concepts through a fictive project. We based the project on three parts, and six steps, as presented in Figure 27: Brief elaboration (part 1); idea generation (part 2); and concept development (part 3). The brief elaboration (part 1) was based on an evaluation of existing cars to highlight weaknesses and new design challenges. Based on this brief, we generated new ideas. The idea generation (part 2) was performed according to Bouchard’s (2003) proposed model of design: with information, generation, and evaluation activities. Thus, ideas were created using a brainstorming session with 10 designers over 10 hours (split into two sessions), based on the design challenges extracted from the first evaluation. A total of 199 ideas (paper representation) were generated. From the ideas initially generated, and following different evaluation phases (video presentation; quick prototyping solutions), we ultimately extracted four interactive prototypes. The interactive prototypes were then physically developed through quick prototyping solutions, such as 3D printing and laser-cutting techniques (concept development, step 3). The digital parts, dedicated to functionality, gesture recognition, lighting, and sensors were worked out and set up with an Arduino prototyping system. Arduino prototypes were created for each of the four concepts that materialized. The physical parts, Arduino systems, and study officer enabled us to make the interactive product work using Wizard of Oz techniques, giving the participants the illusion of actually interacting with the product. All of these elements were finally set up in the user experiences created. Table 7 summarizes the two user experiences (UX1; UX2), and the four interactive prototypes generated (ID1; ID2; ID3; ID4).

The Cards

To assess user's perception of both user experience (Pux) and interactive products (Pid), we used different scales, presented as cards: "sensory level", the "emotional level" and the "semantic level". The sensory level is based on the five human senses and the sense of "motion", as a decisive factor in human-artifact interaction (Lamuth, 2011). It consists in 6 cards. The emotional level consists of 40 emotions. These emotions were associated with a rating of temporality (from 1 to 5), based on a survey of five researchers, to differentiate quick emotions (close to 1) from long emotions (close to 5). The semantic level (23 cards) is based on user perception and understanding of the meaning of the interactive device. All of these criteria were assessed using self-measurement methods to catch participants' subjective state. This method has the advantage of transforming qualitative information into quantitative data, and to apply statistical methods to subjectivity and perception. Table 9, The Table of Criteria', summarizes how cards were created, from simple criteria to the items generated. This means that for each element that was evaluated (a user experience, and an interaction selected both from UX1,UX2, ID1, ID2, ID3, ID4), we collected N measures for each of the cards presented. By so doing, we collected data based on a common measurement method, with the same cards to be able to relate UX and ID evaluations.

CRITERIA	AUTHORS	DESCRIPTION	WHY	ITEMS (card generated)			
SENSORY	LaMuth 2011 Amsel 2005 Oxford dictionary 2015	To see (the eyes / ophthalmoception); to hear (audioception); to taste (gustaoception); to smell (olfacoception); to feel (somesthetic senses); to move (motion)	Sensory involvement of a user while interacting	Taste 1 Hear 2 Smell 3		Motion 4 Touch 5 See 6	
EMOTIONAL	Bradley and Lang 2000 Kim 2011 Rieuf 2013 Kerstin 2013 Scherer 2005 Russell 1980	-40 emotions from the wheel: Alternative dimensional structure of the semantic space for emotions (Scherer 2005). -Valence/arousal model of Russell (1980) will be used in the analysis of emotions.	How an interaction is affecting the user	1Excited t1 2Adventurous t3 3Feeling superior t2 4Aroused t1 5Astonished t1 6Self- confident t3 7Enthusiastic t2 8Determined t3 9Amused t1 10Happy t4	11Impressed t1 12Satisfied t1 13Relaxed t3 14Pleased t2 15Calm t3 16Serious t4 17Conscientious t4 18Peaceful t4 19Contemplative t4 20Longing t3	21Tired t4 2 Melancholic t3 23Hesitant t2 24Embarrassed t1 25Worried t3 26Apathetic t3 27Sad t3 28Uncomfortable t1 29Dissatisfied t2 30Disappointed t2	31Suspicious t2 32Discontented t3 33Bored t2 34Frustrated t1 35Angry t1 36Impatient t3 37Afraid t2 38Annoyed t2 39Tense t1 40Alarmed t1
SEMANTIC	Dias 2009; 2013 Hassenzahl 2000 Krippendorff 2006 Khalaj & Pedgley 2014	-Practical attribute (the use in terms of pleasure and effectiveness) -Symbolic attribute (aspect of esteem and social perception) -Aesthetic attribute (aesthetic impressions)	How to characterize user's perception	PRACTICAL Comprehensible 1a Supporting 2a Simple 3a Predictable 4a Clear 5a Trustworthy 6a Controllable 7a Familiar 8a	SYMBOLIC Interesting 1b Cosly 2b Existing 3b Exclusive 4b Impressive 5b Original 6b Innovative 7b	AESTHETIC Pleasant 1c Good 2c Aesthetic 3c Inviting 4c Attractive 5c Sympathetic 6c Motivating 7c Desirable 8c	
OPPORTUNITIES							

Table 9: Table of criteria

The Scales
We asked participants to characterize their sensory involvement, emotional state, and perception of both the user experience and the interaction, through 69 cards we generated. We used the following three questions for the evaluation:

• *"Was this sensory card very useful, somewhat useful, or not at all useful?"*

• *"Are you in agreement, unsure of, or in disagreement with this card's description of your emotional state?"*

• *"Can you say that one of these words has significant value, or are they both neutral?" This question was used to evaluate two opposing terms (e.g., comprehensible/incomprehensible).*

In response to these questions, each card was rated by participants in terms of a scale from -1 to 1, with 0 indicating a neutral state.

Experimental condition
The different interactive prototypes were tested in controlled conditions (see Figure 28). In a dark room, we installed a cabin (half a car constructed with removable parts that can be used for both generation or evaluation phases during early design). We enhanced this cabin using different elements, to be able to test interactive prototypes and simulate user experiences. We added a projection space, with both a computer and a video projector, to create the illusion of the car moving on the road; a sound system all around the dark room, to immerse the participants in an auditory atmosphere; an interactive prototype space, in order to be able to use and change the different interactive solutions, depending on which evaluation the participants were assessing; and a control prototype space, for the study officer. This space allowed us to make the interactive prototypes function using "Wizard of Oz" techniques.

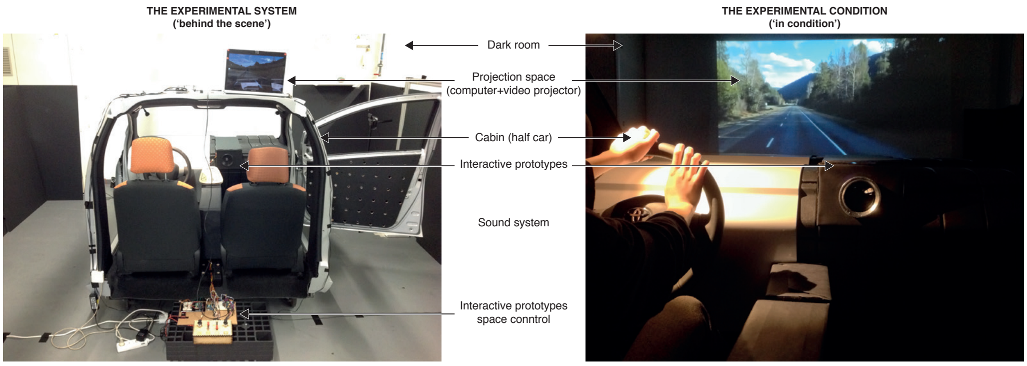


Figure 28: The experimental condition

4.2.3.2 Procedure
The two user experiences (UX1; UX2) and four interactive prototypes (ID1; ID2; ID3; ID4) were evaluated by a panel of 30 participants (see Figure 29, Panel of Evaluated People). In the interests of better understanding, the participants

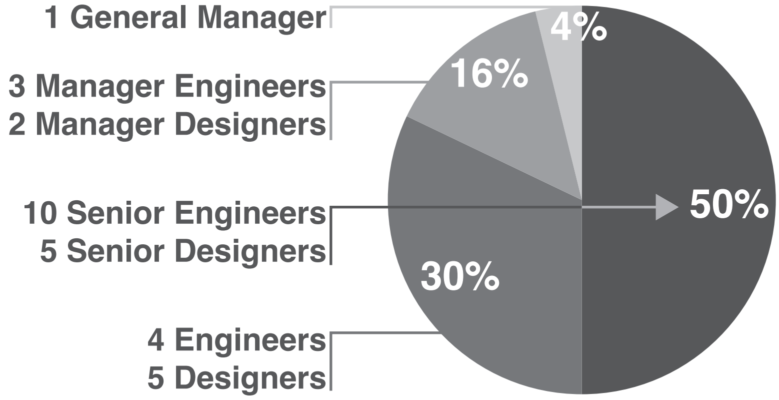


Figure 29: Panel of participants

we invited were engineers and designers. Participants were chosen from wide fields (not only conception). Furthermore, participants possessed the following characteristics: They each had a driver's license; they were able to verbalize; and they had no difficulty watching a screen for 10 minutes.

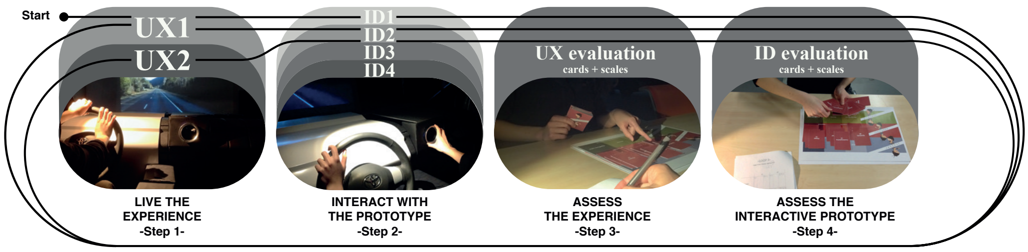


Figure 30: The four steps

The experimentation lasted one hour per participant. Each participant, placed in the experimental cabin in the dark room, performed three sequences (Sequences presented in the table 8), as illustrated in Figure 30 (see Figure 30, The Four Steps). These incomplete plans were affected to participants according to randomised methodology between user experiences and interactive products for each participant as presented in table 10. By doing so, we reduced the impact of habit, discovery, or lassitude that can distort evaluations.

30 DIFFERENT CYCLES for the 30 participants									
(UX2+ID1)	(UX1+ID1)	(UX2+ID1)	(UX1+ID2)	(UX2+ID2)	(UX2+ID4)	(UX1+ID3)	(UX1+ID2)	(UX1+ID4)	(UX1+ID4)
(UX1+ID1)	(UX1+ID4)	(UX2+ID2)	(UX2+ID3)	(UX2+ID3)	(UX1+ID1)	(UX2+ID4)	(UX2+ID3)	(UX1+ID2)	(UX2+ID2)
(UX1+ID2)	(UX2+ID1)	(UX1+ID3)	(UX2+ID1)	(UX1+ID1)	(UX1+ID2)	(UX1+ID1)	(UX1+ID4)	(UX2+ID4)	(UX1+ID2)
(UX1+ID1)	(UX2+ID3)	(UX2+ID1)	(UX2+ID1)	(UX1+ID1)	(UX1+ID1)	(UX2+ID3)	(UX2+ID4)	(UX2+ID3)	(UX2+ID3)
(UX2+ID3)	(UX1+ID4)	(UX2+ID2)	(UX1+ID3)	(UX2+ID2)	(UX2+ID3)	(UX2+ID4)	(UX1+ID2)	(UX1+ID3)	(UX2+ID4)
(UX2+ID1)	(UX2+ID2)	(UX1+ID4)	(UX1+ID4)	(UX1+ID3)	(UX1+ID3)	(UX2+ID2)	(UX2+ID3)	(UX1+ID4)	(UX1+ID4)
(UX1+ID3)	(UX2+ID1)	(UX1+ID4)	(UX2+ID4)	(UX1+ID1)	(UX2+ID2)	(UX2+ID3)	(UX1+ID2)	(UX1+ID2)	(UX1+ID3)
(UX2+ID1)	(UX2+ID2)	(UX2+ID1)	(UX2+ID1)	(UX2+ID2)	(UX1+ID4)	(UX1+ID3)	(UX1+ID3)	(UX1+ID3)	(UX2+ID4)
(UX1+ID1)	(UX1+ID2)	(UX2+ID2)	(UX1+ID2)	(UX2+ID4)	(UX1+ID1)	(UX1+ID2)	(UX1+ID2)	(UX2+ID1)	(UX1+ID4)

Table 10: Table of 30 cycles of evaluation

This Figure 30 represents an example of a participant cycle of evaluation. This example is detailled hereafter:

Example of the cycle ((UX1+ID1);(UX1+ID2);(UX2+ID2)):
Step 1: Live the Experience:
The cabin allowed us to create a particular condition for the user experience. We asked participants to take note of every detail of the entire user experience, because they would have to assess it. Each participant was the driver, so as to simulate driving conditions. In this example, the participant started with the User Experience 1.

Step 2: Interact with the Prototype
We presented to each participant the interactive product itself, and an explanation that the participant had to interact with it; and a short video presentation of the interactive prototype, to present the different functionalities and the ways to interact with it. In this way, we limited the discovery phase of the product, so participants knew how to interact with the prototype and what functions they should perform: Turn on the air vent system; adjust the air flow; adjust the temperature; orient the air flow; and, finally, turn off the air vent. In this example, the participant tested the first Interactive product ID1.
The sequence to test both the User Experience 1 and one Interactive Prototype 1 was named Sequence (UX1+ID1) (see figure 30). A sequence of test took between two and five minutes.

Step 3: Assess the User Experience
In order to collect data, each participant assessed the entire user experience. We used a self-evaluation method based on cards to asses user's perception. We used sensory, emotional, and semantic cards, and the scales previously presented. Each participant was first asked to assess his/her entire user experience on the N scales presented as cards (sensory, emotional, semantic levels).In the example above, it means that we collected a set of N scales for Pux1 first.

Step 4: Assess the Interactive Prototype
To assess the interactive prototype, we used the same cards and scales used in the UX evaluation.

Each participant performed the four steps three times, according to three "sequences" (represented in the example of Figure 30 as sequence (UX1+ID1) (UX1+ID2) and (UX2+ID2)):

- Sequence (UX1+ID1): The first sequence tested one user experience and an interactive prototype. In the example of Figure 30, the user started by testing UX1 and ID1.
- Sequence (UX1+ID2): The second sequence tested the same user experience as the first one, but with a different interactive prototype. In the example of Figure 30, the user tested UX1 and ID2.
- Sequence (UX2+ID2): The third sequence tested a different user

experience, but with the same interactive product as the sequence (UX1+ID2). In this way we highlighted results for the two loops, presented in Table 7 (loop A; loop B).

• Loop A (sequence (UX1+ID1) compared to sequence (UX1+ID2)): we compared the results of the Pux from the sequence (UX1+ID1) and (UX1+ID2), to record if, and how, the interactive prototype influenced the perception of the same user experience. In this example, we tried to observe how the user perceived the UX1 (Pux) when affected by ID1 and ID2.

• Loop B (sequence (UX2+ID2) compared to sequence (UX1+ID2)): we compared the results of interactions from the sequences (UX2+ID2) and (UX1+ID2). Indeed, although it was the exact same interactive product (in this example ID2), the results might be different (≠Pid2) if the two different user experiences (in this example, UX1 and UX2) influenced the perception of the interaction.

In total, by proceeding this way, we collected 180 evaluations from the 30 participants: 90 user experience evaluations (45 of Pux1 and 45 of Pux2), and 90 interactive prototype evaluations (23 of Pid1; 23 of Pid2; 22 of Pid3; and 22 of Pid4).

In this regard, we could do a data analysis in order to relate the 8 conditions of our experiment, each condition made of a pair drawn on one side from UX1,UX2, on the other from ID1, ID2, ID3, ID4. Each pair UX+ID gave us two sets of measures, one set for the perception of the UX, one set for the perception of the ID, each based on the same N scales (sensory, emotional, semantic). That way, we can relate each condition by comparing how one part of the pair influences the perception on the other pair.
Each participant evaluated 3 sequences (one sequence=UX?+ID?). These evaluations of 3 sequences were names ‘cycles’.

4.2.3.3 Data Analysis and Processing

The procedure presented above allowed us to collect 180 evaluations: Each UX has been evaluated 45 times (Pux), and each ID has been evaluated 22 or 23 times (Pid).

The results were condensed for each Pux and each Pid, using an average of each participant’s answers. We reduced the variable of “people” to concentrate our research on the differences between the evaluated elements. Thus, we compared the averaged score of Pux1; Pux2; Pid1; Pid2; Pid3 and Pid4

We used two methods for analyzing the data collected: The first one was a descriptive statistics; and the second one was a principal component analysis.

The descriptive statistics aimed to present and describe the collected data as well as representing averages and confidence intervals. Having no prior model for the distribution of those means, we computed confidence intervals based on an empirical distribution model by using bootstrapping it aimed to reveal findings in order to validate our hypothesis by identifying how an interaction impacts perception of a user experience, and how a user experience impacts the perception of interaction. Indeed, by performing this analysis, we could point out items (cards) that were significantly impacted in user experience perception when the interactive product was changed (loop A). Then, we used the analysis of variance the other way around, to point out items (cards) that were significantly impacted in the interactive product perception when the user experience was changed (loop B).

The principal component analysis aimed to show and represent the axis that we could oppose and use to compare different aspects: First, the impact of the interactive prototype on different perceptions of the same user experience (loop A); second, the impact of user experience on different perceptions of the same interactive prototype (loop B); finally, we compared and opposed the differences between user experience perception in general and interactive prototype perception in general.

These methods of analysis were therefore used to formalize the reciprocal impacts of user experience perception and interaction perception. The following section presents the results.

4.2.4 Results

This section presents the results based on four focuses:

• Finding A aims to formalize the influence of the manipulation of an interaction on the perception of user experience.

• Finding B aims to formalize the influence of the user experience on the perception of interaction. The final ambition is to formalize the reciprocal influence between user experience perception and interaction perception.

• Finding C seeks a better understanding of the differences between user experience perception and interaction perception.

• Finding D aims to highlight the benefit of such data when focusing on only one interactive product.

Finding A: How We Perceive a User Experience Is Influenced by the manipulation of our Interaction

Considering the results related to UX1 and UX2, we can acknowledge that the four interactive prototypes (ID1, ID2, ID3 and ID4) impacted how participants characterized the user experience with the 69 cards. Indeed, the perception of UX1 can be split in four (UX1+ID1; UX1+ID2; UX1+ID3 and UX1+ID4), corresponding to the interaction performed in this user experience. The same can be assumed for the second user experience (UX2+ID1; UX2+ID2; UX2+ID3 and UX2+ID4).

Thus, based on an average of each evaluation (UX1+ID1); (UX1+ID2); (UX1+ID3) and (UX1+ID4) and an average of each evaluation (UX2+ID1); (UX2+ID2); (UX2+ID3) and (UX2+ID4); we used first of all a descriptive analysis (see figure 31, 32 and 33) in order to represent the data and the confidence intervals. The two graphs 31 and 32 (one focussing on Emotions and one on Semantics) are presenting the two user experiences (Pux1 and Pux2), and the difference of perception when evaluated while using interactive products (ID1, ID2, ID3 and ID4). The analysis in figure 33 is presenting the evaluations of Pux1 (top) and Pux2 (bottom) when interacting with the 4 interactive products.

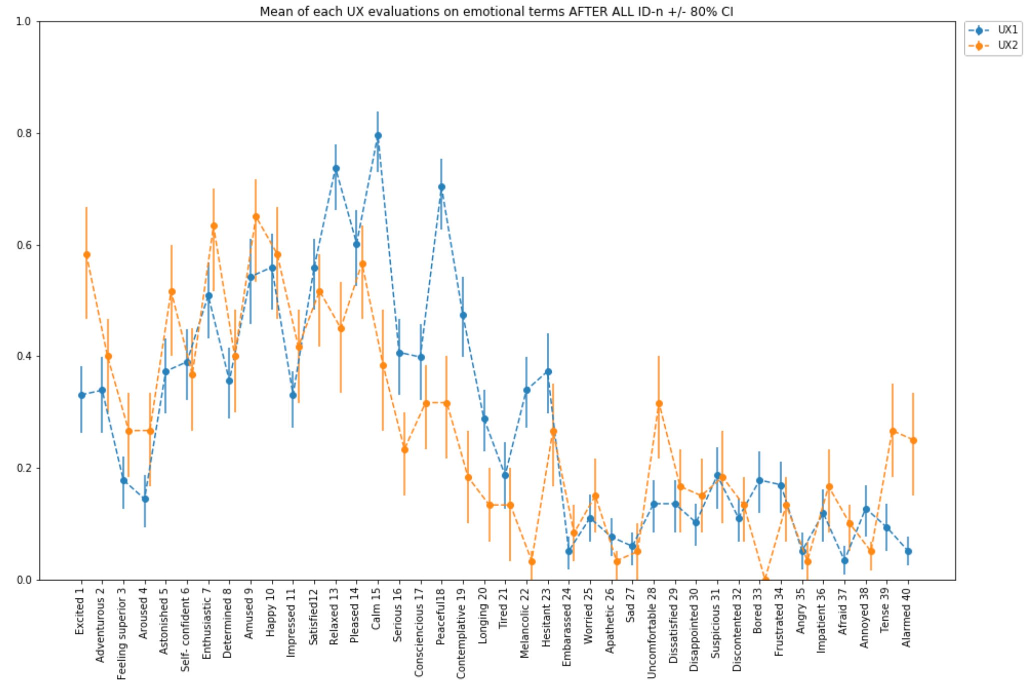


Figure 31: Average values taken for each Pux on the emotional scales after all the ID1-4, and their respective confidence intervals

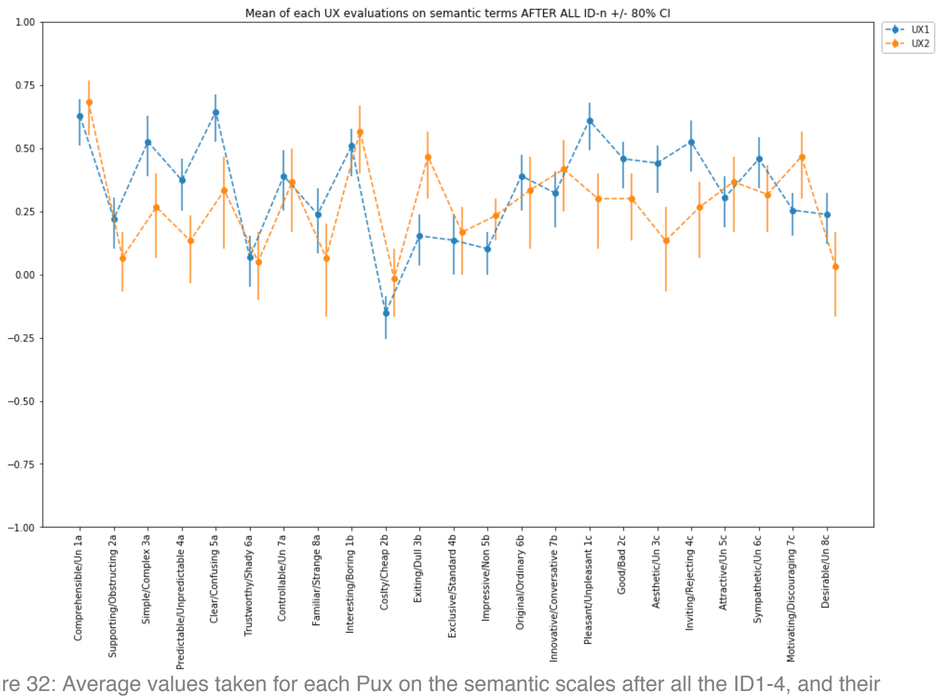


Figure 32: Average values taken for each Pux on the semantic scales after all the ID1-4, and their respective confidence intervals

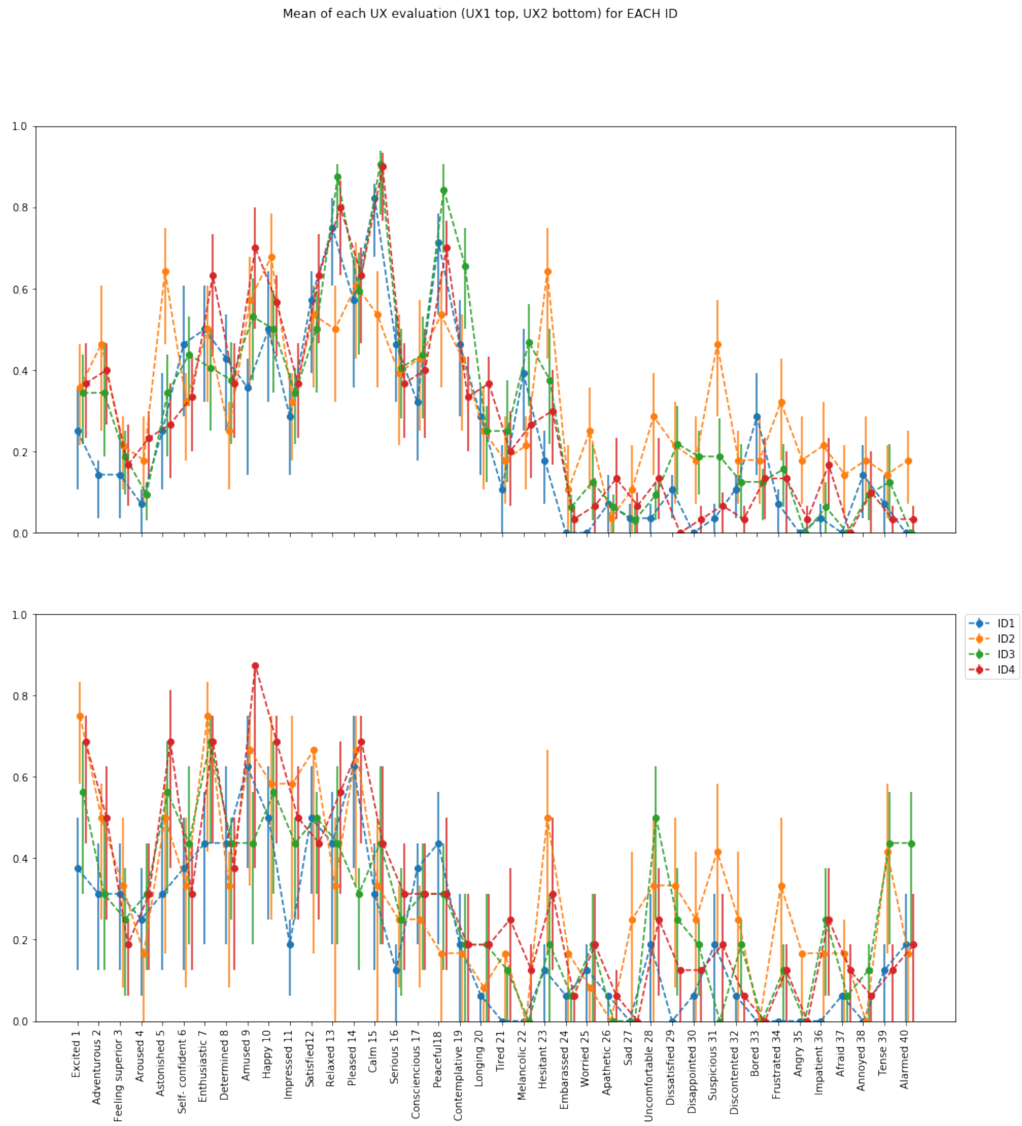


Figure 33: Average values taken for Pux1 (top) and Pux2 (bottom) on the emotional scales after all the ID1-4, and their respective confidence intervals

Based on these graphs, significant terms can be observed to highlight how an interaction mights impact the way we perceive a user experience. We simply use these terms as clue for improving in the futur the way we design interactions and user experiences.
In terms of emotions, the followings terms' results were observed to highlight that different Pux1 and different Pux2 can be assumed: Calm (15); Peaceful (18); Melancholic (22); Uncomfortable (28); Suspicious (31); Tense (39); and Alarmed (40). The semantic part also acknowledged this understanding with the following terms: Simple/ Complex (3a); Clear/Confusing (5a); Strange/Familiar (8a); Standard/Exclusive (4b); and Rejecting/ Inviting (4c).

Finally, using the data based on an average of each evaluations of User Experiences when evaluated whith each Interactive products, we performed two principal component analysis (PCA) presented in Figure 34 and 35. The mapping obtained when computing PCA on the emotional scales only (Figure 34) pointed out two influencing axes, called F1 and F2, covering 72,88%. The horizontal axis, F1 (46,55%) is based on strong influences, such as: Peaceful 0.81; Serious 0.78; Relaxed 0.77; Contemplative 0.69; or Excited 0.57. These terms led us to name this "the arousal axis", from activation to deactivation notions. The vertical axis, F2 (26,33%) is based on strong terms such as: Amused 0.67; Enthusiastic 0.53; or Aroused 0.51. According to these terms, we named this "the valence axis", from pleasant to unpleasant notions. These axes relate directly to the valence/arousal mapping of Russell (1980).

The second mapping obtained when computing PCA on the semantic scales only, presented in Figure 35, was characterized by two other axes, covering 80,72%. The first axis, F1 (55,20%) was influenced by notions such as: Clear 0.86; Exclusive 0.78; Interesting 0.77; Innovative 0.75; or Trustworthy 0.73. According to these terms, we structured this axis from iconic (symbolic) to efficient (practical) notions. The second axis, F2 (25,22%) was mainly influenced by the following terms: Pleasant 0.80; Aesthetic 0.72; or Desirable 0.41. Based on these terms, we organized this axis from aesthetic to unaesthetic notions.

In Figures 34 and 35, we note that a set of user experiences (UX1+ID1; UX1+ID2; UX1+ID3 and UX1+ID4) (in blue), and another set of user experiences (UX2+ID1; UX2+ID2; UX2+ID3 and UX2+ID4) (in red) form groups. In fact, these user experiences (Pux1 and Pux2) were generated by the same music, context, and road. The Pux1 (in blue) was therefore assessed (in terms of emotions) as more "deactivated" (more contemplative and relaxed) than the red one, or as more "aesthetic" according to the semantic part. However, certain distinct gaps are noted between same-color user experiences, signaling the impact of interaction on user experience. For example, if we consider the representation dedicated to emotions, we can see that Pux1 (in blue) are mainly based on relaxed and contemplative notions (according to the horizontal axis). However, if we look at UX1+ID2 and UX1+ID3, they are mainly opposed on the horizontal axis. So, the same user experience can be assessed as "calm and passive", or it can be assessed as more "active and aroused", depending of the interactive product used.

When looking at the representation dedicated to the semantic part, we can clearly see that the blue user experience (Pux1) is considered more "aesthetic" than the red one (Pux2). However, there are different perceptions of Pux1 and Pux2. The less "aesthetic" blue one is UX1+ID2, and the more "aesthetic" red one is UX2+ID4. So, even if the global perception of the blue user experiences is more "aesthetic" than the red one, the interactions can be significant enough to shift perception of the user experience from more "aesthetic" to less "aesthetic".

These two analyses (analysis of variance and principal component analysis) highlight the way participants perceive and assess a user experience

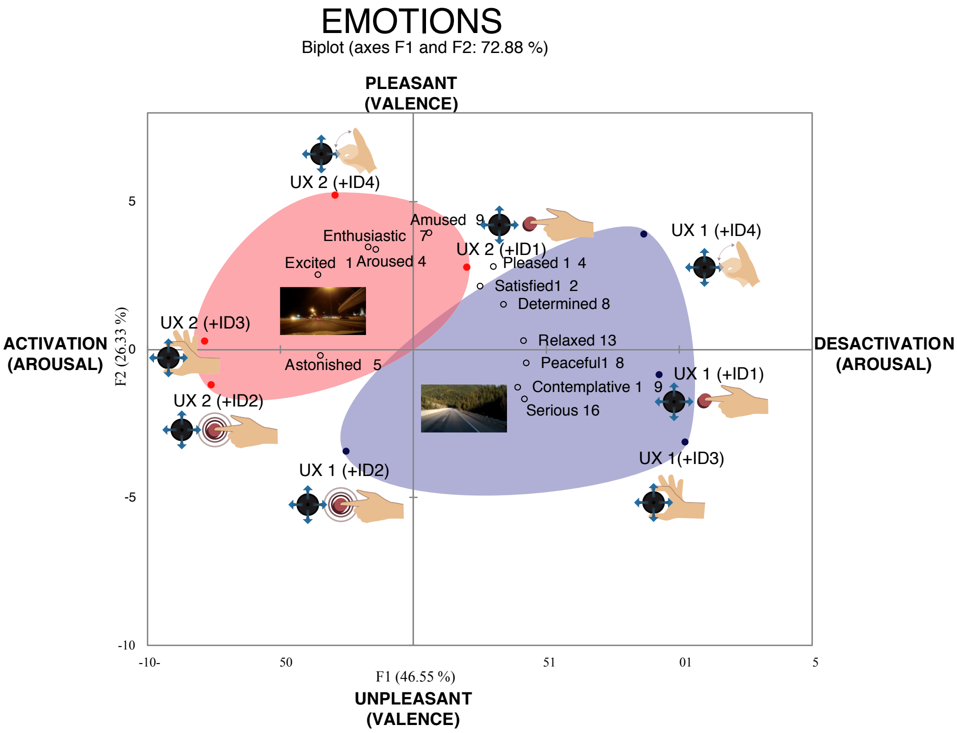


Figure 34: PCA 1 emotion

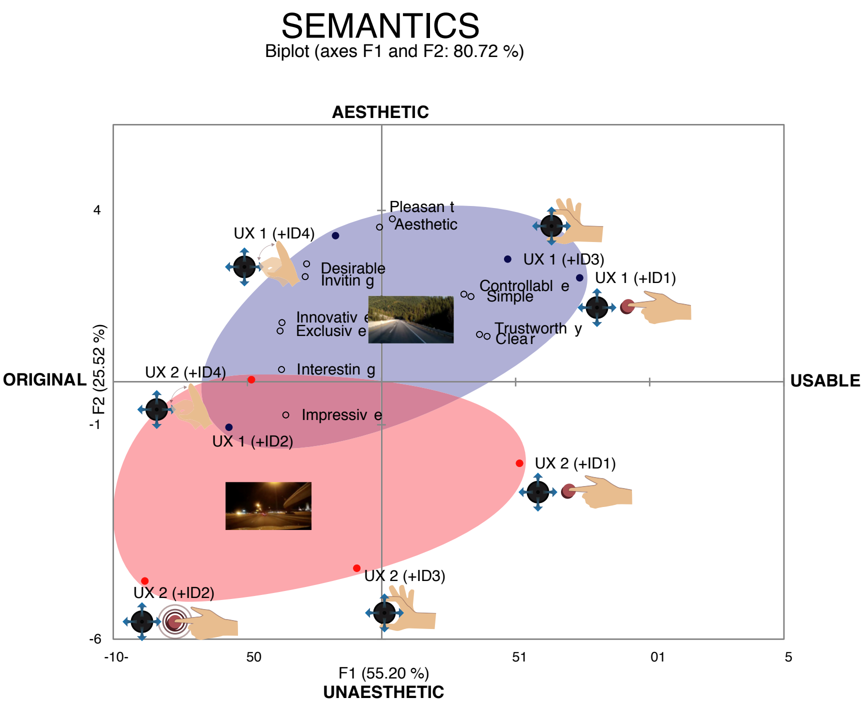


Figure 35: PCA 2 semantic

influenced by the perception of the interaction itself, **pointing out that interaction impacts the perception of user experience.**

Finding B: How We perceive an Interaction is Influenced by the manipulation of our User Experience

When focused on interaction-related results, we note a strong link between user experience and interaction. As a reminder, participants tested the same interaction in different user experiences (UX1 and UX2).

Based on an average of each evaluated interactive product (ID1 to ID4), when evaluated in two different User Experiences (UX1 and UX2), resulting in an analysis of Pid1 in UX1; Pid2 in UX1; Pid3 in UX1; Pid4 in UX1; Pid1 in UX2; Pid2 in UX2; Pid3 in UX2; and Pid4 in UX2; we performed a descriptive analysis (see figure 36, 37 and 38) in order to represent the data and the confidence intervals. The two graphs 36 and 37 (one focussing on Emotions and one on Semantics) are presenting the four Interactive product (Pid1 to Pid4), and the difference of perception when evaluated during the two different User Experiences (UX1 and UX2). The graph 38 present the differences for each interactive product when evaluated in UX1 and UX2.

Additionally, we observed terms that could be judged as significantly different when the entire user experience is changed. The following terms for the perception of emotional items where pointed out: Excited (1); Relaxed (13); Frustrated (34); Angry (35), and Tense (39). The observed oppositions for the semantic parts are the following terms: Comprehensible/Incomprehensible (1a); Simple/Complex (3a); Strange/Familiar (8a); Standard/Exclusive (4b); Original/Ordinary (6b); Innovative/Conservative (7b); and Confusing/Clear (5a). This means that these terms are strongly influenced by the perception of the user

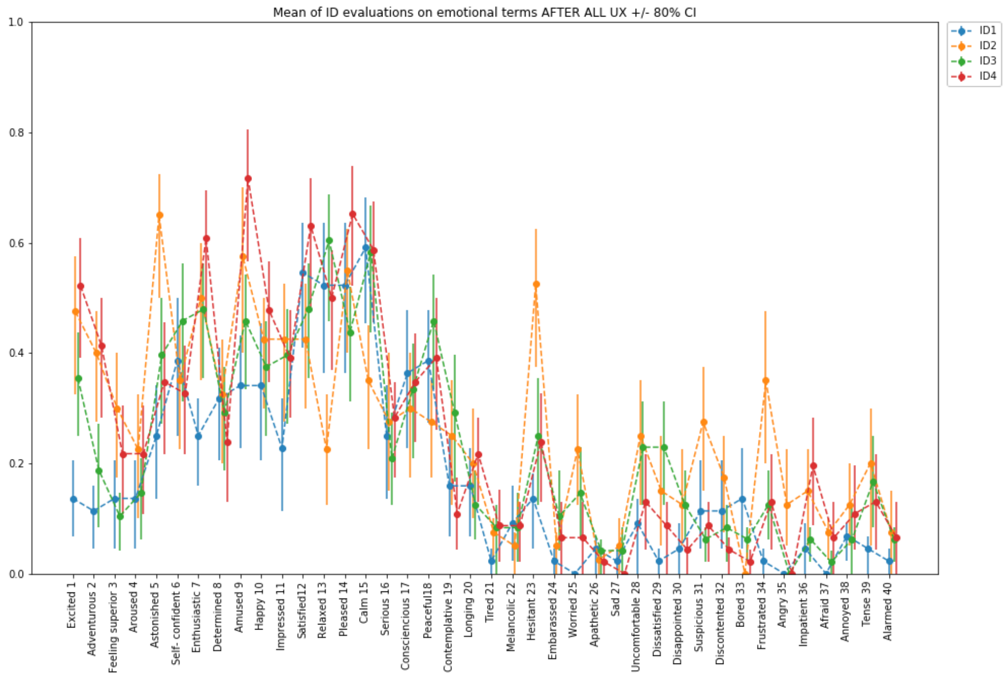


Figure 36: Confidence Intervals between IDs for Emotional Values

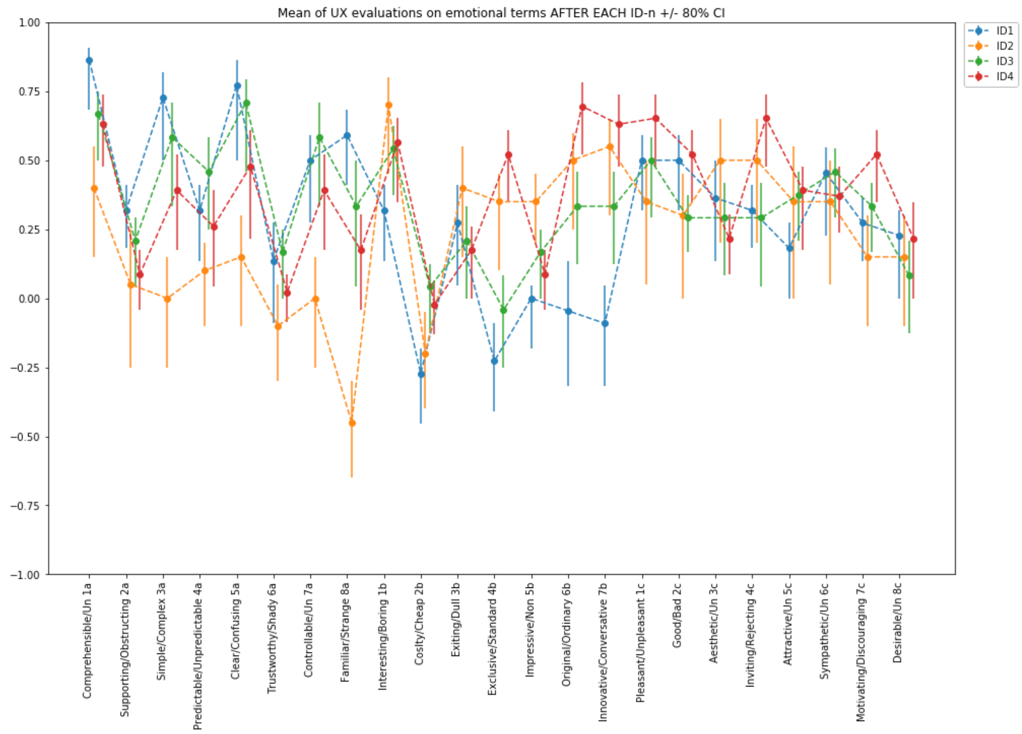


Figure 37: Confidence Intervals between IDs for Semantic Values

Figure 38: Confidence Intervals between IDs for Emotional Values from Pid1 (top) to Pid4 (bottom)

experience, because for the same interaction we collected strong oppositions of items.

Furthermore, a principal component analysis (presented in Figure 39), obtained when computing PCA on the emotional scales only, was created the following representation of the various perceptions of interactions. The axes used were the same as previously used to describe the influence of interaction on user experience. The blue area corresponded to every interaction performed in UX1, whereas the red area corresponded to the interactions performed in the UX2. When looking at the same interaction (e.g., ID1 in UX1 and ID1 in UX2), strong influences of user experience on interactions can be identified according to the gaps.

The representation based on emotions (Figure 39) points out that interactions are more “activated” (horizontal axis) when they are performed in UX2 (red). Interactions were also assessed as more “pleasant” in UX2 (red). When looking at the second representation (see Figure 40), obtained when computing PCA on the semntic scales only, it is interesting to note that user experiences do not strongly influence interaction in terms of “efficiency” (horizontal axis), but impact the notion of “aesthetic” (vertical axis). Indeed, the difference between the same two interactions perceived in two different user experiences is mainly based on the vertical axis.

Finally, the previous analyses highlight that the same interactive product, with the same interactions, can be perceived and assessed differently depending on the user experience that takes place. It points out that characteristics of a user experience deeply impact and influence the perception of an interaction. So, a user experience impacts the way we perceive an interaction.

Finding C: Evolutions and Differences between User Experiences and Interactions

When looking at the information we collected, it is interesting to compare, from a general point of view, the various differences between perceptions of user experience and perceptions of interaction. We performed a principal component analysis in Figure 41, based on an average where:

Pux1= (UX1, ID1) + (UX1, ID2) + (UX1, ID3) + (UX1, ID4) / 4

Pux2= (UX1, ID1) + (UX1, ID2) + (UX1, ID3) + (UX1, ID4) / 4

Pid in UX1= (ID1, UX1) + (ID2, UX1) + (ID3, UX1) + (ID4, UX1) /4

(Every interactive products perceptions when manipulated during UX1)

Pid in UX2 = (ID1, UX2) + (ID2, UX2) + (ID3, UX2) + (ID4, UX2) /4

(Every interactive products perceptions when manipulated during UX2)

Based on the above, in terms of emotions, there were different perceptions between Pux1 (every Pux1) and Pid1 (every interaction in UX1), and between Pux2 (every Pux2) and Pid2 (every interaction performed in UX2). In fact, the user experiences were assessed as more “pleasant” and more “deactivated”, whereas the interactions were more “unpleasant” and “activated”. Furthermore, user experiences are clearly opposed to interactions in terms of user perception of pleasure (valence axis). This opposition is supported by the different emotions closer to user experiences than interactions. Furthermore, the arousal point of view allows us to differentiate user experience from interaction in terms of

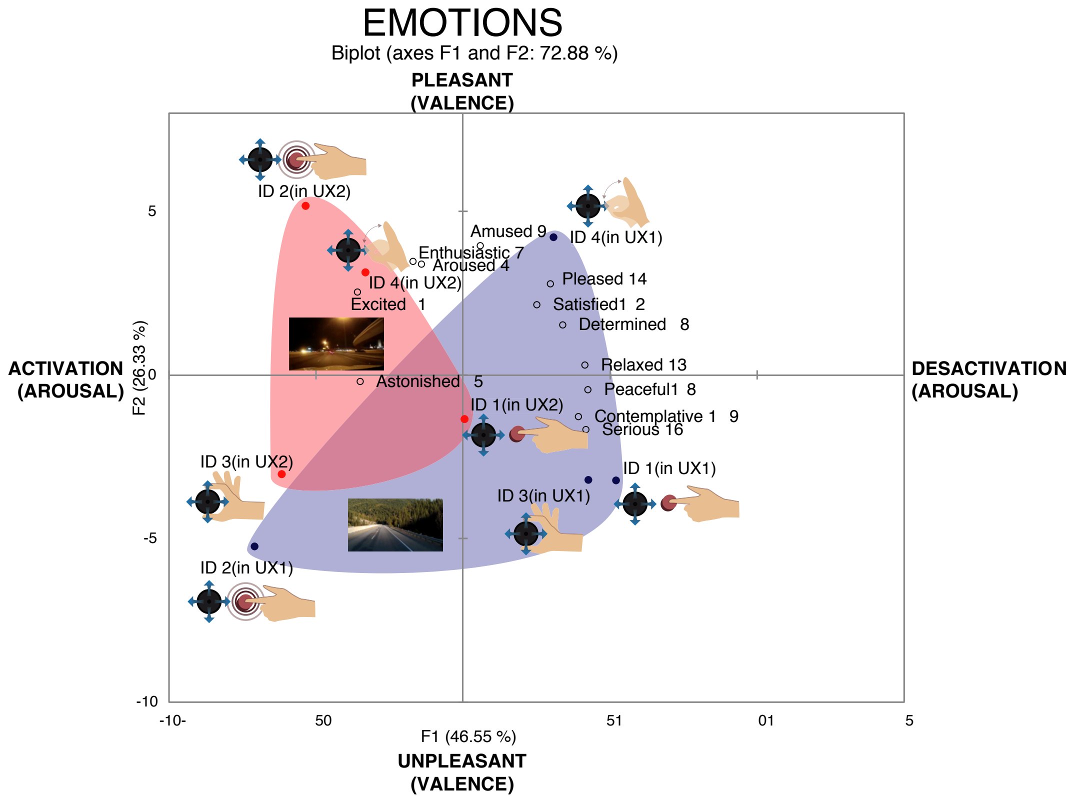


Figure 39: PCA 3 Emotion

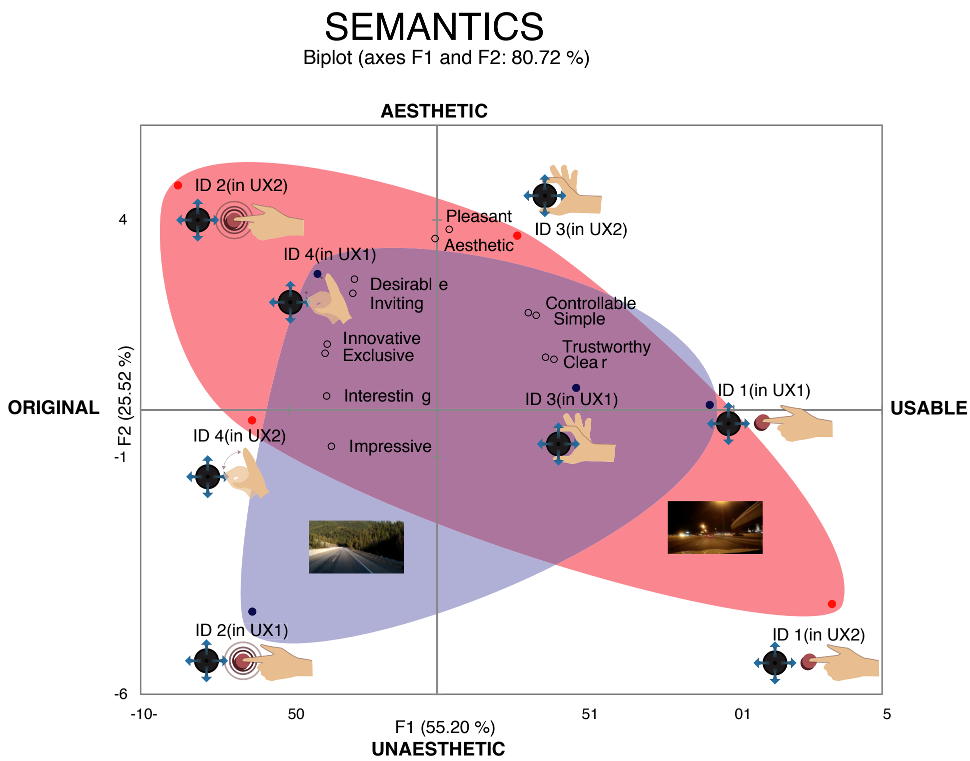


Figure 40: PCA 4 Semantic

impact. In fact, the data highlighted how much the user experience impacted user arousal when interacting. For example, Pux1, assessed as something very calm and melancholic, allowed a better concentration and involvement of the user when interacting with the different interactive products. On the other hand, Pux2 was assessed as more dynamic, alarming and tense, and greatly impacted the perception of the related interactions. However, although user experience impacted interaction in terms of arousal, we can see that the interactions (Pid1, Pid2, Pid3 & Pid4 in UX1, and Pid1, Pid2, Pid3 & Pid4 in UX 2) tend toward something more neutral.

The results can be summarized as follows: In terms of arousal, interactions are more “activated” than the user experiences they are related to. In terms of “valence”, interactions are less pleasant than the user experiences they are related to.

Figure 41: PCA 5 Emotions

Finally, according to an average of the result amounts participants selected to characterize user experiences and interactions, we note that interaction was assessed through semantic notions: 52% of semantics terms were used to characterize interaction. On the other hand, user experiences were assessed mainly with emotional terms: 56% of emotions (44% for interaction). This means that emotions were more involved to describe user experiences than to describe interactions. Furthermore, when looking at emotions related to user experiences or to interactions, we find, according to the rating of temporality we associated with each emotion (see Table 11), that user experiences are more based on long temporal emotions than interactions. Indeed, an average of the emotional temporal rating showed that user experiences obtained a score of

2.5 on a scale of 1 to 5, where 1 is associated with short emotions, and 5 with long emotions. Interactions obtained a score of 2.2 on 5, so is associated with shorter emotions than user experiences.
These results demonstrate that user experience is based more on emotions than interaction, and emotions associated with user experience last longer than those associated with interaction. Furthermore, we also find that the influence of interaction on the semantic perspective is more impactful than the influence of user experience.

Finding D: Data from the Project Perspective

The data collected also allowed us to compare the different interactive prototypes with each other. The experimentation allowed us to translate the subjective self-evaluations of 30 participants into simple numbers, according to three criteria (sensory, emotional and semantic): Thus, Pid4 (gesture recognition) and Pid3 (direct manipulation) were the more appreciated interactive prototypes, with a score of 39% of positive results, followed by Pid2 (augmented knob) with 28%, and Pid1 (simple knob) (23%). In terms of user experience, Pid4 (gesture recognition interactive product) generated the most appreciated user experience, with 37% of positive results, followed by Pid3 (direct manipulation) with 33%; Pid1 (simple knob) with 29%; and Pid2 (augmented knob) with 23%.
This objective protocol for the subjective perception of an interactive prototype was an industrial requirement for two reasons. First of all, Toyota motor designers create and collect many concepts, prototypes, and products. Being able to rank them is therefore appreciated. The second impact of such data in the industrial context is concept improvement. The results highlight the strengths of each project, but also their weaknesses and opportunities for concept or prototype improvement. For example, the Pid1, when assessed during UX1, was evaluated as mainly practical and aesthetic. The weaknesses of this interactive prototype lie perhaps in the symbolic evaluation characterized as “cheap”; “standard”; “ordinary” and “conservative”. These elements have to be considered for project improvement.

Conclusion

The results above highlight four essential elements. First of all, interaction impacts user experience perception in terms of “activation” (emotion) and “originality” (semantic). Second, user experience impacts the perception of the interaction mainly in terms of “pleasure” (emotion) and “aesthetic” (semantic). Third, user experience impacted the emotional side of the user more, whereas interaction impacted mainly the perception of the product (semantic). Finally, these evaluations are also a valuable input from the industrial perspective, because they help to rank different interactive prototypes and highlight the strengths and weaknesses of each element.
The method we used consisted of testing and evaluating interactions and user experiences based on the same scales. By so doing, we used the results to compare the reciprocal influence of interaction and user experience. Researchers who work on product development from a human-centered approach can also use this method. Furthermore, the evaluations we conducted were focused on specific design information, extracted from the theoretical model presented in

the conclusion of the state of the art. Using the theoretical model as a theoretical framework for highlighting evaluation criteria is an approach that can also be used by the community. It is a way to structure both early design phases and evaluation phases of interactions and user experiences.

4.2.5 Discussion

This section presents an interpretation of the results, focusing on the notion of interdependency (4.2.5.1 interdependency). The second part presents the limitations of the experimentation (4.2.5.2).

4.2.5.1 Interdependency

Consistency

We note in the experimentation a strong interdependency between user experience and interaction, implying a certain coherency between them. According to the Oxford Dictionaries (2015), coherency has two definitions, both of which suit our view of user experience and interaction. The first definition acknowledges coherency as “the quality of forming a unified whole”, just as the previous state of the art defines the full relationship between user experience and interaction (interdependency). The second definition is “the quality of being logical and consistent”. This understanding splits user experience from interaction, and attaches a particular significance to both perceptions. Indeed, if user experience forms a whole that encompasses interaction, our experimentation highlighted that the same element (interaction or user experience) evaluated against the other (user experience or interaction) could be perceived as more positive or more negative, depending on the coherency formed by the whole. It points out that the best interaction ever might be less appreciated than a more modest one, depending on its consistency with the entire user experience. The reverse is also true.

This interdependency provides a vision where user experience and interaction must be considered together when designing in the early stages, in order to progressively strengthen this consistency until the concepts meet the final user. According to Bouchard and Aoussat (2003), the activities of the design process can be represented by four levels: The information level (knowledge, needs); the generation level (new ideas; new concepts); the evaluation level (assessing and ranking ideas and concepts); and the communication level (sharing results). If the first two levels attempt to collect and create, based on a single vision of user experience and interaction, the evaluation level should split user experience from interaction to evaluate the gap in perception. The smaller the gap is, the stronger the impact is, resulting in consistency between user experience and interaction.

Intertwined Design Information

The previous PCA highlighted a link between emotional and semantic perceptions. Indeed, according to the results, what was assessed as Calm, was also assessed as more Aesthetic than other dynamic emotional states, which were perceived as more Unaesthetic. Furthermore, the PCAs

point out another relationship between Pleasure and Originality, as opposed to Displeasure, which was related to Usable. This is probably due to the fact that well-known artifacts are considered as more usable than new ones, because they involve stereotypes of use that are almost automatic. On the flip side, originality refers to new usability references.
This parallel points out a direct correlation between emotion and semantics, where both have to be considered when designing. If these results underline this unavoidable opposition between an aesthetic and original perception, as opposed to an unaesthetic and usable perception, it can also be interpreted more broadly: Successive information creates bridges between emotional states and artifact perception. If they affect each other, we may suggest that all the different design information related to a user's perception of his or her state, and a user's perception of an artifact, are also intertwined. What is important to consider then, is that any design information can be independently investigated. We need to design a consistent whole, because all design information has an effect.

Complementarity and Immersibility

Even if there is interdependency between user experience and interaction, and even if they both affect common interactive design information such as emotions and semantics, they impact various design information to different degrees. In fact, the user's emotional state is more impacted by the full user experience dimension, whereas the perception of the product is more influenced by the interactive dimensions. This can be explained by the fact that user experience is more easily perceived by the user as something belonging to him or her, as if the degree of immersion is so impactful that the user translates user experience characteristics to his or her own state. The notion of interaction, however, is less immersive, and can be physically removed from the human body, affecting the perception of the artifact. Context and situation as immersion must also be included as part of the holistic phenomena. Therefore, when designing and evaluating user experiences, it is important to consider how immersive the user experience or the interaction is, because the more immersive it is, the more it affects the user's perception of his or her state. Following on from this understanding, the more separation there is from the user's state, the more the user's perception of the artifact is affected. This understanding is of value in explaining how designers can affect a user's state and a user's perception of an artifact.

Temporality

According to the emotional results, there was also a temporal relationship between user experience and interaction. The user experience impacted long emotions (e.g., Peaceful; Contemplative; Longing; Tired) more than interaction, which was characterized by shorter emotions (e.g., Excited; Aroused; Amused; Impressed). This temporal understanding pointed out notions of temporal scales, as a complementary relation between user experiences and interactions, where both were meaningful. Therefore, the biggest challenge designers face is not just creating meaningful user experiences or interactions, as Mok (1996) suggests, but also the ability to

provide a fluid and logical transition between user experience and interaction, from a large temporal vision to a smaller one. This finding led us to think beyond the emotional perspective. Notions of practicality, efficiency, pleasure and all design information related to both user experience and interaction can be understood from this temporal perspective, where longer terms can be more easily associated with user experiences, while smaller, more subtle but equally powerful terms could be more related to interaction design information.
This temporal understanding of user experience and interaction provides a decisive clue for designing better, smarter, and smoother transitions between user experiences and interactions.

4.2.5.2 Limitations

This research on user experience and interaction attempted to evaluate both dimensions, to formalize their interdependency and to highlight their impacts in terms of design information. However, we were limited by the Kansei criteria we used (sensory/emotional/semantic). Our findings could have been more significant if we had improved the selected terms and considered more criteria, such as motivation, appreciation, and needs. Indeed, the emotional and semantic criteria are interesting for highlighting decisive principles and clues, but are not sufficient to properly assess the full scope of an interactive prototype's impacts on user affect and perception. Furthermore, we could also augment our understanding of user experience and interaction by strengthening and expanding our protocol's scope with the notion of temporality. It could point out notions of habituation, learning, or annoyance when interacting.
Previous studies suggest that multitasking (polychronic) affects our interactions. However, our experimentation was conducted in the absence of other tasks, as would be the case with real driving conditions. Further studies should consider this aspect when evaluating interactive prototypes.
Finally, we recommend to researchers who would like to use the method and approach (using the theoretical model as a framework for evaluating interactions and user experiences) to cover as much as possible the full set of design information presented in the theoretical model. By so doing, it will improve the scope of evaluation, covering both abstract and concrete design information, and both users' reactions and perceptions to products.

4.2.6 Conclusions and Perspectives

In this section we present both the conclusions of the first experimentation, perspectives on the results, and two tools that have been generated based on insight from this first experimentation.

4.2.6.1 Conclusions

Evaluating the subjective perception of interaction and user experience is of value for both theoretical research and the industrial context.
From a research point of view, the objective is to formalize and comprehend as best as possible the links between user experience and interaction in terms of design information (see Figure 15). By so doing, we highlight key principles of interdependency presented as notions of consistency; temporality; intertwining;

complementarity; and immersibility (see Figure 42). Such research aims to develop and strengthen an in-depth understanding of interaction from a user experience point of view. As argued in the state of the art, understanding the link between interaction and user experience is decisive for early design. This research goes one step further in the improvement of this understanding. Nevertheless, there is still a lot of research to conduct before understanding every nuance of the interdependency between user experience and interaction. This research makes available to the community a methodology focused on a human-centered approach, and based on a theoretical model composed of design information that should be considered when designing and evaluating in the early design stages. Furthermore, the tools developed and used during this research (cards of criteria with the protocol) were based on the interactive approach (evaluation of interactive prototypes). Designers, engineers, and ergonomists can use this approach and these tools to test users' affective and cognitive reactions to early concepts and prototypes.

From an industrial point of view, evaluating, ranking and giving "absolute scores" to different subjective perceptions of concepts and prototypes is decisive for the development, improvement, and selection phases. Furthermore, it gathers together divisions and backgrounds in a company (engineering, ergonomic, design) in a common language of comparison: Human-centered perception.

The originality of this research lies in its approach: Understanding the reciprocal impact of interaction and user experience on the user's affective and cognitive reactions. It is pushed by an approach combining both cognitive psychology (the user's affective and cognitive reactions) and artificial intelligence (the product's reactions). Finally, the strength of this research can also be found in the dialogue with the industrial context of TME that allows an every-day real framework for testing, improving, and implementing research tools and methodologies, an industrial context in which cognitive psychology and subjective perception are drastically increasing with the introduction of autonomous driving systems. Leading automotive industries are increasingly focusing on users' experiences with, for example, notions of trust, well-being, and living spaces.

4.2.6.2 Perspectives

Further research will focus on the interactive dimensions of the user experience. We will strengthen and improve the protocol, criteria, and experimental condition, so as to collect more data using subjective and also objective measurement methods. By so doing, we will more accurately analyze the finer notions of temporality and multitasking, to deepen our understanding of physical and digital product characteristics of user perception of interaction.

4.2.6.3 Generated Tools

From this experimentation, three industrial applications emerged, including two tools for evaluating interactions inside the car, based on the same global methodology.

- The first is the Kansei Kabin. This tool is presented in the annex under the name "Kansei Kabin (Evaluation platform)".
- The second is the HMI score. This tool is presented in the annex under the name "F-MHI Score (Evaluation platform)".

• The third is the “Kansei Evaluation Kit”. This tool is presented in the annex under the name “G-Kansei Evaluation Kit (Evaluation platform)”.

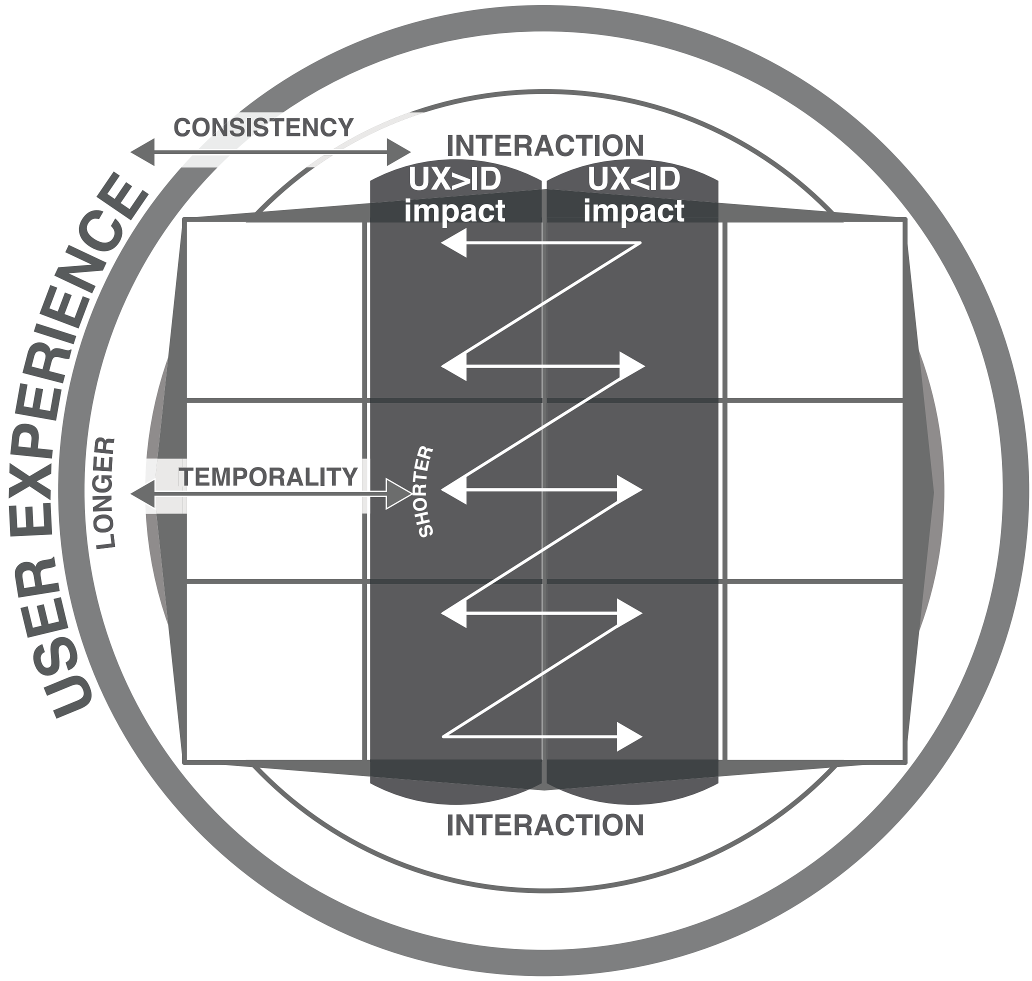
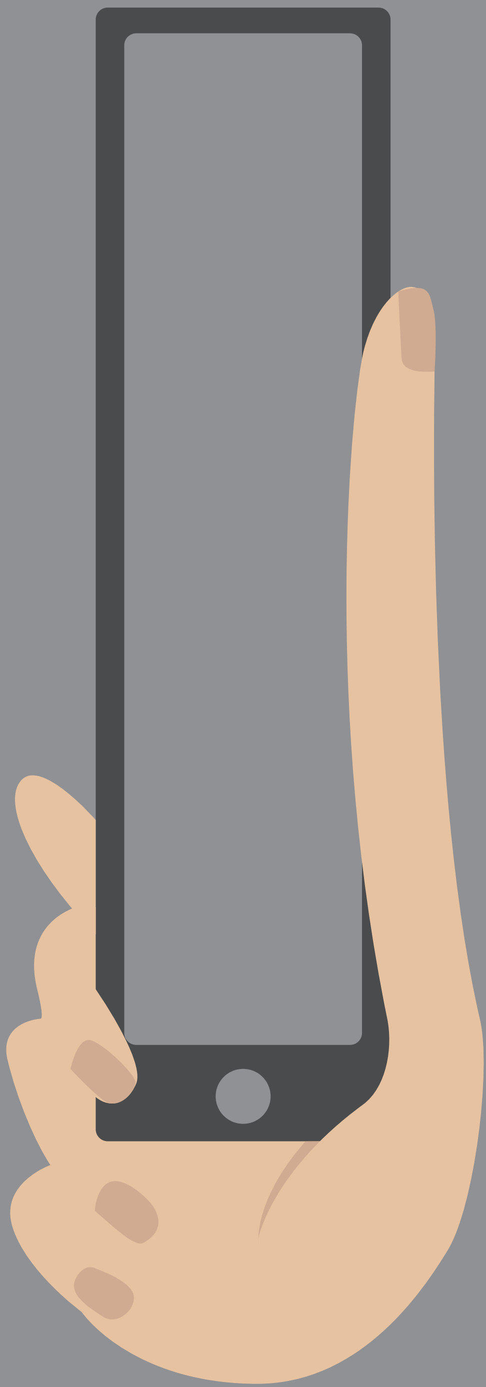


Figure 42: Model of Design Information with highlighted links



«It is far better to adapt the technology
to the user than to force the user
to adapt to the technology»
Larry Marine

4.3 Experimentation 2

The objective of Experimentation 2 is to observe the influence and the relationship between the three dimensions(d) (environment, target, and source) and the design information(i) that the interaction's scope covers in the theoretical model (e.g., Figure 43).

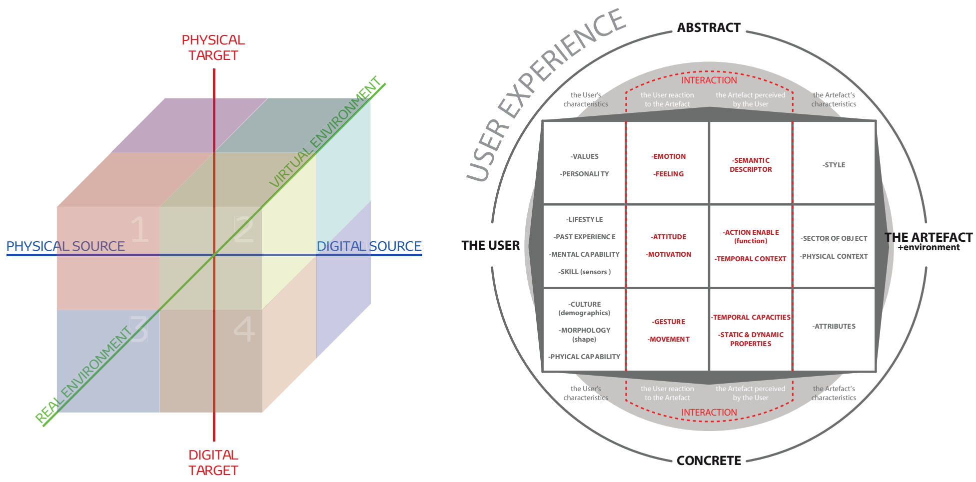


Figure 43: The influence of the three dimensions(d) on the design information(i)

The objective is to observe the relashionship between the dimensions(d) and the design information(i) (boxes underlined by the theoretical model). By so doing, we can identify for each area(a) (eight areas proposed by the three-dimensional mapping (d)) their influence on the design information(i) and the different design principles(p) that they are tackling, and could address in the future.

This experimentation is divided into three parts. The first presents an understanding of our objectives, the second defines a method to achieve them, and the third presents the results.

Before this experimentation, a workshop was performed with students in order to better understand how we could organize questions, and define a protocol for classifying interactive products. Please refer to Annex H for more detail.

4.3.1 Objectives

Experimentation 2 tests the second hypothesis: *"How we experience an interaction with an artefact is affected by the physical/digital paradigm."*

To do so, we explored the link between the three dimensions(d) (environment, target, and source) and its eight areas(a), the design information presented by the theoretical model(i) (e.g., Figure 15) and the principles(p) that interactive products use.

Our goal is to formalize the link between the dimensions(d), the design information(i) (users' affective and cognitive responses), the areas(a), and the principles(p), and to quantify this impact in order to propose a tool that guides and supports designers' choices in the early phases. This experimentation aims to provide three outputs:

1. A better understanding of the interactive taxonomy and its constituents based on the three dimensions(d): To classify the range of interactive products through the three dimensions(d), and thereby improve our understanding of the three dimensions(d) and the eight areas(a), with definitions and examples.

2. Formalizing dimensions' impact(d) on the design information(i): To point out the impact of each interactive product's areas(a) to the design information(i). This could highlight whether some areas(a) are more meaningful and impactful regarding users' affective and cognitive responses.

3. Highlighting principles(p) for new design challenges: To highlight guidelines, new design challenges, and opportunities for interaction design. To do so, this experimentation states he different possible principles(p) of interactive products. These principles(p) consist of some keywords, mostly related to what the interactive product enables the user to do.

4.3.2 Method

The experimentation uses a particular architecture of evaluation, a step-by-step sequence of questions based on a self-evaluation method, to assess an interactive product. The interactive products were evaluated based on 45-second videos. We did not use real products for the simple reason that using videos allows us to evaluate more interactive products in less time; it also allows us to evaluate products that are prospective and concept-based, and therefore do not yet exist. Furthermore, it allows us to simply and quickly test products that usually require complex material and technological support. Finally, this experimentation does not anticipate precise affective and cognitive responses from evaluations, but rather clues and tendencies that can help us to understand the impact of the three dimensions on users' affective and cognitive responses. Thus, 50 products were selected to cover the widest possible spectrum of the three dimensions of the tested framework.

This study was organized through an online survey, where participants were asked to imagine that they were the actors interacting in the video, thanks to human empathy (Rizzolatti, 1999). This section has been divided into three parts: The first part focuses on the **experimental protocol** to evaluate videos. It consists of describing the generated materials to be used during the experimentation. The second part is dedicated to the **procedure**. Finally, the last part proposes solutions for **analyzing the gathered data**.

4.3.2.1 Preliminary Design of the Experimental Support

This "experimental support development" aims at elaborating on the various materials that will be used during the experimentation.

We organized preliminary experimentation that set out to develop an exhaustive list of interactive product principles. These interactive product principles were used as inputs for the final experimentation, which aimed to evaluate 50 videos of interactive products, and the answers to several questions to score each video. The preliminary experimentation started with 12 videos of interactive products that four experts in interaction design discussed.

• The input data: For this preliminary experimentation, two inputs were, namely 12 videos and one question submitted to the panel.

The 12 videos: We selected 12 videos based on their originality, and to cover the widest range of interactive products possible. We collected videos of both existing products, and of prospective and futuristic products as seen in science fiction movies (fake interactive products), as well as research-based interactive products. These videos were re-framed to last 30 seconds.
The question: "After watching video X, what principle(s) or ability(ies) does this interactive product use, according to you?"

4.3.2.2 Procedure of the Preliminary Experimentation

This section describes both the panel of participants that joined this preliminary experimentation and the different steps followed.
For the panel, we asked four interaction design and user experience experts to take part in the experimentation. They are TME members, working in research and development.
To conduct this preliminary experimentation, the four participants performed 12 loops, based on the following four steps:

• Step 1: Watch one video. Participants were asked to watch the first video. This step lasted 30 seconds.

• Step 2: Answer the question. After the video, participants were asked to answer the question presented previously: "After watching video X, what principle(s) or ability(ies) does this interactive product use, according to you?" Each participant had 90 seconds to work on the answer independently.

• Step 3: Present to others. Each participant was asked to present the principles identified to others. This time was also used for discussion, principle improvement, and new principle creation.

• Step 4: Principles highlighted and discussed were then displayed on Post-it notes on a wall.

This four-step loop was reproduced for each video (12 times).
Final step: At the end, we took 45 minutes to discuss, gather, and organize the Post-it notes presented on the wall.

4.3.2.3 Results of Preliminary Experimentation

The procedure presented above allowed us to collect 17 principles to use in the experimentation. These principles were clustered into six boxes (see Table 13). These words, presented as principles of interactive products, were used as input for the final experimentation, described hereafter.

4.3.2.4 Protocol of the Experimentation: The Input Data and Panel

Haptic related	Space Related	Pixel Related	Virtual Related	Computer Related	Numbers Related
Transformable	Asynchro-nize-able (real time / time differences)	Programmable	Independent from gravity	Distributable (shareable	Connectable (to other elements)
Movable	Ubiquit-able (≠ places in same time)	Persona-lize-able		Fusible	Universalizable
Graspable	Spacialize-able (Proximity/ depth)			Voidable (ctrl Z)	
Manipulable				Replicable (ctrl C+ ctrl V)	
Malleable					

Table 11: Principles extracted from the preliminary experimentation

This experimentation used previously developed materials to evaluate videos of interactive products. We decided to employ the four elements developed using the three-part survey:

1. The three dimensions(d).
2. The eight areas(a) that ensue from the three dimensions(d):
    1. Real environment; physical target; physical sources;
    2. Real environment; physical target; digital sources;
    3. Real environment; digital target; physical sources;
    4. Real environment; digital target; digital sources;
    5. Virtual environment; physical target; physical sources;
    6. Virtual environment; physical target; digital sources;
    7. Virtual environment; digital target; physical sources; and
    8. Virtual environment; digital target; digital sources.

3. The subjective perception of the interactive products based on the design information(i) of the theoretical model in Figure 15.
4. The different principles(p) extracted from the preliminary experimentation.

To succeed, we used 50 videos (to be evaluated), an architecture of questions (to evaluate), and the internet (as a framework to evaluate).

The videos

We selected 50 45-second videos, based on their originality, and to cover the widest possible range of interactive products and the best possible spectrum of the three dimensions(d). Researchers in cognitive neuroscience and cognitive psychology have proved the value of this methodology of watching videos of people interacting. According to them, the neuron systems allow users who watch someone performing an action to feel the physiological mechanism for the perception/action coupling (e.g., Keysers, 2011). The neuroscientific community argues that the neurons "mirror" the behavior of the other, as though the observer himself or herself was acting, simply by looking at the other (Rizzolatti, 1999). Based on a video, users can understand goals and intentions (Fogassi et al., 2005), feel empathy (Decety, 2002; Keysers, 2011), understand actions and intentions (Lacoboni, 1999), and infer another person's mental state (beliefs and desires) from the experience of their behavior (Gordon, 1986; Goldman, 1989). We assumed that using real products could lead to more accurate evaluations. Nevertheless, collecting clues and tendencies of results could also prompt us to conclusions on the three dimensions' impact on users' affective and cognitive responses. Table 14 presents some examples of the 50 videos.

VIDEO n°	INTERACTION FOCUS	ORIGINAL LINK
3	The user interacts with the data through the AHNE system	https://vimeo.com/28447850
20	The user interacts with the sound volume through the screen	http://www.youtube.com/watch?v=tb8vD2euXAg
22	The user interacts with mapping through the holographic system	https://www.youtube.com/watch?v=_VFFLVyOEuc
24	The user interacts with the lamp through the wire	http://www.wired.com/2015/03/mit-inventors-turn-power-cords-gadget-interfaces/
27	The user interacts with Leia through the hologram system	https://www.youtube.com/watch?v=s_2GSUXuQ8w
31	The user interacts with the videos through the gestures	https://www.youtube.com/watch?v=PJqbivkm0Ms
36	The user interacts with the robot through the behavioral gesture	http://www.ben-dror.com/pinokio/
37	The user interacts with the car through the steering wheels	http://www.youtube.com/watch?v=dD8oJdq0TiA
39	The user interacts with the phone through the screen	http://www.youtube.com/watch?v=FgTq-AgYITE
46	The user interacts with the data through the screen	https://www.youtube.com/watch?v=zo1n5CyCKr0

Table 12: Example of videos

The Architecture of Questions

The questions were based on a three-part architecture. It started with an introduction, focusing on participants' personal information. Part 1 was composed of questions to position the interactive product according to the three dimensions(d) (e.g., Part 1 in Table 15). Part 2 focused on an understanding of the metaphor and its interactive principles(p). For this part, the 17 principles(p) extracted from the preliminary experimentation were used. Based on Likert scales from 0 to 6, participants were asked to judge every video and their correspondence with every principle(p). Furthermore, an empty box was included in the survey for participants who wanted to add a new principle(p) not already in the list (see Table 15). The last part was based on several questions, constituting an overall perception of the interaction by considering design information(i) boxes highlighted by the theoretical model (see Table 15). This part was the most subjective, because it contained questions related to affective and cognitive responses.

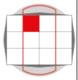
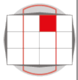
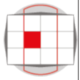
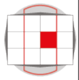
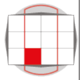
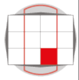
	THREE DIMENSION(d) AND EIHT AREAS (a)				PRINCIPLES (p)	DESIGN INFORMATION(i)					
FOCUS	**Environment**		**Target**	**Source**	**Principle**	**Emotion/ Feeling**	**Behavior/ Motivation**	**Gesture/ Movement**	**Semantic Descriptor**	**Action Enable**	**Static & dynamic Properties**
QUESTION	Was this interaction in a Real or Virtual Environment?	Were the interface and the environment separate or merged?	Was the product physical or digital?	Did this interaction use physical or digital references?	Can the interaction be linked to the following principles?	 How can you describe your Emotional state? Were your Emotions intense?	 Was your attention Focused? Were you very Determined?	 Was your body completely Involved? Was your body involvement Intense?	 Was it Practical? Was it Aesthetically appealing?	 Was it Useful? Was it Usable? Was it Intelligible?(affordance)	 Was it Multisensory? Were your senses Qualitatively involved?
SCALE from 0 to 6	Real world A bit of both Virtual world	Separate A bit of both Merged	Physical A bit of both Digital		Not at all Not significant Very much	Negative Neutral Positive	Not at all Not significant Very much				
REFERENCE	Milgram and Colquhoun 1999	Blackwell 2013	Djajadiningrat 2004	Ishii 2012		Lang 1995	Lalmas, O'brien & Yom-Tov 2013 Ryan & Deci 2000	Moussette 2012	Dias 2013	Lund 2001 Brooke 1996	Camere & Schifferstein 2015

Table 13: Architecture of questions

The Internet Survey

The questions and videos were presented using an internet survey. We used the Typeform software (www.typeform.com) to collect answers, and to present the video hosted on the YouTube platform. Using an internet site presented an opportunity to send the survey to different types of participants, not only TME employees, and to collect the data easily.

The Panel

The videos were evaluated by two different panels of participants, experts and novices. For the experts, we asked 26 engineers and designers working on product development to take part in this experimentation. They completed every question (see Table 13). The 50 videos were divided into 6 Serials of 25 videos each. The novices only completed the most subjective part (questions related to design information, see Table 13). They were Europeans from diverse backgrounds. The 50 videos were divided into 10 Serials of 10 videos each. In total, 150 surveys were completed (30 participants per survey).

4.3.2.5 Data Analysis and Processing

The procedure presented above allowed us to collect 176 surveys fully completed. Each video was assessed by 13 expert participants and 30 novices. The following table (see Table 14) summarizes these elements. Additionnnaly, incomplete plans were affected to participants according to a randomised methodology. By doing so, we reduced the impact of habit, discovery, or lassitude that can distort evaluations. The Table 15 presents the 6 serials that were summited to the expert panel; and the 10 serial summited to the novice panel. Serials 1 and 2 have been completed 5 times, while serial 3, 4, 5 and 6 have been completed 4 times. Serial 7 to 16 have been completed 15 times. The order of videos during the survey itself was also ransomised by the platform of evaluation 'Typeform'.

	PARTICI-PANTS	**VIDEOS EVA-LUATED** (OUT OF A TOTAL OF 50 VIDEOS)	**AVERAGE AGE**	**AVERAGE LEVEL** (SELF-EVALUATION FROM 0 TO 5)	**GENDER** (MALE/FEMALE)
EXPERT	26	25	31	4,9/5	17/9
NOVICE	150	10	29,9	2,6/5	71/79
TOTAL	**176**	**50**	**30,1**	**3,1**	**88/88**

Table 14: Collected data

	EXPERT SERIALS						**NOVICE SERIALS**									
VIDEOS	SERIAL 1	SERIAL 2	SERIAL 3	SERIAL 4	SERIAL 5	SERIAL 6	SERIAL 7	SERIAL 8	SERIAL 9	SERIAL 10	SERIAL 11	SERIAL 12	SERIAL 13	SERIAL 14	SERIAL 15	SERIAL 16
1	1	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0
2	1	0	0	1	1	0	1	0	0	0	0	0	0	1	0	0
3	1	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0
4	1	0	0	1	1	0	1	0	0	0	0	0	0	1	0	0
5	1	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0
6	1	0	0	1	0	1	1	0	0	0	0	0	0	1	0	0
7	1	0	1	0	0	1	1	0	0	0	0	1	0	0	0	0
8	1	0	0	1	0	1	1	0	0	0	0	0	0	1	0	0
9	1	0	1	0	0	1	1	0	0	0	0	1	0	0	0	0
10	1	0	0	1	0	1	1	0	0	0	0	0	0	1	0	0
11	1	0	1	0	1	0	0	1	0	0	0	1	0	0	0	0
12	1	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0
13	1	0	1	0	1	0	0	1	0	0	0	1	0	0	0	0
14	1	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0
15	1	0	1	0	1	0	0	1	0	0	0	1	0	0	0	0
16	1	0	0	1	0	1	0	1	0	0	0	0	0	0	1	0
17	1	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0
18	1	0	0	1	0	1	0	1	0	0	0	0	0	0	1	0
19	1	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0
20	1	0	0	1	0	1	0	1	0	0	0	0	0	0	1	0
21	1	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0
22	1	0	0	1	1	0	0	0	1	0	0	0	0	0	1	0
23	1	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0
24	1	0	0	1	1	0	0	0	1	0	0	0	0	0	1	0
25	1	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0
26	0	1	0	1	0	1	0	0	1	0	0	0	0	0	1	0
27	0	1	1	0	0	1	0	0	1	0	0	0	1	0	0	0
28	0	1	0	1	0	1	0	0	1	0	0	0	0	0	1	0
29	0	1	1	0	0	1	0	0	1	0	0	0	1	0	0	0
30	0	1	0	1	0	1	0	0	1	0	0	0	0	0	1	0
31	0	1	1	0	1	0	0	0	0	1	0	0	1	0	0	0
32	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	1
33	0	1	1	0	1	0	0	0	0	1	0	0	1	0	0	0
34	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	1
35	0	1	1	0	1	0	0	0	0	1	0	0	1	0	0	0
36	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1
37	0	1	1	0	0	1	0	0	0	1	0	0	1	0	0	0
38	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1
39	0	1	1	0	0	1	0	0	0	1	0	0	1	0	0	0
40	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	1
41	0	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0
42	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0	1
43	0	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0
44	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0	1
45	0	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0
46	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0	1
47	0	1	1	0	0	1	0	0	0	0	1	0	0	1	0	0
48	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0	1
49	0	1	1	0	0	1	0	0	0	0	1	0	0	1	0	0
50	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0	1
SOMME	**25**	**25**	**25**	**25**	**25**	**25**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**

Table 15: Serials for Experts and Novices

Finally, the 176 collected survey have been condensed in order to focus on differences between evaluated videos instead of differences between participant perception of the same video. To do so, we made an average of the results for each video: each video has been evaluated by 43 participants. The average allows us to reduce this number of 43 to a simple score per video.
Thus, the collected data consits in a table of 50 evaluated video, through 11 questions based on a 7 points scale (see table 13).

4.3.3 Results

Following the experimentation's objectives, we present hereafter our results according to four parts:
4.3.3.1 (d)/(a): Focuses on the link between the different dimensions(d) and the areas(a) described in the classification.
4.3.3.2 (p)/(a): Observe the different principles(p) associated with the different areas(a).
4.3.3.3 (d)/(i) : Formalizes the influence of the dimensions(d) on the design information(i).
4.3.3.4 (a)/(i) : Compares the areas(a) to the design information(i) in order to highlight their impact.

Each section presents the raw data in the first section (called "raw data"), and then discusses the data in the second part (called "data analysis"). The results are summarized in Table 17.

4.3.3.1 (d)/(a): Interactive Taxonomy

-Raw Data

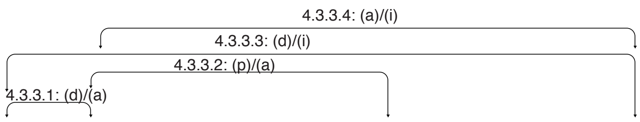
Using a seven-point scale, participants scored the 50 videos. This score allows us to map the videos according to the three dimensions(d).

The three dimensions were illustrated visually in a 3D-cube consisting of eight areas(a) (e.g., Figure 16). It allows us to locate each interactive product according to the score (along axes) participants gave to each video (see Table 13). According to a multiple comparison test (Table 16), the 50 videos scored according to the three dimensions(d) of "environment" (from virtual to real), "target" (from digital to physical), and "source" (from digital to physical) can

VIDEO NUMBER	25	8	17	16	21	46	20	49	12	41	26	7	18	50	31	9	1	37	39	35	6	4	45	34	43
LS means **ENVIRONMENT**	6,0	5,9	5,8	5,6	5,6	5,6	5,5	5,5	5,4	5,1	5,0	4,9	4,9	4,8	4,6	4,6	4,5	4,5	4,5	4,3	4,3	1,9	1,9	1,8	1,6
GROUPS	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A				
																						B	B	B	B
VIDEO NUMBER	25	22	4	11	8	2	43	14	9	29	12	49	46	27	20	31	15	50	7	23	40	41	1	28	3
LS means **TARGET**	6,0	6,0	5,9	5,9	5,8	5,8	5,8	5,8	5,6	5,6	5,6	5,6	5,6	5,5	5,4	5,4	5,4	5,3	5,1	5,1	5,1	5,1	5,0	5,0	5,0
GROUPS	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
VIDEO NUMBER	20	8	10	19	23	39	5	41	27	32	29	50	34	46	49	3	17	15	22	25	14	4	38	35	31
LS means **SOURCE**	5,6	5,0	4,9	4,9	4,9	4,9	4,4	4,4	4,1	3,9	3,1	2,5	2,4	2,3	2,3	2,1	2,1	2,1	2,1	2,0	2,0	2,0	1,9	1,8	1,5
GROUPS	A	A	A	A	A	A	A	A	A	A															
			B	B	B	B	B	B	B	B	B														
									C	C	C	C	C												
										D	D	D	D	D	D	D	D	D	D						
											E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
												F	F	F	F	F	F	F	F	F	F	F	F	F	F
													G	G	G	G	G	G	G	G	G	G	G	G	G
																H	H	H	H	H	H	H	H	H	H
																				I	I	I	I	I	I

VIDEO NUMBER	27	30	38	2	23	29	33	47	32	48	10	3	24	15	22	14	40	42	11	19	28	5	36	13	44
LS means **ENVIRONMENT**	1,6	1,6	1,6	1,5	1,4	1,3	1,3	1,1	1,0	1,0	1,0	0,9	0,9	0,6	0,5	0,5	0,5	0,4	0,4	0,4	0,4	0,4	0,3	0,3	0,2
GROUPS																									
	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
VIDEO NUMBER	34	45	16	17	47	21	38	18	26	48	30	6	35	39	24	37	33	10	19	42	32	5	36	44	13
LS means **TARGET**	5,0	5,0	4,9	4,8	4,8	4,8	4,7	4,6	4,4	4,4	4,4	4,4	4,1	2,4	1,7	1,6	1,5	1,0	1,0	1,0	0,9	0,7	0,4	0,2	0,0
GROUPS	A	A	A	A	A	A	A	A	A	A	A	A	A												
													B	B											
														C	C	C	C	C	C	C	C				
															D	D	D	D	D	D	D	D	D	D	D
VIDEO NUMBER	16	33	45	47	28	2	36	12	1	11	21	26	30	6	18	37	42	9	43	24	40	48	7	44	13
LS means **SOURCE**	1,5	1,5	1,5	1,5	1,5	1,4	1,3	1,3	1,1	1,1	1,1	1,1	1,1	1,1	1,0	1,0	1,0	0,9	0,9	0,9	0,6	0,4	0,2	0,2	0,2
GROUPS																									
	E	E	E	E	E	E																			
	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F					
	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G				
	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H			
	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I

Table 16: Multiple comparison test according to the three axis



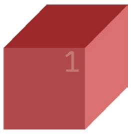
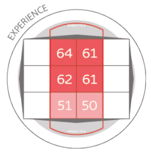
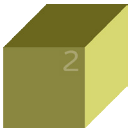
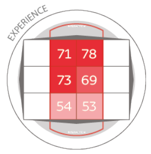
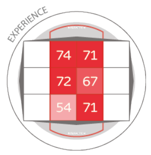
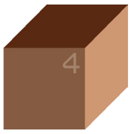
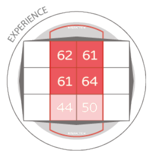
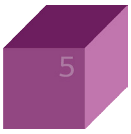
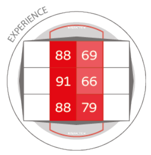
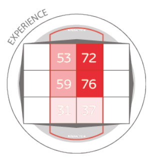
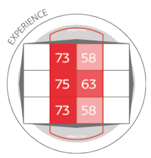
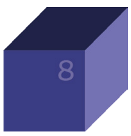
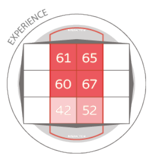
RESULTS - 3 DIMENSION(d) & 8 AREAS (a)					RESULTS -PRIN-CIPLES (p)	RESULTS - DESIGN INFORMATION(i)	
AREAS(a) FROM THE INTERAC-TIVE TAXONOMY		*VIDEO RE-LATED*	*ONE EXAMPLE EXTRACTED*		*5 MOST CITED PRINCIPLES(p)*	*% OF IMPACT ON THE THEORETICAL MODEL(i)*	*COMMENTS*
	1-Real en-vironment; Physical target; Physical sources	13; 24; 42; 44		The user increases or decreases the light by tightening or over tighte-ning the wire node	Movable Transformable Graspable Manipulable Malleable		This full physical and real typology of products are more related to abstract notions like emotion, semantics, behavior and action enablement.
	2-Real en-vironment; Physical target; Digi-tal sources	10; 36; 5		The user inte-racts with the robot through behavioral gesture	Programmable Transformable Connectable Personalizable Movable		The kind of physical targets that use digital sources have been characterized as very powerful for abstract no-tions; mainly for emotion, semantics, and behavior.
	3-Real en-vironment; Digital target; Physical sources	1; 11; 12; 14; 15; 2; 22; 26; 40; 45; 43; 48; 50; 28; 29; 3; 4; 38		The user inte-racts with the data through physical gesture	Graspable Manipulable Movable Malleable Spacia-lize-able		This box, about digital targets that uses physical sources, covers a wide scope of the design information boxes. Only the sensory related part is less covered than the other.
	4-Real en-vironment; Digital tar-get; Digital sources	19; 23; 27; 30; 32; 33; 47		The user interacts with a message through the holographic system	Transformable Programmable Personalizable Connectable Replicable		This box, covers both the abstract design informa-tion (emotion and seman-tics) and the middle part of the theoretical model (behavior and action en-ablement). Nevertheless what is covered is not strongly impacted.
	5-Virtual environ-ment; Physical target; Physical sources	37		The user interacts with the game in a virtual environment through the physical car	Movable Manipulable Transformable Graspable Ubiquit-able		Unfortunately only one video has been related to this box. Thus, the average result might not be significant enough. Nevertheless it seems to impact mainly the left part, dedicated to user reactions.
	6-Virtual environ-ment; Physical target; Digi-tal sources	39		The user inte-racts with the real phone through the screen that propose a new reality (virtual one)	Transformable Personalizable Manipulable Spatialize-Able Connectable		Unfortunately only one video has been related to this box. Thus, the average result might not be significant enough. Nevertheless it seems to impact mainly the right part, dedicated to user perception of the product.
	7-Virtual environ-ment; Digital target; Physical sources	17; 18; 25; 21; 31; 34; 41; 46; 49; 6; 7; 8; 9		The user inte-racts with the digital jellyfish through the tactile rende-ring screen	Manipulable Movable Malleable Graspable Spatialize-Able		This box is strongly covers the left part of the model, dedicated to user reaction to the product, and to the box related to action enablement. Thus, it appears that the product is less important than the user's reactions.
	8-Virtual environ-ment; Digital tar-get; Digital sources	16; 20; 35		The user inte-racts with the sound volume through the screen	Programmable Personalizable Replicable Connectable Voidable		This full digital and virtual box has been assessed as more related to abstract and middle design information boxes. Nevertheless, this impact is not very strong.

Table 17: Result of experimentation

be split into several groups, according to the differences of variation collected in participants answers. It appears that the "environment(d)" axis can be split into two groups (real and virtual); the "target(d)" axis into four groups (one is clearly what we showed as "digital", but the "physical" part has been divided by the analysis into three groups, as three nuances of the physical target); and the "source(d)" into nine groups (as nine significant nuances from the physical sources to digital ones).

The multiple comparison test highlighted that in these 50 videos, some interesting differences can be highlighted. In order to show these differences, we have drawn the bootstrapped confidence intervals for each group obtained through the multiple comparison. For each of the dimensions ENVIRONMENT, TARGET, SOURCE, and for each of the groups (see table 16: A-B for ENVIRONMENT, A-D for TARGET, A-I for SOURCE), we show on figure 44 the mean (dot) and 95% confidence interval (error bar) of the individual evaluations made by our panel on each video of this group (7 points likert scale, 6 = virtual, 0 = physical). We can observe here strong differences, and a confirmation of the conceptual distinction between physical/virtual on each of those axis. More specifically, the ENVIRONMENT is strongly separated with videos that fall in very distinct groups on the real/virtual scale. The TARGET dimension had also strong distinction in the perception of the physical/virtual scale with 3 or 4 groups showing in our data. Last, the SOURCE has a range of continuous groups, showing a more nuanced distinction between the perceptions of the videos in our panel. We think that this nuance can also be seen as an indication of the difficulty in the interpretation of the SOURCE dimension.

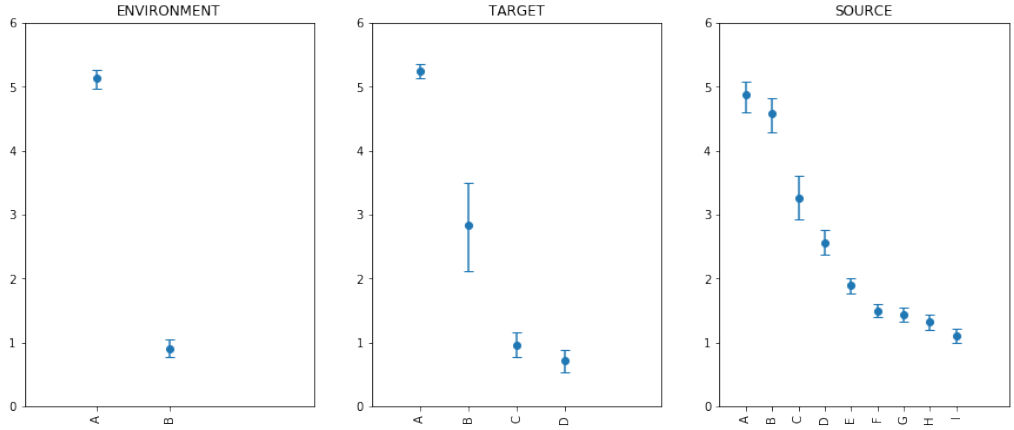


Figure 44: Mean and Confidence interval of Evaluations

However, because this typology of interactive products was based on user perception, we pointed out interesting notions on these three dimensions(d): The way users believe that an environment(d) is real or virtual is closely related to the perception of the link between the interface(d) and the environment(d). Indeed, according to a linear regression (dependants variables are scales of perception and independant one are the three dimensions), there is a close link between the environment(d) (from real/virtual) and the question about interface and environment (from separated to merged). The linear regression highlighted that the more an environment(d) seems to be merged with an interface, the more it appears to be real for the user, because there is no separation between his or her reality and the interactive product. On the other hand, if the interactive product and the environment(d) look distinct, it appears to be perceived as more virtual for the user, because the separation between the two brings something that feels “fake”, or “created”. When watching the Minority Report video (No. 31) and the Iron Man one (No. 22), for example, we can acknowledge that they are very close in terms of interactions. Nevertheless, for No. 31, the data are represented on a screen, separate from the environment, whereas No. 22 represents the data through a holographic system that convinces the user that the environment(d) is merged with the interactive product. This resulted in a more appreciated interaction. Thus, the way we design the product impacts the perception of the reality, according to this notion of merging with the environment(d) where the user interacts with the interactive product itself.

Data Analysis

The proposed taxonomy is one way to differentiate an interactive product from the human perception of physical and digital properties. Eight areas(a) were highlighted according to three dimensions(d) (environment, target, and source). This taxonomy could be even more precise by differentiating more groups within the eight areas(a), as the multiple comparison test highlighted (e.g. Table 16). However, starting with only eight areas(a) to classify interactive products is already challenging, because the classification is not static: Indeed, according to our analysis, interactive products can be assessed differently depending on people’s knowledge, culture, society, and many more parameters highlighted by the theoretical model of design information(i) (e.g., Figure 15). Furthermore, as the results show, we collected several rules. For example, according to Figure 16, a real environment seems to be more impactful in terms of “semantics”. Designers specifically can use these rules as methods and clues to design new interactive products. Thus, the three dimensions become dimensions the designer can play with to influence users’ affective and cognitive responses(i).

Both designers and researchers can use this taxonomy and its analytical results to see and understand the impact of different conception choices on users’ affective and cognitive responses, such as environment, target (product properties), and source (reference of perceived properties).

4.3.3.2 (p)/(a): Interactive Principles

Raw Data

This part is related to the different principles(p) that the interactive metaphors provide. Indeed, based on the preliminary experimentation, we extracted 17 principles(p) for both physical and digital properties. According to the assessment of every video using the “principles part” presented previously (“principles part” in Table 18), participants had the opportunity to link each video to one or more principle(p) based on a scale from 0 to 6. The collected evaluations have been first of all reduced based on a average method (100 x score from 0 to 6, divided by 6), to score each video according to the 17

principles. Then, we used the results of the taxonomy (in table 17) (where each area contain X number of videos) to quantify per Area the percentage of impact for each principle.
This resulted in the table (table 18), that characterizes the eight areas(a) through the 17 principles.

	Area 1 (a)	Area 2 (a)	Area 3 (a)	Area 4 (a)	Area 5 (a)	Area 6 (a)	Area 7 (a)	Area 8 (a)
Movable (p)	70 %	40 %	63 %	20 %	100 %	20 %	58 %	10 %
Transformable (p)	68 %	53 %	39 %	60 %	80 %	100 %	34 %	13 %
Malleable (p)	43 %	10 %	49 %	16 %	70 %	30 %	53 %	10 %
Graspable (p)	55 %	10 %	66 %	24 %	90 %	10 %	57 %	13 %
Manipulable (p)	48 %	7 %	74 %	34 %	100 %	40 %	79 %	20 %
Universalizable (p)	13 %	17 %	21 %	34 %	10 %	20 %	12 %	10 %
Connectable (p)	23 %	53 %	22 %	47 %	30 %	30 %	18 %	33 %
Ubiquitable (p)	3 %	0 %	5 %	27 %	80 %	0 %	5 %	27 %
Asynchronize-able (p)	0 %	3 %	2 %	10 %	0 %	0 %	3 %	0 %
Spacialize-able (p)	13 %	30 %	47 %	24 %	70 %	40 %	45 %	7 %
Fusible (p)	0 %	7 %	14 %	13 %	10 %	10 %	2 %	27 %
Void-able (p)	0 %	30 %	7 %	23 %	0 %	10 %	8 %	30 %
Replic-able (p)	23 %	27 %	23 %	46 %	10 %	10 %	15 %	53 %
Distribuable (p)	15 %	3 %	24 %	27 %	0 %	0 %	3 %	30 %
Programmable (p)	48 %	77 %	21 %	60 %	20 %	30 %	12 %	77 %
Personalizable (p)	20 %	53 %	29 %	56 %	20 %	80 %	28 %	80 %
Independent from gravity (p)	5 %	7 %	23 %	23 %	0 %	0 %	3 %	0 %

Table 18: Principles results

The highlighted interactive principles(p) provided a richer and better understanding of the eight interactive areas(a).

Based on this table 18, we also performed a Principal Component Analysis (PCA) non-normed (see Figure 45), to represent visually how "interactive principles(p)" could be organized on a surface. Thus, we used the 6 of the 8 areas as observation labels, and the 17 principles as variables. It resulted in a PCA presented in figure 45. The two axes have been interpreted based on Areas positions on the mapping. Thus, we used the notions of Target and Source to better understand and read the mapping.

The total variance is 75%. Both the notion of "target(d)" (vertical axis), and "source(d)" (horizontal axis), are represented in this PCA. However, we removed areas(a) 5 and 6, because they were not adequately representative (only one video comprised these areas(a)).
It appears that there is a clear opposition between physical sources(d) and digital ones(d) (horizontal axis). However, all of these physical sources(d) cover the vertical axis from physical to digital target(d). This means that the videos used very physical sources(d) with physical targets(d) such as "transformable(p)" or "movable(p)". At the same time it shows that physical sources(d) could also be used for digital target(d). For example, the terms "manipulable(p)", "graspable(p)" and "malleable(p)" that have been considered as physical sources(d), were mainly used to characterize digital target(d). This observation is also valid for

digital sources(d): "programmable(p)", "connectable(p)", or "voidable(p)" have been considered digital sources(d), mainly used in the videos to support a physical target(d). Thus, it showed that, independent from real or virtual notions, the physical or digital sources(d) could be used by physical and digital targets(d).

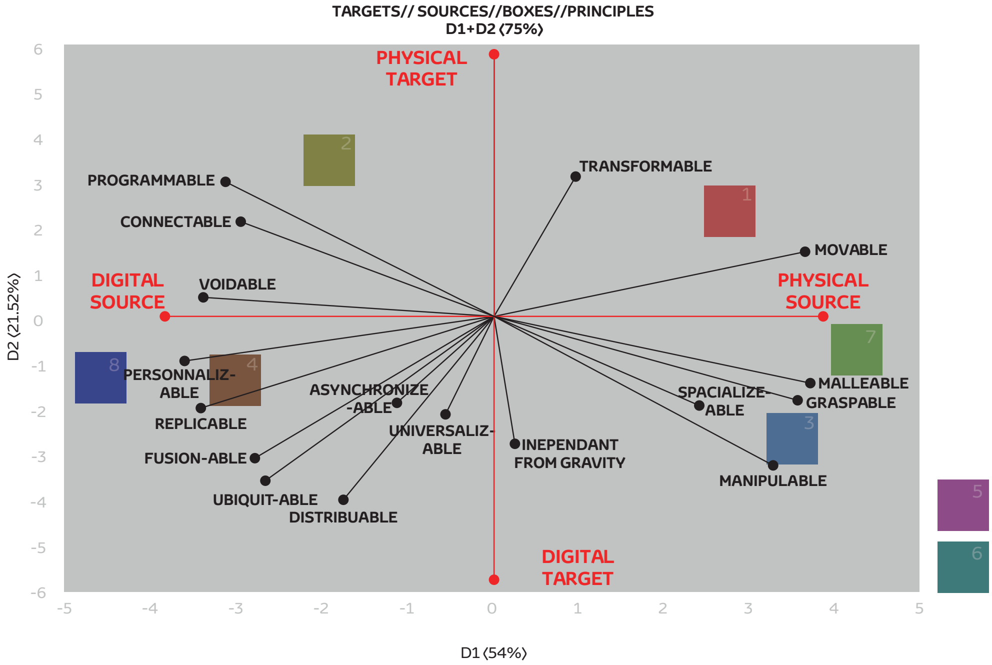


Figure 45: PCA Principles and Areas mapping according to Target and Source

Data Analysis

Going back to the state of the art, and more specifically to the definition of metaphors, the study highlighted the power of metaphors in interactive products. Even if this study focused on physical and digital proprieties of both the target(d) and the source(d) in metaphor, the study combined both the understanding of interactive product and metaphor. It raises powerful notions of interaction and metaphors. Furthermore, the principles(p) that were highlighted in the preliminary experimentation are mainly related to what the product allows one to do, and to dynamic properties (such as "moveable(p)" or "manipulable(p)"). These principles(p) outline one key characteristic of interaction design: The notion of time and sequence. Indeed, as presented in the definition of interaction, time is decisive, because interactions are sequences of actions. Thus, metaphor and interaction design can easily be differentiated from metaphor and product design by this notion of sequence and temporality in metaphors. Even if the conceptual structure of metaphor defended by Lakoff and Johnson (1980) is an involvement of all natural dimensions of our experience (color, shape, texture, sound), the notion of metaphor and interaction make sense in terms of the notions of time, narration, and temporality. Thus, metaphor in interaction design relates to sequential conceptual structure, where the source references another entity to increase meaningful interactions and user experiences.

Finally, regarding this point about sequence and time, we encourage designers to make a point of exploring the benefit of metaphors in interaction design, using the angle of a sequence of actions, when considering the source(d).

	Evaluation results						LS mean ENVIRONMENT	LS mean TARGET	LS mean SOURCE
	Emotion	Semantic	Behavior	action enab	Gesture	Properties	REAL VIRTUAL	PHYSICAL DIGITAL	PHYSICAL DIGITAL
VIDEO 1	82	69	62	62	36	92	4,5	5,0	1,1
VIDEO 10	64	70	68	70	43	50	1,0	1,0	4,9
VIDEO 11	74	79	68	68	60	67	0,4	5,9	1,1
VIDEO 12	70	77	75	78	57	76	5,4	5,6	1,3
VIDEO 13	71	66	59	57	75	61	0,3	0,0	0,2
VIDEO 14	73	76	84	71	63	64	0,5	5,8	2,0
VIDEO 15	84	85	72	71	61	61	0,6	5,4	2,1
VIDEO 16	77	68	73	71	54	61	5,6	4,9	1,5
VIDEO 17	73	49	77	65	78	74	5,8	4,8	2,1
VIDEO 18	66	65	79	58	48	63	4,9	4,6	1,0
VIDEO 19	49	52	49	56	35	49	0,4	1,0	4,9
VIDEO 2	73	77	81	67	78	65	1,5	5,8	1,4
VIDEO 20	50	59	52	64	35	45	5,5	5,4	5,6
VIDEO 21	81	60	53	71	79	50	5,6	4,8	1,1
VIDEO 22	73	73	81	71	59	79	0,5	6,0	2,1
VIDEO 23	66	62	64	73	65	50	1,4	5,1	4,9
VIDEO 24	65	57	51	59	43	44	0,8	1,5	0,7
VIDEO 25	66	56	76	61	82	51	6,0	6,0	2,0
VIDEO 26	78	69	77	72	49	58	5,0	4,4	1,1
VIDEO 27	74	69	67	74	31	51	1,6	5,5	4,1
VIDEO 28	75	72	65	60	45	60	0,4	5,0	1,5
VIDEO 29	81	67	85	63	77	71	1,3	5,6	3,1
VIDEO 3	72	76	78	69	64	69	0,9	5,0	2,1
VIDEO 30	53	59	59	70	35	45	1,6	4,4	1,1
VIDEO 31	69	70	81	69	61	59	4,6	5,4	1,5
VIDEO 32	60	55	64	60	40	48	1,0	0,9	3,9
VIDEO 33	80	69	67	55	61	59	1,3	1,5	1,5
VIDEO 34	69	56	70	54	79	59	1,8	5,0	2,4
VIDEO 35	54	69	54	64	37	51	4,3	4,1	1,8
VIDEO 36	74	84	72	58	73	54	0,3	0,4	1,3
VIDEO 37	88	69	91	66	88	79	4,5	1,6	1,0
VIDEO 38	76	63	59	54	40	58	1,6	4,7	1,9
VIDEO 39	53	72	59	62	31	37	4,5	2,4	4,9
VIDEO 4	71	73	70	81	44	62	1,9	5,9	2,0
VIDEO 40	62	63	53	55	28	81	0,5	5,1	0,6
VIDEO 41	82	51	87	59	76	43	5,1	5,1	4,4
VIDEO 42	63	63	69	63	37	47	0,4	1,0	1,0
VIDEO 43	70	64	70	77	41	88	1,6	5,8	0,9
VIDEO 44	56	56	67	66	49	47	0,3	0,3	0,2
VIDEO 45	73	60	72	64	48	82	1,9	5,0	1,5
VIDEO 46	79	59	79	68	84	60	5,6	5,6	2,3
VIDEO 47	52	63	59	60	40	46	1,1	4,8	1,5
VIDEO 48	67	66	65	61	60	88	1,0	4,4	0,4
VIDEO 49	51	42	82	51	76	44	5,5	5,6	2,3
VIDEO 5	75	82	79	79	47	55	0,4	0,8	4,4
VIDEO 50	76	77	72	60	59	56	4,8	5,3	2,5
VIDEO 6	82	52	78	60	88	44	4,3	4,4	1,1
VIDEO 7	74	65	69	67	57	77	4,9	5,1	0,2
VIDEO 8	79	54	71	64	64	62	5,9	5,8	5,0
VIDEO 9	81	71	73	67	81	69	4,6	5,6	0,9

Table 19: Data Linear Regressions

4.3.3.3 (d)/(i): Influence of Dimensions(d) on Design Information(i)

Raw Data

The aim of this part is to use the evaluations of the interactive products to compare the three dimensions(d) from the taxonomy with the design information(i) from the model (e.g., Figure 15). By doing so, we want to formalize and observe if their is a relationship between the gradualness of the three dimensions (Environment, Target and Source) and users' perception of Emotion, Semantic, Behavior, Action, Gesture and Properties.

To do so, we performed three linear regression that we represented in one graph (e.g., Figure 46 and Table 20). Each linear regression is focussing on one dimension (Environment, Target or Source) as presented in table 19.

-We used as independant variable, the average score of each video related to the central design information(i) boxes from the model (e.g., Figure 15) (Emotion, Semantic, Behavior, Action, Gesture and Properties). As it is presented in Table 19, this score is expressed in percentage (0 to 6 scales translated in %).

-As dependant variables, we used the average score of each dimensions (Environment, Target or Source) extracted from the multiple comparison test

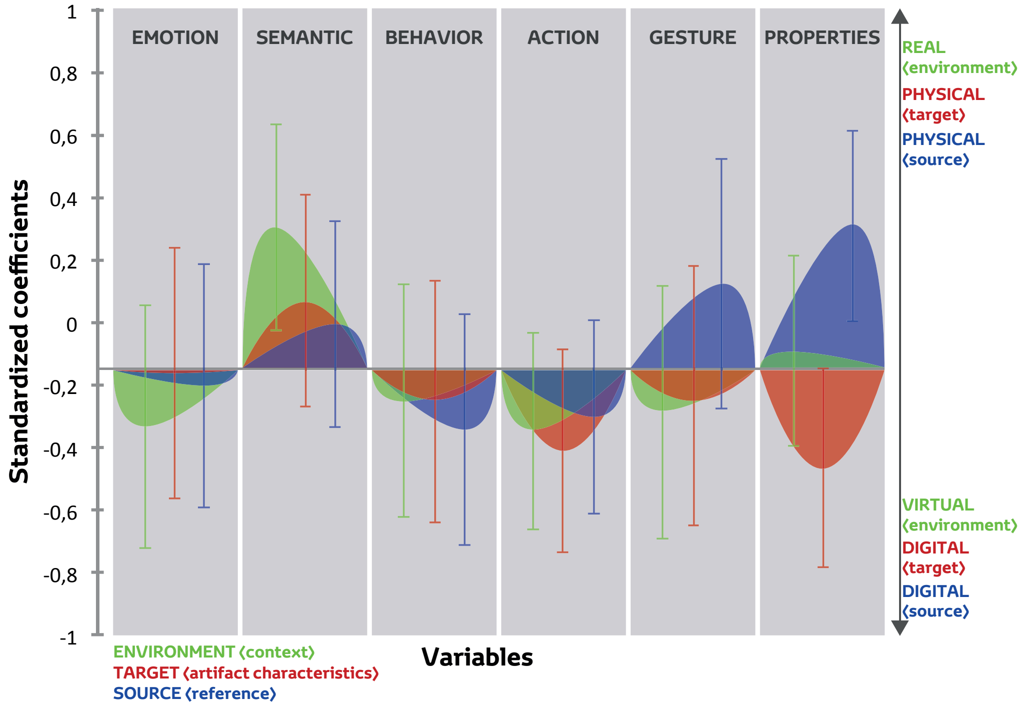


Figure 46: Influence of Dimensions(d) on Design Information(i)

	Source	Va-lue	Stan-dard error	t	Pr > ltl	Lower bound (95%)	Upper bound (95%)
ENVIRON-MENT	Emotion	0,18	0,19	0,94	0,35	-0,21	0,57
	Semantic	-0,45	0,16	-2,77	0,01	-0,78	-0,12
	Behavior	0,10	0,19	0,53	0,60	-0,27	0,47
	action enable	0,19	0,16	1,22	0,23	-0,12	0,50
	Gesture	0,13	0,20	0,67	0,51	-0,27	0,53
	Properties	-0,06	0,15	-0,36	0,72	-0,36	0,25
TARGET	Emotion	0,01	0,20	0,07	0,94	-0,38	0,41
	Semantic	-0,21	0,17	-1,24	0,22	-0,54	0,13
	Behavior	0,10	0,19	0,52	0,60	-0,28	0,48
	action enable	0,25	0,16	1,60	0,12	-0,07	0,57
	Gesture	0,09	0,20	0,42	0,68	-0,33	0,50
	Properties	0,31	0,16	2,00	0,05	0,00	0,62
SOURCE	Emotion	0,05	0,19	0,25	0,80	-0,34	0,44
	Semantic	-0,14	0,16	-0,88	0,38	-0,47	0,18
	Behavior	0,19	0,18	1,03	0,31	-0,18	0,56
	action enable	0,15	0,15	0,97	0,34	-0,16	0,46
	Gesture	-0,27	0,20	-1,36	0,18	-0,67	0,13
	Properties	-0,46	0,15	-3,02	0,00	-0,76	-0,15

Table 20: Influence of Dimensions(d) on Design Information(i)

presented in table 16. Each dimension is based on an opposition between Real and Virtual; or Physical and Digital.

-Thus, we performed thre linear regressions to formalize the relationship between the 6 variables from the theoretical model, and the 3 dimensions.

We obtained the results presented in Figure 46 (e.g., Figure 46 and Table 20). (R2 are the following: Environment: 0,242; Target 0,251; Source 0,209)
According to that kind of representation, we can extract some tendancies that can be used in creation design phases. For example, it seams that Properties may explain the axis of Source (from physical to Digital); Or Semantic may explain the axis of environment (from real to virtual)

It appears that each dimension(d) is related to the design information(i) extracted from the theoretical model differently. As we showed in the state of the art, an interactive experience combines the environment(d), the target(d), and the source(d) in an entire experience. Thus, rather than observing the differences between dimensions(d), the following section took the interactive artifact's point of view by analyzing each area(a) extracted from the taxonomy. Therefore, using an average of video results for each of the eight areas(a) highlighted by the three dimensions(d) mapping, we represented on the theoretical model the varying impact on the design information(i) in percentages. Table 17, Part "results design information", summarizes these results.

Data Analysis

The interactive principles that have been presented can be considered as notions or clues for future design challenges. Actually, following the understanding previously presented, which defended that both worlds (physical and digital) should be considered when designing interactive products, we can assume that both a physical target which uses digital sources (Areas 2 and 6, called hereafter Territory 1), or a digital target which uses physical sources (Areas 3 and 7, called hereafter Territory 2), can be improved. The following representation (see Figure 47) extracted from the previous PCA (see Figure 45), shows some elements that can be assumed as new and future opportunities for concept creation: Territory 1, composed of physical targets that use digital sources, could be improved by the interactive principles that could move into this territory (represented by dotted arrows). Indeed, by so doing, designers could improve the experience of interaction.
Elsewhere, this is also something that can be defended for the second territory. This digital target, which uses physical sources, could be enhanced by principles such as "transformable" or "movable". By so doing, we could improve or create concepts that use even more of these physical principles, and finally improve the experience of interaction.
As has been said of this state of the art about image schemas (Johnson, 1987), one danger of such inventories of principles is that they are never complete. Thus, these principles can be used as clues or challenges for designing more efficient or powerful experiential interaction, but the list is not exhaustive; it

must be expanded and improved. On the figure 47, we mapped Areas 5 and 6 according to their supporsed place. Indeed these two areas were not used to generate the representation of this PCA, nevertheless, because they are based on the axis of Target and Source, we supposed that they should be placed on the figure as represented.

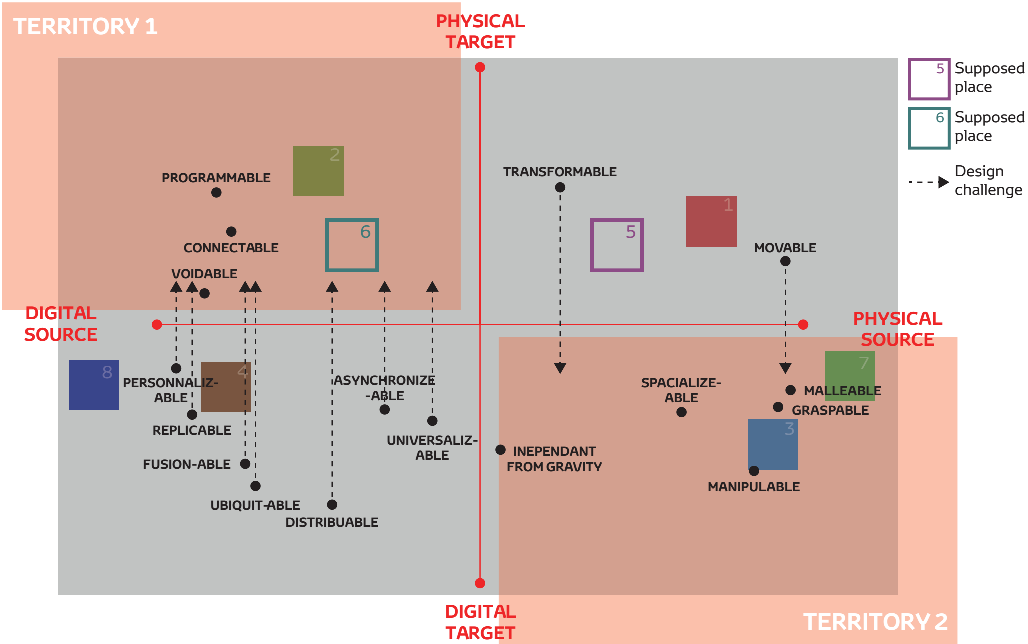


Figure 47: Futur Design Challenges

4.3.3.4 (a)/(i): Eight Areas(a) and their impact on the Design Information(i)

Raw Data

This part paralleled the eight areas(a) described by the three-dimensional(d) taxonomy with the results from the videos about the impact on the different design information(i) of the model (Figure 15): To better see how these interactive areas(a) impacted both user responses and user perception(i) of the interactive product, we used a PCA (e.g., Figure 48).

For this PCA, we only used the areas 1(a), 2(a), 3(a), 4(a), 7(a), and 8(a). The two areas 5(a) and 6(a), represented by only one video, were ignored because of their weak representation. Two elements were correlated: The eight areas(a) (composed of an average of every video in Table 17), as observation labels; and the six design information(i) described by the theoretical model (e.g., Figure 15) as variables. Thus, we obtained the following representation (see Figure 48). Based on this PCA (total variance: 88.80%), we interpreted two new axes to better understand and discuss it: The first one differentiates positive from negative results. Based on this axis, we can clearly observe that areas 2(a), 3(a), and 7(a) were considered more meaningful (qualitative and quantitative impact of affective and cognitive responses users experience) than areas 8(a), 4(a), and 1(a). What they have in common is the following: Areas 2(a), 3(a), and 7(a) combine both physical and digital elements (independently from the notion of real or virtual) (physical target(d) with digital source(d), or digital target(d) with physical source(d)). Thus, it appears that areas(a) combining both dimensions(d) of physical and digital were more appreciated and more related to meaningful experiential interactions. Areas 8(a), 4(a), and 1(a), independent from the notion of environment(d) (real or virtual) are either completely physical (physical target(d) and physical source(d): Area 1(a)) or completely digital (digital target(d) and digital source(d): Areas 4(a) and 8(a)).

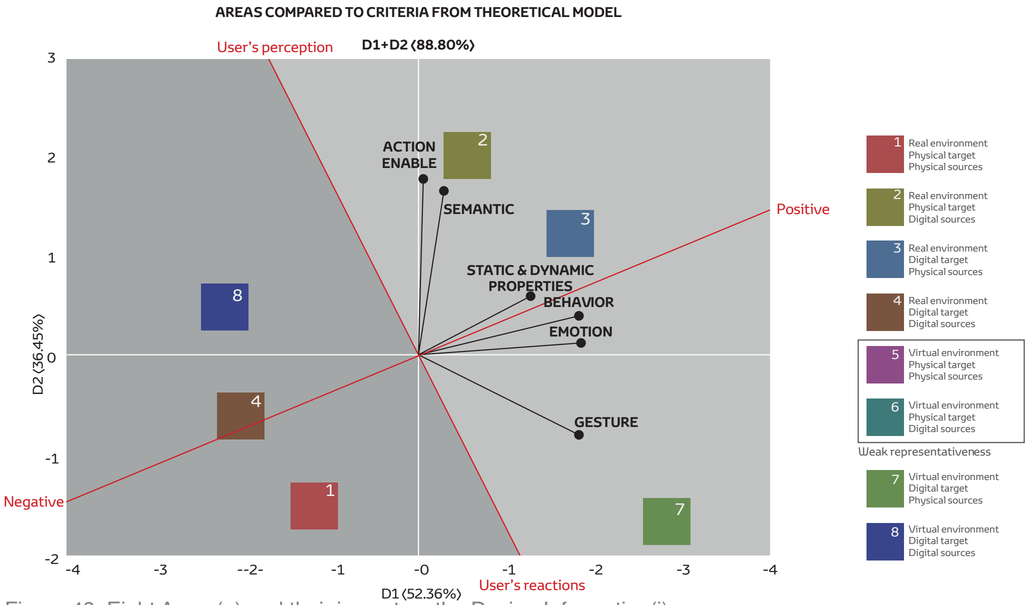


Figure 48: Eight Areas(a) and their impact on the Design Information(i)

Finally, according to the evaluation of the 50 videos by 176 participants, the taxonomy of eight areas(a) of interactive artifacts were justified as a valuable way to classify interactive products. We pointed out how participants characterized the impact of these eight interactive areas(a) using the model of design information(i) (Figure 15). These different elements are represented in Table 17.

Data Analysis

Meaningful interactions (interactions impacting the design information from the theoretical model) were interactions that combined both the physical and digital worlds (areas 2, 3, and 7 from the interactive taxonomy), in contrast to interactions that combined two identical worlds (areas 1, 4, and 8). Indeed, both worlds (the physical and the digital) have their characteristics and advantages. It can be summarized as follows: What the physical brings to any interaction is the human language of things. Thus, humans are attached to materiality that seems to impact them through richer perception (senses) of the product (practical, aesthetic, and symbolic notions). On the other hand, the digital and virtual worlds bring greater possibilities regarding "action enablement" and "user's behavioral impact". Furthermore, emotions are regarded as more influential in the virtual environment.

The user experience approach of interactive products leads us not to consider the dimensions independent from one another, but instead in terms of the full experience of the interactive product: The combination of the three dimensions perceived by the user and hosted in one interactive product. It considered to be key. Thus, taking advantages of both worlds (physical target + digital source or digital target + physical source) increase the impact on users' actions and perception of the interactive product, creating more meaningful experiential interaction. Following this understanding of combining two worlds, it has been shown that areas 2, 3, and 7 were more meaningful than the others. Furthermore, we assume that though area 6 was not covered by enough videos to be evaluated, it can also be considered as one strong territory of research.

Thus, if these eight areas of interaction cover the scope of physical and digital interaction from a user experience point of view, the study highlighted that interactive area numbers 2, 3, 6 and 7 are four fields that should be considered when designing meaningful interactive products. These interactive areas only give clues and guidelines for understanding and designing future interactive products. The right balance between the physical and digital target and source, depending on the environment where it takes place, still needs to be designed.

4.3.4 Conclusions and Limitations

This section presents both the conclusions extracted from this experimentation, and its limitations.

4.3.4.1 Conclusions

This research developed a taxonomy resulting in eight areas(a) of interactive products using the human perception(i) of physical and digital dimensions(d): Environment(d), target(d) (product properties), and sources(d) (perceived references). It resulted in a method, a tool, taxonomy, and design challenges.

First, the study matches a method to quickly evaluate and classify interactive products using subjective human perception. This protocol takes into consideration the senses involved, the physical and digital interactions, and the subjective perception (overall perception) of user experiential interaction. It proposes an open-basis and a step-by-step architecture for evaluating any interactive products. This simple common base can then be augmented and improved through more scales, keywords, and questions, depending on the purposes of any researchers in interactive products from disciplines of user experience design, human factors, computer science, artificial intelligence or researchers in design methodology. This method and database are today used in TME to evaluate and correlate both interactive products from every horizon and automotive-related interactive products, such as the steering wheel, the navigation system, the HVAC, etc. By clustering all these interactive products according to the taxonomy, we can link automotive-related components with everyday and future interactive products. By doing so, we can compare and improve automotive products with any interactive products (such as those evaluated in this experimentation) through the physical and digital paradigms.

Second, we describe a three-dimensional(d) tool that gives clues and challenges for designers using physical and digital perception. For example, this tool can be used to expand, improve, and clarify an interaction design brief in early design phases by encouraging designers to consider the balance between the three dimensions(d), as well as the impact of each dimension(d) on the human affective and cognitive responses. Additionally, the principles(p) described are the beginning of an endless list, which can be used as clues and key notions to evaluate interactive products, and as challenges when designing interactive products.

Finally, this research presents the taxonomy itself, using a database of 50 interactive products evaluated by 176 participants. Using this database, we emphasize the link between physical and digital interactions, leading us to a key finding that experiential interactions (independent from the environment) are more meaningful when designed with both physical and digital principles(d): Physical targets(d) combined with digital sources(d), or digital targets(d) combined with physical sources(d). Thus, it sets a new milestone in both the understanding of interaction design using physical and digital properties within the scope of user experience, and in the understanding of metaphors in interaction design.

4.3.4.2 Limitations

Even if it has been shown in the procedure that evaluating videos of people interacting is valuable, results could have been more precise if evaluations were performed with real product tests. Thus, we should consider the results as tendencies and clues, rather than as exact results. Furthermore, the sustainability of the examples displayed in this taxonomy can be short, because human perception evolves very quickly. Thus, it needs to be updated, fed, and improved by new evaluations of everyday products and new concepts to keep this taxonomy updated. Additionally, we need to conduct more evaluations with products that can be associated with areas 5 and 6. Indeed, it appears that only one video per area has been linked. This is due to several reasons: These interactive areas might not be enough, or not yet investigated by the design community; the videos that were selected may not cover the full scope of interactive products; or these typologies are too strange to be covered by the design community.

«Metaphors are capable of creating
new understanding and, therefore, new realities»
George Lakoff & Mark Johnson (1980)

4.4 Experimentation 3

The objective of this experimentation is to test the third hypothesis: *"The metaphorical approach can be used to improve the way we design interactions in the physical/digital paradigm."*

This experimentation seeks to explore and clarify how we should position the metaphorical approach within the design process. It is composed of five parts. The first part (4.4.1) presents our objectives. The second part (4.4.2) defines a method for success. The third part (4.4.3) presents the protocol. Finally, the fourth part (4.4.4) presents the results of our experimentation, followed by a discussion of these results in the fifth part (4.4.5).

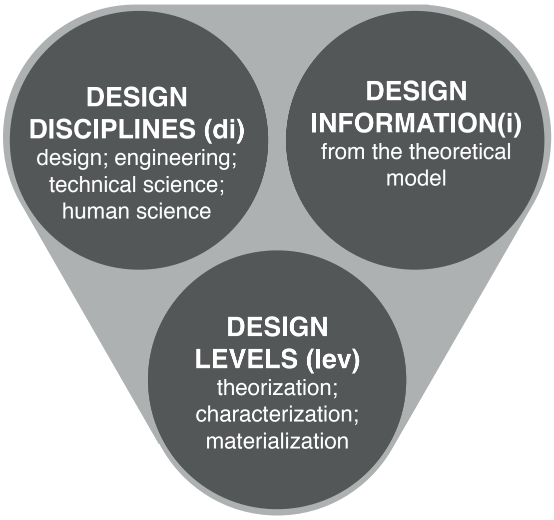


Figure 49: Experimentation 3: confront the three insights

This experimentation allowed us to oppose and play with the three components described by the literature review, as presented in Figure 49.

4.4.1 Objectives

The objective of this experimentation is to develop a tool to support the use of metaphors in early design.

Following the previous two experimentations, we formalized the link between user experience and interaction, and highlighted the influence of the three dimensions(d) on the design information(i), pointing out that the notions of target(d) and source(d) influence the way we experience interactions. Based on that, this experimentation focuses on the way we can use this metaphorical approach for designing interactive products.

We need to understand how metaphors can be used as a strategy for designing using the physical and digital paradigms; on which level(lev) (why, what, and how) the use of metaphors for designing interaction is most appropriate; and what design information(i) is tackled by the use of metaphors within the interaction design scope.

In this way we can strengthen and formalize an understanding of metaphor within the interaction design scope. This could be of value for researchers in the field of cognitive psychology, emotional engineering, Kansei design, and user experience research and industrial designers working on products, user experience and interaction design.

4.4.2 Method

To achieve the above objectives, an experimentation was set up to test metaphors' specificities and design information(i) tackled on the three design levels(lev) during the generative phase. Thus, a tool was developed, focusing on metaphors' physical and digital properties. This tool aims at representing sources that can be used to improve or create different targets within the scope of interaction design. This experimentation was divided into three phases, as presented in Table 21

1. Define the tool (workshop): This phase aimed at defining what kind of information does the tool (the sources) need to be composed of in order to support the creation of interactive products through metaphors.

2. Test and improve the tool (workshop): This phase aimed at improving and calibrating the tool (the sources).

3. Evaluate the tool (evaluations): This phase aimed at evaluating the tool specificities and relevance. Additionally, it aimed at describing the design information(i) tackled by the tool.

Thus, phases 1 and 2 aim at formalizing the tool, which is finally evaluated in the third phase. These two phases are explained in the following section.

4.4.3 Protocol

As illustrated in Table 21, this experiment was divided into three phases. The first and second were dedicated to the creation and improvement of the tool, while the last phase was dedicated to the evaluation of the tool.

4.4.3.1 Preliminary Studies before Experimentation

1. Define the tools: In this phase, we organized a workshop, lasting four and a half hours, where six participants worked on "what a metaphorical source should look like to support the different generation phases". This workshop was composed of three steps:

• The first step was dedicated to the understanding of metaphors (see Figure 50). It consisted of explaining and presenting metaphors.

• The second step was an understanding of the three design phases: Theorization, characterization, and materialization. This step was based on a presentation using examples, and the definition of the three design phases.

• The last step consisted of defining a format, content, example(s), and a rhythm for each tool (Theorization(lev), Characterization(lev), and Materialization(lev)). Additionally, we selected six sources to formalize the tool: "Chameleon"; "Time control"; "Plasticine"; "Mind control"; "Spider-Man" and "Ctrl+c/Ctrl+v".

A summary of what was discussed in this first phase is presented in Table 21. Based on these inputs, that can be considered as guidelines, we formalized a first version of the metaphorical approach.

2. Test and improve the approach: Based on the first formalization of the tools, we organized three workshops of two people in order to test and improve the tools. These three workshops lasted three hours each. These workshops were divided into five steps, as presented in Figure 51.

• The first step was dedicated to an understanding of the metaphorical approach (definition and examples).

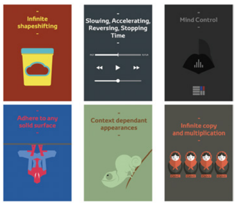
		WHY-theorization	WHAT-characterization	HOW-materialization
-1- Define	Format	Collective; small & flat cards	Digital for interactive system; 2 or 1 person	Customizable tool where you can add things
	Content	Keywords + representation;	Narration; Action verb	Static & dynamic properties
	Example	Abstract representation	3 steps scenario; story board; Video & Gif	« Like sources »
	Rhythm	Quick like 1 or 2 minutes	30 min/ interaction; 3 to 5 concepts	Hours & hours for real materialization
	Formalization of the first version of the tool			
-2- Test and improve	Format	-Cards could be a bit bigger; Duplicate the version for big screen; Need more metaphors		-Empty box to create your own composition -Make the boxes more open, more visible (transparency)
	Content	-Bigger word for more focus on properties -Cards 'time stopping' & 'Mind control' have to be easier to understand -Cards to propose your own metaphor	-Only Gifs and keywords -Hierarchy of Gifs +/- 6 gif per source -Keywords in bigger -Color is important, but not too much colors	-Add more senses
	Example		-Gif not in loop, but one by one (play mode) -Gif example have to be more concrete(more product related)-Keywords could be separated?	-Examples are too close from the source(too literal)-Add feedback (light; sound... etc...)
	Rhythm		-Rhythm could be improvedif designers could choose which gifplays, and if they could stop it.	-Could be alone or in group
	Formalization of the second version of the tool			
-3- Evaluate the impact	-EXPERIMENTATION ITSELF-			

Table 21: Table of preliminary workshop

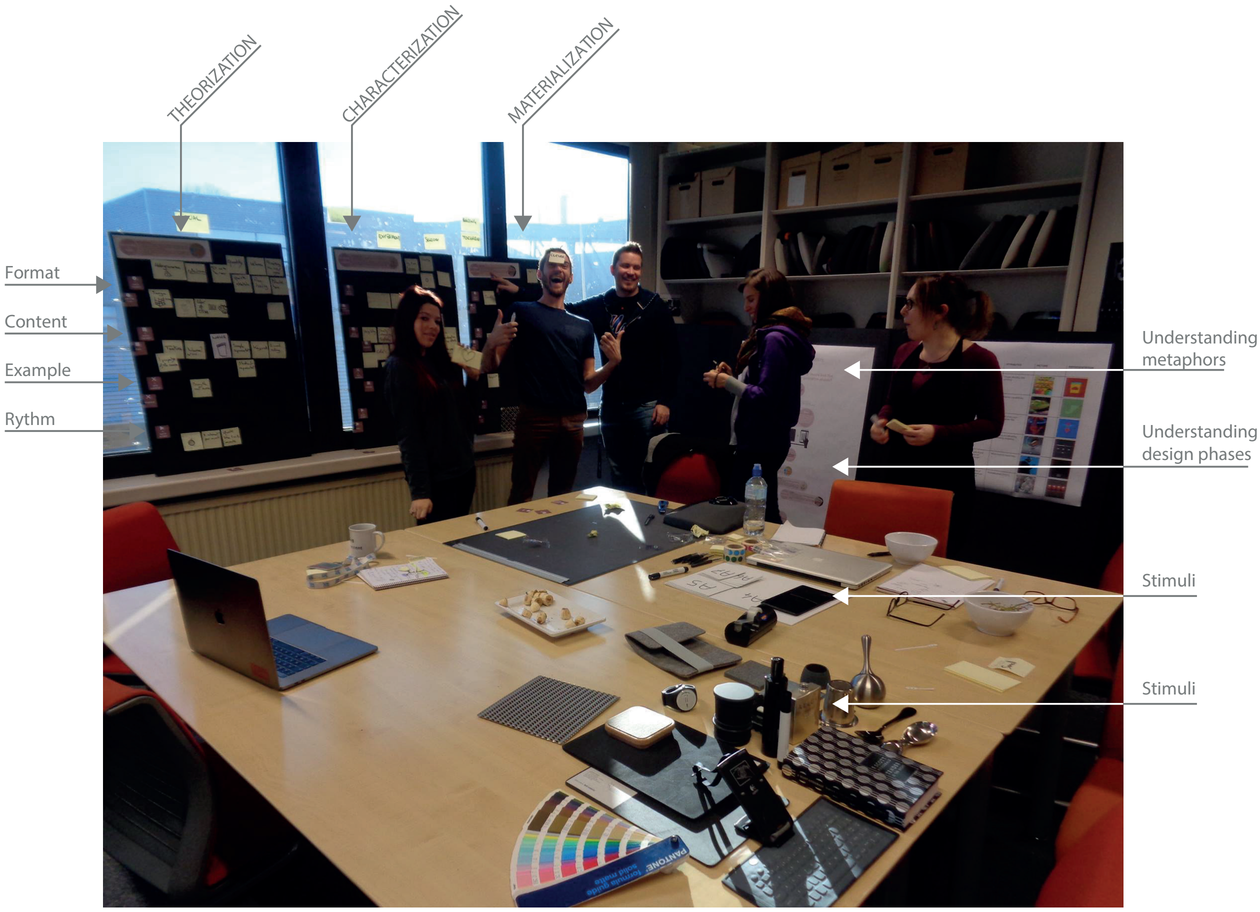


Figure 50: Workshop 1 defining the tool

• The second step was focused on an understanding of the three design levels (theorization(lev), characterization(lev), and materialization(lev)).

• The third step was a presentation of the formalized tools that participants would have to use and evaluate.

• The fourth step was dedicated to the use of the tools. It was based on three different design challenges, at three different stages of the design process. The first challenge was simple idea generation, focused on cars' lighting and pedestrian recognition. The second challenge was oriented at idea improvement and concept creation. It was based on an idea of gesture interaction between the user and a car's HVAC (system to increase and decrease temperature and air inside the car). Finally, the last design challenge was the materialization of a

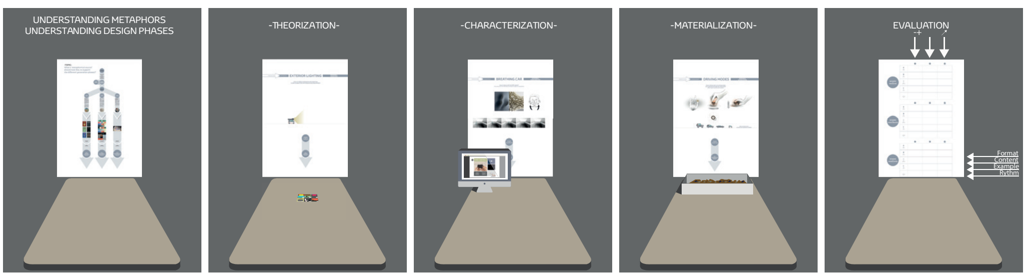


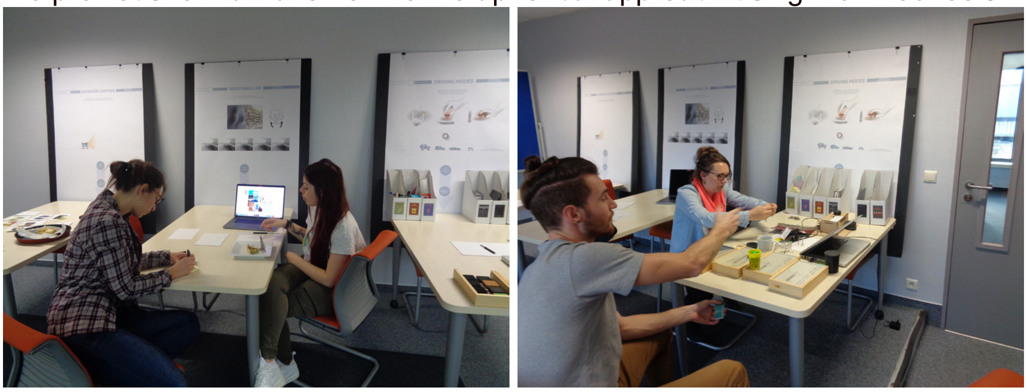
Figure 51: Test and improve the tool in five steps

concept, based on driving modes and how to change driving modes inside the car. Based on these design challenges, participants created solutions with the tools.

• The fifth step was the evaluation of the tools themselves. A table was used to evaluate the format, the content, the examples, and the rhythm according to negative points, positive points, and the scope of improvement. The results of this workshop are presented in Table 21.

Based on these feedbacks, a new version of the tools was formalized. This second version of the tools is presented in Table 21.

3. Evaluate the metaphorical approach impacts: This third phase is described as the experimentation itself in the following sections. It starts with the previous formalization of the metaphorical approach using the three tools.



Picture 3: Workshops conducted with designers to test the tools

4.4.3.2 Support Material of the Experimentation 3

The Tools

The three formalizations extracted from the two previous phases were used as the input of this phase. As presented in Table 21, the three formalizations aim at presenting the six sources (Chameleon; Time control; Plasticine; Mind control; Spider-Man; Ctrl+c/Ctrl+v) according to three different design phases (Theorization(lev), Characterization(lev), and Materialization(lev)). The tool dedicated to the Theorization level consists of a set of cards composed of “properties” and a simple representation. The tool for the Characterization level consists of an interactive PDF composed of “Gifs” (short videos without sound) and “keywords”. The Materialization tool is a box of products and samples related to labels. These three formalizations of sources are the focus of this experimentation.

The Preliminary Workshops Outcomes

In this experimentation we used the preliminary outcomes from the workshops as input of this evaluation. Indeed, in order to show the kind of results that were created in terms of forms and contents, we displayed the different creations from the preliminary workshops on the vertical boards. For the Theorization and Characterization levels, these creations consist of drawings. However, for the

Materialization level, they consisted of drawings, pictures, and videos (sound oriented). The boards present both the outcomes of the workshops and the initial design challenges on which outcomes were based. Belows we present the types of result that were displayed (see Figure 52).

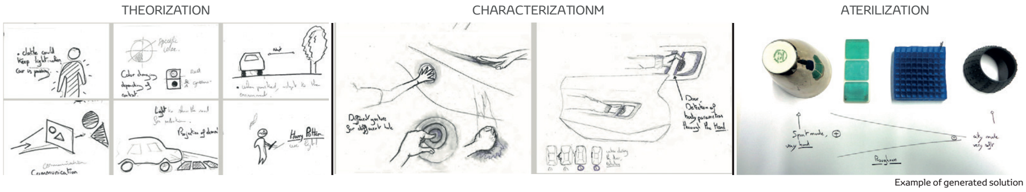


Figure 52: Examples of the collected outputs of the previous workshops

The Survey
The survey was presented online, hosted by Typeform (www.typeform.com). It consists of five parts, formalized into five tables, as presented in Figure 53. Table 22 summarizes these tables.

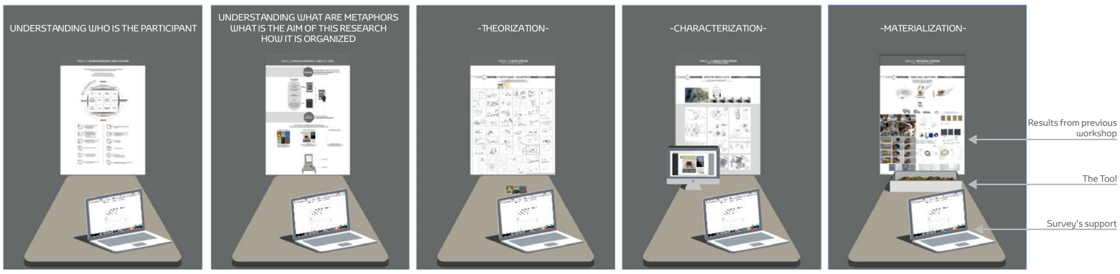


Figure 53: Evaluation of the tool: the survey

	Part 1 - Table 1			Part 2 - Table 2	Part 3, 4 and 5		
Question	As a member of Toyota Motor Europe, you are:	Which is (are) the discipline(s) related to your activities in Toyota motor Europe?	Through your activities, which design information are you tackling?	In this example, is this interaction using a specific source?	Would you say that this tool tackles the design information of « … »?	Would you say that this tool helps to create many alternatives?	Would you say that this tool helps to create rich and meaningful alternatives?
Reference		Moggridge (2006)	Mahut (2017)		Mahut (2017)	Mahut (2017)	Mahut (2017)
Answers	-Engineer -Designer -Ergonomist -Product planner	-Design disciplines -Human science disciples -Engineering disciplines -Technical science disciplines	Each design information box from the theoretical model (name of the box+ definition+ examples)	-No it is not -Yes probably using a source like 'a shaker' -Yes probably a source like 'a Pen'. Boxes to tick	Each design information box from the theoretical model (name of the box+ definition+ examples)	From a general point of view on the tool	From a general point of view on the tool
How	Boxes to tick	10 point Likert scales	7 point Likert scales		7 point Likert scales	7 point Likert scales	7 point Likert scales

Table 22: Architecture of question

TABLE 1: The first part aims at understanding who the participant is
As TME members, was he/she an engineer, designer, product planner or ergonomist? Answers were collected with a simple box to tick. The second question aims at understanding which discipline is related to his/her activities. For that, we used the four design disciplines(di) presented by Moggridge (2006): “Design disciplines(di)”; “Human science disciplines(di) ”; “Engineering disciplines(di)”; and “Technical Science disciplines(di)”. Answers were collected using 10- point Likert’s scales. The goal of the question was to give participants the opportunity to describe their disciplines differently than merely stating their backgrounds. For example, someone could describe his or her discipline as 70% “Design disciplines(di)” and 30 % “Human Science disciplines(di) ». The last aim was to be able to map participants’ activities on the theoretical model of design information(i) (see Figure 15). To do so, we listed and defined the design information(i) boxes one by one. Each box was linked to a 7-point Likert scale. We asked participants which design information(i) they were tackling in their activities. The three questions on backgrounds, disciplines, and activities were thus used to understand the participants as precisely as possible.

TABLE 2: The second part aims at presenting metaphors and the aim of this research
The second table presented the definition and an example of what metaphors are in interaction design. This table also presented the aim of this study (represent and use sources in interaction design), and how the survey is organized. In order to test participants’ understanding of metaphors, two questions based on two case studies were posed. Based on 30-second videos, participants were asked to choose between three answers what could be the source used in two examples.

TABLE 3: The third part aims at evaluating the Theorization tool
The third table presents the tool, and the results from the preliminary workshops. The aim for the participant is to evaluate what he/she thinks the tool could help him/her to work on (on the theorization level). To map what it could help to work on, we used the theoretical model of design information(i) (see Figure 15). Based on the 12 boxes, we displayed one question per box: “Would you say that this tool tackles the design information(i) of …?” After covering the 12 boxes with the same question, we asked the participants to judge whether this tool (here at the Theorization level) could produce many alternatives (quantity notion), and whether it could bring rich and meaningful alternatives (quality notion).

TABLE 4: The fourth part aims at evaluating the Characterization tool
This part is the same as the third part. The questions were the same, but it was dedicated to the Characterization level.

TABLE 5: The fifth part aims at evaluating the Materialization tool
This part was the same as the third and fourth parts. The questions were the same, but it was dedicated to the Materialization level.

The order of tables 3, 4 and 5 was affected to participants according to a randomised methodology. By doing so, we reduced the impact of habit, discovery, or lassitude that can distort evaluations. The 6 Serials that were affected to participants is presented in table 23.

Serial 1	3,4,5	7 Participants	2 Designers	3 Engineers	1 Ergonimist	1 Product Planner
Serial 2	4,5,3	7 Participants	2 Designers	3 Engineers	1 Ergonimist	1 Product Planner
Serial 3	5,3,4	6 Participants	2 Designers	2 Engineers	1 Ergonimist	1 Product Planner
Serial 4	5,4,3	6 Participants	2 Designers	2 Engineers	1 Ergonimist	1 Product Planner
Serial 5	3,5,4	6 Participants	2 Designers	2 Engineers	1 Ergonimist	1 Product Planner
Serial 6	4,3,5	6 Participants	2 Designers	3 Engineers	0 Ergonimist	1 Product Planner

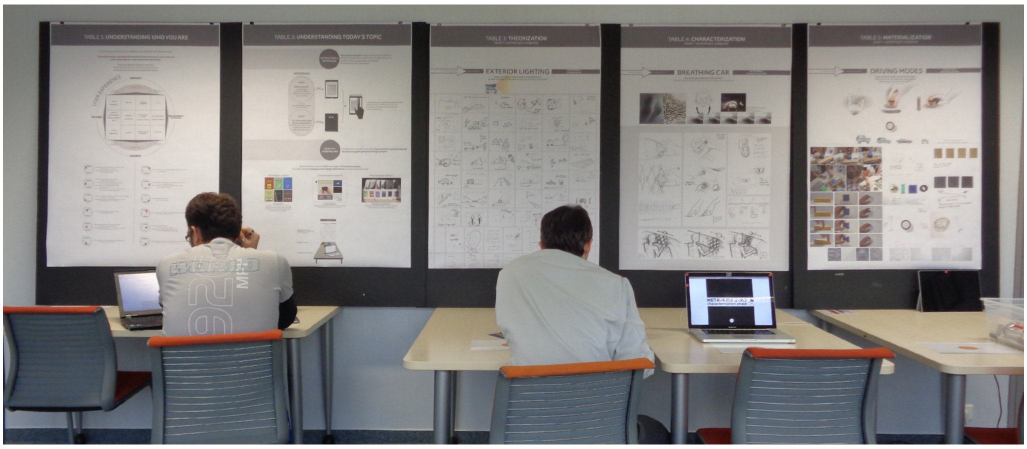
Table 23: Serials

The Panel

A total of 38 participants completed and submitted the survey. These participants were TME members involved in product development. This limited scope of participants (only TME members) is due to the confidentiality of the data showed. Among the participants were people from different divisions such as Ergonomic, Advanced Technology, Concept planning, Electronics, Kansei Design, Material Engineering, Body Design, and Vehicle Performance. They have backgrounds in engineering, design, product planning, and ergonomics. Twenty-four males and fourteen females completed the entire survey.

4.4.3.3 Data Analysis and Processing

The procedure presented previously allowed the collection of 38 fully completed surveys. The collected surveys provided data on participants' disciplines and the metaphorical approach in terms of design information(i) (the tool at its three levels: theorization; characterization and materialization). The collected data are analyzed and discussed in the following sections (see Picture 4 of two participants completing the survey).



Picture 4: Two participants completing the survey

4.4.3.4 Results

The collected data was analyzed according to four different parts, following the experimentation's objectives. These parts are represented in Table 24. Thus, four elements were analyzed as follows:

1- Understanding and formalizing a vision of **design disciplines(di)** and what **design information(i)** (from the theoretical model) **each discipline** is tackling. This is presented in section 4.4.3.4.1

2- Understanding and formalizing the impact of the **design levels(lev)** (theorization, characterization, and materialization) on the different **design information(i)** (from the theoretical model). It is presented in section 4.4.3.4.2

3- Correlating the **design disciplines(di)** to the three **design levels** in order to highlight and formalize reciprocal impacts. It is presented in section 4.4.3.4.3.

4- Comparing the **design information(i)** tackled by **design disciplines(di)** in everyday activities to **design Information(i)** tackled by design disciplines at the three **design Levels**, in order to highlight the benefit of the metaphorical approach. It is presented in section 4.4.3.4.4.

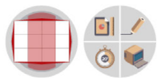
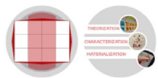
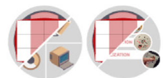
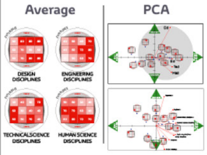
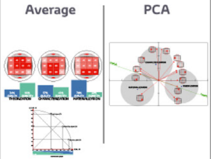
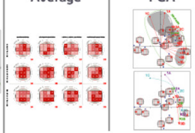
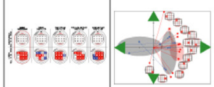
Section	4.4.3.4.1	4.4.3.4.2	4.4.3.4.3	4.4.3.4.4
Input data	 Design Information, Design Disciplines	 Design Information, Design Levels	 Design Disciplines, Design Levels	 Result 1, Result 2
Analysis method	Average, PCA 	Average, PCA 	Average, PCA 	Average, PCA 
Highlight	SCOPE OF TACKLED DESIGN INFORMATION PER DISCIPLINE	SCOPE OF TACKLED DESIGN INFORMATION PER DESIGN LEVEL	THE TOOL SCOPED DISCIPLINE PATH	THE TOOL VALUE PER DISCIPLINE

Table 24: Section organization

4.4.3.4.1 Design Disciplines(di) and Design Information(i)

"Part 1" in Table 22 allows the collection of data according to participants' **design disciplines(di)** and the **design information(i)** tackled by their activities. These data were used to calculate a weighted average. To do so, we used the results of the **design discipline's scales(di)** (four scales from 1 to 10 to assess what participants are working on in terms of disciplines; see Table 22 for more details) to put weight on **design information(i)** answers. For example: 1) a participant working on engineering discipline(di) at 8 on 10 (80%), and 2) his or her activities are tackling the **design information(i)** of "value and personality" at 4 on a 6-point scale (66,6%), leads to 3) (discipline(di) answers x design information(i) answers)/ total discipline(di) answers.

Thus, an average of all **discipline(di)** answers allows the formalization of a color map of what each **discipline(di)** is tackling in terms of **design information(i)**. The figure presents the color maps (see Figure 54).

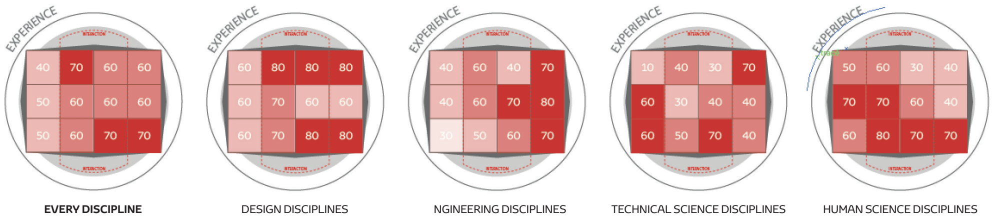


Figure 54: Design Disciplines(di) and Design Information(i) results

The results are expressed in percentages. Colors were applied in order to highlight which **design information(i)** box was more tackled by the **discipline**. According to these results, we can see that disciplines in TME are more focused on the right parts of the model ("Every discipline" map) (with for example, an average of 70% on the right part of the model). For a car manufacturer, this was expected. We can also state that the three most tackled aspects of **design information(i)** are "emotions" (70%) (very abstract related to the user), "attributes" (70%) and the "static/dynamic properties" of the product (70%) (very concrete **design information(i)**). From a **discipline-related(di)** perspective, we can see that **design disciplines(di)** link high and low levels of abstraction. Furthermore, we can also state that it is more related to the right of the model: to the product side. Engineering disciplines(di) are very close to the product, in both abstract and concrete **design information(i)**. Furthermore, engineering disciplines(di) also tackle the "action enable" (70%) box of **design information(i)**. Technical science disciplines(di) seem to use the user experience approach to tackle user's design information(i), "static and dynamic properties" of the products (70%), and even "style" (70%) design information(i). Finally, the human science disciplines(di) tackle both the user's and the product's design information(i) on concrete and middle-concrete notions.

Thus, we used the data to formalize what design information(i) is tackled by the **design disciplines(di)** in TME (Figure 54).

Furthermore, we also used the data to map the **design disciplines(di) and design information(i)** using a PCA (see Figure 55). Figure 55 displays the four design disciplines(di) (variables) and the 12 **design information(i)** boxes (observation labels), as presented in table 25. Based on this mapping, and based on how the different design information from the theoretical model were displayed, two axes were interpreted to explain the organization of the data: The vertical axis sorts the data from more abstract (Style; Emotion, Semantic and Value & Personality), to more concrete (Gesture & Movement; Culture...) **design information(i)** and the horizontal axis sorts the data from user-oriented (Culture; Value and Personality...) to product-oriented (Product attributes; Style; Static & Dynamic Properties...) **design information(i)**. Based on how the different disciplines in TME are organized according to the two axes, we can draw the scope of **design disciplines(di)** within TME. As we can observe

	Values & Personality	Lifestyle; Past Experience...	Culture & Morphology	Emotions	Behavior & Motivation	Gesture	Semantic Descriptor	Action Enable & Temporal Context	Static & Dynamic properties	Style	Sector of Object & Physical Context	Product's Attributes
Design Disciplines	57,9	59,1	52,1	77,9	69,0	65,1	74,2	66,8	76,9	77,0	63,3	77,3
Human Science Disciplines	47,0	57,9	51,0	67,3	65,6	65,2	50,0	63,6	72,8	60,4	58,1	77,5
Technical Science Disciplines	36,0	50,9	46,9	63,4	53,3	53,4	45,8	59,5	66,7	59,2	54,8	61,3
Engineering Disciplines	40,9	49,4	41,3	66,5	59,7	56,1	49,6	66,2	66,0	67,0	66,3	73,0

Table 25: Data used for PCA

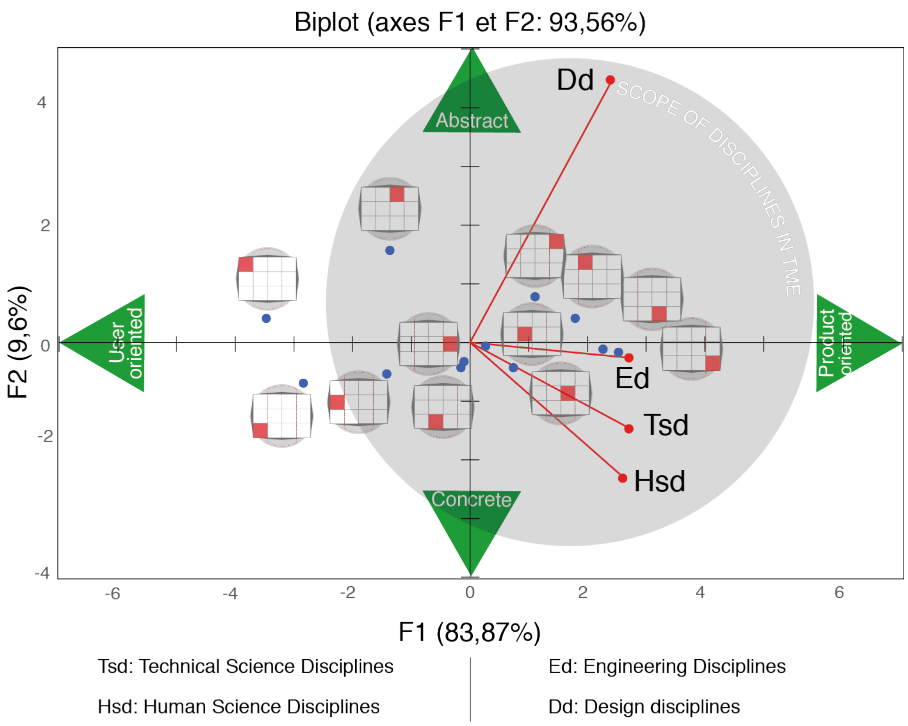


Figure 55: PCA of the different disciplines

on the figure 55, the scope (in grey) seams more oriented toward the product (right side of the horizontal axis) than the user. Furthermore, we can also see that the **design disciplines(di)** are more oriented toward abstract **design information(i)** than other disciplines.

The data were also used to formalize another PCA (see Figure 56) in order to map **design disciplines(di)** and participant backgrounds (variables) according to the **design information(i)** tackled in their everyday activities (observation labels), as presented in table 26.

		Values & Personality	Lifestyle; Past Experience...	Culture & Morphology	Emotions	Behavior & Motivation	Gesture	Semantic Descriptor	Action Enable & Temporal Context	Static & Dynamic properties	Style	Sector of Object & Physical Context	Product's Attributes
DISCIPLINES	Design Disciplines	57,9	59,1	52,1	77,9	69,0	65,1	74,2	66,8	76,9	77,0	63,3	77,3
	Human Science Disciplines	47,0	57,9	51,0	67,3	65,6	65,2	50,0	63,6	72,8	60,4	58,1	77,5
	Technical Science Disciplines	36,0	50,9	46,9	63,4	53,3	53,4	45,8	59,5	66,7	59,2	54,8	61,3
	Engineering Disciplines	40,9	49,4	41,3	66,5	59,7	56,1	49,6	66,2	66,0	67,0	66,3	73,0
BACKGROUND	**Designer**	**64,1**	**61,5**	**55,1**	**79,5**	**70,5**	**66,7**	**87,2**	**70,5**	**84,6**	**85,9**	**65,4**	**75,6**
	Engineer	**32,3**	**51,0**	**52,1**	**61,5**	**54,2**	**58,3**	**40,6**	**64,6**	**71,9**	**53,1**	**46,9**	**59,4**
	Ergonomist	**33,3**	**50,0**	**58,3**	**75,0**	**66,7**	**91,7**	**33,3**	**50,0**	**58,3**	**25,0**	**8,3**	**83,3**
	Product Planning	**43,8**	**47,9**	**27,1**	**47,9**	**56,3**	**39,6**	**41,7**	**54,2**	**41,7**	**56,3**	**79,2**	**66,7**

Table 26: Data used for PCA

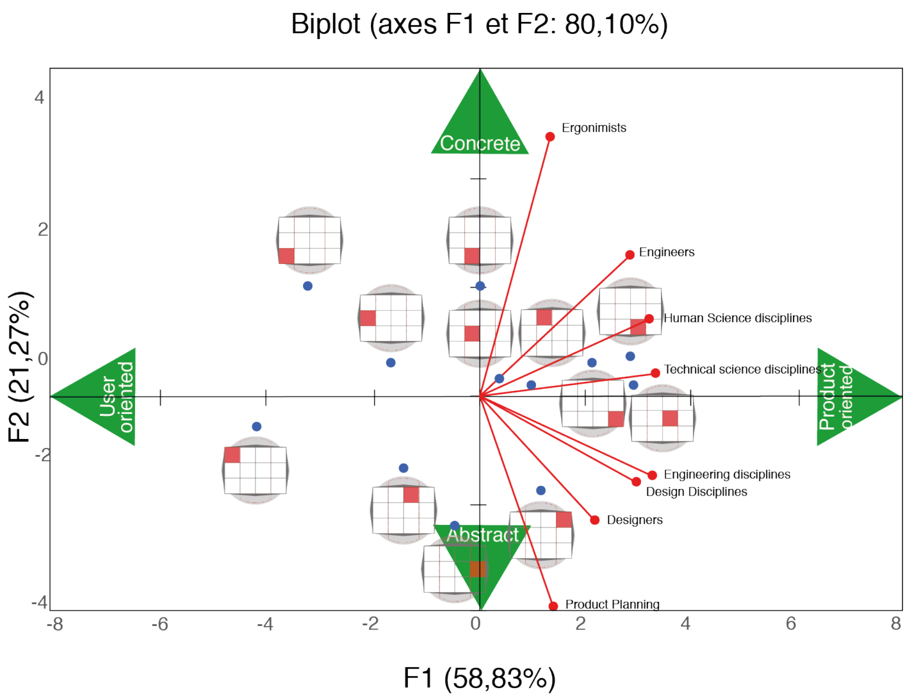


Figure 56: PCA of the different disciplines and participant's backgrounds

As we used the same observation labels (design information (i)) but with different variables, we obtained a mapping were the design information (i) were displayed like on the figure 55. Thus, we used the same axis to explain this mapping. According to this mapping, links between participant backgrounds and **design disciplines(di)** were formalized. For example, it can be seen that designers are very close to **design disciplines(di)** and **design information(i)** such as "style", "action enable" and "attributes of the product", whereas, on the other hand, engineers are not that close to engineering disciplines(di). Instead, it seems that engineers at TME encompass other disciplines such as Human Science Disciplines(di) and Technical Science Disciplines(di). Finally, ergonomists and product planners are far from the rest of the disciplines(di). This may be explained by the fact that participants have only one background name (designer, engineer, ergonomist) but may in reality belong to more than one design discipline(di) that describes their activities. Finally, when looking the two PCAs, the top scores in percentage (93.56% on the left and 80.10% on the right) highlight that using the backgrounds when analyzing the data brings more variance. Thus, the way participants described their work through disciplines perspective seams more accurate than using their background.

4.4.3.4.2 Design Levels(lev) and Design Information(i)

Parts 3, 4 and 5 in Table 22 allows to collect information on the three different design levels (Lev). As presented in Table 22, different questions were submitted to participants. 12 questions, according to each design information were first of all displayed; and 2 questions (one on the number of alternatives the tool helps to create; and one one the quality and the meaningfulness of idea generated thanks to this tool) were submitted to understand the quantity and quality of alternatives the tool helps to create.
Based on questions with 7 point scales answers, we made first an average of participants answers, and translated this average into percentage. It led us to formalize which design information(i) the metaphorical approach is tackling (see Figure 57) for each design level (Lev). The general vision (model on the left in Figure 57) presents, from a broad perspective, the metaphorical approach allowed, based on an average of the different design levels (Lev).

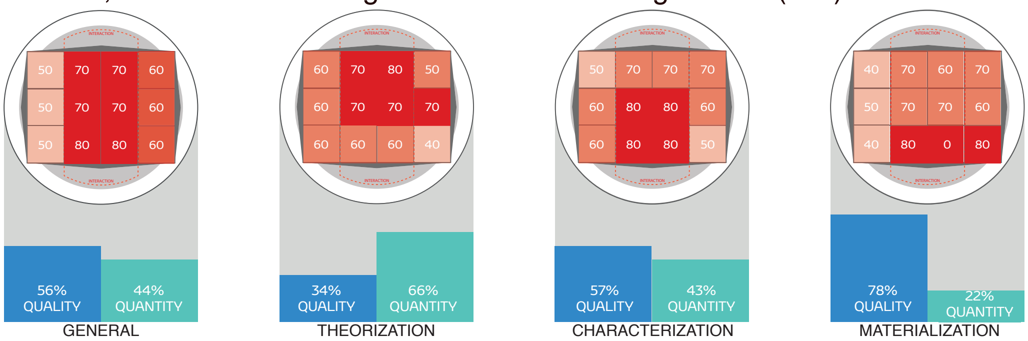


Figure 57: Design levels(lev) and Design Information(i)

According to this representation, we can see that the two central columns seems to be more often tackled by the approach than the rest. These columns are realted to “reaction of the user” and “product perception” (see figure 15)

Thus, the metaphorical approach covers interaction-related **design information(i)**, from abstract to concrete **design information(i)**. Furthermore, the approach also seems to tackle more often the product’s characteristics than the user’s characteristics.

Finally, three models were formalized to represent the three **design levels(lev)** (see Figure 56): Theorization; characterization and materialization. These formalizations result in an analysis of the **design levels(lev)** and the **design information(i)**.
Three types of data were used for this investigation:

1. Which design information(i) is tackled by each tool;
2. The notion of quality of given alternatives; and
3. The notion of quantity of given alternatives.

These three types of data allowed formalizing Figure 57.

Based on these representations, we can see that the tool on the theorization level(lev) is tackling more abstract **design information(i)**. It appears that the **design information(i)** of "semantic descriptors" is the most important one here. The tool on the characterization level(lev) covers **design information(i)** that is interaction-related in the middle of the model. Furthermore, it covers both abstract and concrete **design information(i)**. Finally, the tool on the materialization level(lev) is oriented towards concrete elements such as "gesture and movement", "static and dynamic properties" and "attributes" of the product. In addition, the data corresponding to quality and quantity of alternatives that can be designed are also represented. The balance between quality and quantity in terms of percentage was formalized as a column (see Figure 57).

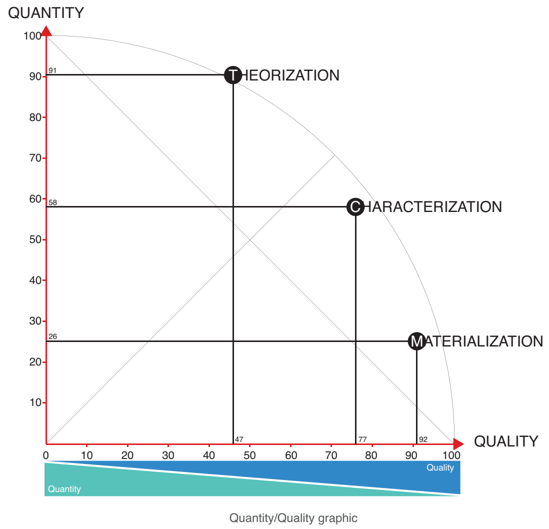


Figure 58: Design Levels(lev) and the link between quality and quantity

To better understand the link between quantity and quality in terms of the three **design levels(lev)**, the data extracted from the surveys (scales from 0 to 6 converted to percentages) were used to map the **design levels(lev)** on two axes. Figure 58 represents the result. The Theorization level, for example, has been related to 91% in quantity; and 47% in quality (but we can also consider the link between quality and quantity as a single measure, where : 91% + 47% = 138% can also be noted as 66% + 34% = 100%, as presented in figure 57.

We can see that the theorization level(lev) is more oriented toward quantity than quality. The characterization level(lev) is more balanced, even if quality predominates over quantity. Finally, on the materialization level(lev) quality was assessed as having a greater impact than quantity. These three design levels punctate the design process.

To better understand how the different **design levels(lev)** tackle the **design information(i)**, we used the data presented in table 27 to perform a PCA (see Figure 59). We used as variable the different design levels (Lev) and as observation labels the different design information. We inverted this PCA (compared to the others) in order to map the design information (i) according to the three design levels (Lev).

This PCA was just performed to map the results, not to validate anything.

	Values & Personality	Lifestyle; Past Experience…	Culture & Morphology	Emotions	Behavior & Motivation	Gesture	Semantic Descriptor	Action Enable & Temporal Context	Static & Dynamic properties	Style	Sector of Object & Physical Context	Product's Attributes
THEORIZATION	57	58	61	70	70	65	80	71	58	48	67	45
CHARACTERIZATION	47	58	56	65	79	80	68	80	84	70	64	51
MATERIALIZATION	40	50	45	66	70	82	64	68	92	72	58	77

Table 27: Data used for PCA

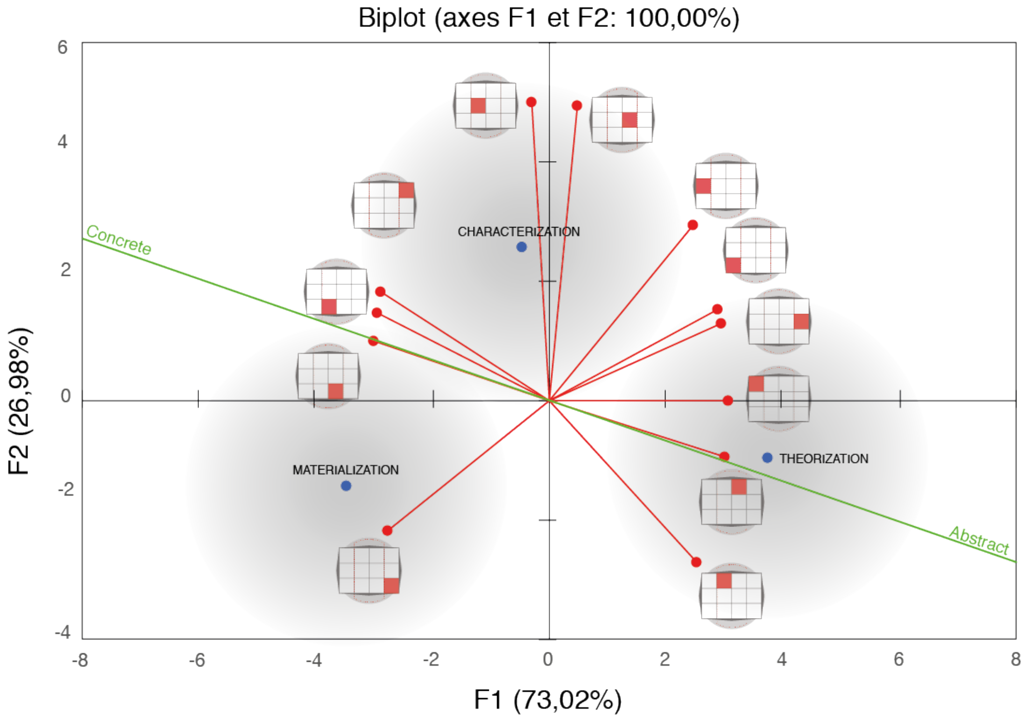


Figure 59: Mapping of the three levels(lev) and the design information(i)

Indeed, a PCA with only three observations is not representative. This is why we finally collected a PCA with 100% (F1+F2). This PCA presents the three design levels(lev), and the 12 **design information(i)** that were mapped. This representation shows that some **design information(i)** are very oriented towards one **design level(lev)**. For example, the theorization level(lev) is very close to the design information(i) “semantic descriptor”. However, some design information(i) is further, or more in-between two **design levels(lev)**. For example, “user’s past experiences” or “user’s culture and morphology” are in between, and somehow out of the scope of the theorization and characterization levels(lev).

4.4.3.4.3 Design Disciplines(di) and Design Information(i) from Design Levels(lev).

Using the collected data, each design level(lev) was assessed by each **design discipline(di)**. Thus, this data can be used to point out which **design information(i)** is tackled by each **design discipline at each design level(lev)**. Figure 60 presents these results, expressed as percentages. There are many differences that can be highlighted. For example, when looking at the theorization level, we can clearly see how each design discipline(di) tackles different design information(i). When the design disciplines are focused on abstract notions such as "semantic descriptor", engineering disciplines(di) are more oriented towards concrete dimensions such as "gesture" and "action enable". Furthermore, technical science disciplines(di) tackled through the theorization level(lev) are very oriented on user **design information(i)**, whereas human science disciplines(di) tackle "product semantic descriptor" and "product sector of object".

Thus, these data are of value for highlighting which design disciplines(di) are focused on at every **design level(lev)**.

Based on these data, a PCA was formalized in order to map every result presented in Figure 60. To do so, every result was given a number and a letter, as can be seen in Figure 60. We used these associations of number+letter as variables, and the different purcentage of design information as observation labels.Thus, this PCA is based on 12 variables (1A, 1B, 1C, 1D, 2A, 2B, 2C, 2D, 3A, 3B, 3C, 3D; and 12 observation labels for the 12 design information(i) from the theoretical model.

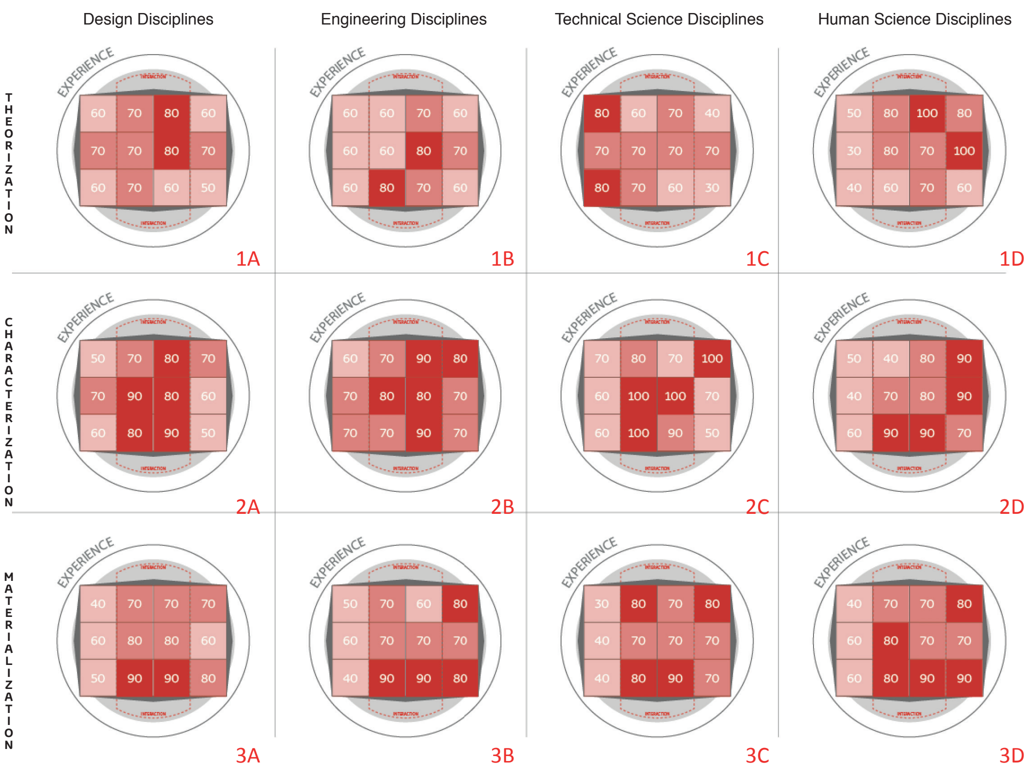


Figure 60: Design Disciplines (di) and Design Levels(lev) according to Design information

Biplot (axes F1 et F2: 73,14%)

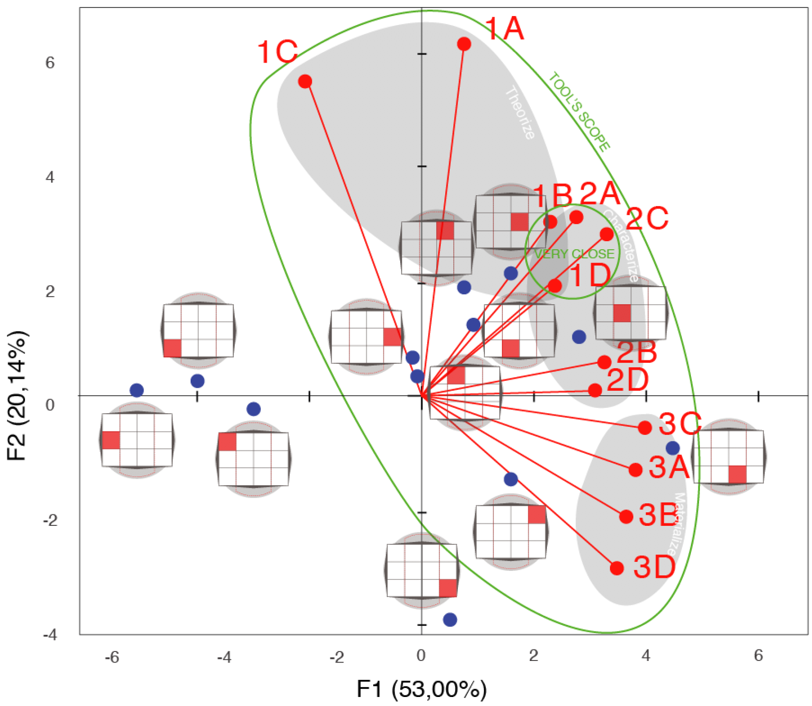


Figure 61: Different Design Levels(lev) combined with the Design Disciplines according to their impact in term of Design Information(i): mapping

Biplot (axes F1 et F2: 73,14%)

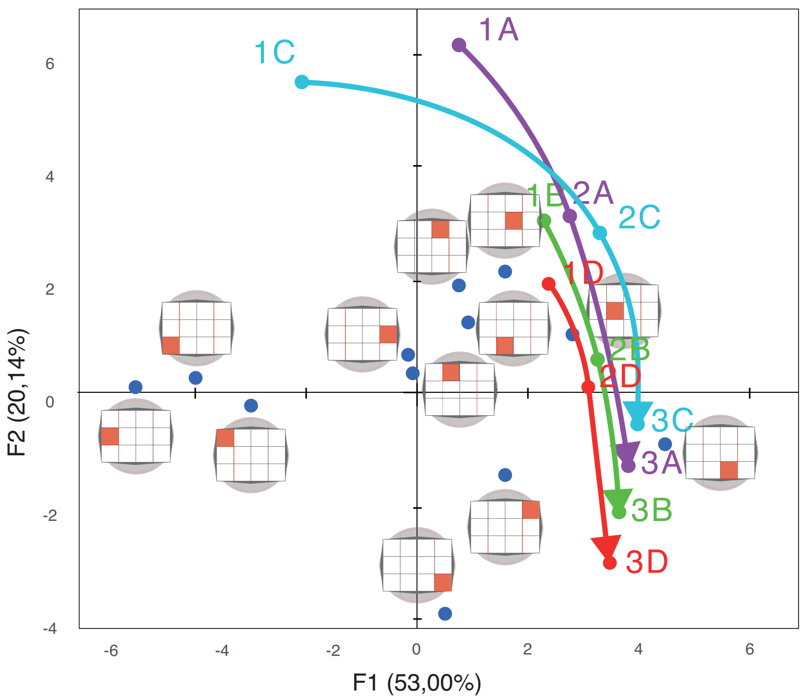


Figure 62: Different Design Levels(lev) combined with the Design Disciplines according to their impact in term of Design Information(i): mapping and trajectories

This resulted in the mapping of the different **design levels(lev)**, combined with the design disciplines according to their impact in terms of **design information(i)**. This result is presented in Figure 61.

The PCA highlights the scope of the metaphorical tool (green area) and the three **design levels(lev)** independently (grey areas). The mapping also shows that the theorization level(lev) and the characterization level(lev) overlap slightly. This is due to the fact that 1B, 2A, 2C, and 1D are very close. This means that engineering disciplines(di) and human science disciplines(di) work on the same kind of design information(i) at the theorization level(lev) as the design disciplines(di) and technical science discipline(di) do at the characterization level(lev).

From a broader perspective, we can see the scope of the tool, and the **design information(i)** that is not really in that scope ("user's characteristics" **design information(i)**).

Furthermore, we describe the different trajectories of Theorization(lev) (1); Materialization(lev) (2), and Characterization(lev) (3) based on the same PCA (see Figure 62). Figure 62 shows the three steps and their relation during generation phases. As we can see, the smallest trajectory is related to human science disciplines(di), and the longest corresponds to technical science disciplines(di) and design science disciplines(di), demonstrating that the broader scope of **design information(i)** belongs to these two disciplines.

4.4.3.4.4 Design Information(i) from the Design Disciplines(di) Perspective, Compared to Design Information(i) from the Design Levels(lev).

The data can also be used to compare the **design information(i)** that is usually tackled by the different **design disciplines(di)**, versus the design information(i) that is tackled by **design disciplines(di)** with the metaphorical approach. By so doing, we can highlight what **design information(i)** is tackled more often (increase or decrease) when using the metaphorical tool.

Thus, the two types of data were opposed: from one side by design disciplines with **design information(i)** from every activity (models in top of Figure 63), and from the other side by **design disciplines(di)** with **design information(i)** when using the metaphorical tool (using an average between the three **design levels(lev)**) (models in bottom of Figure 63). The comparison is presented in Figure 63. We highlighted in red the **design information(i)** that the metaphorical approach increases, and in blue the **design information(i)** that the tool decreases compared to the initial one.

These results were mapped with a PCA to show the differences between **design disciplines(di)** with or without the metaphorical tool, in terms of the **design information(i)** tackled. For this PCA, we used the design disciplines without (4 disciplines) and with the tool (4 disicplines) as observation labels; and the different design information (12 design information) from the theoretical model (percentage) were used as variables. The results are presented in Figure 64.

Based on this mapping, two axes were formalized in order to explain how results are displayed: One axis from "user-oriented" to "product-oriented" design information(i), and the other axis from "lower percentage" to "higher

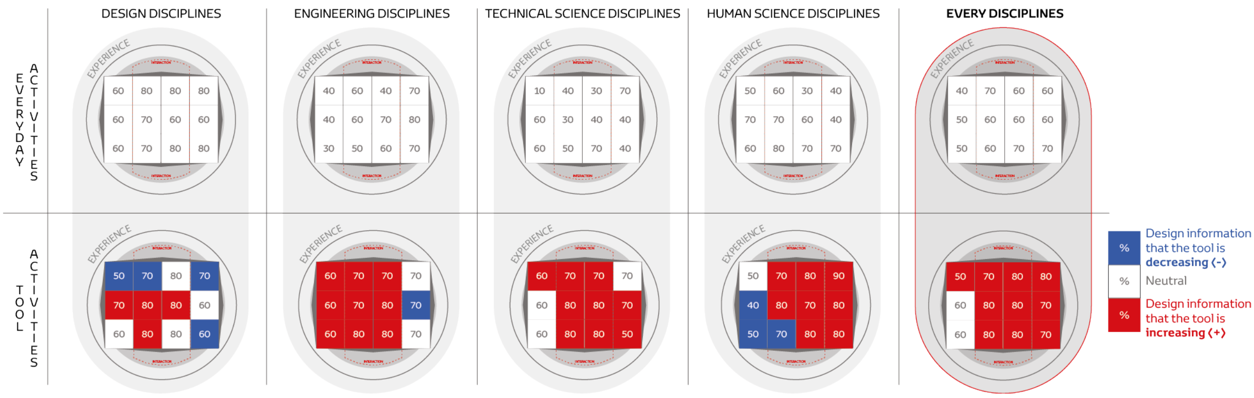


Figure 63: Design Disciplines(di) with Design information(i) from every activity, and Design Disciplines(di) with Design Information(i) when using the metaphorical appraoach

percentage" of **design information(i)** results. These axes show that the metaphorical approach allows each **design discipline(di)** to improve its **design information(i)** percentage. Furthermore, it shows that the design disciplines(di) have a smaller benefit. Indeed, as we can see, the gap between technical science(di), engineering(di), and human science(di) disciplines, with or without the metaphorical approach, is bigger than for the **design discipline(di)** with or without the metaphorical approach.

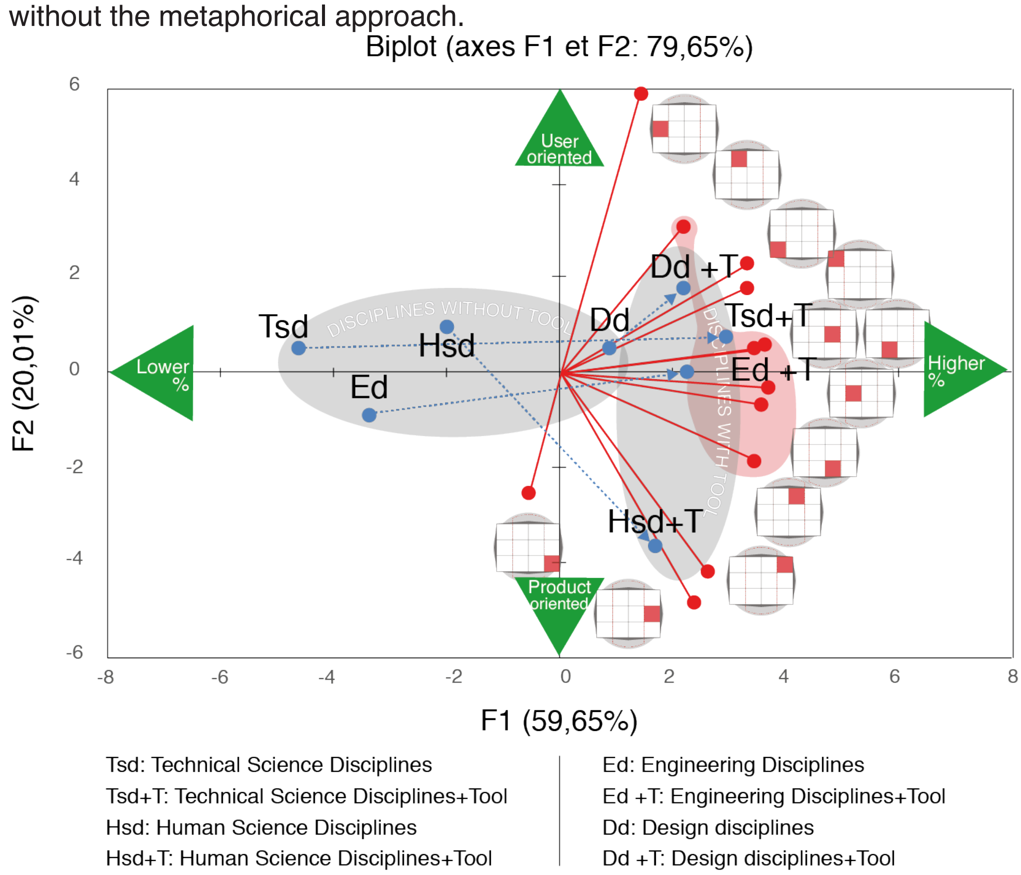


Figure 64: Design Disciplines(di) with Design information(i) from every activity, and Design Disciplines(di) with Design Information(i) when using the metaphorical appraoach: mapping

4.4.3.5 Discussion

Based on the previous results, we can describe two major axes: The first is related to the participant's disciplines(di), background and activities, and the second is related to the metaphorical tool in terms of the three design levels.

4.4.3.5.1 Disciplines, backgrounds and activities

The data we collected about participants resulted in an in-depth understanding of the connections between **design disciplines(di) and design information(i)**. Four elements elicited by the results can be highlighted.

Backgrounds and Design Disciplines(di)

Based on the previous results, the notion of **design disciplines(di)** presented by Moggridge (2006) is different from the backgrounds of participants that have been evaluated. According to our results, the **design disciplines(di)** approach is more valuable, because participants were free to describe what they really work on, instead of merely giving their job's name.

Design Disciplines(di) and Specificities

As shown in the figure on **design disciplines(di) and the design information's(i)** impact, each **design discipline(di)** tackles different **design information(i)** (see Figure 54). There are no good or bad people to involve in project development, only the right ones, at the right moment, depending on the **design information(i)** one is trying to obtain. The two axes proposed by the theoretical model can easily be used to distinguish **design discipline** values: The levels of abstraction (from abstract to concrete design information(i)) and the focus between user-oriented and product-oriented.

Multidisciplinary

The results prove the necessity of a multidisciplinary approach in early design. Indeed, in order to tackle the broader scope of **design information(i)**, it is more valuable to work with different **design disciplines(di)**, because **design disciplines(di)** do not tackle the same kind of **design information(i)**.

Design Disciplines and tools in general

According to our results, design disciplines use the same tool in different ways (see Figure 63). Even if our results are only dedicated to the metaphorical tool, they may be extended to other tools. It could be that the more a tool is related to abstract **design information(i)**, the more it is used in different ways by different disciplines.

Thus, the good participant is the right one. As discussed, the way we can choose participants to involve in a design team depends on the design information(i) we are looking for. This **design information(i)** is related to **design disciplines(di)**. Thus, when designing interaction, the **design disciplines(di)** have to be carefully selected depending on which **design Information(i)** one is trying to obtain.

4.4.3.5.2 Metaphorical Approach

This second part focuses on the metaphorical approach, and the formalized tools corresponding to the different **design levels(lev)**, in order to provide both a better understanding and some research territories to tackle. Five different points are discussed below.

The Scope of the Metaphorical Approach

As has been shown, designing using the metaphorical approach allows the employment of different **design disciplines(di)** (see Figure 60). From a broad perspective, the approach tackles mainly **design information(i)** listed in the two central columns of the theoretical model. Even if the balance shifts somewhat in favor of the product on the user/product axis, the results show that the metaphorical approach using the formalized tools focuses on interaction-related **design information(i)**. We can therefore say that we succeeded in formalizing tools for designing interactions using the metaphorical approach.

Design Levels(lev) and Design Information

According to results presented in Figure 57, the three design levels of Theorization(lev), Characterization(lev), and Materialization(lev) tackle different **design information(i)**. Indeed, as shown by PCA 59 (see Figure 59), the three **design levels(lev)** cover different spaces of **design information(i)**. Thus, going back to the initial question, “At which design level(lev) should we use a metaphorical approach to design interactions?”, the answer is: All of them. The **design levels(lev)** all tackle different **design information(i)**, leading us to assume that every **design level(lev)** is valuable. The only important thing when designing interaction and user experiences is to choose the right level in terms of what one is looking for.

Quantity/Quality

When looking at the quantity/quality opposition (see Figure 58), we can observe a very logical chain between the three levels, starting from the tool on the theorization **level(lev)**, poor in quality by high in quantity, to the highest in quality, but of very reduced quantity. This highlights the link between design **levels(lev)** and the design development process.

Levels of abstraction to differentiate Design Disciplines

It is interesting to see how design disciplines considered the tools at the three design **levels(lev)**, because the levels of abstraction are also a way to distinguish design disciplines. The more concrete example is how engineering disciplines at the theoretical **level(lev)** are close to design disciplines at the characterization **level(lev)**. This can be explained by the fact that they work on the same level of abstraction but at different design **levels(lev)**. Thus, the way people handle a tool depends on their design disciplines, and the level of abstraction is a valuable way to distinguish between design disciplines.

Tools' value

According to the results, it has clear that the metaphorical approach can be a valuable way to work on interaction-design information(i) (see Figure 64). We mapped how each design **discipline(di)** improves its **design Information(i)** with the support of the metaphorical approach. The results reveal that the metaphorical approach is valuable for every **design discipline(di)**. However, the discipline on which the improvement is the less important is the **design discipline(di)**. This can be explained by the fact that the metaphorical approach relies on abstract notions (see Figure 64). Even if different concrete **design information(i)** is tackled and improved in terms of the metaphorical approach, the biggest improvement is related to abstract notions. Furthermore, it has also been demonstrated that **design disciplines(di)** initially already tackle abstract **design information(i)**. Thus, it is logical that the smallest contribution of this tool is associated to **design disciplines(di)**. In parallel, the metaphorical approach improves the interaction-related **design information(i)** of every **design discipline(di)**. Therefore this approach allows participants to improve both abstract and concrete **design information(i)**. Additionally, we can see in Figure 64 that the biggest benefit is in respect of abstract **design information(i)**. It shows that the metaphorical approach helps generative design sessions to be more creative, and to be more oriented towards abstract notions such as emotions and the semantic description of products. This can be related to the "perceived Kansei qualities" presented by Gentner (2014) (pleasure, meaning and emotions).

Finally, the good **design level(lev)** is the right one. As discussed, the **design level(lev)** that needs to be considered when designing interaction depends on which **design information(i)** we are looking for. This way of thinking anchors **design levels(lev)** in the design process. Indeed, the design development of the interactive product implies different **design levels(lev)** that employ different **design information(i)**. Metaphors can be used to improve the way we design interactions from a user experience perspective. The three proposed formalizations of the tool employ different **design information(i)** that punctuates the development of interactions.

4.4.3.5.3 Limitations

Three elements have been highlighted as limitations of this research. The first is how participants evaluated the three formalizations of the tool. The protocol asked participants to assess how the three formalizations could support their design activities. However, it could have been even more meaningful (but also taking longer, and more difficult for participants) to ask them to use the three formalized tools, and to discuss after their viewings. Second, we only tested the metaphorical tool with this protocol. It could have been interesting to test and compare more tools based on the same protocol. Finally, it could have been interesting to test the influence of the number of participants when designing interaction, for example by testing the tools with one participant, then with five and finally with 10. In this way we would have better understood the influence of the number of participants on the design process, and how participants handle the three formalizations of the metaphorical tool, based on the number of participants in the design team.

4.4.4 Conclusion

Going back to the initial hypothesis, “The metaphorical approach can be used to improve the way we design interactions through the physical/digital paradigm”, we can conclude that the metaphorical approach can be used, and can improve the way we design interactions from a user experience perspective. This approach can be used at any of the three **design levels(lev)**. Indeed, we have found that there is no single good level for designing interaction using the metaphorical approach, there is just the right level. As we have shown, the metaphorical approach tackles different **design information(i)** at each **design level(lev)** (Theorize(lev); Characterize(lev) and Materialize(lev)). Thus, this study formalized which **design information(i)** is tackled by the three **design levels(lev)**.

Second, we showed that different **design disciplines(di)** handle the metaphorical approach differently. We formalized how the four **design disciplines(di)** presented by Moggridge (2006) handle the metaphorical approach in terms of **design information(i)** (from the theoretical model). The differences between the design disciplines(di) highlight both the specificities of each and the value of the multidisciplinary way of designing. Furthermore, we have formalized a vision of every **design discipline(di)** and its impact in terms of **design information(i)** that can be used to better assemble a design team during early design sessions. Additionally, we have invited both the research and industrial communities to use this protocol and the way of formalizing people’s **design information(i)** scope as a strategic tool to measure people and design team scopes. It can be valuable to better understand who the participants are, and when and where to involve them, depending on what one is looking for, and to compose the most efficient design team possible.

Finally, as we presented in the state of the art, the metaphorical approach can be used as a tool. We have shown with this experiment that the metaphorical approach can be a valuable way to design interactions and user experiences in early design phases. The metaphorical approach improves interaction-related **design information(i)** of every **design discipline(di)**. Furthermore, while we have shown that this approach allows participants to improve both abstract and concrete **design information(i),** we have also shown that the biggest benefit is for abstract **design information(i)**. The metaphorical approach helps designers in generative design sessions to be more creative, and to be more oriented towards abstract notions such as emotions and the semantic description of products.

«The best ideas come as jokes.
Make your thinking as funny as possible»
David Ogilvy

4.5 Conclusion on Experiments

As explained in the overall presentation of the experiments (see 4.1), three hypotheses were presented, leading to three experimentations. Together, they cover the seven key notions described by the state of the art:

1. Model of Design Information (i);
2. Three-Dimensional Taxonomy (d);
3. Areas (a);
4. Principles (p);
5. Design Process;
6. Design Levels (lev); and
7. Design Disciplines (di).

The three experimentations developed in this research focus on the following question: *How can an understanding of human-product interactions improve early user experience design?* The hypotheses were developed in order to answer this problematic, and in turn led to the development of the three experimentations (see Figure 65).

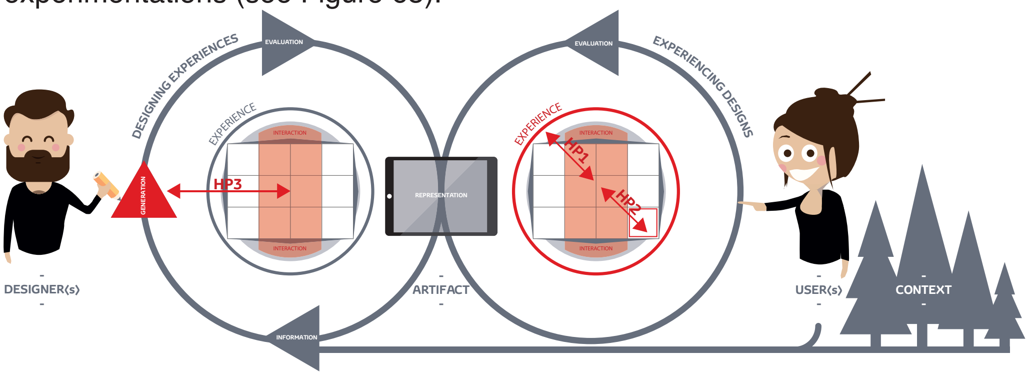


Figure 65: Hypotheses representation

The first experimentation measured the reciprocal impact of user experience and interaction. By so doing, we enriched and improved the understanding of interaction within the scope of user experience. This experimentation is based on abstract design information: The emotional reactions of the user and the semantic description of interactive products. This empirical evaluation highlighted five notions that emerged from this interdependence:

• Consistency: Providing a vision where user experience and interaction have to be considered together when designing in the early stages.

• Intertwining: Pointing out continuous relay of design information between user experience and interaction.

• Temporality: Describing the dimensional relationship and the importance for designing of a fluid and logical transition between user experience and interaction;

• Complementarity and immiscibility: Where user experience impacts more on emotional design information, while interaction impacts more on artifact perception notions.

• This experimentation explored and formalized the links between user experience and interaction. This very broad approach makes available to the community a user-centered methodology, and some tools for evaluating user experiences and interactions. Furthermore, the highlighted notions from the interdependency can be used as guidelines for designing right interactions and user experiences.

By formalizing the connection between user experience and interaction, we improved and enriched the design process, as proposed by the first hypothesis: "The formalization of the connection between user experience and interaction could improve and enrich the design process."

The second experimentation proceeds from the results of the first experimentation. Knowing that there is a notion of interdependency between user experience and interaction, we explored how simple properties (physical and digital paradigms) of an interactive product impact the interaction users are experiencing (experiential interaction). Thus, we measured the impact of the three axes extracted from the state of the art on affective and cognitive responses (model of design information). By so doing, we provided a better understanding of the interactive taxonomy and its constituents based on the three dimensions(d). Furthermore, we also formalized dimensions' impact(d) on the design information(i), in order to explain how these parameters could be used for designing interactive products. Finally, we highlighted principles(p) that can be used as new design challenges.

This experimentation emphasized the link between physical and digital interactions, leading to a key finding:

Experiential interactions (independent from the environment) are more meaningful when designed with both physical and digital principles(d): Physical targets(d) combined with digital sources(d), or digital targets(d) combined with physical sources(d). This sets a new milestone in the understanding of interaction design through physical and digital properties within the scope of user experience, and in the understanding of metaphors in interaction design.

Thus, the second experimentation revealed that our interactions with an artifact are affected by the physical and digital paradigms (target and source), as suggested by the second hypothesis: "The way we experience an interaction with an artefact is affected by the physical/digital paradigm."

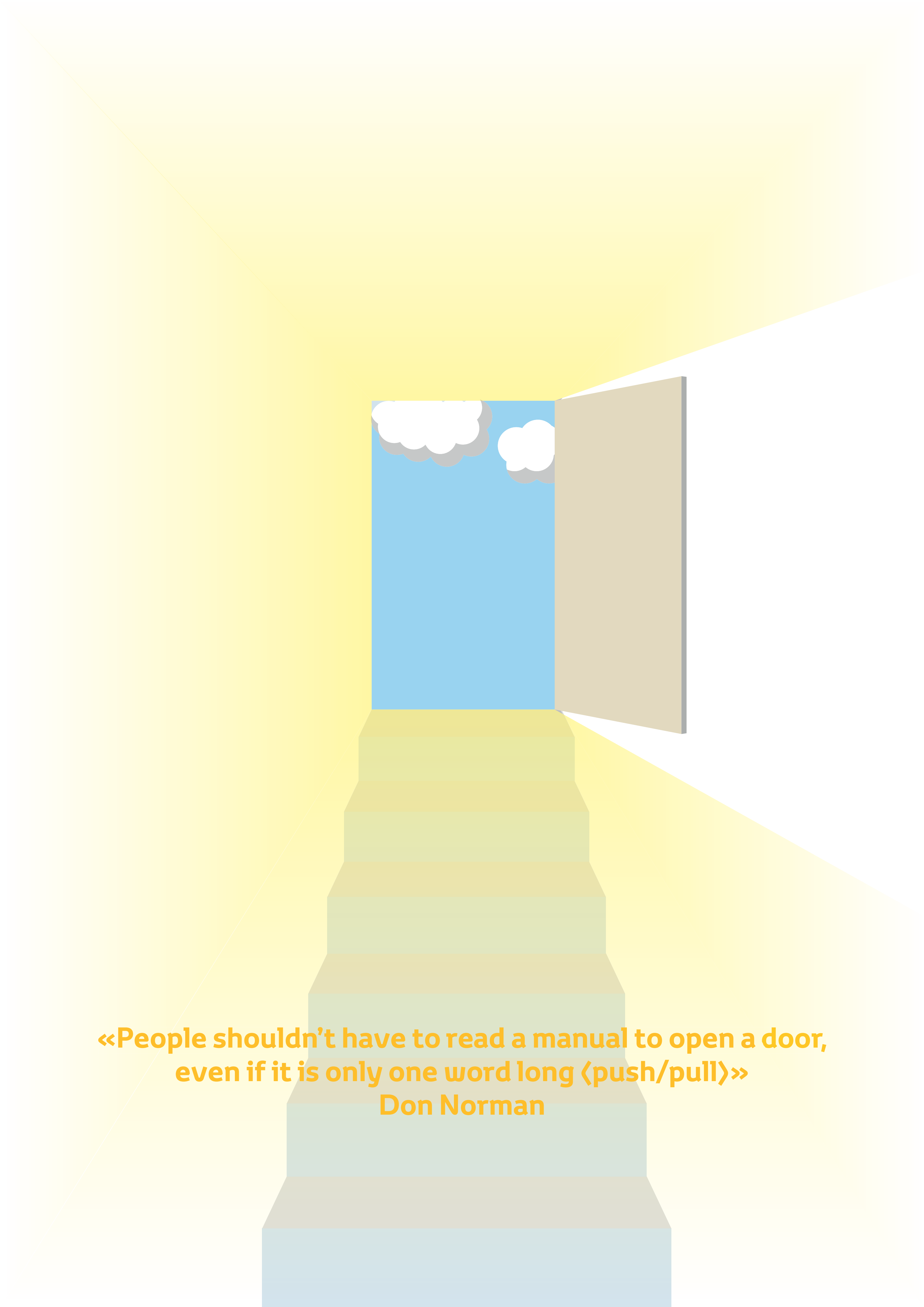
The third experimentation follows on the previous experimentations' insights. The first experimentation proved that we can impact the user experience with interactions. The second experimentation proved that an interaction created with a target and a source that are opposed in terms of physical and digital properties is more meaningful. Finally, we proved that we can use the metaphorical approach as a tool to create interaction. Thus, the third experimentation focused on how to implement this metaphorical approach to design interactive products. This experimentation aimed at understanding and formalizing a metaphorical approach within a design process for creating interactions. We showed that the metaphorical approach should be formalized using different variations of the tool, in order to tackle different design levels (theorize; characterize; materialize). These three formalizations of the metaphorical approach were used to highlight that each level(lev) employs different design information. This is why the metaphorical approach is valuable at each level of the creation process. The difficulty is to choose the right level in order to convey the right design information during creative sessions. Second, we showed that different design disciplines(di) handle the metaphorical approach differently. We formalized how the four design disciplines(di) presented by Moggridge (2006) handle the metaphorical approach in terms of design information(i) (from the theoretical model). This pointed to the value of multidisciplinarity in conception. The methodology can also be used in order to formalize people's scope of design information, in order to involve them at the right moment of the design process.

Finally, we showed through this study that the metaphorical approach can be a valuable way to design interactions and user experiences in early design stages, as suggested by the third hypothesis: "The metaphorical approach can be used to improve the way we design interactions through the physical/digital paradigm."

When considering the three experimentations, we can acknowledge that an interaction can impact a user experience. Also, we acknowledge that the physical and digital paradigms are powerful notions: Playing with the target's and the source's physical and digital properties when designing interactive products can improve meaningfulness of the lived interaction, according to the second experimentation. With the third experimentation we highlighted that we can use the metaphorical approach for designing interaction and user experiences at three different levels (theorization; characterization and materialization).

Thus, the experimental flow evolves from the broader scope of user experience and interaction to the smaller one of the metaphorical approach for designing interactive products.

Going back to the initial question, *"How can an understanding of human-product interactions improve early user experience design?"*, we showed that by better understanding and formalizing the parameters of interaction (design information(i)), and their impacts on the user's affective and cognitive reactions, we can improve early user experience design. Methodologies can be strengthened and developed, and tools can be created to support designers' approach to the design process. In this research we focused on an artifact's physical and digital properties, but other design information(i) can also be tackled.


«People shouldn't have to read a manual to open a door,
even if it is only one word long ‹push/pull›»
Don Norman

-

5 CONTRIBUTIONS

-

This chapter discusses the academic and industrial contributions of this research.

5.1 Academic Contributions

This chapter brings together the academic findings of this thesis, and shows how they contribute to research and design practice. Four elements are presented: The model of design information, the taxonomy of interactive products, the process for designing through the physical and digital paradigms, and the different principles.

5.1.1 Model of Design Information

The model of design information (already presented as a summary of the state of the art, and presented in Figure 66 as a reminder), maps the different components of the user experience, highlighting the area of interaction, and pointing out all the design information that has to be considered in the interactive approach of designing or evaluating user experiences and interactions in early design phases. This model is a variation of the models of Ortiz Nicolàs and Aurisicchio (2011), and Gentner (2014): The difference and improvement lie in the focus on interaction-related design information.

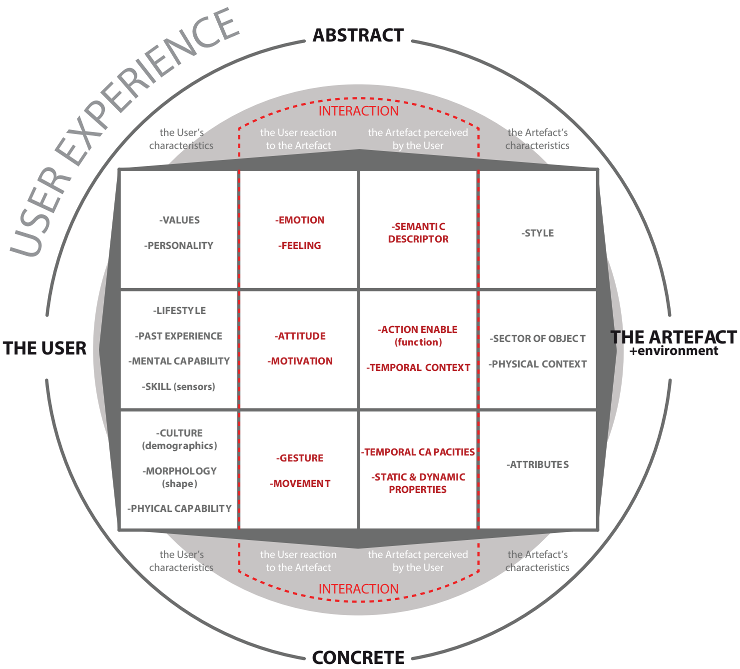


Figure 66: Model of Design Information

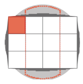
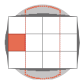
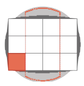
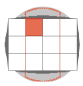
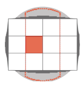
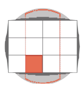
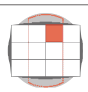
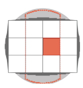
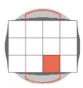
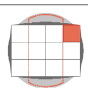
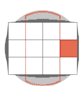
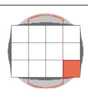
POSITION ON MODEL	RELATED COLUMN	CATEGORY NAME	DESCRIPTION	EXAMPLE	REFERENCE
	User's characteristics	**Value**	These words represent final or behavioural values.	Ambitious, open-minded	Nurkka 2008
		Personality	Words to illustrate the user mind in general	Enthusistic, vibrant	Govers & Mugge 2004
		**Lifestyle**	Combination of values of the user	Work hard and play hard	
		Past Experiences	Previous experiences lived by the User	I already played with it	Parrish 2008
		Mental capability	User's capability in intellectual notion	Number of command he can remind	
		Skill	based on user's personal capacities and skills;	driver licence	Overbeeke et al 2002
		**Culture**	The culture of a user covers his/her age, gender, nationality, function, and organisational affiliation	Young (20-29) Europeans	Gero 2010
		Morphology	Related to the outward appearance of the user	Body shape, structure, handicap	
		Physical capability	Action enable by the physical capabilities of the user	Able to reach something at 2 meters	Overbeeke et al 2002
	User's reaction to the Artefact	**Emotion**	Targeted emotion to be felt by the user	Joy, surprise, interest	Russel 1980 Plutchik 1980
		Feeling	User's generals sensations	Pain, mood	Lang 1995
		**Attitude**	characteristics of the user in his relation;	discovered, learn	Lalmas, O'brien & Yom-Tov 2013
		Motivation	The different motivational degrees affecting user's behavior	motivated by fun, motivated by somebody putting pressure	Deci & Ryan 2000
		**Gesture**	Movement of a part of the user's body used as input	Hand and body movements	Moussette 2012
		Movement	the reason of the gesture	move to play, move to explore	Krippendorff 2006
	Artefact perceived by the User	**Semantic descriptor**	Adjectives related to meaning and characteristics.	Playful, romantic, traditional	Dias 2013 Hassenzah 2000
		**Action enable**	Function, usage	Create, relax, communicate	Lund 2001 Brooke 1996
		Temporal context	Notion of time in the interaction	Narrative description of an interaction	Lin and Cheng 2011
		**Temporal capabilities**	based on product characteristics	feedback, active touch; visual feedback, pressure, grape	Maes 2009
		Static & dynamic properties	Static: vision, shape, texture, tactual, olfactory Dynamic: Auditory, Visual changes, force feedback, vibration feedback, olfactory feedbacks	opacity changing, shape changing, light signal, fast rythm	Camere, Schifferstein 2015
	Artefact's characteristics	**Style**	Characterization of all levels together through a specific style.	Edge design	Dias 2013
		**Sector of object**	Object or sector being representative for expressing a particular trend	Tennis, wearable computing	Kim et al 2012
		Physical context	Physical elements surrounding the product	In a modern living room	Forlizzi 2007
		**Attributes**	Attributes of the product, as concrete characteristics	80 kg; Ral 9010; wood;	Minge 2013

Table 28: Design information description

This model contributes to the understanding of user experience and interaction through a formalized representation. It describes both information related to user-artifact interactions and experience, and information related to what we should consider when designing early interactions and user experiences. The different boxes of design information are described in Table 28.

This model can be valuable in both the academic and industrial worlds: It helps to map and identify what design information is related to user experience and interaction design. This model can also be used for evaluating interaction and user experience in order to highlight design challenges, as shown in the different experimentations. Finally, this model can also be used as a way to identify people involvement in the different phases of the design process. By so doing, it can help to organize and structure design teams according to the design information employed.

With the extreme growth in the evolution of technologies, artifact's intelligence and artifact's humanization, we can imagine that the model could be inverted: Instead of spreading design information from the user to the artifact, where the user has a personality, values, emotions, motivation, and other very human-oriented design information, we could imagine the reverse. The artifact could be designed with a personality, values, a culture, emotions, feeling, etc. Thus, we imagine that we can easily switch the two main elements (user-artifact). In this way, we invite designers to design the artifact differently as a human being, as the element interacting with the user. Thus, we propose a variation of our model, no longer from the user to the artifact, but from the one to the other, where the one could be either the user or the artifact, depending on how people want to use the model (see Figure 67).

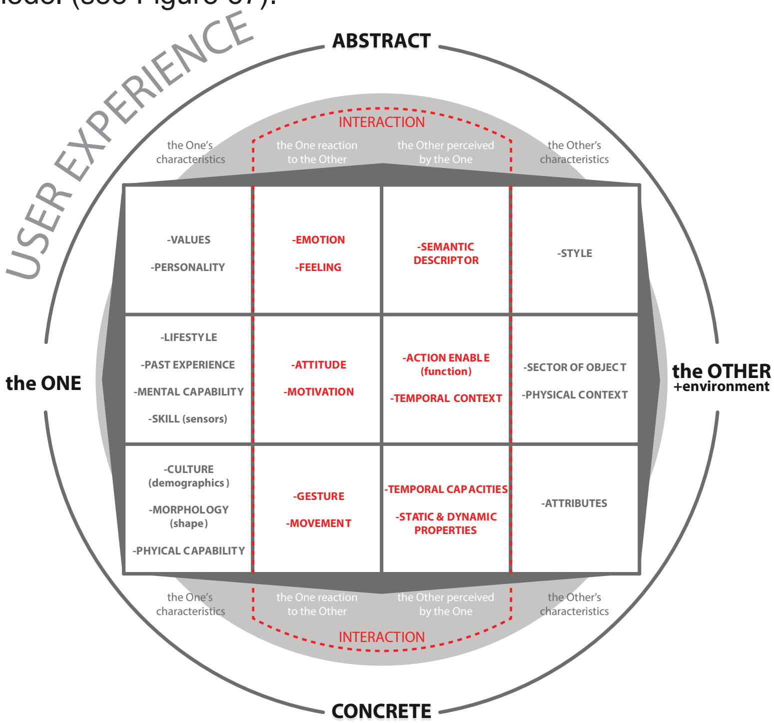


Figure 67: Model of design information: variation

5.1.2 Taxonomy of Interactive Products

Classifying interaction in terms of the user perception of physical and digital dimensions(d), environment(d), target(d) (product properties), and sources(d) (perceived references), developed a taxonomy of interactive products (see Figure 68). Using this taxonomy, we emphasized the link between physical and digital interactions, leading us to a contribution proving that experiential interactions (independent from the environment) are more meaningful when designed with both physical and digital principles(d): Physical targets(d) combined with digital sources(d), or digital targets(d) combined with physical sources(d). This sets a new milestone in the understanding of interaction design using physical and digital properties within the scope of user experience, and in the understanding of metaphors in interaction design.

The developed taxonomy might help to map typologies of interactive products in a three-dimensional space. We encourage the research community to acquire and improve the framework of this taxonomy, in order to make more precise the finer areas in every highlighted area. Table 29 summarizes and describes these areas.

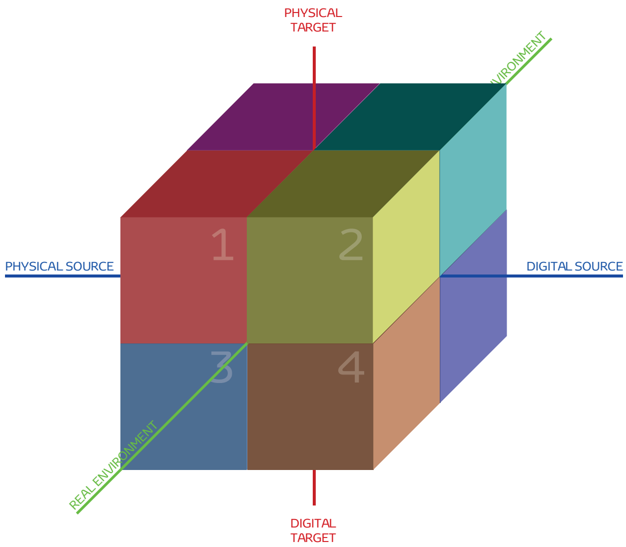


Figure 68: Taxonomy of interactive products

5.1.3 Metaphorical Approach to the Design Process

In this research, we proved that the metaphorical approach can be used at different levels of the generation phase of interaction design: The Theorization level, the Characterization level, and the Materialization level. Indeed, using the metaphorical approach can be useful at each level, because we proved that this approach involves design information that increases meaningful user experience. Furthermore, we highlighted the complementarity of these three levels. Each level involves different design information. This leads our research, not toward the question of “which level was adapted to the use of the metaphorical approach”, but to “what are the specificities of each level when using the metaphorical approach”.

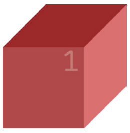
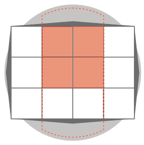
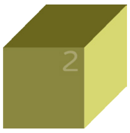
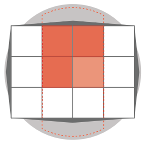
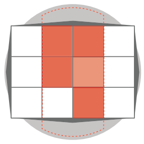
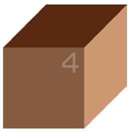
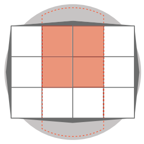
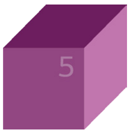
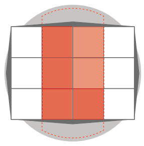
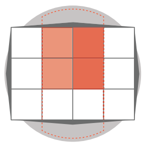
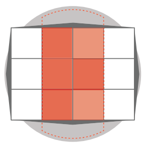
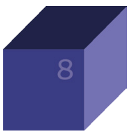
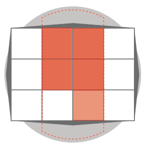
3 DIMENSION(d) & 8 AREAS (a)		-PRIN-CIPLES (p)	DESIGN INFORMATION(i)	
AREAS(a) FROM THE INTERAC-TIVE TAXONOMY		*5 PRIN-CIPLES(p)*	*% OF IMPACT ON THE THEORETICAL MODEL(i)*	*COMMENTS*
	1-Real en-vironment; Physical target; Physical sources	Movable Transformable Graspable Manipulable Malleable		This full physical and real typology of products are more related to abstract notions like emotion, semantics, behavior and action enablement.
	2-Real en-vironment; Physical target; Digi-tal sources	Programmable Transformable Connectable Personalizable Movable		This kind of physical targets that use digital sources have been characterized as very powerful for abstract notions; mainly for emotion, semantics, and behavior.
	3-Real en-vironment; Digital target; Physical sources	Graspable Manipulable Movable Malleable Spacia-lize-able		This area, about digital targets that uses physical sources, covers a wide scope of the design information boxes. Only the sensory related part is less covered than the other. This is a part that can be improved with better physical sources.
	4-Real en-vironment; Digital tar-get; Digital sources	Transformable Programmable Personalizable Connectable Replicable		This area, covers both the abstract design infor-mation (emotion and semantics) and the middle part of the theoretical model (behavior and action enablement). Nevertheless what is covered is not strongly impacted.
	5-Virtual environ-ment; Physical target; Physical sources	Movable Manipulable Transformable Graspable Ubiquit-able		Unfortunately only one video has been related to this area. Thus, the average result might not be significant enough. Nevertheless it seems to impact mainly the left part, dedicated to user reactions.
	6-Virtual environ-ment; Physical target; Digi-tal sources	Transformable Personalizable Manipulable Spatialize-Able Connectable		This area seems to impact mainly the right part, dedicated to user perception of the product. The user part might be improved with more physical engagement of the user (immersive environ-ment).
	7-Virtual environ-ment; Digital target; Physical sources	Manipulable Movable Malleable Graspable Spatialize-Able		This typology strongly covers the left part of the model, dedicated to user reaction to the product, and to the design information related to action enablement. The perceiption of the product might be improved with more meaningful semantic notions. Additionally, the static and dynamic pro-perties could be improved with physical sources.
	8-Virtual environ-ment; Digital tar-get; Digital sources	Programmable Personalizable Replicable Connectable Voidable		This full digital and virtual area has been as-sessed as more related to abstract and middle design information. Nevertheless, this impact is not very strong.

Table 29: Description of the eight ereas

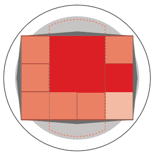
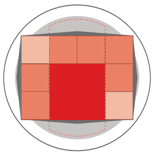
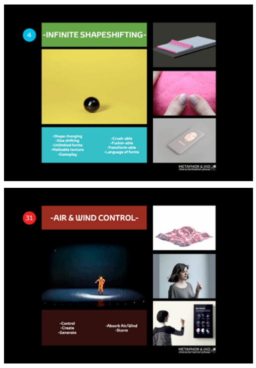
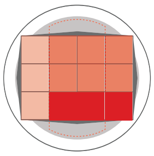
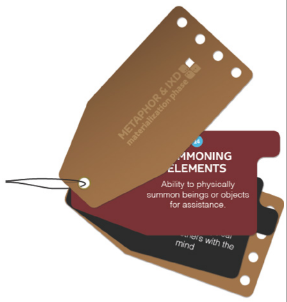
LEVEL	DESIGN IN-FORMATION	DETAILS	FORMALIZATION
Theorization It underlies needs, emotions and associated practices.		The theorization's level(lev) is tackling more abstract Design Information(i). We also highlighted that the Design Information(i) of 'semantic descriptors' is the most important one at this level. Furthermore, the experiementation 3 showed that the theorization's level(lev) is oriented toward quantity more than quality of generated solutions.	
Characterization It addresses the things people can do through an interactive product.;		The characterization's level(lev) is covering Design Information(i) that are interaction-related in the middle of the model. Furthermore, it covers both abstract and concrete Design Information(i). The characterization's level(lev) is more balanced in terms of generated solutions: the quality predominates on quantity.	
Materialization It addresses acting through an object on an operational, sensory-motor level (turn a button, play on an interface…), and makes given functionality accessible in an aesthetically pleasing way.		The materialization's level(lev) is oriented towards concrete elements such as' gesture and movement'; 'static and dynamic properties' and 'attributes' of the product. Additionally, the quality of the materialization's level(lev) has been assessed as stronger than the quantity of generated solutions.	

Table 30: Design Levels(lev) description

Following this approach, we formalized a tool for designing interaction and user experiences based on the three levels (see Table 30).

We encourage the community to use this metaphorical approach in order to: formalize new tools, improve the one we formalized, increase general understanding of the metaphorical approach in interaction design, and, finally, improve and explore its use within the design process.

5.1.4 A Set of Principles

The fourth highlighted element is the notion of principles(p). These principles were highlighted in this research as a way to differentiate interactive products in terms of the physical and digital paradigms. These principles can be used to better define and understand users' perception of interactive products.

Additionally, these principles can be used as a design challenge for the early development of interactive products.
This list of principles can be improved and expanded with new keywords related to physical or digital capabilities. We encourage the community to both strengthen this list and implement it within the design process (see Table 31).

GENERAL NAME	PRINCIPLE	DETAILS
Haptic related	Transformable	From one state to another
	Movable	From one place to another
	Graspable	Take with hands
	Manipulable	Handable
	Malleable	Deform the shape
Space Related	Asynchronize-able	Real time / time differences
	Ubiquit-able	Different places in same time
	Spacialize-able	Proximity/depth
Pixel Related	Programmable	Plan of sequential actions
	Personalize-able	Adapt to people and things
Virtual Related	Gravityless	Independent from gravity
Computer Related	Distributable	Shareable
	Fusible	From 2 to 1 element
	Voidable	Ctrl Z
	Replicable	Ctrl C+ ctrl V
Numbers Related	Connectable	To other elements
	Universalizable	For all

Table 31: Design Principles description

5.1.5 Conclusion on Academic Contribution

Four major academic elements have been highlighted in order to contribute to the progress of the research community with regard to the understanding and improvement of interaction and user experience in early design. These elements have been presented as improvements on existing theories, methodologies, and tools. They do not constitute an end in themselves, but are a step forward in the research that can be improved, increased and even hijacked for broader purposes.

These elements support the design process. The last column in Table 32 (Summary of Academic Contributions) presents the contribution to the design process. The academic contributions resulted in four different, but potentially complementary, contributions to the same design process.

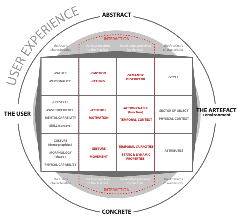
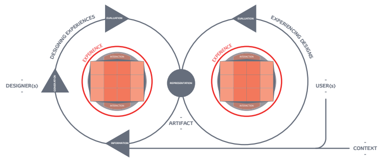
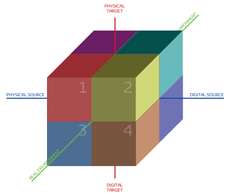
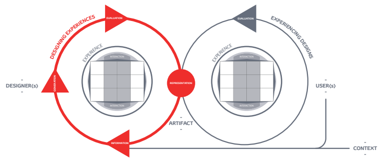
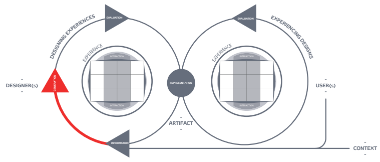
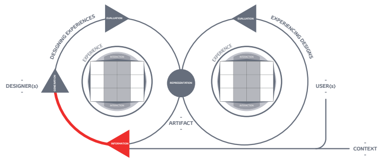
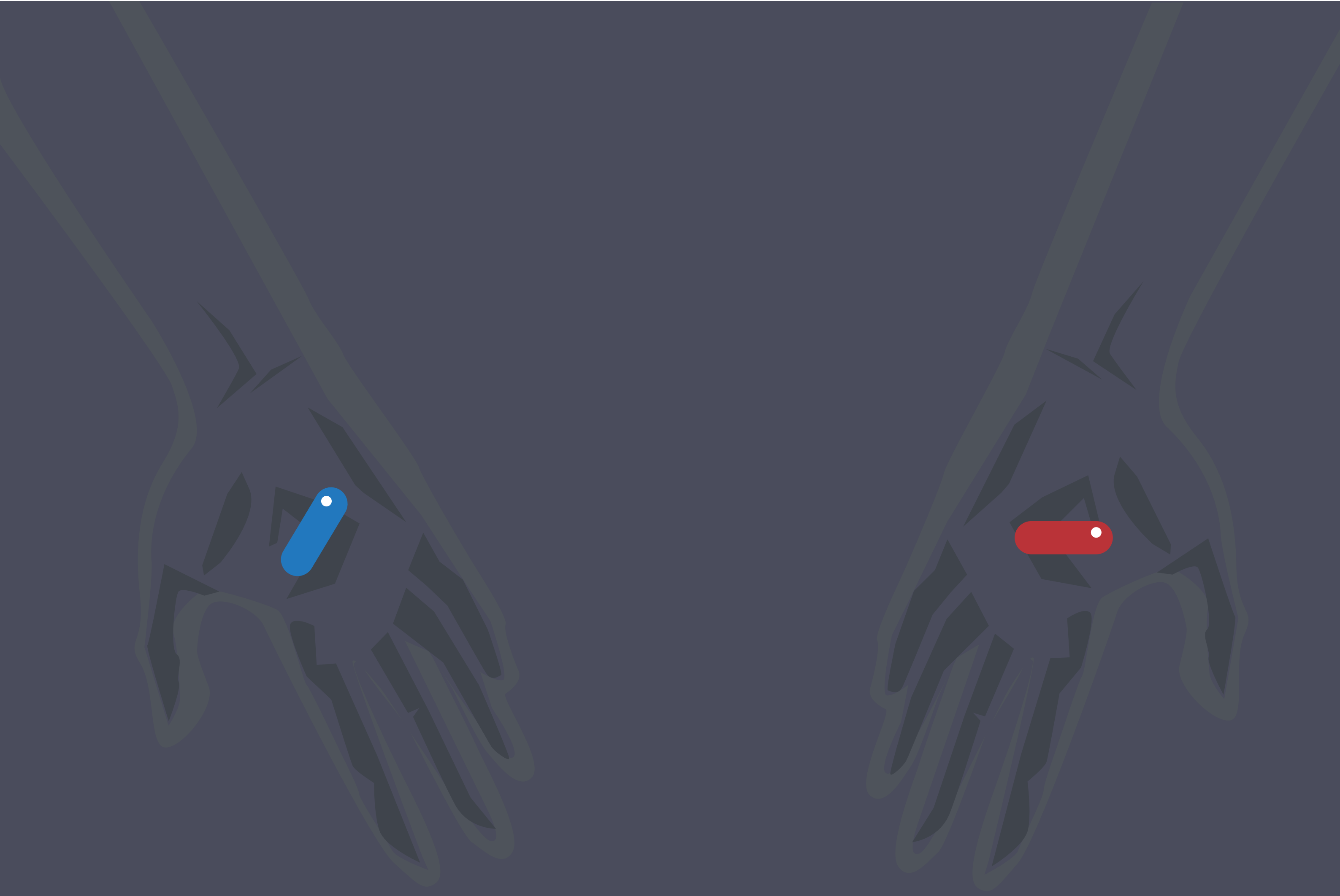
SUMMARY OF ACADEMIC CONTRIBUTIONS			
NAME, DESCRIPTION & CHAPTER		**REPRESENTATION**	**POSITION WITHIN THE DESIGN PROCESS**
Model of design information: Model of User Experience and Interaction, where design information are displayed from user to artifact (horizontal axis), and from abstract to concrete (vertical axis)	5.1.1		
Taxonomy of interactive products: 8 areas of interactive products, displayed through three axis: environment; target and source.	5.1.2		
Metaphorical approach: The use of metaphor for designing Interactions and User Experiences.	5.1.3		
Principles: Product principles consisting of keywords mostly related to what the interactive product enables the user to do.	5.1.4		

Table 32: Summary of academic contributions



«The main goal is not to complicate the already difficult life of the consumer»
Raymond Loewy

5.2 Industrial Contributions

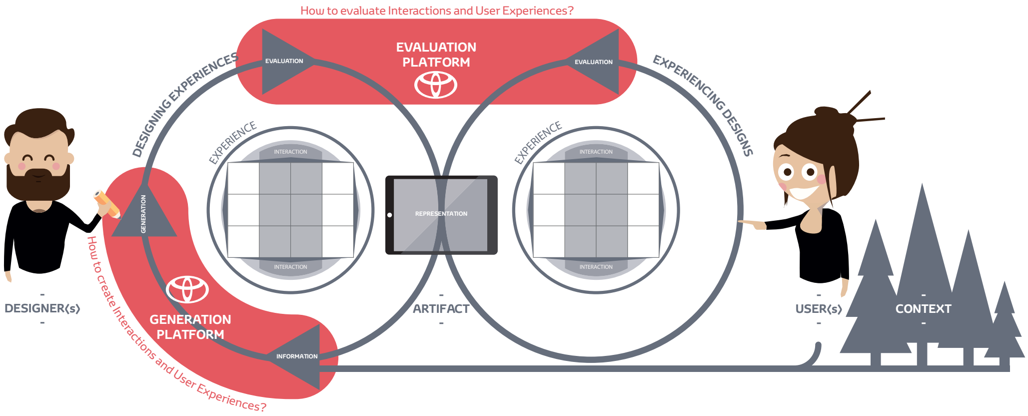


Figure 69: Representation of the Evaluation and the Generation platforms according to model of litterature Review

As stated at the beginning of this research, the industrial contribution aims at enriching and improving the way TME, and more specifically the Kansei Design Division, evaluates and generates interactions from a user experience point of view.

In this research we used three experimentations to develop different tools and methodologies that support this purpose. Since the moment they were created for the purpose of this research, they have been adopted in various projects. In this way, they also contributed to integrating the Kansei design approach into Toyota’s product development.

Studies presented in this research permitted a better understanding and defined the approach in an industrial context. In addition to these theoretical contributions, two types of practical industrial contributions can be highlighted. They are detailed in the sections below. The first type corresponds to new tools supporting the design activities that have been created. The second type corresponds to the new design methodologies for creating interactions in early design stages.

5.2.1 Development of New Tools

New tools have been created during the course of this research. They all support experience-centered design activities, with specific focus on interaction-oriented design information. As stated before, these tools support and improve the way interactions are generated and evaluated during early design.

Tables 33 and 34 summarize the tools that were developed, in relation to the experimentation that supported their creation. It also presents their suggested position within the design process. As explained, some tools were created in order to support interaction in early design. For example, the tool C (Kansei Kabin) supports the representation of ideas during brainstorming sessions. The tool J (SuperInteraction) supports the creation of interaction, but by introducing new abstract notions in “information activities” to strengthen “generation activities”. On the other hand, the evaluation of interaction is supported by tools such as tool G (Kansei Kit), that supports both designers

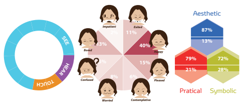
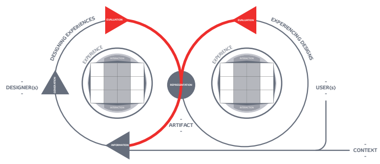
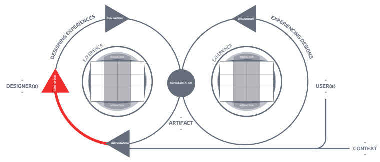
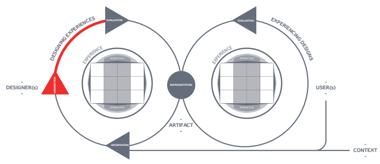
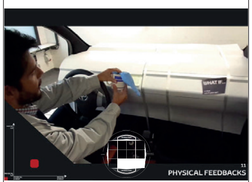
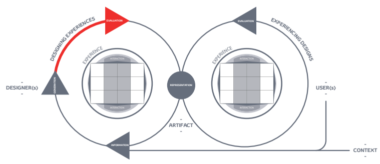
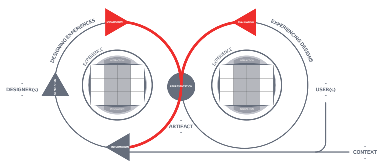
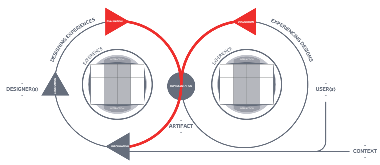
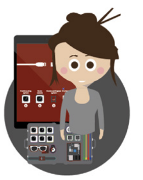
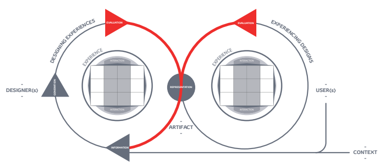
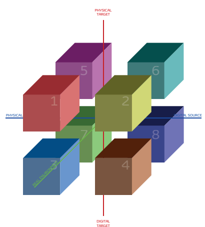
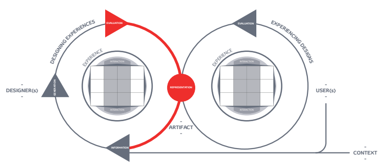
SUMMARY OF TOOLS: INDUSTRIAL CONTRIBUTIONS			
NAME, DESCRIPTION & EXPERIMENTATION		**REPRESENTATION**	**POSITION WITHIN THE DESIGN PROCESS**
A- Car's evaluation Evaluation criteria for assessing one component in cars.	Exp1		
B- Kansei Kards Cards for brainstorming. Tackling different design information, and involving different typologies of Interactive products.	Exp1		
C- Kansei Kabin Exp1 Half car augmented with sensors to formalize and record in-situe ideas, gestures, scenario and more.	Exp1		
D- Koncept Evaluation Methodology for evaluating ideas and concept. It is based on the physical and digital paradigm, and on design information.	Exp1		
E- Kansei Kabin Tool for evaluating low-tech prototypes in a controlled environment. Based on half a car with projection and sound system.	Exp1		
F- HMI Score Methodology for evaluating few components in a car. Based on objective and subjective measurement methods, translated into a simple score of HMI.	Exp1		
G- Kansei Kit Open tool for evaluation of components in car. BAsed on objective and subjective measurement methods. Can be improved by any list of keywords or components.	Exp1		
H- Kansei Klassification Evaluation method based on 3 axis for classifying interactive products. Not only automotive components can be assesed and classified into the 3D representation.	Exp2		

Table 33: Generated tools - part 1

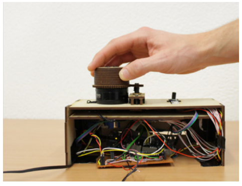
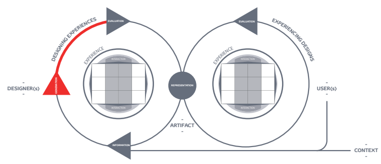
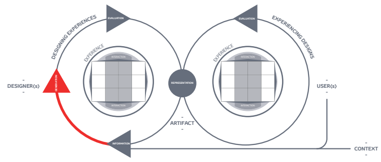
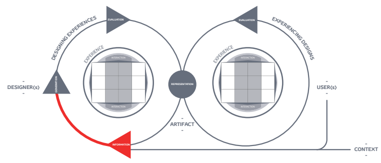
I- Kansei Knob Programmable knob to create the right sensation. Can also be used to look for the right shape, texture, material (...) of the knob depending of the turning feeling.	Exp3		
J- Superinteraction Set of metaphorical sources for creative session. Based on superhuman.	Exp3		
K- Scenario Kards Cards for setting up quickly a scenario of use. Based on context, type of driving, point of view of narrator...	Exp3		

Table 34: Generated tools - part 2

and users (customers) in the evaluation of in-car interactions. By so doing, it may highlight weaknesses and new design challenges that feed the information activity that designers use during generation activities.

5.2.3 Creation of New Methodologies

Three new types of methodologies related to interaction and user experience were detailed and discussed in relation to the experimentations. The methodologies are presented below from a design practice perspective.

Metaphorical Methodology

The first methodology developed by this research is a methodology for designing interactions and user experiences based on the metaphorical approach.

Figure 70 illustrates that this methodology falls within the full design process. More specifically, this methodology supports the “generaction” activity,

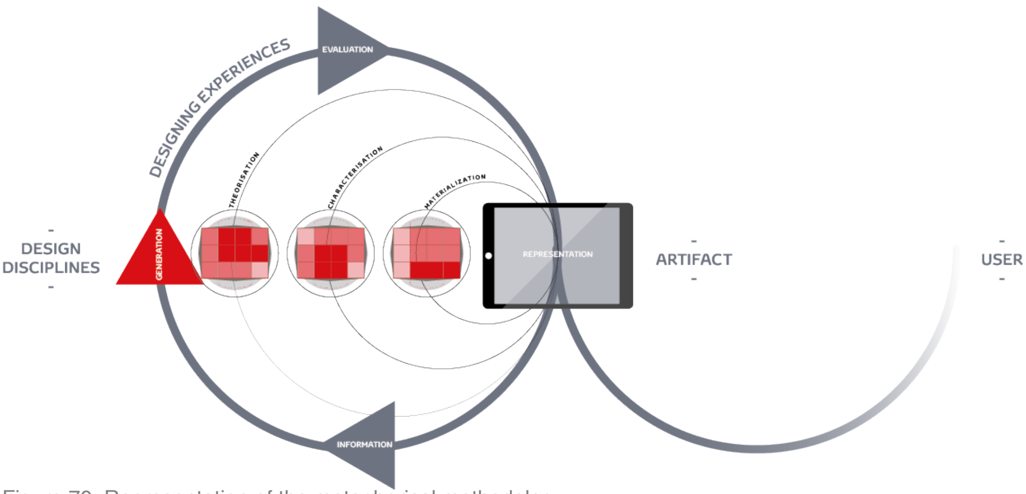


Figure 70: Representation of the metaphorical methodology

as described by Bouchard (2003). Three levels were presented: Theorization, Characterization, and Materialization. As proved in experimentation 3, the three levels support the design of different information. Three variations of the tool were developed, based on the physical and digital paradigms. Figure 71 presents a simplified version of how designers could choose between the different levels of the generation activity. Furthermore, it also clarifies the way designers should use physical or digital sources according to their target properties. It finally leads to one of the six tools' variations.

This methodology proposes new ways of designing interaction and user experiences through the physical and digital paradigms. The Superhuman approach is one option that we consider inspiring. Nevertheless, many tools can be created following the physical and digital paradigms.

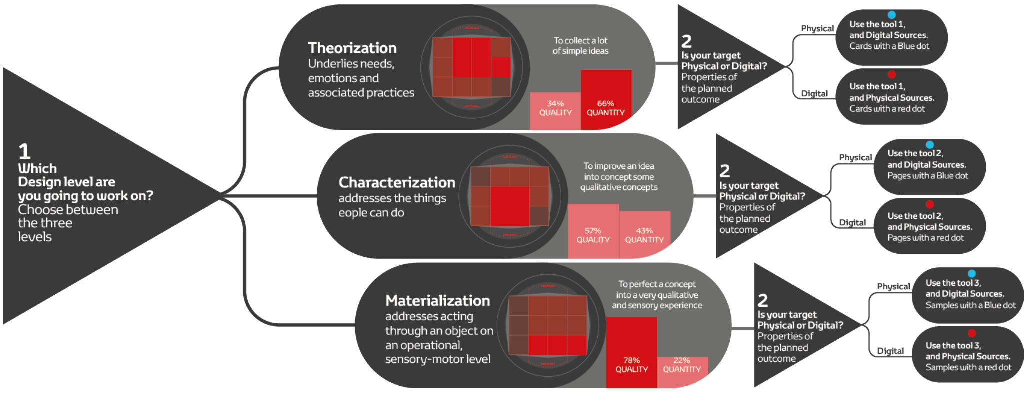


Figure 71: step by step instructions of the metaphorical methodology

Disciplines Methodology

When focusing on design development actors, we can acknowledge different disciplines, as presented in experimentation 3. Considering that different disciplines are involved in the design process, and knowing that multidisciplinary teams tackle a broader scope of design information, a methodology was developed during the research to evaluate disciplines and people's scope of design information. Indeed, the linear hierarchies that we used are evolving toward multidisciplinary organizations for more flexible networks. Thus, the developed "strategical oriented" methodology simply consists of correlating disciplines' scopes of design information (people) with projects' needs (based on the level at which the generation activity will be tackled). By doing this comparison, we can select and involve the right disciplines to create an adapted design team. The methodology is based on a set of questions that feed the theoretical model of design information (see Figure 71).

Evaluation Methodology

The third methodology that was developed during this research relates to being able to evaluate ideas, concepts, prototypes, and products based on the interactions and user experience approach. Specific tools were proposed to support different needs, and different levels of evaluation (see the previous part on "tool development"). However, the developed methodology aims at using these tools in order to evaluate, using the same criteria, different ideas, concepts, prototypes, or products, in order to compare them (see Figure 72). By comparing them, we can potentially stop or differently orient a project before the final stages. It is of interest for time and cost reduction.

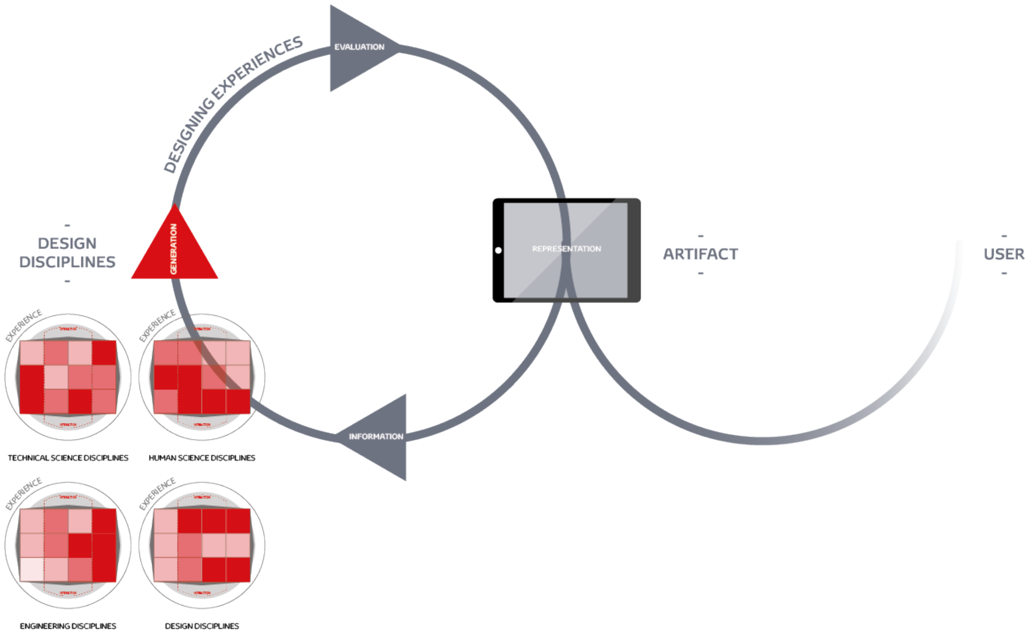


Figure 72: Representation of the Discipline methodology

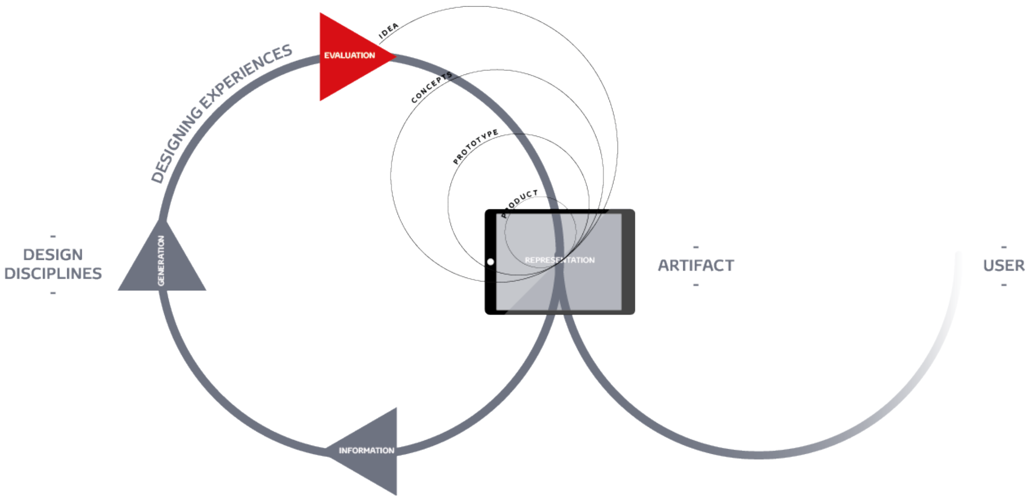
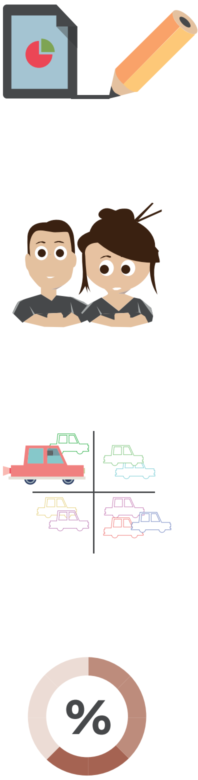


Figure 73: Representation of the evaluation methodology

By doing these evaluations, we can distinguish four types of results, as presented in Figure 73:



1. Highlight design challenges: Evaluations are useful for highlighting weaknesses and new design challenges. In this way we can improve projects through new design activities.

2. Do target setting: The results could be used to define whether a project is dedicated to specific targets, and potentially reinforce the way products can fit specific targets with regard to new design activities.

3. Do benchmarking: Evaluate a project (idea, concept, prototype, or final product) against competitors can be done to highlight potential forces or weaknesses that need to be reinforced or improved by new design activities. Furthermore, it can also be used simply as a way to position projects in terms of competitors' products (mapping).

4. Highlight a final score: Finally, these evaluations are also a way to give a simple score to interactions and user experience. Giving a simple score is of value for highlighting a cross-divisional and unified result.

Figure 74: The four types of results

5.2.4 Uptake of the Industrial Contribution in Toyota Motor Europe Activities

In this section, we will present how these tools and methodologies are supporting different types of projects from the Kansei Design Department at TME. This discussion is based on know-how and knowledge transfer that had already happened at the time of writing this dissertation, as well as a more general view on how the industrial contributions of this research could further be included in the organization.

As this research follows an action research approach, it can be described as an iterative process involving research and practice activities. The different contributions detailed previously have therefore been created having in mind both academic relevance and industrial utility. The metaphorical methodology (experimentations 1 and 3) were organized as part of real new concept development projects (work on Toyota New Global Architecture). For reasons of confidentiality, the focus of these cases has been placed on the set-up, tools, methodologies, and structure, rather than on the exact aspects and communication activities of the resulting representations. Furthermore, we used the second experimentation as a way to improve our understanding of the metaphorical approach.

The methodology of the evaluation was first tested in experimentation 1, and improved in experimentation 2, before being used in real evaluation for car benchmarking, target setting and resolving design challenges.

The discipline methodology was first tested in experimentation 2, and improved in experimentation 3. The collected insight has been discussed and shared with management for further involvement in strategic organizations.

Uptake of the tools and methodologies

Having been used as part of the theory of the experiments, the metaphorical and evaluation methodologies were again used in subsequent new concept development projects of the Toyota Lexus brands. This uptake in TME's Kansei Design Department includes the reuse of the related tools for both generation and evaluation activities. The added value of the different industrial contributions has also been recognized by design team members from other functional departments (engineering, product planning, styling, electronics), by TME's top management, as well as by several top engineers of vehicle development. Tools such as the Kansei Kards, the MHI score, and the Superinteractions are now even used with other methodologies than the one for which they were created.

Kansei Kards (what if) and Superinteraction were appreciated by the division involved in new concept development projects for their ability to convey abstract design dimensions during generation activities. Furthermore, their ease of use was appreciated by Toyota members.

The evaluation methodology and the different tools related to it were highly appreciated by Toyota top management, for the efforts made in focusing on subjective dimensions. The human-centered approach has been highlighted as a increasingly decisive way to differentiate brands, by focusing on user experience rather than objective product dimensions. The methodology of evaluation with the specific user journey has been used to evaluate different in-car interactive products of by different divisions of both Toyota and its competitors (Advanced Technology/ Electronics/ Noise and Vibration/ Vehicle Dynamics). This methodology will also be used in the coming months to evaluate differences of perception between different cultures. Toyota is first of all planning to evaluate Japanese, European, and US perceptions of interactive products, corresponding to the three Toyota Research and Development centers, in order to highlight design challenges by culture.

Finally, the different tools and methodologies that have been generated are developing and improving the structure of the Kansei Design Division itself. The division aims to become increasingly "agile", with tools, methodologies, and skills that can be used at different moments of the design process. With such a flexible organization, the ambition of the division is to step back from the usual design process, and to position itself as a satellite that can operate at different steps of the design process.

«Design is a plan for arranging elements in such a way as best accomplish a particular purpose»

Charles Eames

5.3 Summary of the Contributions

This research will be concluded with an overview of the different contributions that have been set up. These contributions have been organized in Tables 35 and 36.

The first part is descriptive and helps to detail the context of this study: The study of user-artifact interactions from the user experience approach (related to construction from the state of the art and the three experiments). No tool is related to these elements, that are insights rather than methodologies (see Tables 35 and 36).

The second part is prescriptive. It proposes the three methodologies, with tools that could support the design process. This part focuses more on the application of the descriptive part (see Tables 35 and 36).

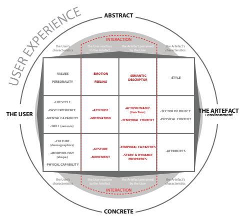
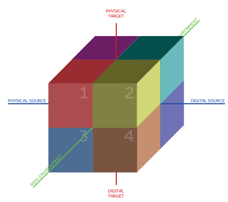
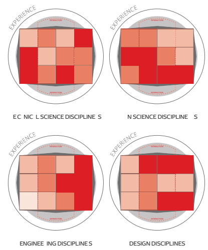
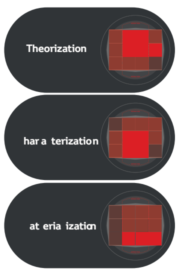
TYPE OF CONTRIBUTION	SUMMARY OF THE CONTRIBUTIONS		TOOL
Descriptive	Design information exchange during early design activities, foccussed on Interactions		Ø
	3 axes and 8 areas decribing a taxonomy of interactive products through the physical and digital paradigm		Ø
	Description of disciplines' scope of design informations		Ø
	Levels' description in early generation activities		Ø

Table 35: Contributions - Part 1

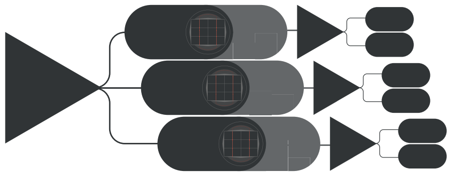
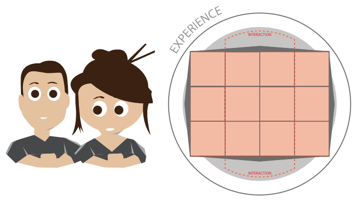
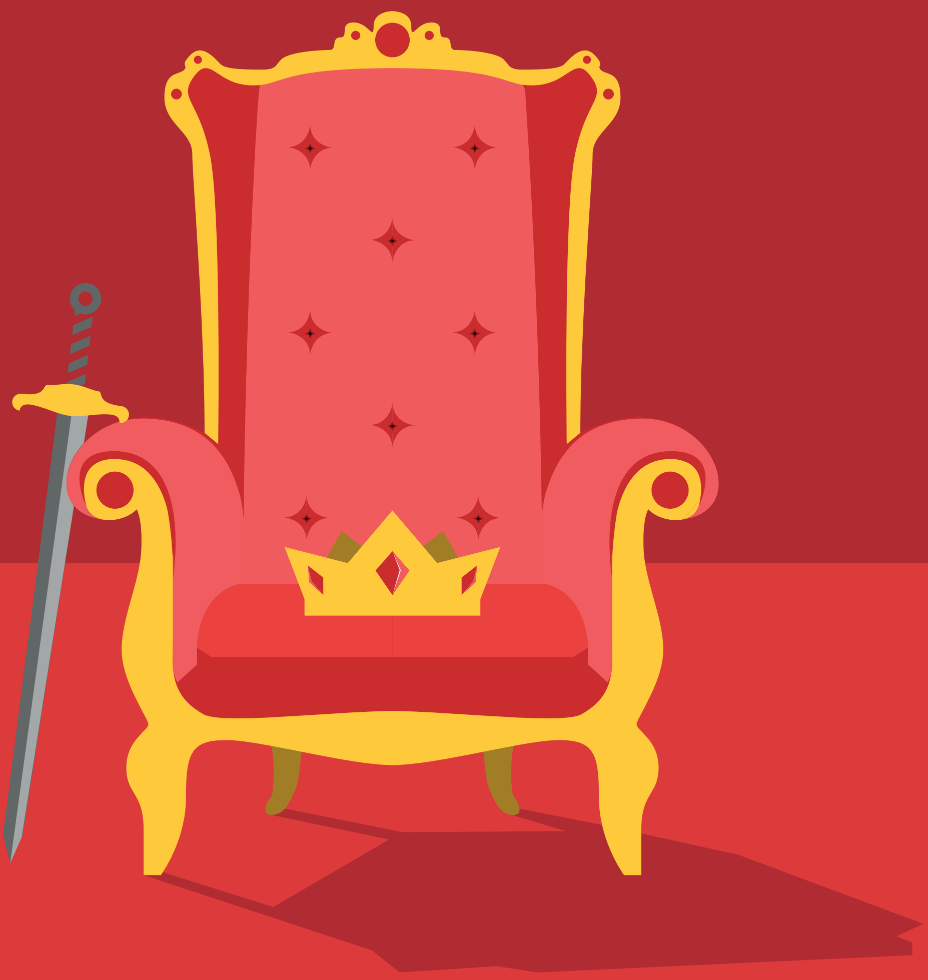
Prescriptive	Metaphorical approach of the physical & digital paradigm (+principles)		I H J B C K
	Evaluation method for assessing affective and cognitive perception of Interactive products/ concept/ idea		A D E F G H
	Managing method for assessing peoples and disciplines' design scope		G

Table 36: Contributions - Part 2

Thus, the research has resulted in different contributions that could be tackled by the academic context as well as by the industrial context. We encourage researchers and designers to explore these tools and methodologies in order to simply use, improve, or even hijack their purposes.



«There are 2 rules for success:
1. Never tell everything you know.»
Roger H. Lincoln

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6 CONCLUSIONS AND PERSPECTIVES

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6.1 Conclusions

This research is the fruit of a long-standing collaboration between CPI laboratory from Arts & Métiers ParisTech and the Kansei Design Division from Toyota Motor Europe. The research began in 2015 with the wish to develop an original approach that could still fall within a logical flow with previous research projects (master's thesis, Ph.D. thesis and internal studies) (Gentner, 2014). The aim of the research was to gather and create knowledge and know-how that could support the industrial design process in the way we design interactions from a user experience point of view. Furthermore, the research began with the desire to clarify the link between physical and digital products from a user-centered and interaction point of view.

During the first months of the research, the experiential dimensions applied to the interaction design scope emerged as key notions, and the related fields of research became influential areas of the literature review. Until then, the scope of the activities conducted by Kansei Design Division, in collaboration with the CPI laboratory, was focused on the user experience and Kansei Design approach. **The very interaction-oriented focus of this research brings a new milestone in the collaboration, leading to a consideration of users-artifacts affective and cognitive responses, and how could these insights might be used within the early design process.**

When defining the theoretical background of this research, a link therefore had to be created between the notions of interaction from the user experience perspective (affective and cognitive processes) and the artifact physical and digital dimensions.

Based on this original field of study, the research discussed experience-centered design activities, undertaken by design disciplines in order to improve the industrial design process for evaluating and designing interactions. This area of research was selected because it had been observed that, even though experience-centered tools and methodologies supporting design activities existed, the uptake of industrial experience-centered approaches oriented toward user-artifacts interaction, and more specifically the physical and digital paradigms, and the industrial design process had been studied only poorly.

The three experimentations of this research explored the way we can generate and evaluate interactions from a user experience perspective. With the help of newly created tools and methodologies, we explored how users experience interactions, from a physical and digital perspective, and how these insights might influence the way we design early interactive products. This perspective led us to investigate the metaphorical approach when evaluating and designing interactions. By so doing, we explored, formalized, and tested a methodology for designing interactions using the metaphorical approach. We also evaluated how the nature of this methodology can impact the scope of design information in early design; the multicultural design disciplines involved in concept development; and the moment for involving that kind of methodology from a design process perspective.

In each of the three experiments, the affective and cognitive dimensions of interactions related to both end users and design teams were a major topic of discussion. The way interactions might influence abstract types of affective (emotions) and cognitive (semantic) reactions were discussed in experimentation 1, and more broadly (both abstract and concrete design information) in experimentation 2. Finally, experimentation 3 detailed how a methodology could help to tackle the affective and cognitive dimensions of interaction during the design process, questioning the roles of designers' disciplines in multicultural design teams.

To summarize, the originality of this research lies in the four points listed below.

1. Fields of Study

In this research, we combined two major fields of research: The first is the user-centered approach of cognitive psychology (Atkinson & Shriffin, 1968; Helander & Kalid, 2006); and the second one is the product-centered approach of artificial intelligence and computation (Schomaker et al, 1995; Andrist et al., 2014). Through these two fields, we explored user experience (Ortiz Nicolas & Aurisicchio, 2011; Gentner, 2014), interaction (Krippendorff, 2006; Hassenzahl, 2010; Hekkert & Cila, 2015) and perception (Saussure, 1916; Lakoff & Jonhson, 1980; Yanagisawa, 2016).

2. Experiential Interaction

The view of interaction was based on user perception instead of objective product characteristics, to create experiential interaction in early design. This resulted in, for example, the taxonomy of interactive products.

3. Physical and Digital Paradigm through Metaphors

The research combined the physical and digital paradigms in interaction (Ishii, 2012; Milgram et al., 1994; Pine, 2009) with the metaphorical approach (Hekkert & Cila, 2015; Lakoff & Jonhson, 1980) for designing interactions in early design.

4. Tools and Methodologies

The set of developed tools and methodologies dedicated to the creation and evaluation of user experiences and interactions in early design has been presented both as the "way to" study and as "results of" this research.

This research finally led to both academic and industrial contributions. In terms of the former, it made it possible to formalize the interdependency between user experience and interactions, as well as highlighting a formalized taxonomy of interactive products using the metaphorical approach of physical and digital interactions.

Regarding the latter type of contribution, the different experiments allowed us to propose new tools and methodologies for evaluating interactions from a user experience perspective. Moreover, the way we can design interactions from a user experience perspective has also been tackled using the metaphorical approach. This resulted in a methodology composed of tools that support the way we can design what the users will perceive and feel when interacting with an artifact, before the artifact itself materializes.

«The interface governs transformations
from interior state to exterior relation»
Branden Hookway

6.2 Perspectives

This research created ways to evaluate and design interactions from the user experience perspective in the early phases of the product development process. It also contributed to better understanding and formalizing the interdependency between user experience and interactions, as well as the impact of physical and digital properties on the design information.

The metaphorical approach of interaction developed in this research has shown promising results, but some of its limits could also be identified. For example, the number of interactive products evaluated do not permit covering the eight areas equally. In that sense, further research should be conducted on the impact of metaphors on user's affective and cognitive perception. Additionally, knowing that the evaluations are based on the user's perception makes the validity of the collected results very short term. The impact of temporal notions such as novelty or surprise need to be further explored in order to improve the proposed approach.

Logically, the model of design information can also be improved and further explored in terms of the impact of temporality (the ways users are experiencing their interactions), and also by exploring the impact of culture on users' different affective and cognitive reactions when interacting with an artifact. Actually, we could consider many design information boxes to study the impact on the full user experience, as presented in Figure 75.

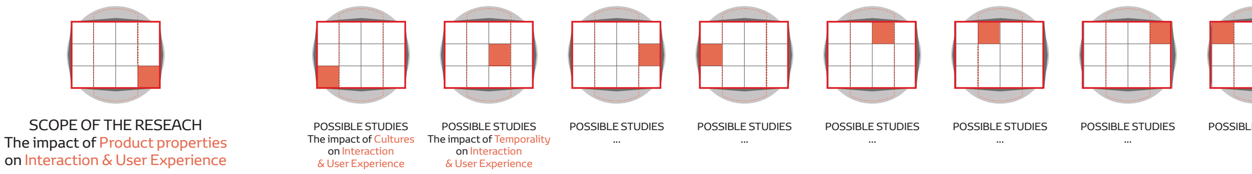

Figure 75: Possible futur studies according to theoretical model of design information (i)

This research focused on proposing to the industrial context of the automotive industry a process for designing and evaluating artifacts using the human perception approach. This process takes the reverse historical way of designing in the huge and very product-oriented automotive industry, based on our research designs for affective and cognitive reactions. **The artifact is just a materialized way to reach these meaningful interactions and user experiences,** nothing more. This is why we adopted the metaphorical approach for designing interactions. In further studies, it would be very interesting to investigate how this metaphorical approach for designing interactions in early design might be used. These studies would have to answer questions such as: "How can metaphorical sources fit a global experience?" Or: "How much can the intended metaphor be perceived in the final user-artifact interaction?" Or: "If there is a gap between 'intended metaphor' and 'perceived metaphor', is information lost, or is this a way to highlight that designing using metaphor is simply independent of experiencing metaphors?"

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ANNEXES

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	ACTIVITIES	GENERAL UNDERSTANDING	WHAT IT COULD BE USED FOR?	WHICH TOOL CAN SUPPORT THIS ACTIVITY	REFERENCES
OBJECTIVE	Brain area reading	Which parts of the human brain are activated when performing or focusing on specific task?	Useful for the judgement of beauty and ugliness Useful for emotional understanding (visceral response to stimuli/ positive emotionality/ cheerfulness and calmness) Useful for sensory involvement (senses used are brain located) Useful for motivational engagement (motivation for social engagement)	FMRI (Functional Magnetic Resonance Imaging);NIRS (Near-infrared spectroscopy; indicating neutral activity); PET (Position Emission Topography)	Yeh and al 2015; Thayer & Lane, 2000; 2009 Geisler et al., 2010 Craig, 2002; Porges, 2011
	Movement tracking	Quantifying general body movements	Highlight sensory involvement (body parts that are used) Highlight behavioral state (the body as a state translation) Highlight behavioral cues (disgust, fear…)	Algorithm based on video (The Shi & Tomasi and the Pyramidal Lucas- Kanade algorithms); video-oculographic technique (VOG)	Bouguet 2000 LaMuth, 2011
	Head tracking	Observe head movements when interacting	Sensory use of the head (what the user is looking at; is the user making effort to listening to something…) Emotional states translation of head position (someone proud, embarrassed, shy…) Behavioral movement (disgust, fear…)	(video based on nose root…)	
	Eyes movement	Activity focused on what the user is looking at when interacting	Sensory involvement of eyes (even touch for peripheral interactions) Emotional states of the user (tired, bored, existed…) Semantic understanding (eg. number of time he is looking something to understand it…)	(video oculographic techniques, eye gaze system, MobileEye system)	
	Speech recording	Collect information based on verbal expressions	Emotional cues (translate expression and their rate into emotional states of the user) Motivational engagement of the user (translate expression, their rate and intensity into motivational states) Sensory involvement (translate expression and their rate into sensory understanding) Semantic understanding (to highlight errors, success and even how much time the user asks for help)	Sound recorder; Fly on the wall; …	
	Grip pressure	Grip pressure measurements for force involvement data	Sensory static and dynamic pressure distributions	capacitive sensors, film sensors, strain gages…	Mahmut & Kemal 2008; Maggiorana et al 2001; Garinei & Marsili 2014
	Attractive zones	Highlight what zones are observed by the user	Sensory cues on eyes use and peripheral interactions Semantic understanding (warning zones, pleasure zones, fast or slow understanding…)	Eye tracking systems	Mc Duff 2013
	Sense involved	Observation of which senses are involved when interacting with something	Understand the impact of each sense for each task (number of time, how long) Understanding habit of users Highlight how users manipulate things (with one or two hands…)	Video recording; sound recording; eye tracking systems…	LaMuth, 2011
	Perspiration	Measuring the perspiration when interacting	Detect emotional state of a user: stress; discomfort; Detect physical engagement of a user: effort of someone to perform a task	(electrodermal responses, galvanic skin)	
	Heart rate	Heart rate translate objectively a body states	Emotional user's states: the heart rate allows to measure the emotional impact on someone (eg. arousal indicator) Motivational engagement of a user based on his heart rate.	Electrocardiogram; blood pressure…	
	Respiration	Measure user's respiration	Respiration can be used to read stress or fear in user's states	Stethoscope…	
	Facial expression	Observe facial expression of a user to highlight non-verbal cues.	Useful for emotional state understanding Useful for opinion and semantic understanding (cultural research on facial expression)	Affectiva; Zygomatic EMG; Corrugator EMG; electrocardiography; Cohn-Kanade database…	Matsumoto 1989

Table 37: Objective and Subjective measurement methods - Part 1

OBJECTIVE	Pupil dilatation	Measuring the pupil diameter to highlight information	Emotional state of the user (the size of the pupil transcribe emotional state and mental activity)	Eye tracking; Dark Pupil Tracking technique…	Dean 2011 Hess & Polt 1964
	Body temperature	A way to highlight temperature of specific body zones	Highlight hands manipulation area on something Highlight emotional state based on temperature	Infrared thermography…	
	Salivation	Measure salivation of users	Emotional state of a user (eg. stress) by measuring swallow frequency	Absorption method, swallow frequency, parodic gland…	
	Learnability	How performance change over time	Semantic understanding (how and when users reach proficiency in using a product)	Video recording; Fly on the wall…	
	Time on task	How quickly users can perform a task	Understand notion related to cognitive and physical ergonomic	Video recording; Fly on the wall…	LaMuth, 2011
	Efficiency	Amount of effort required to complete a task	Semantic understanding (number of steps or actions to complete a task/ ratio of task success rate to average per task)	Video recording; Fly on the wall…	Rieuf (2013)
	Task success	Are users able to complete a task?	Semantic leaning of success (highlight success or not/ levels of success based on degree of completion/the experience in finding an answers/the quality of the answers given.	Video recording; Fly on the wall…	
	Errors	Error measure when Interacting	Semantic learning (understanding the number of mistakes made while attempting to complete a task, and if the user notice that it was a mistake…)	Video recording; Fly on the wall…	
	Manipulation areas	Highlight which areas are used when interacting	Sensory involvement (how many times he touches this area or this one… highlight distances of manipulation)	Eye tracking systems; simple camera with post-production treatment; hand tracking system…	
	...	...			
SUBJECTIVE	Positioning my state/ vision	Ask the participant to compare his perception of the interaction to other element (from a preselected list, or not)	Sensory : Likert scale for each senses… Emotional: Likert scale for each emotion (based on Geneva Emotional Wheel; or Russel 1983 or Scherer 2005); emotional state scale (Premotool)… Semantic: Scale of perceive Kansei (31 adjective from not at all to very much); semantic opposition (based on Khalaj & Pedgley 2014 or Hassenzahl 2006)… Motivational: Likert scales based on five motivational regulation (Deci & Ryan) or Hedonic and utilitarian motivations (Lynn O'Brien 2014); or image based scale… Values: Likert scales based on Rokeach; Osgood's differential (« strong or weak? »)… Cultures: Likert scales or words pair association based on selected cultural semantics. Meanings: Likert scales or words pair association based on selected meanings. …		Rouveray (2006) Keltner, Ekman, Gonzaga, & Beer (2003)
	Identify my state/ vision	Ask the User to describe what happened through a temporal story	Sensory: Cards of senses could be used to identify or rank user's perception. Emotional: Cards of emotional state could be used to identify or rank user's perception of his states. Semantic: Cards of semantics could be used to identify or rank user's perception. Motivational: Cards of motivations could be used to identify or rank user's perception. Values: Cards of values could be used to identify or rank user's perception. Cultures: Cards of cultures could be used to identify or rank user's perception. Meanings: Cards of meanings could be used to identify or rank user's perception. …		Rouveray (2006) Dias (2013)
	Discuss about it	Ask the user to answer to a selected set of questions. It could be open answers or check-list answers.	Sensory: interview; discussion, focus group Emotional: interview; discussion, focus group Semantic: interview; discussion, focus group Motivational: interview; discussion, focus group Values: interview; discussion, focus group Cultures: interview; discussion, focus group Meanings: interview; discussion, focus group …		Dias (2013) Bohrn et al (2013)

Table 38: Objective and Subjective measurement methods - Part 2

SUBJECTIVE	Compare to other things	Positioning the user's perception of the interaction between scales and words oppositions.	Sensory: more or less '…' (sensory characteristics) than this/these one?; Hundred euro test; … Emotional: more or less '…' (emotional characteristics) than this/these one?; Hundred euro test; … Semantic: more or less '…' (semantic characteristics) than this/these one?; Hundred euro test; … Motivational: more or less '…' (motivational characte-ristics) than this/these one?; Hundred euro test; … Values: more or less '…' (values characteristics) than this/these one?; Hundred euro test; … Cultures: more or less '…' (cultural characteristics) than this/these one?; Hundred euro test;… Meanings: more or less '…' (meanings characteristics) than this/these one?; Hundred euro test; … …		Ryan 1 Deci (2000)
	Tell my story	Ask the participant to identify his perception between a selected set of elements	Sensory: Diary journal; interview; discussion Emotional: Diary journal; interview; discussion Semantic: Diary journal; interview; discussion Motivational: Diary journal; interview; discussion Values: Diary journal; interview; discussion Cultures: Diary journal; interview; discussion Meanings: Diary journal; interview; discussion …		Dias (2013)
	Answer to selected question	Create open discussion with one or several user to highlight words	Sensory: Simple questionnaire to relate how was the interaction (open or close answers); Sentence completion (sentence with missing word(s) for letting the user complete the sentence with his own word, or with selected list of words) Emotional: Simple questionnaire to relate how was the interaction (open or close answers); Sentence completion (sentence with missing word(s) for letting the user complete the sentence with his own word, or with selected list of words) Semantic: Simple questionnaire to relate how was the interaction (open or close answers); Sentence completion (sentence with missing word(s) for letting the user complete the sentence with his own word, or with selected list of words) Motivational: Simple questionnaire to relate how was the interaction (open or close answers); Sentence completion (sentence with missing word(s) for letting the user complete the sentence with his own word, or with selected list of words) Values: Simple questionnaire to relate how was the interaction (open or close answers); Sentence com-pletion (sentence with missing word(s) for letting the user complete the sentence with his own word, or with selected list of words) Cultures: Simple questionnaire to relate how was the interaction (open or close answers); Sentence completion (sentence with missing word(s) for letting the user complete the sentence with his own word, or with selected list of words) Meanings: Simple questionnaire to relate how was the interaction (open or close answers); Sentence completion (sentence with missing word(s) for letting the user complete the sentence with his own word, or with selected list of words) …		IDEO (2003) Lund 2001
	....	....	...		

Table 39: Objective and Subjective measurement methods - Part 3

A- Car's Evaluation (Evaluation Platform)

The first draft of the evaluation platform was used to evaluate the HVAC, in order to highlight new design challenges that could be used in creative sessions.
To reach the goal of evaluating interactions from the user experience perspective, we used the three major Kansei criteria. The first is the "sensory level". This is the easiest one to understand, because the sensory involvement of a user while interacting is inevitably decisive. The second criterion is the emotional level, focused on an understanding of how the interaction affects the user. The last criterion is the semantic evaluation. This phase is divided according to our previous state of the art: because the user or the artifact perceives stimuli through their characteristics, it proposes to understand their ability to do that at the sensory level. The understanding of interaction as user or artifact characteristics produces "responses" in terms of cognitive and affective processes.

The Sensory criterion

The first Kansei criterion one is the sensory level, which focuses on the sensory involvement of a user while interacting. For example, while driving, a user needs his or her capacity to see, hear, grasp the steering wheel, and so on. Human sensors allow the user to capture information. We can also talk about human physiological capacities that can be divided into exteroceptive, proprioceptive, and interoceptive senses (LaMuth, 2011), and chronoception.

According to the research community (e.g., Schifferstein et al., 2015), sensory properties can be divided into two groups: Static properties and dynamic properties. Static properties have been listed above. We can highlight the visual domain (intrinsic properties of the material), the shaping of the product (refers to the qualities coming from manufacturing), the texture, the tactile aspect (tactile experience given by the material itself, i.e., its warmth and softness, and other qualities related to a decorative pattern, which is perceived not only through the tactile system but also through vision), and the olfactory properties.

However, because our study focuses on interactive properties, we can also acknowledge the dynamic qualities of the product: Auditory, visual changes, force feedback, vibration feedback, and olfactory feedback.

Evaluating users' sensory involvement is helpful to obtain information such as time to find an element, the attractiveness of elements, zones, sounds, and whether it is a peripheral interaction or not. All of these data can be collected by both objective and subjective measurement tools, such as eye tracking, camera, hand tracking, and by users' description of sensory perceived significance, through discussions and questionnaires.

The Emotional Criterion

The second criterion is the emotional one, focused on an understanding of how an interaction affects the user. According to Bradley and Lang (2000), user emotional responses to stimuli can be measured in terms of three dimensions: Language events, physiological events, and behavioral events. These three types structure this overview, but the language category is extended to psychological responses in a wider sense (Kim, 2011; Rieuf, 2013; Kerstin, 2013).

Accordingly, three kinds of information can be collected: The psychological impact on the user; the physiological impact; and the behavioral impact.

• The psychological impact on the user (or the artifact) is difficult to measure, because most of the time it is based on a self-measurement method, according to Rouveray (2006). This method consists of assessing one's own subjective state when interacting with a product. This method has the advantage of transforming qualitative information into quantitative data, and thus allows us to apply statistic methods to subjectivity.

• The second impact is the physiological impact. This criterion tries to determine a subject's emotional state by interpreting the physiological responses to a stimulus. According to Rieuf (2013), physiological and motor responses help to interpret the indirectly observable emotional state of a subject. However, it seems that there is a risk to using physiological measurements to measure an emotional state, because researchers need to interpret the collected data (Nagasawa, 2004; Rouveray, 2006).

• The third criterion is the behavioral impact, which is based on facial expression, postural and eye tracking, hand gesture examination, etc. It contributes to the formalization of the emotional states. For instance, researchers such as Keltner, Ekman, Gonzaga, and Beer (2003) have developed a taxonomy linking facial muscular contractions with emotional state. Once again, the collected data need to be interpreted. For example, with a face recognition system, how does one determine whether a smile means "I am happy" or "I am embarrassed"? This is why evaluating only one of these three impacts is not sufficient to reach a conclusion on the emotional state. Indeed, data and results need to be combined.

The emotional criterion is also based on objective and subjective measurement tools. To collect objective data, different tools can be used, such as an electrocardiogram, face reader tools to translate facial expressions into emotional states (the "affectiva tool", McDuff, 2013). The subjective data can be collected by emotional cards that the user can point out after the experience. Both objective and subjective emotional data allow an understanding of the user's emotional reaction to an interaction. The following table shows criteria, measurement methodologies, and examples of tools for this emotional criterion..

The Semantic Criterion

The semantic criterion focuses on the way the user perceives the artifact. This criterion can be understood in terms of three kinds of attributes, the practical, the symbolic and the aesthetic. Indeed, the subjective part of interaction that the cognitive system and sign theory bring, highlights the specific meanings that the user gives to the system. This thesis bases the semantic criterion on Dias' understanding of artifact perception (2009; 2013), who states that a product is perceived according to three criteria:

• The practical attribute: This is related to use in terms of pleasure and effectiveness.

• The symbolic attribute: This is about the aspect of esteem and social perception.

• The aesthetic attribute: This is focused on aesthetic impressions that are felt about an object through the senses.
Objective measurement tools can be relevant for describing specific data, such as task success, learnability, efficiency, number of errors, time per task, etc, in others words mainly “practical attribute” information. On the subjective side, self-measurement methods aim at understanding the user’s perception of interaction and experience by using a larger scope.

These three criteria were used to assess the user experience of the HVAC (see Figures 76 and 77).

Figure 76: The three evaluated HVAC

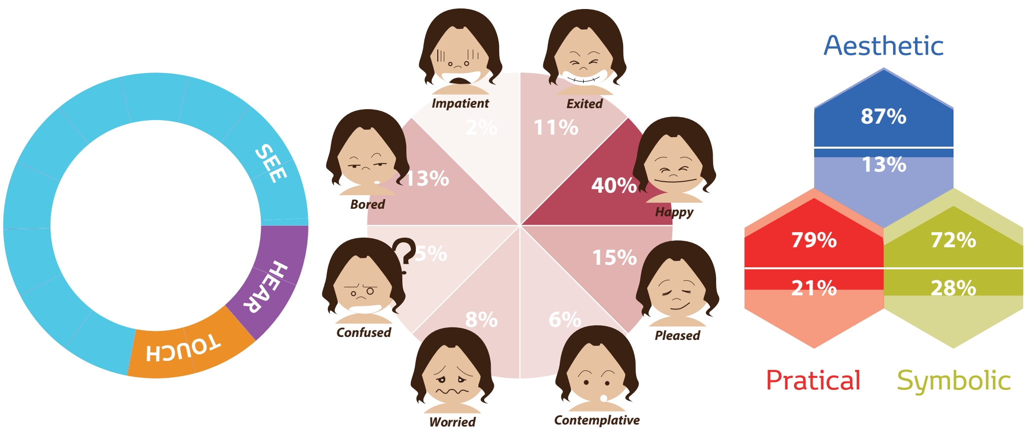


Figure 77: Results representation

Furthermore, we added a temporal dimension to our first evaluation platform. We split the experiential interaction into unilateral interaction and reciprocal interaction. Unilateral interaction allows participants to evaluate products without an operating system. Reciprocal interaction allows participants to discuss the notion of functional interactions.

Thus, three criteria were used for this study: The sensory (based on the five senses + motion, materialized through cards); the emotional (based on the psychological part, using the Geneva Emotion Wheel translated into cards); and the semantic criterion (based on practical, symbolic and aesthetic notions translated into cards with two-term oppositions). We only collected subjective data, because this study was only based on cards to position the state and perception of the participants. Eventually, eight participants evaluated three different HVACs.

We used these evaluations to create a first version of the evaluation platform, and in order to find some design challenge for the first experimentation (example of results in Figure 77).

B- Kansei Kards (Creation Platform)

In order to organize a brainstorming session during the first experimentation, we formalized a tool for designing interactions. To do so, we used two inputs:

- Input 1: Typology of interactive products

We described a state of the arts focused on 11 families of interactive products. These families were somehow simplistic and not at equal levels. Nevertheless, they were a starting point for approaching interactive products.

- Input 2: Major criteria of reflection

The second input was a selection of six Kansei research criteria.

Based on these two inputs, we created brainstorming cards that could cover inputs 1 and 2. This resulted in 26 cards, based on a simple question: The "What If" cards. These cards were oriented to the automotive context (Figures 78 and 79). Figure 78 shows the links between inputs 1 and 2, and the 26 cards.

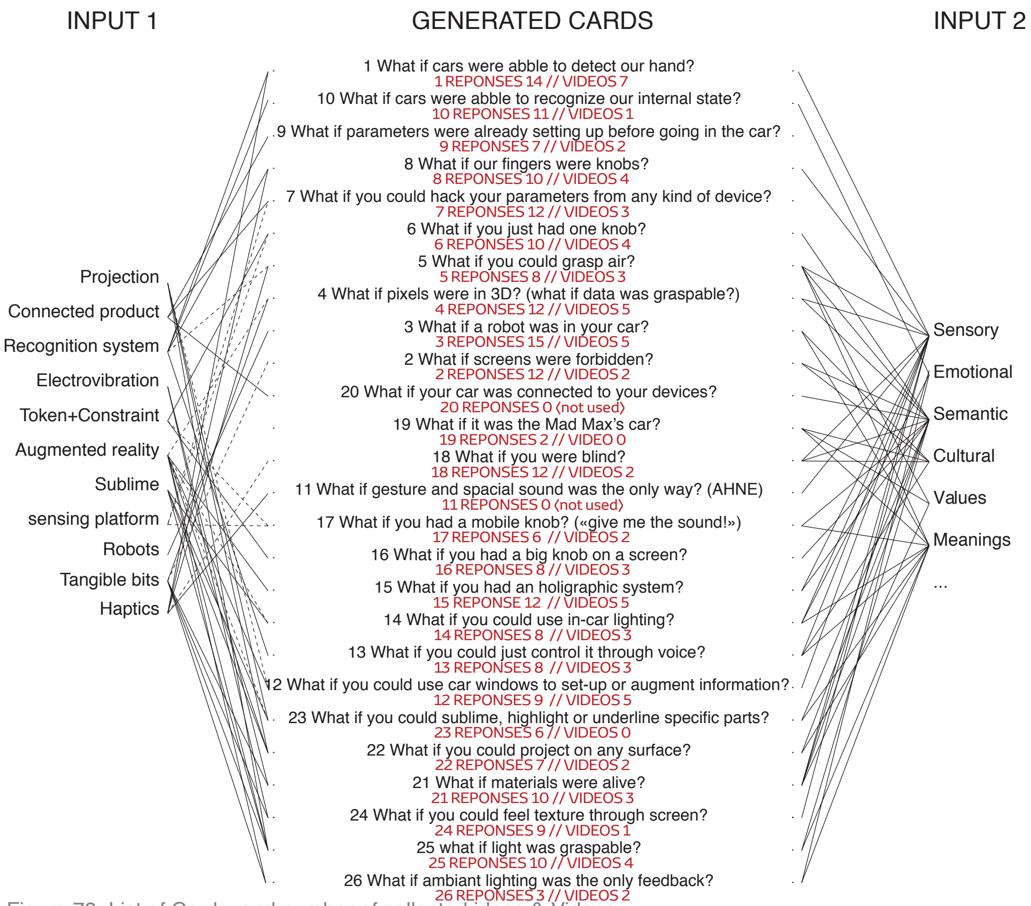


Figure 78: List of Cards, and number of collected ideas & Videos

Picture 5: Workshop to test the ‘what if’ cards

Figure 79: The cards that have been improved

After the first experimentation, and the different ideas that were generated and analyzed, we improved this tool: The 26 cards that we used, allowed us to collect 199 ideas. Of these 199 ideas, 77 were formalized from paper to video presentations (see Figure 77, parts in red). Based on that, we selected 22 cards (of the 26 initially created) to be improved.

Additionally, we used the mapping (design information(i)) of each idea per card to calculate an average. This average allowed us to point out what every card is potentially eliciting in terms of design information (i) results. The cards are presented in Figure 79. These Kansei Kards can be multiplied according to trends and new technological evolutions.

C- Kansei Kabin (Creation Platform)

After the brainstorming session, we used what is called the "Kansei Kabin" in order to create interactive products. The Kansei Kabin is simply half a car, where every part is customizable and movable. The Kansei Kabin allows brainstorming sessions, as we used; quick prototyping support; scenario creation; story telling

Picture 6: Workshop involving the Kansei Kabin

Picture 7: Workshop involving the Kansei Kabin

support; role play, etc. Many sensors can be added to the Kansei Kabin, for example, Arduino systems for quick prototyping solutions; cameras to record scenarios and discussions; simple paper and pen for in-situ drawings, etc. (see Pictures 6 and 7).

D- Koncept Evaluation (Evaluation Platform)

After the brainstorming sessions recorded by the Kansei Kabin, we evaluated every formalized idea in order to select which one to develop. To do so, we used three idea evaluation methods.

1. Every recorded idea was associated with a scale of precision. This scale allows defining whether the generated idea is precise or not. This 4-degree scale was created from the largest vision (needs) to the smallest (sensors).

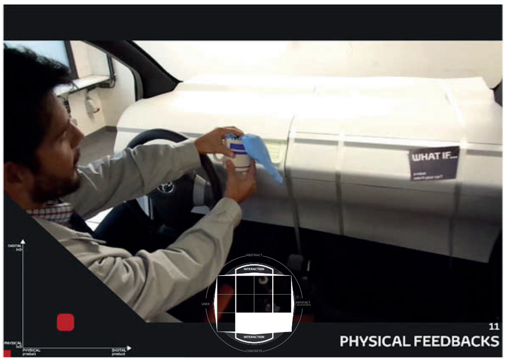


Figure 80: Example of analysed video

2. The second evaluation method was a double axis to start a first approach of the physical and digital paradigms. The first axis was about properties of the idea created (from physical to digital). The vertical axis was about the perception of the properties, from the physical to the digital perception of the interactive properties.
3. The last evaluation method was the theoretical model of design information(i). The goal was simply to see what kind of design information each idea is tackling.

Based on these three evaluations, we selected which ideas were the most interesting to develop.

E- Kansei Kabin (Evaluation Platform)

In experimentation 1, we described the experimental condition used to evaluate concepts. It consisted of the Kansei Kabin, with added sensors that support the evaluation methodology. For more information, see the protocol of experimentation 1 (4.2.3.1).

NEEDS	ACTIONS	MEASURE	SENSORS:
-Scenario -Principles -...	-which gesture -which order -which command -...	-body measure -voice measure -contextual measure -...	-trackers -sound recorder -contextual sensors -...

Table 40: Scale precision for selection of concepts

F- HMI Score (evaluation platform)

Following the evaluation we did for the first experimentation, we decided to create a simple tool to evaluate quickly and simply HMI in the cars. To do so, we worked on a way to translate and unify interaction criteria into a simple HMI score. This score was optimized by both objective and subjective measurement methods.

The evaluation framework is based on a user journey, with simple tasks to perform (objective evaluation based on data collection), and on a self-assessment questionnaire (subjective evaluation). This tool can be used to:

1. Highlight a unified and cross-divisional HMI score based on objective and subjective measurement methods.
2. Do some benchmarking, in order to compare results to other competitors, based on the same criteria.
3. Highlight weaknesses and new design challenges, by looking at specific elements with a bad score that can be improved in new design phases.
4. Do some target settings, by highlighting from the design brief what a future consumer will want and need. By putting weights to these criteria, we can highlight which car or which concept can fit this target, and how to improve them.

This tool was tested in an evaluation of two cars, based on three components (head-up display; combimeter, and infotainment system), with nine experts at TME.

Picture 8: Collected data for analysis

Picture 9: HMI evaluations with participants

G- Kansei Evaluation Kit (evaluation platform)

The HMI score previously presented was conceived as a way to get an HMI score of the car. It was based on four highlighted components, with specific tasks to perform, and on specific evaluation criteria. It resulted in a cross-divisional HMI score.

Another version of the evaluation platform was developed, namely the Kansei Evaluation Kit. It is based on an open program, where divisions can select any components in a car to evaluate (or add new ones); they can select in terms of which criteria they will evaluate the tool (or add new ones); they can select pre-defined tasks for the survey or add new ones; and finally, they can use the predefined sensors that the kit is proposing or add new ones.

This tool was developed using a simple tablet application, as presented in Figure 82. It is based on 11 steps:

1. Enter the application with Toyota member access.
2. Select the criteria to use for the evaluation.
3. Select the component(s) to evaluate in the car.
4. Describe the condition of the test (static/dynamic; type of road; density of traffic; role of participant(s); meteorological conditions).
5. Set the different sensors according to criteria (some sensors have to be set up, such as facial reading system, electrocardiogram, scene camera).
6. Once everything is set up, the evaluation can begin.
7. The application starts to record (time, image, etc.).
8. The application asks the participant to follow instructions and tasks that are based on components selected for the evaluation. Once the participant performs the task, he or she can simply say “OK, I did it”.
9. When the tasks have been completed, several questions are put to the participants. The first set of questions is generally an overview.
10. The second set of questions is based on the criteria selected for evaluation. This is the subjective evaluation part.
11. Finally, the participant can see his or her results, based on criteria previously selected. The participant can also see mappings with all previously evaluated products and another kinds of results.

The Kansei Evaluation Kit is an adaptable evaluation platform that translates and unifies every criterion into a simple score through objective and subjective measurement methods. This tool can be improved with new criteria, new tasks, and new sensors that participants will add.

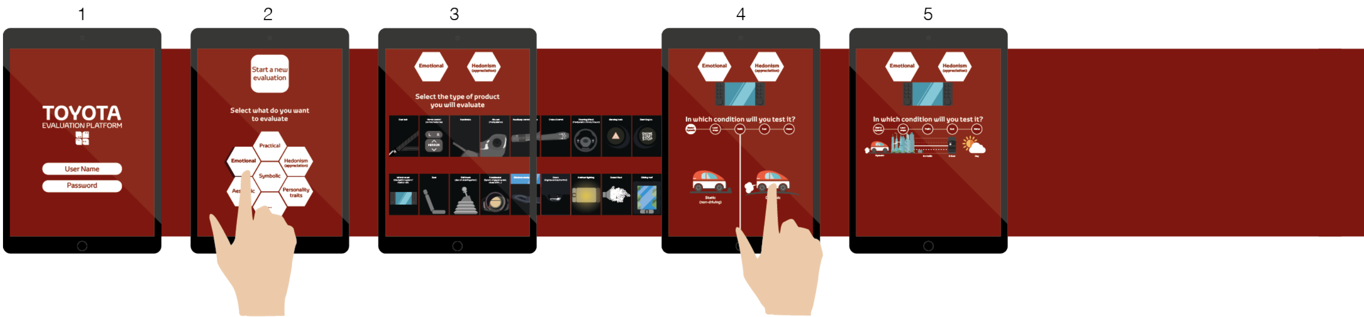
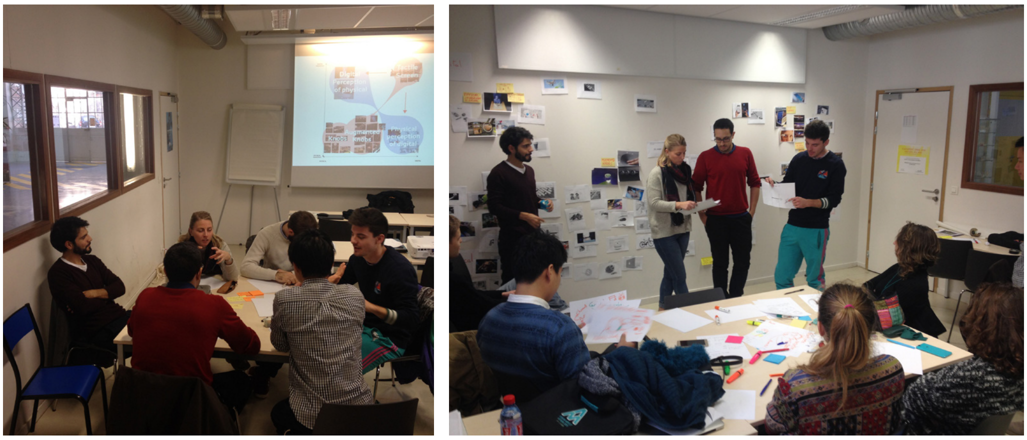


Figure 82: Application dédicated to the Kansei Evaluation Kit

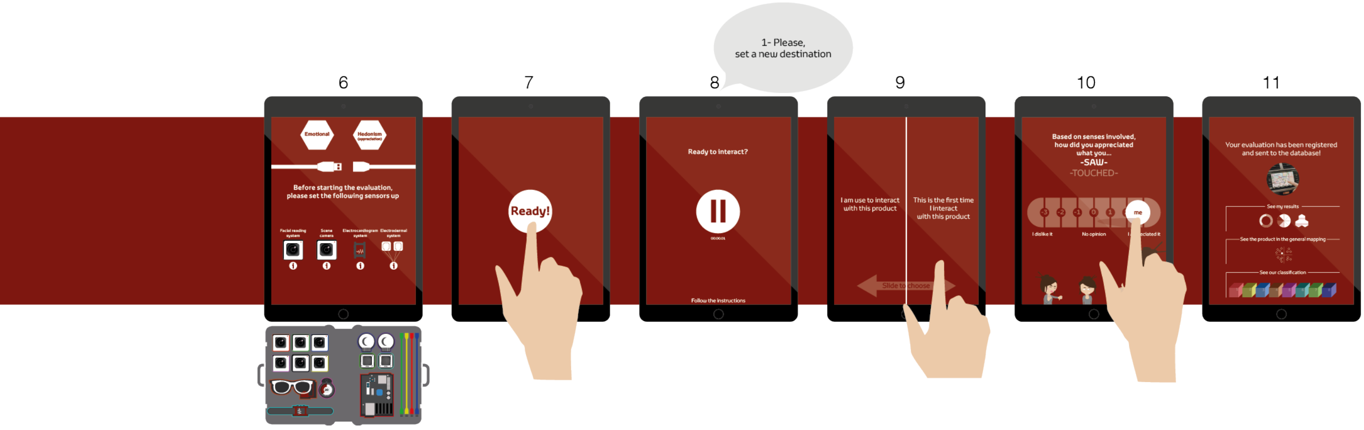
H- Kansei Klassification (preliminary workshop)

In order to propose a taxonomy of interactive products, a workshop was set up with students from Arts et Métiers ParisTech. The 18 participants explored the link between the objective properties of products (from physical to digital), and the perceived properties of interactive products (from physical to digital). We asked participants to bring five pictures of interactive products they liked. After presenting them, they mapped them on a wall on two axes.



Picture 10: Workshop with student form Arts et Métiers Paristech on the Kansei Klassification

This resulted in a mapping of interactive products, based on two axes. The mapping allowed us to highlight different areas of interactive products: For example, an interactive product based on physical objective properties and physical perceived properties was characterized as the area of “knobs”. On the other hand, an interactive product based on digital objective properties and digital perceived properties was characterized as “tactile screen”. These two areas only play with one kind of property (physical or digital). Nevertheless, two areas were highlighted: based on physical objective properties combined with digital perceived properties. Participants called this the “digital perception of physical”. Finally, the last area was highlighted based on the digital objective properties of physical perception. Participants called this the “physical perception of digital”.



Thus, even if this mapping only displays four areas of interactive products, and even if the axis is not perfect, participants highlighted that different families of interactive products can be differentiated according to the physical and digital paradigms. The mapping 81 presents the output of this workshop.

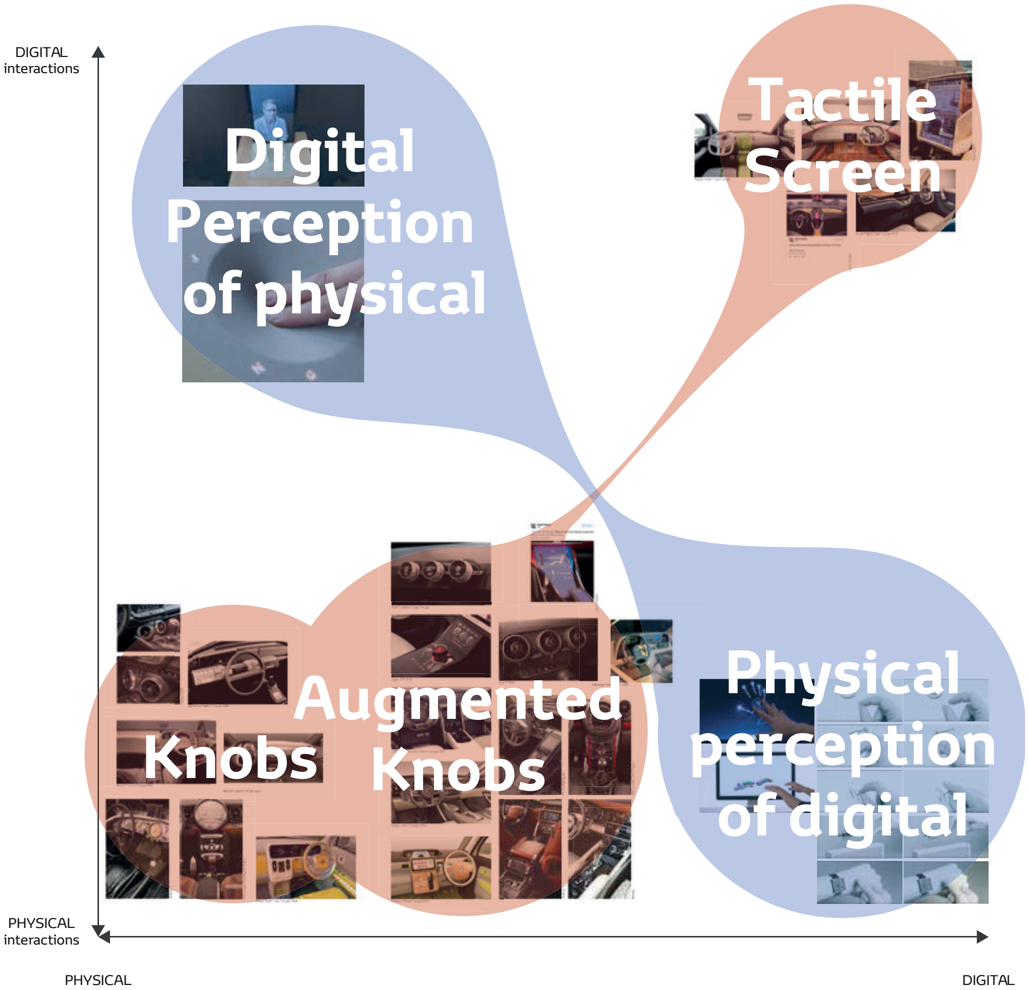


Figure 81: Mapping of the preliminary workshop: physical and digital paradigm

Experimentation 2 helped us to improve this tool: In the second experimentation, we improved the evaluation of interactive products based on simple questions. This resulted in a methodology for classifying interactive products along three axes. This protocol takes into consideration the senses involved, the physical and digital interactions, and the subjective perception (overall perception) of user experiential interaction. It proposes an open-basis and step-by-step architecture for evaluating and classifying any interactive products.

This classification can be used to improve an interactive product by playing with axes. By doing this, the designer can deliberately choose which area should host the created interactive product.

I- Kansei Knob (Collaboration with Tue) (Creation Platform)

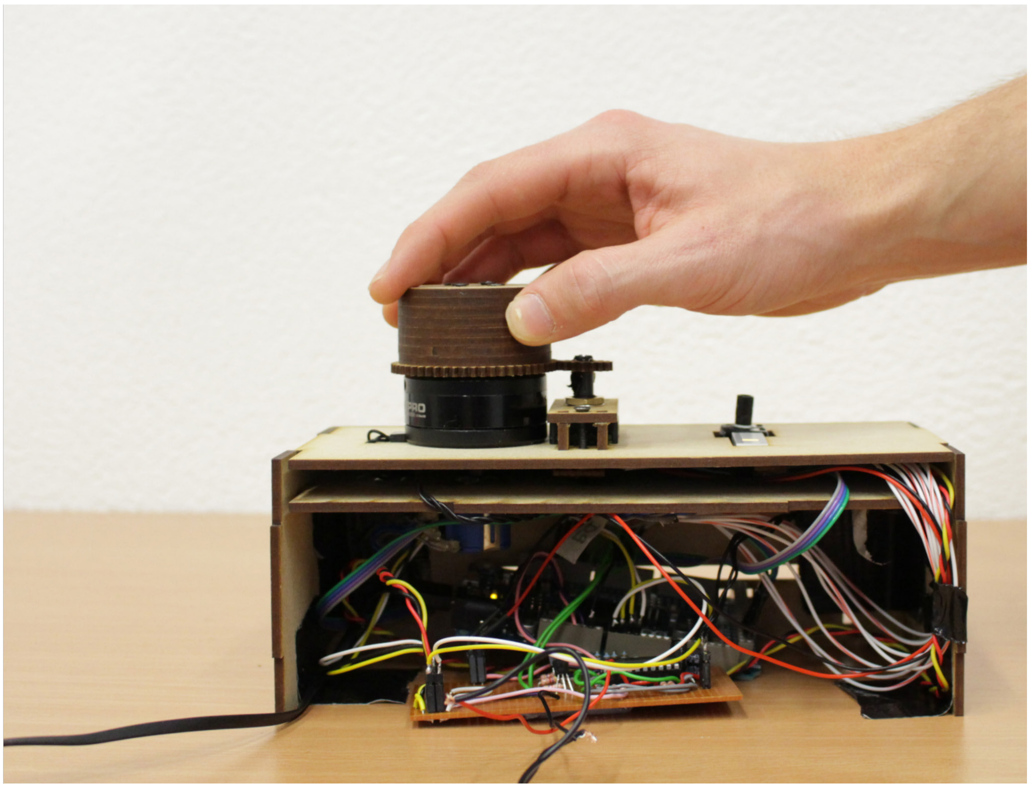
This research started with Shyam C.J., Vincent van Rheden and Pierre Levy from Tue. We conceived a prototype to demonstrate the opportunities of a dynamic haptic knob as part of a concept. It is base on different components: This research started with Shyam C.J., Vincent van Rheden and Pierre Levy from Tue. We conceived a prototype to demonstrate the opportunities of a dynamic haptic knob as part of a concept. It is based on different components:

- A three-phase induction motor: Actuate the rotational axes of the knob. (A three-phase induction motor has more precision and torque in comparison to a normal DC motor. This allows us to rotate the knob by a single degree with reasonably high force.)
- A rotary encoder: To create a tight feedback loop of the state of the motor. (The rotary encoder that was selected in the end has 1024 steps per rotation, meaning that approximately every third of a degree of rotation can be read.)
- An Arduino DUE. (In order to be able to read out, and let the motor react as fast as possible, an Arduino DUE was selected. This Arduino has, in comparison to other Arduino boards, a very high speed (84 MHz clock), meaning it is capable of reading out sensor values without lagging the software program.)
- A potentiometer and an Arduino UNO. (The screen software of the envisioned prototype was developed in Flash and mapped to the rotation of the knob. A 10-rotation potentiometer provides feedback on the motor status for this screen software. The values of rotation are read out in Flash via an Arduino UNO that runs the Firmata Library (a standard Arduino software package)).

This resulted in a prototype to test rotary feelings as presented in Picture 11.

This prototype, dedicated to a specific concept, was improved in order to become a tool for the creation platform: We add to this prototypes three sliders to be able to change in real time the three properties that the motor allows to change: Arclength per click, Torque snap (force), and Noth self-centering. By doing so, the designer can use these sliders in order to change and search for the perfect feeling according to what they are trying to develop.

Furthermore, we added to the motor a way to easily include different shapes. For example, a 3D-printed shape can be added very easily in order to test different textures, materials, softness, etc. (the switch part in Figure 83).



Picture 11: Kansei Knob

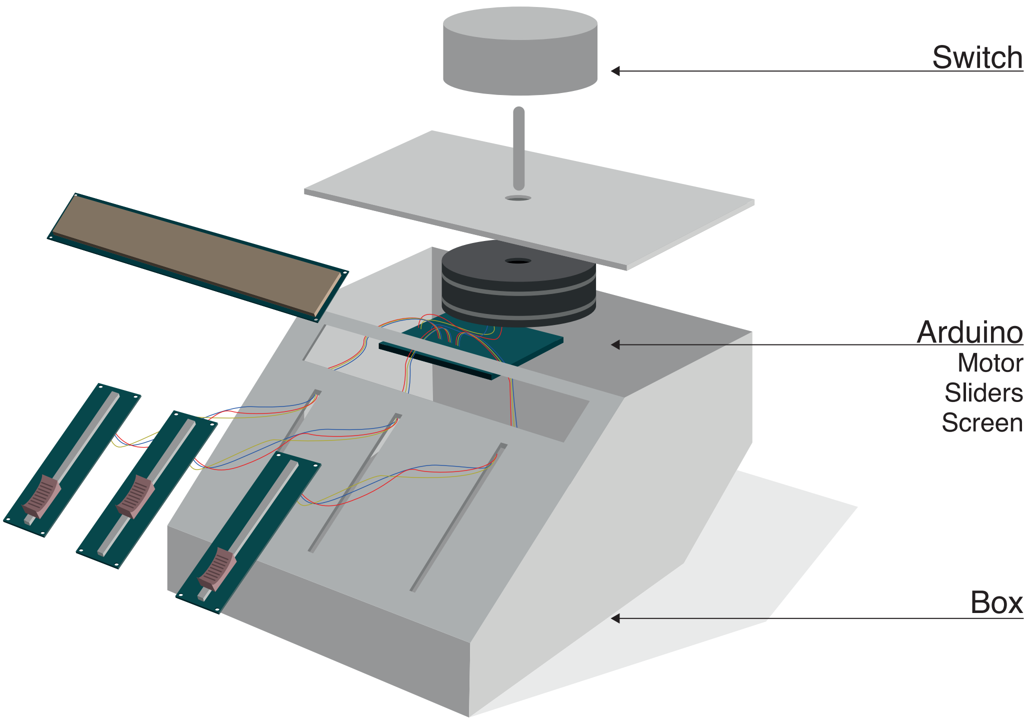


Figure 83: Kansei Knob

J-Superinteraction Tool (creation platform).

Just before the third experimentation, a workshop with six participants was organized in order to test the feasibility of using a specific metaphor in concept development. The metaphor we used was based on “Super-human”.

The principle is simple. If a normal human + a super capability = super human, then a normal product + a super capability = super interactive product.

Thus we extracted some super-capabilities of Super-humans in order to apply it in the scope of interactive products. Twelve cards were created, six cards representing physical sources, and six cards representing digital sources. In this workshop, we asked participants to use these cards as a way to improve their creativity. One design challenge was created to test these cards: “How will we interact and influence the behavior of the car in the future? Think about the future for our steering wheel. Think about the functions we will need. Think about how will we interact with it.”

Picture 12: Workshop with students of Arts et Métiers Paristech

Finally, 45-minute discussions with participants allowed us to collect oral feedback. According to this feedback, the metaphorical approach is very interesting, and allows collecting unexpected ideas in creativity sessions. However, the cards were sometimes difficult to understand. This feedback suggested thinking more about the size/contents/examples and time per cards in brainstorming sessions.

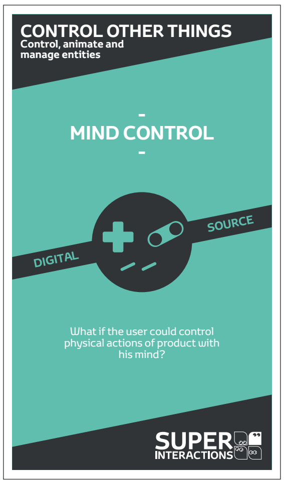


Figure 84: Example of a superhuman card used during the workshop

We improved this approach according to the last experimentation insight. Indeed, the second experimentation highlighted that the physical and digital paradigms is a powerful notion: Using the metaphorical approach to play with the target’s and source’s physical and digital properties when designing interactive products, has been pointed out as meaningful.

The third experimentation revealed that we can use the metaphorical approach for designing interaction and user experiences at three different levels (theorization;

characterization and materialization).
Combining these two insights led this research to the development of a tool for designing interactive products through the metaphorical approach, while also involving the physical and digital paradigms. It resulted in the creation of the Superinteraction Tool (creation platform).

1. List of super-capabilities of superhumans

First of all, we listed the different super-capabilities, based on their names. This data has been extracted from the superheroes database (http://www.superherodb.com). Some definitions have been simplified, and families have been created to regroup super-capabilities. Every source has been materialized in a card with information, in order to organize a workshop for evaluating the card's potential.

NAME OF CARD	FAMILY	DEFINITION	SOURCE
EMPATHY	EMOTIONS Read or sense emotions	What if the Interaction could adapts itself based on emotions or feelings of the user?	PHYSICAL SOURCES
ADAPTABILITY TO ENVIRONMENTAL ELEMENTS	CONTEXTUAL The relation with the environment	What if the way we interact with the product could digitally depends of the environment in witch it takes place?	
ENERGY CONSTRUCTS	MATERIALIZATION Toward materialization	What if the user could digitally creates complex physical shapes (such as giant boxing gloves or cages) or even functio-nal machinery out of solid energy?	
ILLUSION	REALITY CHANGES Change perception of things	What if the Interaction could digitally alter or deceive user's perceptions of something?	
ELEMENT SEN-SING	RECOGNITION determine & track element around	What if the interaction could helps the user to sense or recognize products or peoples around?	
AUGMENT SENSES	AUGMENT/REDUCE Augment & reduce physical original capabilities	What if the interaction could impact (augment or reduce) user's senses (see, smell, taste, feel and/or hear)?	
MIND CONTROL	CONTROL OTHER THINGS Control, animate and ma-nage entities	What if the user could control physical actions of product with his mind?	DIGITAL SOURCES
SHAPESHIFTING	MORPHING Change form, color, density...	What if the interaction could physically change the shape of the product (or only its perception)?	
DUPLICATION	FROM A TO B Temporal changes	What if the Interaction could gives clues of past and future physical versions of the product?	
INNATE CAPABI-LITY	KNOWLEDGE & LIKE GODS Capabilities related to gods	What if the interaction could makes the user physically understand something without the need of studying or previous experience?	
CROSSDIMEN-SIONAL AWARE-NESS	DIMENSIONAL MANIPULA-TION Spiritual & crossdi-mensional manipulation	What if the interaction could physically makes the user sense or feel actions and events in other dimensions (Real/ Virtual)? (Or just somewhere else: outside the car, at home...)	
GRAVITY MANI-PULATION	GRAVITY Manipulate the link with gravity	What if the Interaction could emancipate the product from the perception of gravi-tational dependancy?	

Table 41: Tested superhuman power during the workshop

2. Which super-capabilities could be used?

A workshop was organized in order to select which super-capabilities should be investigated for the tool development. Eight participants attended this workshop that lasted two hours. During this workshop we mapped every card according to two axes: The vertical axes sorted the super-capabilities from “easy to understand” to “hard to understand”, and the horizontal axis from “hard to rely on product development” to “easy to rely on product development”.

FAMILY	SOURCE NAME	DEFINITION
MIMICRY	Vortex breath	Ability to extract property, or strength from something.
	Power mimicry or absorption	Ability to reporduce something
	Substance mimicry	Ability to borrow properties
	Animal mimicry	**Ability to reproduce properties; behaviour; appearance (…) of animals**
	Metamorphosis	Ability to change one’s physical, biological form to mimic the appearance, characteristics and/or power set of other individuals
	Animal morphing	Ability to reproduce forms
CHANGE FORM, COLOR, DENSITY…	**Biological manipulation**	**Ability to alter/impact biological makeup.This includes, but is not limited to, genetic alterations, physical distortion/augmentations, healing, disease, and biological functions**
	Molecular manipulation	Ability to manipulate the molecules of objects and/or one’s self on a molecular level
	Mass manipulation	Ability to increase or decrease mass in an object or in itself
	Invisibility	Ability to change appearance (color) until disparition
	Shapeshifting	**Change color, structure, form…**
	Density/size shifting	Ability to increase or decrease its density or size
	Deform & reformability	Ability to explode and reform it mass
	Density control	Ability to increase or decrease the natural density of an object and/or one’s self
	Elasticity	Ability to stretch, deform, expand or contract one’s body into any form imagi-nable
	Elemental transmutation	The ability to alter chemical elements, changing them from one substance to another by rearranging the atomic structure.
	Animal morphing	Ability to reproduce forms
ENERGY MA-NIPULATION	Energy conversion	Ability to absorb one form of energy and convert it into another form of energy
	Kinetic absorption	Ability to absorb kinetic energy utilize it in some way, such as by converting it into physical strength.
CONTROL OTHER THINGS	Astral projection	Also known as astral travel, this is the ability to separate and control one’s astral body (product)
	Technopathy	**Ability to manipulate technology. Manifested as a special form of electri-cal/telekinetic manipulation, a special form of «morphing» which allows physical interaction with machines, or even a psychic ability that allows for mental interface with computer data**
	Electric manipulation	**Ability to control, generate or absorb electricity and electric phenomena**
	Mind control	**The ability to control (or to be control) the actions of others with the mind**
	Possession	Ability to take control and inhabit the body of something
	Animation	Ability to transfert energy, and to bring inanimate objects to life
AUGMENT/ REDUCE ORIGINAL MENTAL CAPABILITY	Memory manipulation	Ability to erase or enhance the memories of another or itself
	Power negation	Ability to cancel the superpowers of others.
CALL OTHER ENTITY	**Summoning**	**Ability to summon beings or objects for assistance.**
PRECIOUS-NESS	Irreversability/ vulnerability/ fragility (positive way)	Ability to be impactable to one or more forms of physical, mental, and spiritual damage and influence from irreversible way

Table 42: Final Superhuman capabilities - part 1

KNOWLEDGE & LIKE GODS	Precognition	replay the past, present and futur.
	Omnipresence	Ability to be present anywhere and everywhere simultaneously
	Innate capability	**Ability to know or understand something without the need of studying or previous experience.**
	Omnilinguism	Ability to understand any form of language, a natural polyglot. This can be accomplished in various ways.
	Omniscience	Ability to know anything and everything
	Psychometry	replay the past, present and futur.
RECOGNI-TION	**Echolocation/ Spacialize- able/ proprioception**	**Ability to determine location of objects or of himself, in the environment**
	Tracking	**Ability to track an individual or object in an area**
	Elements sensing	**Ability to sense or recognize elements (products or people)**
DIMENSIO-NAL MANIPU-LATIONS	Crossdimensional awareness	Ability to detect actions and events in other dimensions.
	Dimensional travel	**Ability to travel between two or more dimensions, realities, realms, etc.**
	Spiritual mediumship	Ability to see and communicate with the dead
	Probability manipulation	Ability to alter probability
FROM A TO B (GEO-GRAPHIC CHANGES)	Electrical transportation	Ability to travel in anything that is electrical to enter through devices such as televisions, electrical poles or computers
	Teleportation	**Ability to move from one place to another without occupying the space in between**
	Telepathy	Ability to read the thoughts of, or to mentally communicate with others
FROM A TO B (TEMPORAL CHANGES)	Time travel	Ability to travel back or forth through time
	Duplication (temporal)	Ability to bring past and future versions of oneself back to the present.
	Time manipulation	Ability to affect the flow of time by slowing, accelerating, reversing, or stopping it
EMOTIONS	**Empathy**	**Ability to detect or sense the emotions or feelings of others**
	Empathy	Ability sense emotions or feelings
LUMINOSITY MANIPULA-TION	Darkness or shadow manipulation	Ability to create or manipulate light without being a light…
	Light manipulation	**Ability to tetect, change, augment (…) color & brightness of light.**
ELECTRICAL MANIPULA-TION	Microwave manipulation	The ability to convert ambient electromagnetic energy into microwaves and manipulate it into various effects such as heat, light, and radiation
	Magnetism manipulation	Ability to control and/or generate magnetic fields
REALITY CHANGES	**Illusion**	**Ability to alter or deceive the perceptions of another. Can be sensory, a light or soundbased effect, or an alteration of mental perceptions. May overlap with reality warping when it is possible to interact with the illusions.**
	Reality warping	Ability to change or manipulate reality
CARE & RESURREC-TION	**Resurrection**	**Ability to come back to life after being crashed as well, or to bring others back to life**
	Healing factor	Ability to heal rapidly and with greater finality from any injury.
ALTER/ AFFECT THE FOUR ELEMENTS	**Air and wind manipulation**	**Relation between effort and affect**
	Cold and ice manipulation	**Ability to reduce the kinetic energy of atoms and thus reduce temperature.**
DEMATERIA-LISATION	Inorganic	Ability to transform completely into an inorganic substance while retaining organic properties
	Disintegration	Ability to disintegrate itself
	Liquification	Ability to turn partially or completely into a liquid
	Sublimation	Ability to dematerialize itself (from solid to gaze, or from solid to liquid)
MATERIA-LIZATION (opposed from dematerializa-tion)	Energy constructs	Ability to create complex shapes (such as giant boxing gloves or cages) or even functional machinery (such as fire extinguishers or laser rifles) out of solid energy
	Concussion beams	Ability to generate or transform various forms of energy into a «solid» or concussive beam of energy
AUGMENTA-TION A+B=C	**Parts substitution (adaptable/ augmentable)**	**Ability to replace or change parts with those of another thing.**
MERGING / DUPLICATING	**Merging/ fusionability**	**Ability to temporarily merge two or more beings into a single being**
	Duplication (of things)	**Ability to create duplicates itself.**

Table 43: Final Superhuman capabilities - part 2

AUGMENT/ REDUCE PHYSICAL ORIGINAL CAPABILITY	**Power negation (reduce)**	**Delete/ or turn off elements**
	Augment agility / reflexes	**Ability to be augmented, or to augment itself in inprove and augment its capabilities (faster/higher/ stronger…)**
	Augment senses	**Ability to see, smell, taste, feel and/or hear more than a normal product.**
	Augment strength	**Ability to have a level of strength much higher than normally possible given their proportions.**
	Augment vision	**Ability to see/feel through atoms**
	Augment speed	**The ability to move, run, fly, react, think, and sense at speeds much faster than a normal product**
GRAVITY	Wallcrawling	Ability to adhere to solid surfaces, including walls and ceilings
	Gravity-less	Ability to manipulate or generate gravitons, or other types of gravitational interactions
	Gravitational manipulation	**Independant from gravity**
CONTEXTUAL	**Adaptability to environmental elements**	**Ability to develop a resistance or immunity to whatever they were injured by or exposed to. This effect can be permanent or temporary.**
	Contextual empathy	**Ability to sense the overall wellbeing and conditions of one's immediate environment and natural setting stemming from a psychic sensitivity to nature**

Table 44: Final Superhuman capabilities - part 3

Each axis was based on a five-point scale. Participants also had the opportunity to merge two or more super-capabilities that were too close in terms of meaning. The results are presented in Figure 85. Based on this evaluation, 32 cards were selected. The selected cards are in bold in Tables 42, 43 and 44.

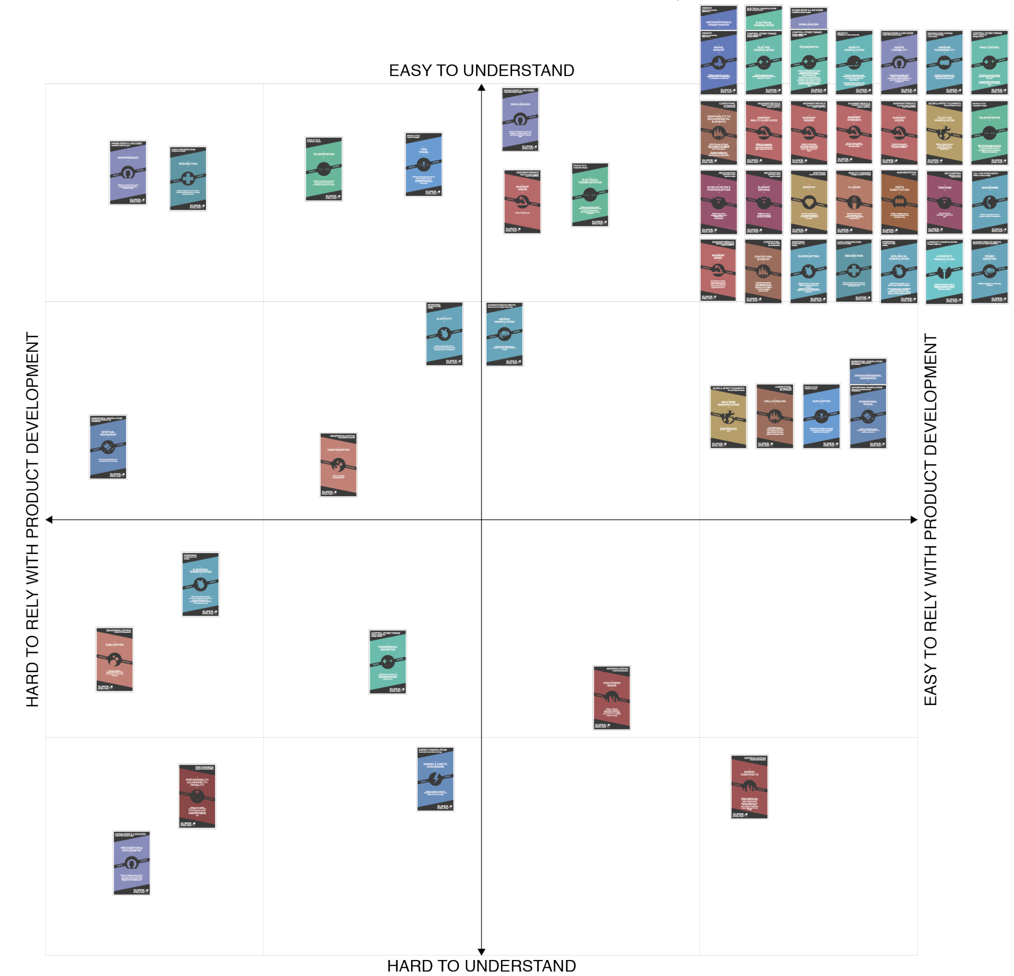


Figure 85: Mapping of Superhuman cards to range them according to two axes

3. Materialize the tool: Theorization level

As we demonstrated in the third experimentation, the metaphorical tool at the theorization level should gather some simple information. Based on these insights, we materializes cards as illustrated in Figures 86, 87 and 88.

4. Materialize the tool: Characterization level

The metaphorical tool at the characterization level also gathered some simple information according to the results of the third experimentation. Based on these insights, we materialized the interactive PDF as illustrated in Figures 89, 90 and 91.

5. Materialize the tool: Materialization level

The metaphorical tool at the materialization level also gathered some simple information according to the results of the third experimentation. Based on these insights, we materialized the tool as illustrated in Figure 92.

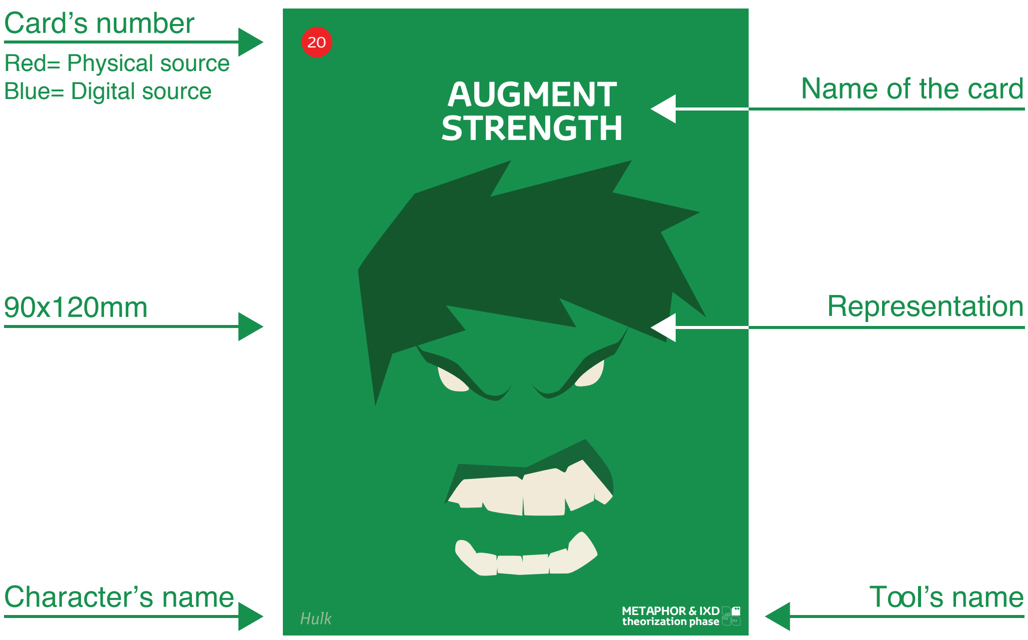


Figure 86: Structure of Superhuman Cards

SUPERINTERACTIONS METAPHOR & IXD theorization phase

Figure 87: Selected Physical sources

SUPERINTERACTIONS METAPHOR & IXD theorization phase

Figure 88: Selected Physical sources

SUPERINTERACTIONS METAPHOR & IXD characterization phase

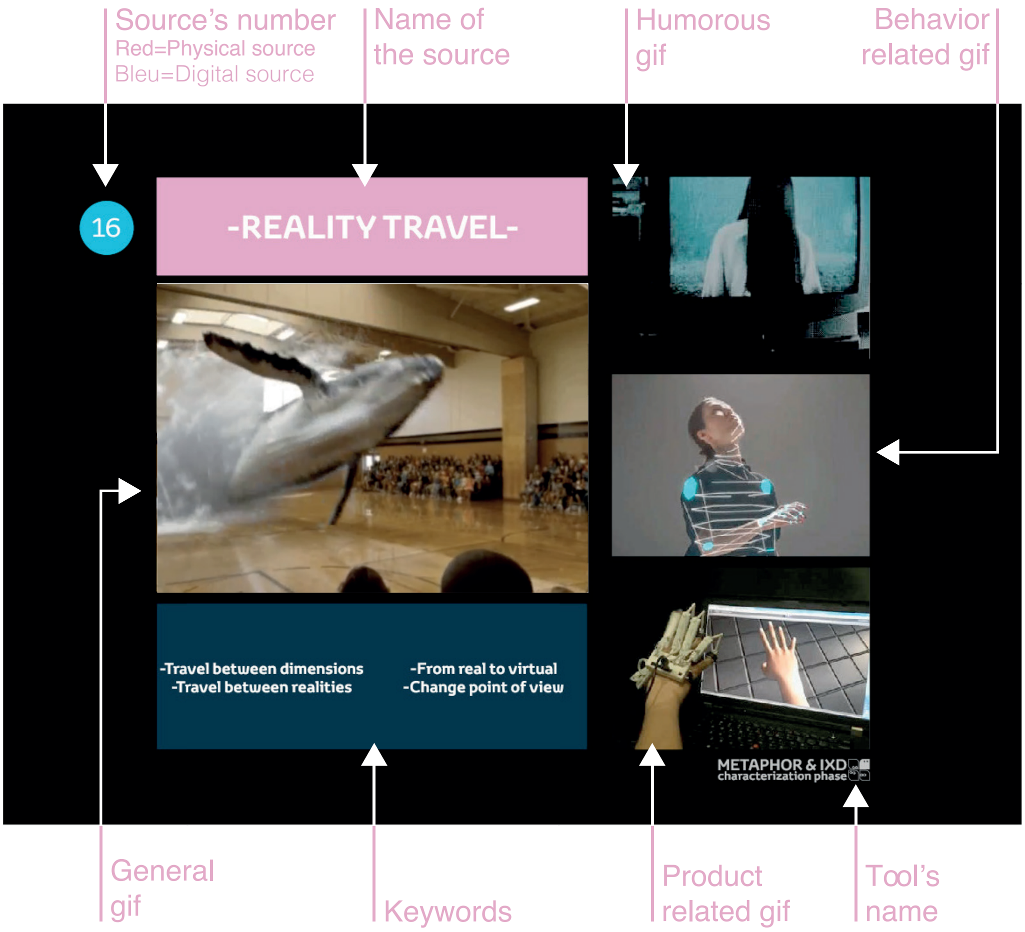


Figure 89: Structure of Superhuman Interactive PDF

Figure 90: Example of interactif pdf pages (digital sources)

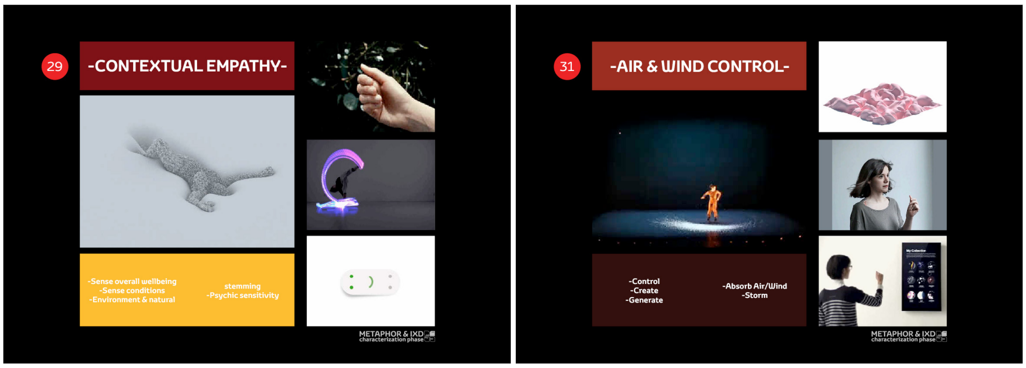


Figure 91: Example of interactif pdf pages (physical sources)

SUPERINTERACTIONS METAPHOR & IXD materialization phase

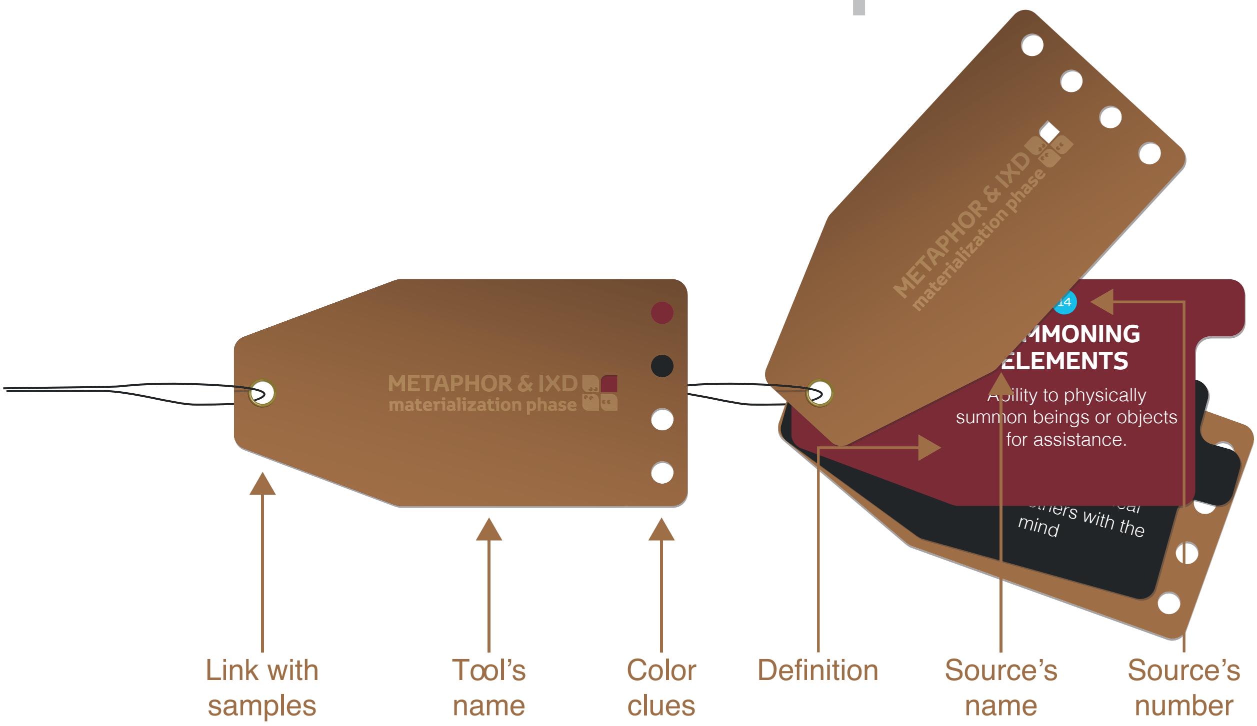
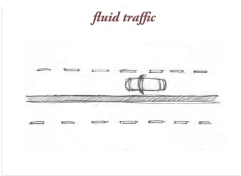
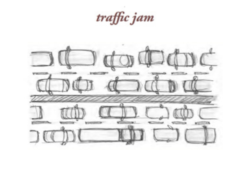
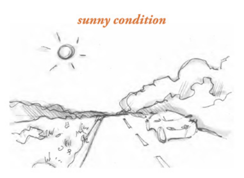
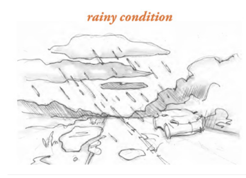


Figure 92: Structure of materialization tool

K-Scenario Kards (Creation Platform)

In order to create quick scenarios in creativity sessions, we developed a set of cards with Juliette Martin, a designer at TME. This set of cards can be used to set the different parameters to start storytelling and scenario creation, as we did during a creativity workshop (see Picture 13). The following Figure describes the different elements with which we constructed the cards (see Figure 93). These cards could easily be transformed into dice for creating random stories.

FAMILY	TRAFFIC CONDITIONS	
NAME	Fluid traffic	traffic jam
CARD		

FAMILY	WEATHER CONDITIONS		
NAME	Sunny condition	Rainy condition	Snowy condition
CARD			

FAMILY	DRIVER CONDITIONS		
NAME	Active driving condition	Passive (but focus) driving condition	Passive driving condition
CARD			

FAMILY	ROAD CONDITIONS		
NAME	City condition	Mountain condition	Highway condition
CARD			

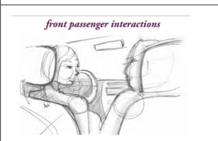
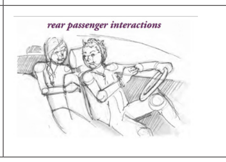
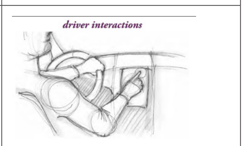
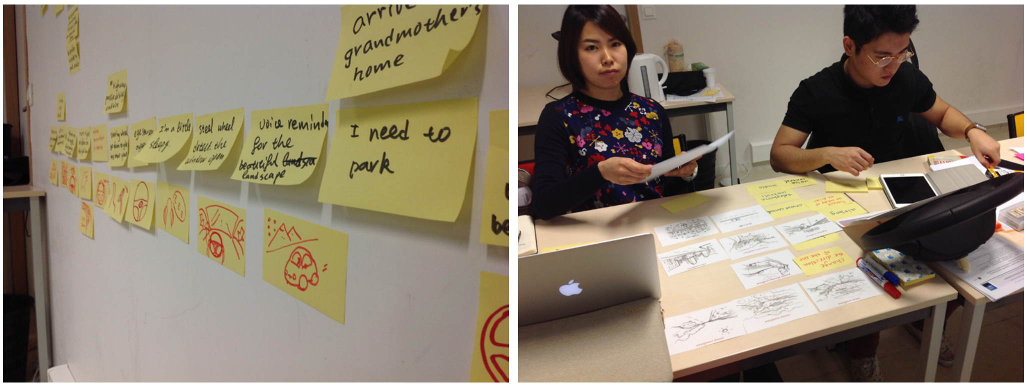
FAMILY	INTERACTION CONDITIONS			
NAME	Child or baby interactions	Front passenger interactions	Rear passenger interactions	Driver interaction
CARD				

Figure 93: Generated Scenario Kards



Picture 13: Scenario Kards in workshop to test their use

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-
LIST OF TABLES
-

Table 1: LCPI thesis also tackling Kansei related studies 32
Table 2: Definition of User Experience according to the litterature 49
Table 3: Main principles of Interactions summarized 54
Table 4: The three fields: Kansei Design/ Emotional Design and Affective computing 75
Table 5: Model of design activities, defintion and tools 79
Table 6: Summarized litterature review 88
Table 7: Two User Experiences and four Interactive products 106
Table 8: Table of evaluated elements 107
Table 9: Table of criteria 109
Table 10: Table of 30 cycles of evaluation 111
Table 11: Principles extracted from the preliminary experimentation 134
Table 12: Example of videos 135
Table 13: Architecture of questions 136
Table 14: Collected data 137
Table 15: Serials for Experts and Novices 137
Table 16: Multiple comparison test according to the three axis 138
Table 17: Result of experimentation 139
Table 18: Principles results 142
Table 19: Data Linear Regressions 144
Table 20: Influence of Dimensions(d) on Design Information(i) 145
Table 21: Table of preliminary workshop 155
Table 22: Architecture of question 158
Table 23: Serials 160
Table 24: Section organization 161
Table 25: Data used for PCA 163
Table 26: Data used for PCA 164
Table 27: Data used for PCA 167
Table 28: Design information description 182
Table 29: Description of the eight ereas 185
Table 30: Design Levels(lev) description 186
Table 31: Design Principles description 187
Table 32: Summary of academic contributions 188
Table 33: Generated tools - part 1 192
Table 34: Generated tools - part 2 193
Table 35: Contributions - Part 1 199
Table 36: Contributions - Part 2 200
Table 37: Objective and Subjective measurement methods - Part 1 210
Table 38: Objective and Subjective measurement methods - Part 2 211
Table 39: Objective and Subjective measurement methods - Part 3 212
Table 40: Scale precision for selection of concepts 219

Table 41: Tested superhuman power during the workshop 227
Table 42: Final Superhuman capabilities - part 1 228
Table 43: Final Superhuman capabilities - part 2 229
Table 44: Final Superhuman capabilities - part 3 230

-

LIST OF PICTURES

-

Picture 1: Maserati Bomerang 1972 and Tesla model X 2015 17
Picture 2: Workshops during design project. Generation of ideas 108
Picture 3: Workshops conducted with designers to test the tools 157
Picture 4: Two participants completing the survey 160
Picture 5: Workshop to test the ‘what if’ cards 217
Picture 6: Workshop involving the Kansei Kabin 218
Picture 7: Workshop involving the Kansei Kabin 218
Picture 8: Collected data for analysis 220
Picture 9: HMI evaluations with participants 221
Picture 10: Workshop with student form Arts et Métiers Paristech on the Kansei Klassification 222
Picture 11: Kansei Knob 225
Picture 12: Workshop with students of Arts et Métiers Paristech 226
Picture 13: Scenario Kards in workshop to test their use 237

LIST OF FIGURES

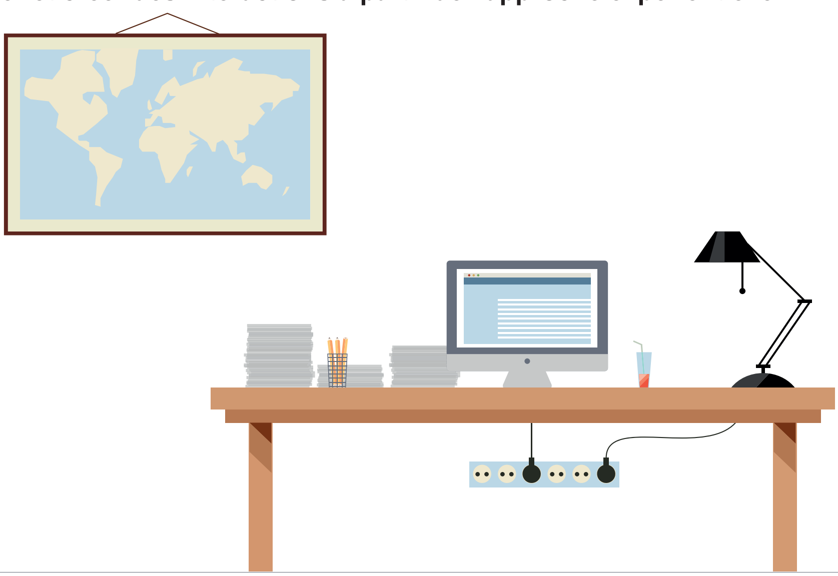
Figure 1: A car From Japon to Europe 22
Figure 2: Design practices representation 24
Figure 3: LCPI scope of research and postion of our research whitin this scope 31
Figure 4: Past project between TME-KD and LCPI 35
Figure 5: Model of Litterature review scope 39
Figure 6: Model of Experiencing Designs scope 43
Figure 7: Representation of Sign Theory according to Saussure & Pierce 48
Figure 8: Temporal representation, reproduced from Krippenforff 2006 51
Figure 9: Temporal representation in Interaction 52
Figure 10: Miami model of Interaction reproduced from Schomaker et al 1995 53
Figure 11: Norman's model of interaction 53
Figure 12: Representation of the link between User Experience and Interaction 56
Figure 13: Representation of metaphor 61
Figure 14: Model of Experiencing Designs scope 64
Figure 15: Model of User Experience scope 65
Figure 16: Three dimensional taxonomy 66
Figure 17: Model of Designing Experiences scope 69
Figure 18: Kansei Experience framework reproduced from Gentner 2014 71
Figure 19: The three fields from the User and Artifact perception 76
Figure 20: The three fields representation 77
Figure 21: Model of Design information reproduced from Gentner 2014 80
Figure 22: Representation of Design activities/ Design levels and Design Information 81
Figure 23: Model of Designing Experiences scope 83
Figure 24: Model of Litterature Review scope 87
Figure 25: Hypotheses representation 95
Figure 26: Representation of the Evaluation and the Generation platforms according to model of litterature Review 97
Figure 27: Concept development process 105
Figure 28: The experimental condition 110
Figure 29: Panel of participants 111
Figure 30: The four steps 111
Figure 31: Average values taken for each Pux on the emotional scales after all the ID1-4, and their respective confidence intervals 115
Figure 32: Average values taken for each Pux on the semantic scales after all the ID1-4, and their respective confidence intervals 115

Figure 33: Average values taken for Pux1 (top) and Pux2 (bottom) on the emotional scales after all the ID1-4, and their respective confidence intervals 116
Figure 35: PCA 2 semantic 118
Figure 34: PCA 1 emotion 118
Figure 36: Confidence Intervals between IDs for Emotional Values 119
Figure 37: Confidence Intervals between IDs for Semantic Values 120
Figure 38: Confidence Intervals between IDs for Emotional Values from Pid1 (top) to Pid4 (bottom) 120
Figure 39: PCA 3 Emotion 122
Figure 40: PCA 4 Semantic 122
Figure 41: PCA 5 Emotions 123
Figure 42: Model of Design Information with highlighted links 129
Figure 43: The influence of the three dimensions(d) on the design information(i) 131
Figure 44: Mean and Confidence interval of Evaluations 140
Figure 45: PCA Principles and Areas mapping according to Target and Source 143
Figure 46: Influence of Dimensions(d) on Design Information(i) 145
Figure 47: Futur Design Challenges 147
Figure 48: Eight Areas(a) and their impact on the Design Information(i) 148
Figure 49: Experimentation 3: confront the three insights 153
Figure 50: Workshop 1 defining the tool 156
Figure 51: Test and improve the tool in five steps 156
Figure 52: Examples of the collected outputs of the previous workshops 158
Figure 53: Evaluation of the tool: the survey 158
Figure 54: Design Disciplines(di) and Design Information(i) results 162
Figure 55: PCA of the different disciplines 163
Figure 56: PCA of the different disciplines and participant's backgrounds 164
Figure 57: Design levels(lev) and Design Information(i) 165
Figure 58: Design Levels(lev) and the link between quality and quantity 166
Figure 59: Mapping of the three levels(lev) and the design information(i) 167
Figure 60: Design Disciplines (di) and Design Levels(lev) according to Design information 168
Figure 61: Different Design Levels(lev) combined with the Design Disciplines according to their impact in term of Design Information(i): mapping 169
Figure 62: Different Design Levels(lev) combined with the Design Disciplines according to their impact in term of Design Information(i): mapping and trajectories 169
Figure 63: Design Disciplines(di) with Design information(i) from every activity, and Design Disciplines(di) with Design Information(i) when using the metaphorical apraoach 171
Figure 64: Design Disciplines(di) with Design information(i) from every activity, and Design Disciplines(di) with Design Information(i) when using the metaphorical apraoach: mapping 171
Figure 65: Hypotheses representation 177
Figure 66: Model of Design Information 181
Figure 67: Model of design information: variation 183
Figure 68: Taxonomy of interactive products 184
Figure 69: Representation of the Evaluation and the Generation platforms according to model of litterature Review 191
Figure 70: Representation of the metaphorical methodology 193
Figure 71: step by step instructions of the metaphorical methodology 194
Figure 72: Representation of the Discipline methodology 195
Figure 73: Representation of the evaluation methodology 195
Figure 74: The four types of results 196

Figure 75: Possible futur studies according to theoretical model of design information (i) 207
Figure 76: The three evaluated HVAC 215
Figure 77: Results representation 215
Figure 78: List of Cards, and number of collected ideas & Videos 216
Figure 79: The cards that have been improved 217
Figure 80: Example of analysed video 219
Figure 82: Application dédicated to the Kansei Evaluation Kit 223
Figure 81: Mapping of the preliminary workshop: physical and digital paradigm 223
Figure 83: Kansei Knob 225
Figure 84: Example of a superhuman card used during the workshop 226
Figure 85: Mapping of Superhuman cards to range them according to two axes 230
Figure 86: Structure of Superhuman Cards 231
Figure 87: Selected Physical sources 232
Figure 88: Selected Physical sources 233
Figure 89: Structure of Superhuman Interactive PDF 234
Figure 90: Example of interactif pdf pages (digital sources) 234
Figure 91: Example of interactif pdf pages (physical sources) 235
Figure 92: Structure of materialization tool 235
Figure 93: Generated Scenario Kards 236

ABSTRACT:
Users' experience with products recently became a major differentiation factor for products and services companies (such as Toyota Motor Europe), leading to deeper researches on both user experience and interaction. These researches preach for a deeper consideration of the subjective perception rather than artifacts' objective properties.
From this approach of '**design research' through the subjective perception,** this study intends to understand and formalize the reciprocal influence between Interaction and user experience, highlighting which parameters are affecting subjective reactions. From these parameters, this research isolated the artifact's physical and digital properties in order to highlight its effects on **user's affective and cognitive reactions**.
By doing so, this research resulted in both academic and industrial contributions. In terms of the former, it made possible to **formalize the interdependency between User Experience and Interactions**, to define **a taxonomy of interactive products through the metaphorical approach of physical and digital interactions** and to **materialize a methodology with tools for both evaluating and designing interactions from the User Experience perspective.**

RÉSUMÉ:
L'expérience que les utilisateurs vivent est récemment devenue un facteur majeur de différenciation pour les entreprises de produits et de services (comme Toyota Motor Europe), les poussant à mener des recherches plus approfondies dans les domaines de l'expérience utilisateur et de l'interaction. Ces recherches amenent à une plus grande considération de la perception subjective plutôt que celle des propriétés objectives des produits.
Partant de cette approche de la **'recherche en design' à travers la perception subjective,** cette étude tente de comprendre et de formaliser les influences réciproques des interactions et des expériences utilisateur en définissant quels paramètres affectent les réactions subjectives. À partir de ces paramètres, cette recherche a isolé les propriétés physiques et digitales d'un produit dans le but de mettre en avant leurs **effets sur les réactions affectives et cognitives d'un utilisateur.**
Grâce à cette approche, cette recherche aboutit à des apports à la fois scientifiques et industriels: elle a rendu possible **la formalisation de l'interdépendance entre l'expérience utilisateur et les interactions**, la mise en place d'une t**axonomie des produits interactifs à travers l'approche métaphorique des interactions physiques et digitales** et enfin la matérialisation d'une **méthodologie et d'outils pour à la fois évaluer et créer des interactions à partir de l'approche expérientielle**.



FRENCH VERSION

ÉLABORATION D'UNE MÉTHODE DE CONCEPTION KANSEI À TRAVERS LES **INTERACTIONS PHYSIQUES ET NUMÉRIQUES**

Theo Mahut Phd student
Carole Bouchard (Professor) academic director
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TOYOTA
Kansei Design Toyota Motor Europe
ARTS ET MÉTIERS ParisTech
Laboratoire Conception Produits Innovation

FRENCH VERSION

Cette partie est la seule où je vais parler personnellement. Mon nom est Théo Mahut et je suis designer, avec deux diplômes de niveau Master : un en Design Industriel et un en Innovation et Conception de Produit. Je suis amoureux des produits justes et mémorable, les produits capable de toucher l'âme d'une personne. Toute cette magie que les produits génèrent pendant nous interagissons avec eux est un territoire d'étude incroyable que j'ai décidé d'explorer à travers cette thèse. Mon intention est d'apprendre le plus possible à la fois du monde industriel et du monde académique. J'espère un jour être le designer que j'ai toujours voulu être.

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TABLE DES MATIÈRES
-

REMERCIEMENTS

GLOSSAIRE

LISTE DES ACRONYMES

SYNOPSIS

1 CONTEXTE DE LA RECHERCHE
1.1 Contexte industriel
1.1.1 Toyota Motor Corporation (TMC) et Toyota Motor Europe (TME)
1.1.2 Division de conception de Toyota Motor Europe Kansei
1.1.3 Pratiques de conception
1.2 Contexte de la recherche
1.2.1 Histoire de la recherche en design
1.2.2 Positionner cette dissertation dans le champ de recherche du LCPI Arts et Métiers ParisTech
1.3 Historique de la collaboration industrielle et de recherche

2 REVUE DE LA LITTÉRATURE
2.1 Expérimenter des designs
2.1.1 Le cadre
2.1.2 Interaction
2.1.3 Interaction expérientielle
2.1.4 Une approche métaphorique des interactions physiques et numériques
2.1.5 Résumé des conceptions expérimentées
-1- Modèle d’information de conception (i)
-2- Taxonomie tridimensionnelle (d)
-3- Zones (a)

-4- Principes (p)

2.2 Concevoir des expériences

2.2.1 Champs de conception
2.2.2 Disciplines de conception (di)
2.2.3 Processus de conception
2.2.4 Niveaux de conception (lev)
2.2.5 Information sur la conception
2.2.6 Concevoir des interactions par l'approche métaphorique
2.2.7 Concevoir des expériences: résumé
5- Processus de conception
6- Niveaux de conception (lev)
7- Disciplines de conception (di)

2.3 Résumé et déclarations de l'état de la technique

3 QUESTION DE RECHERCHE ET HYPOTHÈSES

3.1 Question de recherche

3.2 Hypothèses

3.2.1 Les trois hypothèses
3.2.2 Hypothèses qui soutiennent le développement des plateformes

4 EXPÉRIMENTATIONS

4.1 Introduction

4.2 Expérimentation 1

4.2.1 Objectifs
4.2.2 Terrain expérimental
4.2.3 Méthode
4.2.4 Résultats
4.2.5 Discussion
4.2.6 Conclusions et perspectives

4.3 Expérimentation 2

4.3.1 Objectifs
4.3.2 Méthode
4.3.3 Résultats
4.3.4 Conclusions et limites

4.4 Expérimentation 3

4.4.1 Objectifs
4.4.2 Méthode
4.4.3 Protocole
4.4.4 Conclusion

4.5 Conclusion sur les expériences

5 CONTRIBUTIONS

5.1 Contributions académiques

5.1.1 Modèle d'information de conception

5.1.2 Taxonomie des produits interactifs
5.1.3 Approche métaphorique du processus de conception
5.1.4 Un ensemble de principes
5.1.5 Conclusion sur la contribution académique

5.2 Contributions industrielles

5.2.1 Développement de nouveaux outils
5.2.3 Création de nouvelles méthodologies
5.2.4 Adoption de la contribution industrielle dans les activités de Toyota Motor Europe

5.3 Résumé des contributions

6 CONCLUSIONS ET PERSPECTIVES

6.1 Conclusions
6.2 Perspectives

ANNEXES

Annexes
A- Évaluation de la voiture (plateforme d'évaluation)
B- Kansei Kards (Plate-forme de création)
C- Kansei Kabin (Plate-forme de création)
D- Koncept Evaluation (Plate-forme d'évaluation)
E- Kansei Kabin (Plate-forme d'évaluation)
F- Score HMI (plateforme d'évaluation)
G- Kit d'évaluation Kansei (plateforme d'évaluation)
H- Kansei Klassification (atelier préliminaire)
I- Kansei Knob (Collaboration avec Tue) (Plate-forme de création)
J-Superinteraction Tool (plateforme de création).
K-Scenario Kards (Plate-forme de création)

RÉFÉRENCES

LISTE DES TABLEAUX

LISTE DES PHOTOS

LISTE DES FIGURES

FRENCH VERSION

REMERCIEMENTS

-

GLOSSAIRE

-

Les termes suivants représentent certaines des notions clés utilisées dans cette recherche. Les courtes définitions expliquent comment ces notions doivent être comprises dans les pages suivantes.

Expérience utilisateur: un phénomène dynamique provenant des caractéristiques de l'utilisateur et des artefacts qui interagissent dans un contexte spécifique, impliquant des réponses personnelles des utilisateurs et des attributs d'artefacts perçus (plus de détails sur cette notion dans la section 2.1.1)

Interaction: l'action accomplie par l'utilisateur ou par l'artefact les uns sur les autres qui influence ou modifie les systèmes moteur, perceptif, cognitif et affectif de l'utilisateur (plus de détails sur cette notion dans la section 2.1.2)

Interaction expérientielle: une séquence d'interactions unilatérales et réciproques (plus de détails sur cette notion dans la section 2.1.3)

Informations sur la conception: informations sur les concepts discutés au sein d'une équipe de conception (plus de détails sur cette notion dans la section 2.1.5)

Disciplines de conception: les disciplines impliquées dans les différentes phases de conception (plus de détails sur cette notion dans la section 2.1.5)

Principe: consiste en des mots-clés principalement liés à ce que le produit interactif permet à l'utilisateur de faire (plus de détails sur cette notion dans la section 2.1.5)

-

LISTE DES ACRONYMES

-

Les acronymes suivants seront utilisés dans le texte non pas comme un moyen d'abréger des mots, mais comme un moyen de faire référence à une notion plus élevée.

(i): Informations de conception du modèle théorique

(d): Dimensions de la taxonomie

(a): Zones mises en évidence par la taxonomie

(p): Principes de caractérisation des produits interactifs

(lev): Niveaux de conception

(di): Disciplines de conception

-

SYNOPSIS

-

Et si les volants de voiture étaient digitaux ?
Grâce à la recherche et aux évolutions, on peut admettre que aujourd'hui la technologie est illimitée. Dans l'absolu, tous les éléments avec lesquels nous interagissons pourrait devenir digitaux. C'est par exemple d'autant plus vrai pour les éléments liés à l'information avec lesquels nous interagissons dans la voiture. Nous avions l'habitude d'interagir physiquement avec ce genre de composants, comme cette Maserati boomerang de 1972(voir image 1 sur la gauche). Néanmoins, les évolutions technologiques nous permettent de transposée ses interactions physiques en interaction complètement digital, À travers un simple écran. La tesla model X de 2015(image 1 sur la droite) est un exemple de ce mouvement de digitalisation extrême.

Picture 14: Maserati Bomerang 1972 and Tesla model X 2015

Aujourd'hui les constructeurs automobiles peuvent digitaliser pratiquement tout dans une voiture, dont le volant. Alors pourquoi garder quelque chose de physique ? Pourquoi ne pas avoir simplement un écran avec un cercle digital qui permettent au conducteur de tourner? D'un point de vue objectif, choisir entre le physique ou digitale, soulève des questions de prix, d'efficacité, de temps par tache, et même de standardisation.
D'un point de vue plus global, l'expérience utilisateur peut aussi être considéré. Cela soulève de nouvelles questions comme «que ressent utilisateurs ?», et «comment est-ce qu'il ou elle perçois il apprécie les performances de conduite il interactions avec ce véhicule ? ». C'est le genre de perspective que cette recherche va considérer. Ainsi, en nous focalisant sur les interactions physiques digitales à partir de cette façon subjective de percevoir ces notions comme la confiance, les impacts émotionnels, les interactions intuitives, et plus largement les expériences utilisateurs mémorables, nous amène À considérer la façon

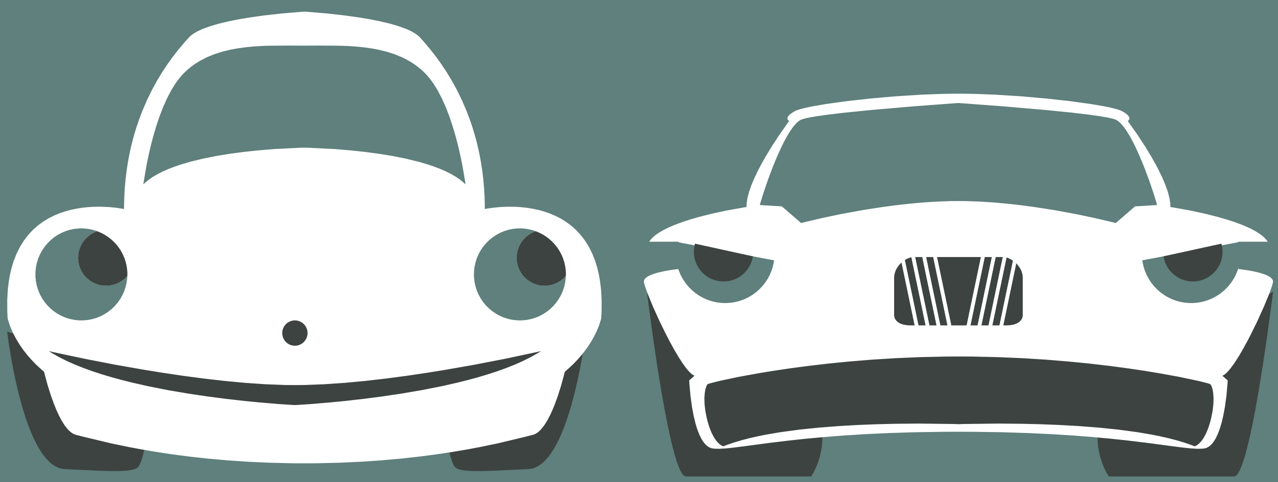
dont nous pouvons les concevoir.

Ce qui est intéressant dans l'exploration du rapport entre le physique et le digital, c'est la quantité d'interaction entre ces deux options. Par exemple, sur l'écran de cette Tesla model X, on peut voir des boutons digitaux avec une ombre. Cette ombre joue avec l'illusion d'avoir des boutons physiques, mais avait quand même temps une capacité infinie de changer de forme. Cette tendance, connu sous le nom de «Skeuomorphisme", est un exemple de cette frontière floue entre les propriétés physiques et le digitales.

Notre hypothèse et que la juste expérience utilisateur pourrait dépendre d'un équilibre parfait entre les interactions physiques et digital. Combiner ces deux dimensions pourrait en effet permettre d'exploiter les avantages des deux mondes.

Afin d'explorer ce point de vue plus loin, un projet de recherche a été initié au LCPI des Arts et Métiers Paristech et la division Kansei Design de Toyota Motor Europe.

Le chapitre un de cette recherche présente le contexte général dans lequel cette recherche s'inscrit. La revue littéraire, en chapitre deux, explore à la fois la relation entre un utilisateur rien objet (vivre le Design) d'un point de vue expérience utilisateur, et la relation entre le designer est un objet (Design d'expériences). C'est exploration conduit la recherche vers une question centrale À propos de la compréhension des expériences utilisateur-produits comme une façon d'améliorer l'expérience utilisateur. Trois hypothèses sont proposés, et 3 expérimentations sont présentés. La première formalise l'impact réciproque entre une expérience utilisateur et des interactions. La seconde explore l'impact des propriétés physiques et digital sur les expériences d'interaction. La troisième expérimentation développe un outil pour créer les interactions à partir de l'approche métaphorique. Les questions de recherche et hypothèses sont présentés en chapitre trois, et les expérimentations sont présentées et discutées en chapitre quatre. Cette recherche aboutit a des contributions À la fois académique et industrielle, aboutissant à une amélioration du processus de conception des interactions, à partir du paradigme physique digital. Enfin, la conclusion en chapitre six présente les perspectives futur pour cette recherche.



«The car is the closest thing we will ever create to something that is alive»
William Lyons

«La voiture est la chose la plus proche
d’une entité vivante jamais créée»

-
1 CONTEXT DE RECHERCHE
-

1.1 Contexte Industriel

Ce chapitre décrit le contexte industriel, en partant du champs le plus large de Toyota motor Corporation, jusqu'à la plus petite perspective des pratiques de conception dans la division Kansei Design.

1.1.1 Toyota Motor Corporation (TMC) et Toyota Motor Europe (TME)

La recherche prend place dans la division Kansei Design de Toyota Motor Europe (TME), la filiale Européenne du constructeur automobile Japonais Toyota Motor Corporation. Toyota Motor Corporation (TMC) est une entreprise de conception et de distribution de véhicules automobiles, principalement orienter vers le marché des consommateurs. Cette entreprise a été fondé par Sakichi Toyoda. Son premier essai commercial fut une machine à tisser pour ça mère. Son but est de commercialiser et de développer des produits accessibles, avec utilisateur au centre de son processus de conception.

Établir en 1937, l'entreprise grandit de manière exponentielle pendant le boom économique du Japon à la suite de la seconde guerre mondiale. Cette croissance, même dans une période propice, a aussi été possible grâce à l'innovation du système de production, le "Toyota Production System". Ce système basé sur une production sans gaspillage, l'amélioration continue et le principe du zéro défaut. Ce développement de manière internationale, Toyota depuis les 5 dernières années atteint quatre fois la position de meilleurs constructeurs automobiles à l'échelle mondiale, en terme de véhicules produits. Avec 332 000 employés et un capital de 387 000 000 000 002 ¥(4,21 billions de dollars), Toyota est aussi l'entreprise automobile la plus importante, d'après le Millward Brown. L'entreprise a conservée une forte culture d'entreprise pendant son développement, connu sous le nom de Toyota Way. C'est ensemble de principes pour but d'améliorer les activités de l'entreprise. Ce projet de recherche est situé dans le contexte actuel des méthodologies d'amélioration de la conception. TMC produit des véhicules pour ces deux marques différentes : Toyota et Lexus. La deuxième entreprise produit des voitures de luxe, mais c'est trop cherché a été conduit dans le contexte voiture Toyota.

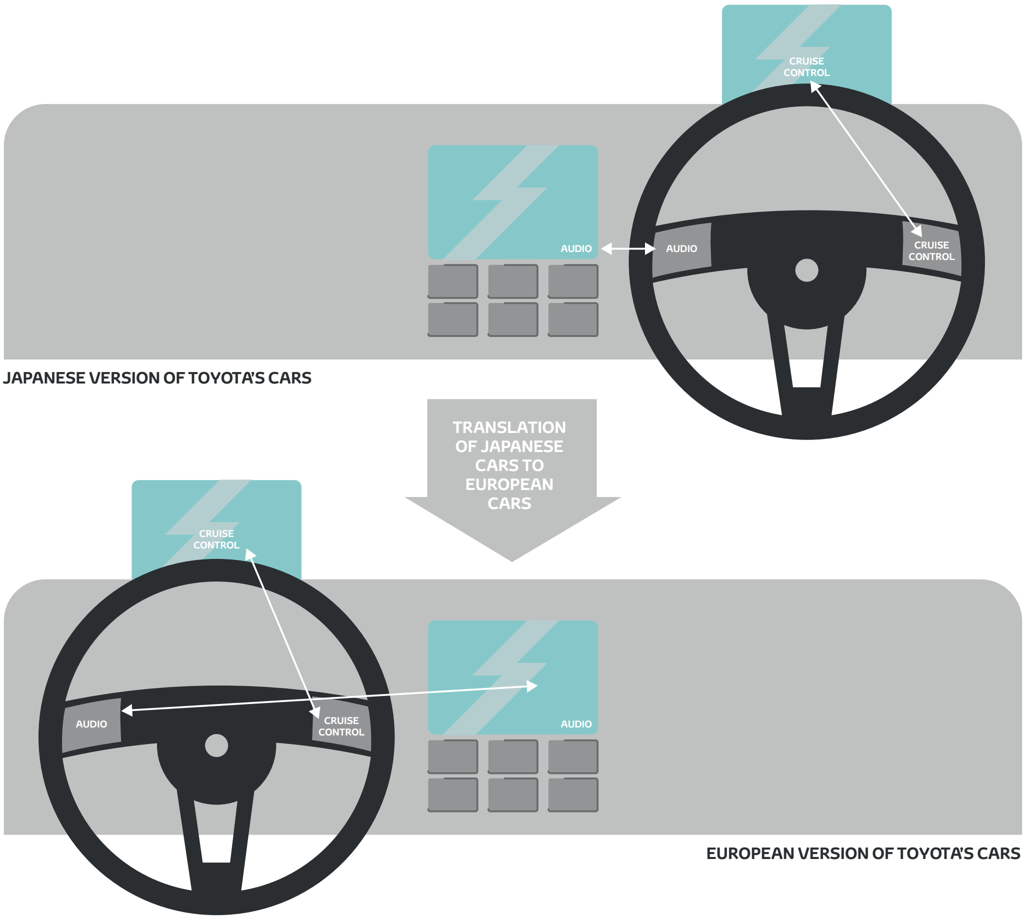


Figure 94: A car From Japon to Europe

1.1.2 Toyota Motor Europe Kansei Design Division

Toyota Motor Europe est la filiale européenne de TMC. En plus de son rôle standard de filiale (activités européennes de recherche et développement, fabrication, vente, etc.), le rôle de TME est d'adapter les véhicules développés au Japon à des spécificités européennes (du design aux dimensions morphologiques), afin de développer des voitures pour le marché européen. Par exemple, comme on peut le voir sur la figure 1, lorsqu'une voiture est conçue au Japon pour le marché japonais et qu'elle est ensuite envoyée en Europe, certains ajustements doivent être effectués. Dans cet exemple simple, il est clair que le volant est sur la droite, et que les fonctions associées sont logiquement positionnées: l'audio qui est à gauche sur le tableau de bord se trouve également à gauche sur le volant. Cependant, lorsqu'il est introduit en Europe, le volant change de position, conformément à la législation de certains pays européens, introduisant des incohérences de facto dans les voitures.

Dans le cadre du département de recherche et développement de TME, la division Kansei Design a pour objectif de développer, mettre en œuvre et utiliser des méthodologies et des outils liés à Kansei pour contrer ces incohérences. La division Design de Kansei est présentée étape par étape «comme un nouveau domaine, réexaminant la philosophie japonaise comme un moyen d'inspiration pour faire face aux problèmes actuels de la recherche en design» (Levy 2013) et une nouvelle interprétation plus proche de la subjectivité des utilisateurs. sa matérialisation par des problèmes de conception de produits. L'approche du design Kansei est basée sur un «point de vue non réductionniste, qui peut être utilisé à la fois pour se concentrer sur, et pour comprendre, les phénomènes de perception et d'expérience, intrinsèquement contextualisés» (Levy 2013). Les objectifs de la division design kansei sont de trouver des approches qui aident à rompre avec une vision standardisée du monde, à travers une perspective sensible centrée sur l'humain. Les études de la division Kansei Design de Toyota sont axées sur la génération de plus grandes énergies pour le dynamisme, et plus d'opportunités pour la créativité. En termes de cette philosophie, la conception de Kansei à TME a été décrite au début comme un moyen d'introduire des approches d'ingénierie de Kansei dans le cadre de la pensée de conception. L'objectif était de définir l'espace de conception (compréhension), de créer des propositions adaptées à cet espace (création), et d'évaluer des propositions basées sur le Kansei des utilisateurs (évaluation) (Gentner, 2014, Bouchard, 2009). Aujourd'hui, l'approche de Kansei Design développée par TME vise à améliorer la manière dont l'expérience utilisateur peut être impliquée dans les premières phases du processus de conception.

1.1.3 Pratiques de conception

L'originalité et la particularité de la division Kansei Design de TME résident dans le fait qu'elle repose sur des pratiques d'expérience utilisateur, par opposition aux pratiques de design industriel. De toute évidence, il existe un terrain d'entente entre les deux: les pratiques de conception basées sur «design ambition», articulées par Henry Cole et Richard Redgrave dans The Journal of Design and Manufactures, et développées par des gens comme Peter Behrens, qui combine l'industrie et les arts avec une approche centrée sur l'humain, pour créer ce qui a été récemment mis en évidence comme les «effets du design» (Kenya Hara).

Si les pratiques de conception peuvent être reconnues comme la philosophie commune entre les pratiques de conception industrielle et les pratiques d'expérience utilisateur avancées chez Kansei Design Division, les trois principales distinctions entre les pratiques de conception industrielle et les pratiques de conception d'expérience utilisateur peuvent être résumées comme suit: outils, et le cercle relationnel.

Tout d'abord, en termes de méthodologie, alors que les pratiques de design industriel créent des produits pouvant donner un sens particulier à l'utilisateur, les pratiques de conception de l'expérience utilisateur se focalisent sur les réactions de l'utilisateur (significations, sentiments, ...). Ainsi, les produits conçus peuvent être les mêmes, mais le schéma de conception, en termes de méthodologie, est différent. L'exemple le plus évident en est certainement le dossier de conception lui-même, qui est orienté sur le plan fonctionnel et matériel pour les pratiques de conception industrielle et orienté émotionnellement, sensationnellement ou expérientiellement vers les pratiques de conception de l'expérience utilisateur.

Deuxièmement, une partie de l'originalité des pratiques de conception est qu’il s’agit d’une profession généraliste (et passion) avec de vastes territoires d’application. Ainsi, entourer les pratiques d’un concepteur avec différents spécialistes a toujours été nécessaire. Néanmoins, alors que les designers industriels créent leur propre relation avec les stylistes, les modélisateurs et bien d’autres spécialistes en fonction de la mission sur laquelle ils travaillent. Les pratiques d’expérience utilisateur conduisent au développement d’une communauté de psychologues cognitifs, d’experts en informatique affective ou même de chercheurs en design Kansei.

Troisièmement, lorsque l’on considère les pratiques de conception, il est important d’utiliser des outils et d’inclure des étapes de conception qui permettent la création du produit final. En effet, les outils des designers sont ce qui permet l’évolution des pratiques des designers. Selon Bouchard (2003), le cycle d’information sur la conception comprend différentes étapes: information, production, évaluation et décision, et communication. Ces étapes de conception courantes utilisent des outils et des méthodologies appropriés en fonction des pratiques de conception de l’expérience industrielle ou de l’utilisateur. En effet, même si le produit final est l’objectif commun, les outils, les méthodologies, le support, etc. dépendent des pratiques.

Enfin, nous pouvons reconnaître le solide background commun des pratiques de design industriel et des pratiques d’expérience utilisateur utilisées par l’équipe de Kansei Design. Néanmoins, malgré tous ces éléments communs, certaines spécificités permettent de distinguer ces pratiques, notamment en ce qui concerne la méthodologie, les outils et les personnes avec lesquelles l’équipe travaille. C’est pourquoi l’équipe de Kansei Design a adopté cette maxime: Puisque la conception d’expérience utilisateur offre une alternative intéressante et une approche de conception complémentaire solide aux pratiques de conception industrielle dans la conception de produits, la communauté peut adopter, créer et renforcer des outils appropriés.

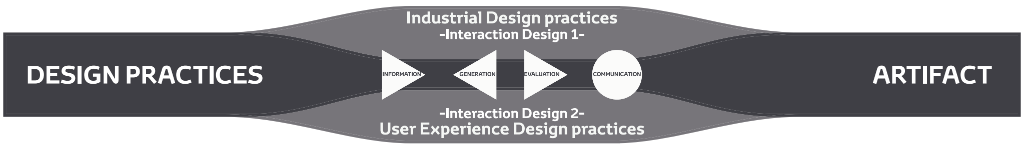
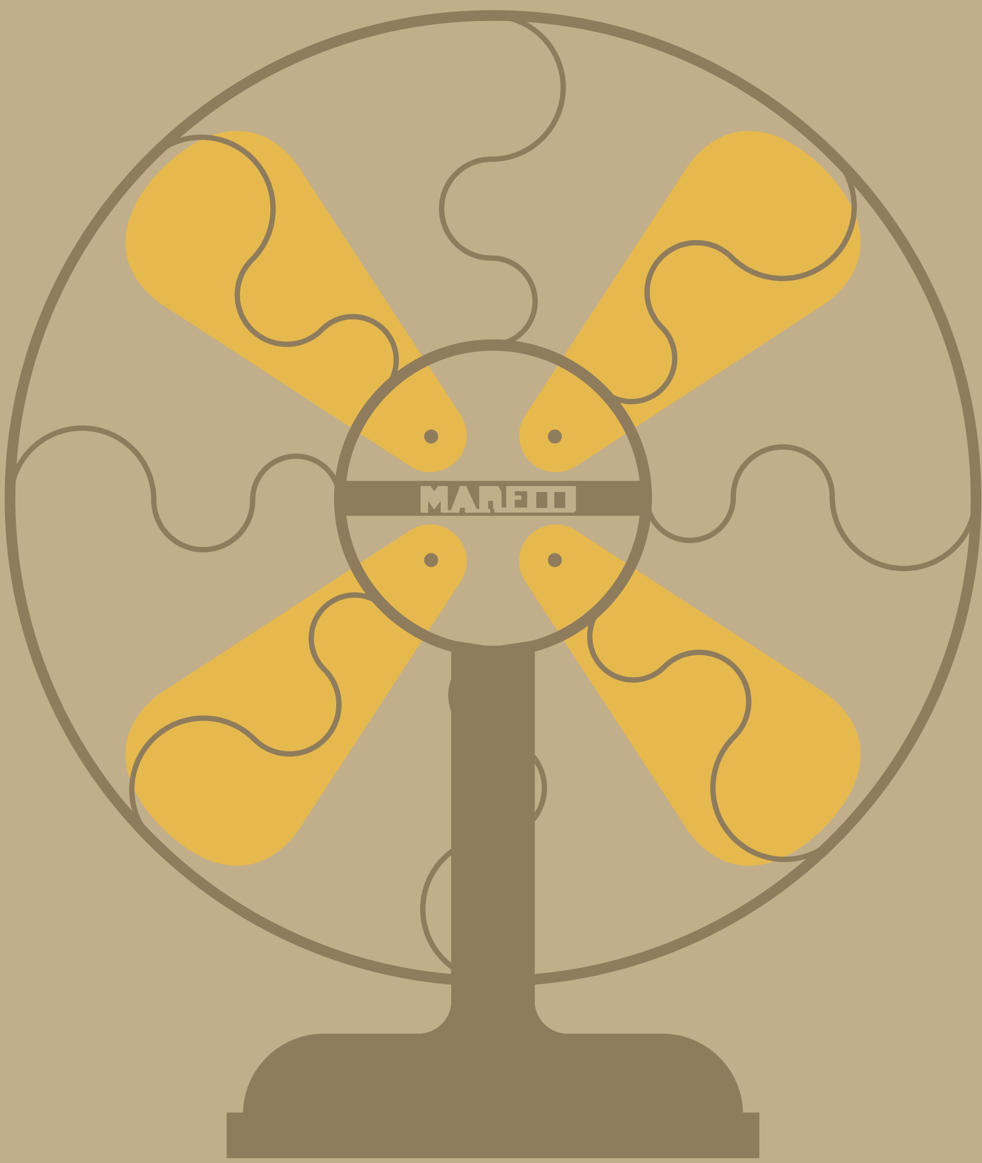


Figure 95: Design practices representation

Différencier les pratiques de conception industrielle et les pratiques de conception de l’expérience utilisateur, il est intéressant de mettre en évidence une typologie particulière des produits. Lorsque nous examinons des produits de conception interactive, nous pouvons reconnaître deux visions différentes des pratiques de conception industrielle et des pratiques de l’expérience utilisateur: Les pratiques de conception d’interaction reposent sur le même terrain commun que les pratiques de conception. Néanmoins, selon la maxime ci-dessus, même si les pratiques de design industriel commencent par le domaine commun et large des pratiques de conception, nous pouvons admettre une double vision des pratiques de conception d’interaction correspondant respectivement aux pratiques de design industriel et aux pratiques de conception. En effet, la conception d’interaction peut être comprise en termes de pratiques de conception industrielle en tant que produit matérialisé, interface ou quelque chose de physiquement manipulable. Ou, nous pouvons considérer la conception d'interaction en termes de pratiques d'expérience utilisateur, en soulignant l'approche des interactions homme-produit: Une approche découlant de la psychologie cognitive, la conception Kansei, l'intelligence artificielle et d'autres fondamentaux des pratiques d'expérience utilisateur. Le deuxième groupe de pratiques est l'objet de cette thèse.



«Experience wihout theory is blind,
but theory without experience is mere intellectual play»
Immanuel Kant

«L’expérience sans théorie est aveugle,
mais la théorie sans expérience n’est qu’un simple jeu intellectuel»

1.2 Contexte de la recherche

Cette section décrit le contexte dans lequel cette recherche a lieu. Tout d'abord, l'histoire de la recherche en design est présentée. Ensuite, cette thèse s'inscrit dans le champ de recherche mené au LCPI Arts et Métiers ParisTech.

1.2.1 L'Histoire de la recherche en Design

Le mot «conception» est ambigu, car il couvre à la fois la notion de planification (des produits et des systèmes) et de «donner des formes» (Koskinen et al., 2013). Le design est également un terme ambigu car il peut être compris en termes de six significations différentes en anglais seulement. Considérant le «design» comme un nom et non comme un verbe, cela peut signifier, selon la base de données wordnet:
1- L'acte d'élaborer la forme de quelque chose;
2- Un schéma d'arrangement;
3- Un travail décoratif ou artistique;
4- Un croquis préliminaire indiquant le plan pour quelque chose;
5- La création de quelque chose dans l'esprit; et
6- Un résultat anticipé qui est prévu ou qui guide les actions planifiées d'une personne.
Deserti (2011) décrit le design en fonction de quatre piliers: l'avenir (conception visionnaire); acte technique (conception technique); présent (conception situationnelle); et acte créatif (design romantique). Ces quatre piliers ont été cartographiés selon un axe horizontal allant de l'acte créateur à l'acte technique (questionne la notion de rationalité dans le design), et d'un axe vertical du futur au présent (traitant d'une exploration de nouvelles opportunités ou de l'exploitation au sein de les limites d'un contexte donné). Il semble qu'il ne soit pas facile d'identifier les limites actuelles de la conception.

La section suivante consiste en un bref aperçu de l'histoire de la recherche en design. Deux champs complémentaires sont présentés: L'approche du design thinking, qui fait référence à une manière de penser et d'agir en termes de design; et l'approche de l'interaction homme-machine (IHM), qui marque la naissance de la recherche liée à l'interaction.

L'APPROCHE DE LA PENSÉE DE CONCEPTION

Depuis les années 1920, les chercheurs ont entrepris de définir le design comme une science, en combinant sa dimension artistique avec la science et la technologie (Cross, 2007). Une entrée clé peut être tracée à 1919, avec la création de l'école de Bauhaus. Cette école a cherché à réconcilier l'art et la technologie en utilisant un nouvel ensemble de pratiques, et est considérée par beaucoup comme la première école de design moderne.
Dans les années 1960, des efforts ont été déployés pour développer le domaine du design en science, en appliquant une méthodologie et des processus scientifiques pour comprendre comment le design fonctionne. Cross (2001) décrit la lutte qui a commencé à se dérouler au début des années 1960, lorsque

des tentatives ont été faites pour «faire du design une science» et faire entrer le champ dans l'objectif des sciences rationnelles. Il souligne la référence du technologue radical Buckminster Fuller à la «décennie de la science du design».
Dans les années 1970, la notion de design comme «mode de pensée» dans les sciences est née. Cette approche peut être attribuée à l'informaticien et lauréat du prix Nobel Herbert A. Simon (1969), The Sciences of the Artificial. Une grande partie du travail de Simon portait sur le développement de l'intelligence artificielle et sur la possibilité de synthétiser des formes de pensée humaines.
Dans les années 1980, Cross (1982) a discuté de la nature de la résolution de problèmes par les concepteurs. Il a comparé la résolution de problèmes des concepteurs aux problèmes non liés au design que les gens développent dans leur vie quotidienne.
Au fil du temps, le «Design Thinking» a progressé et a fait son chemin dans divers domaines de spécialisation, les penseurs de ces domaines explorant les processus cognitifs dans leurs propres domaines et, finalement, la pensée conceptuelle s'est déplacée dans un espace propre.
Depuis les années 1990, le mouvement Design Thinking a rapidement gagné du terrain, avec des pionniers tels que IDEO et d.school qui formalisent un chemin à suivre pour les autres. Des universités prestigieuses, des écoles de commerce et des sociétés avant-gardistes ont adopté la méthodologie à des degrés divers, la réinterprétant parfois en fonction de leur contexte spécifique ou des valeurs de la marque.
Dans cette recherche, l'approche Design Thinking est utilisée comme science pour concevoir des réactions affectives et cognitives vécues par les utilisateurs. Diverses méthodologies et outils soutiennent cette manière d'inclure la science dans la discipline de conception.

L'APPROCHE D'INTERACTION HUMAIN-ORDINATEUR

«L'interaction homme-machine (IHM) est un domaine de recherche et de pratique apparu au début des années 1980, initialement comme un domaine spécialisé en informatique englobant les sciences cognitives et l'ingénierie des facteurs humains» (Carroll, 1996).
Historiquement, la conception d'interaction a évolué en termes d'objectifs et de préoccupations.
Pour en revenir aux années 50, 60 et 70, les interactions et les interfaces ont été manipulées par les opérateurs et non par les utilisateurs. Les cuirassés, les avions de combat, les centrales électriques et les premiers ordinateurs avaient tous des opérateurs formés. Cela a changé radicalement avec le développement et la vulgarisation de l'informatique personnelle dans les années 1970. Il comprend à la fois des logiciels personnels et des plates-formes informatiques personnelles.
Ainsi, les ordinateurs sont passés des laboratoires aux postes de travail de bureau. Ce phénomène a donné naissance au vaste projet de la science cognitive. Ce projet intégra l'intelligence artificielle, la psychologie cognitive, l'anthropologie cognitive, la linguistique et la philosophie de l'esprit à la fin des années 1970. Parmi eux, le programme de la science cognitive devait articuler «l'ingénierie cognitive». Selon Foley (1982), l'IHM était l'un des

premiers exemples d'ingénierie cognitive. Dans les années 80, l'infographie et la recherche documentaire ont émergé très rapidement (Carroll, 1996).
Selon Carroll (1996), l'intérêt technique original et constant de HCI était et est le concept d'utilisabilité, parce que la convivialité est un moyen d'aborder les pratiques sociales du travail. À l'origine, la facilité d'utilisation était articulée de manière un peu naïve dans le slogan «facile à apprendre, facile à utiliser». Ce simple slogan a donné une identité à la notion d'utilisabilité en informatique. Cependant, à l'intérieur de HCI, le concept d'utilisabilité a été ré-articulé et reconstruit presque continuellement, et est devenu de plus en plus riche et curieusement problématique. L'utilisabilité englobe souvent des qualités telles que le plaisir, le bien-être, l'efficacité collective, la tension esthétique, la créativité accrue, le flux, le soutien au développement humain et autres (Grudin, 2012).
Bien que Myers (1998) définisse le cadre académique original de HCI en tant qu'informatique, et qu'il se concentrait initialement sur les applications de productivité personnelle, principalement l'édition de texte et les tableurs, le domaine s'est constamment diversifié et dépassé (Myers, 1998). «Il s'est rapidement étendu à la visualisation, aux systèmes d'information, aux systèmes collaboratifs, au processus de développement du système et à de nombreux domaines du design» (Myers, 1998).
Lorsque les ordinateurs se déplaçaient de plus en plus dans les maisons et d'autres aspects de la vie des gens, il y avait une évolution de la conception de l'interface vers quelque chose de plus large: la conception d'interaction. Selon Mok (1996), «le plus grand défi auquel sont confrontés les concepteurs en informatique n'est pas de maîtriser les différentes technologies qui sont ses compagnons constants, mais d'introduire du sens et de la vie dans les produits et services du côté humain» (Mok, 1996, page 4).

Aujourd'hui, HCI est enseigné dans de nombreux départements et facultés qui traitent des technologies de l'information, y compris la conception, les études de communication, la psychologie cognitive, les sciences de l'information, les sciences géographiques, les systèmes d'information de gestion et l'ingénierie industrielle. La recherche et la pratique que HCI englobe s'inspirent et intègrent tous ces champs d'application.

Enfin, les pratiques HCI, comparées à l'informatique elle-même, sont devenues plus grandes, plus larges et beaucoup plus diversifiées. Il s'est élargi depuis son orientation initiale sur «le comportement individuel et générique des utilisateurs pour inclure l'informatique sociale et organisationnelle, l'accessibilité pour les personnes âgées, le bien-être, les déficiences cognitives et physiques et l'interaction pour tous, avec des problèmes environnementaux. des expériences et des activités humaines »(Carroll, 2004). HCI s'est étendu des applications bureautiques pour inclure «jeux, apprentissage et éducation, commerce, santé et applications médicales, planification et réponse d'urgence, et systèmes pour soutenir la collaboration, la communauté et la mobilité» (Caroll, 2004) d'une perspective personnelle à une perspective communautaire . Il est passé de simples interfaces utilisateur graphiques à des techniques et des dispositifs d'interaction intenses, à des interactions tangibles, à la spécification d'interface utilisateur basée sur un modèle, aux interactions multimodales et à une foule d'interactions omniprésentes, portables et contextuelles.

1.2.2 Positionner cette thèse dans le champ de recherche du LCPI Arts et Métiers ParisTech

La première section décrit ce que la LCPI est, dans l'ordre, dans la deuxième section, de positionner la recherche dans cette portée. Enfin, la dernière section positionne cette recherche en termes de thèses et de recherches connexes menées par d'autres sous les auspices de la LCPI.

Qu'est-ce que la LCPI?
Le LCPI - Laboratoire de Conception de Produits et d'Innovation peut se traduire par «Laboratoire de Design et d'Innovation de Produits» - est un laboratoire de recherche situé à Paris, en France, et appartenant à l'école nationale d'ingénieurs Arts et Métiers ParisTech. Les recherches menées par la LCPI visent à optimiser le processus de développement du produit. Sa vision à long terme se concentre sur la numérisation de ce processus. L'optimisation des processus repose sur deux axes de recherche: le premier est dédié à la Formalisation et à la Numérisation des Travaux de Conception, le second est lié à la Formalisation et la Numérisation du Processus de Conception. Ces deux axes se nourrissent et s'enrichissent mutuellement.
L'objectif de la LCPI est de développer les connaissances afin d'améliorer les processus de conception et d'innovation. Ce développement conduit à la construction de modèles théoriques de compétences de conception et de processus de conception liés à l'activité de conception de produits, de systèmes et de services innovants. Ces modèles sont évalués dans le contexte opérationnel afin de valider les connaissances, les méthodologies et les outils. Leur intégration contribue à la fois au progrès scientifique et industriel. Les résultats de cette recherche sont des modèles et des outils qui enrichissent différents niveaux:
Le modèle de processus: Formalisation du processus décisionnel ou des activités.
Modèles méthodologiques: Formalisation des activités de compétences.
Outils de conception: Proposition d'outils méthodologiques et technologiques.
Le périmètre de recherche de la LCPI appartient au Génie Industriel et plus spécifiquement à la science de la conception.

Positionner la recherche dans le champ d'application de la LCPI
Le but de la LCPI est de proposer et de développer un modèle informatique du processus de conception innovant. Cette optimisation repose sur deux axes complémentaires: L'axe des compétences, centré sur l'enrichissement du processus de conception par l'intégration de nouveaux savoirs et outils; et l'axe du processus, en se concentrant sur la formalisation du processus général de conception pour mieux le comprendre et l'optimiser. De ces deux axes, trois points émergent:
1. Formalisation, représentation et technologies intelligentes: Ce point concerne la formalisation et la représentation intelligente des savoirs disciplinaires. Elle

consiste à formaliser les connaissances sur les disciplines pour créer une formalisation théorique innovante qui supporte la conception de nouveaux outils pour le processus de conception. Ces outils se concentrent sur la représentation, la simulation et l'interaction. Les systèmes de prototypage virtuels et physiques sont principalement utilisés.
2. Gérer et soutenir dans le contrôle. Ce deuxième point est relativement nouveau en laboratoire et dans le milieu de la recherche. Elle concerne la formalisation des activités et les retours d'expérience, afin de soutenir les décisions de soutien aux phases de gestion. Elle consiste à identifier et formaliser les paramètres et les indicateurs qui doivent être pris en compte lors des processus de conception innovants.
3. Ingénierie des produits, systèmes et conception de services. Le troisième point introduit une dimension opérationnelle, expliquant pourquoi il se situe entre les deux axes. Il vise à accompagner les chefs de projets en termes de méthodologies et d'outils, à accompagner le processus innovant et à en enrichir la qualité, tout en réduisant le temps de conception.

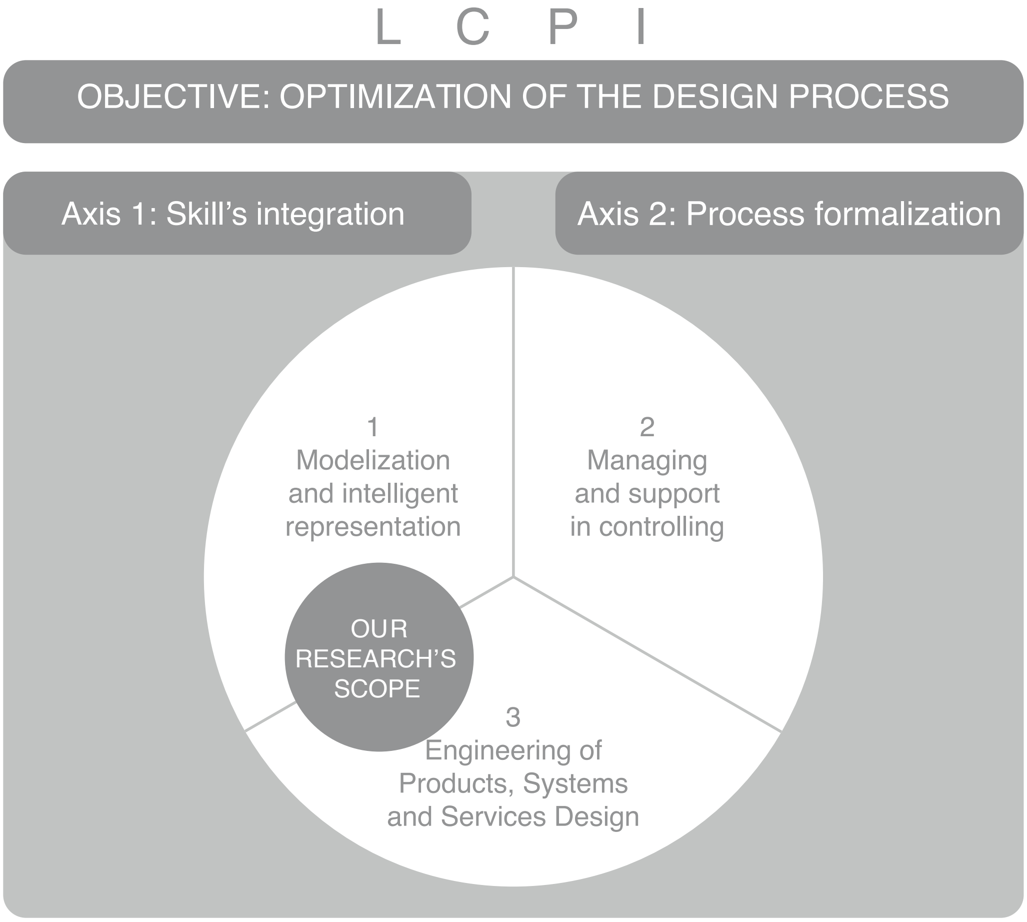


Figure 96: LCPI scope of research and postion of our research whitin this scope

Ainsi, ces trois points se complètent et s'enrichissent mutuellement dans trois directions: les disciplines de conception opérationnelle (point 1); processus de

conception opérationnelle (point 3); et niveau décisionnel (point 2). Le modèle suivant formalise cette structure.
En termes de portée de cette recherche, cette thèse peut être positionnée entre deux points: le premier et le second. Elle concerne le premier point (disciplines de conception opérationnelle) car cette recherche aborde également une perspective de connaissances disciplinaires afin de formaliser des modèles théoriques qui soutiennent la conception de nouveaux outils et méthodologies. Elle concerne le troisième point (processus de conception opérationnelle) car la recherche vise également à optimiser le processus de conception à travers des méthodologies et des outils. La figure 3 illustre la position de la recherche dans le champ de recherche de la LCPI.
Positionner la recherche en termes de recherche connexe par d'autres auprès de la LCPI

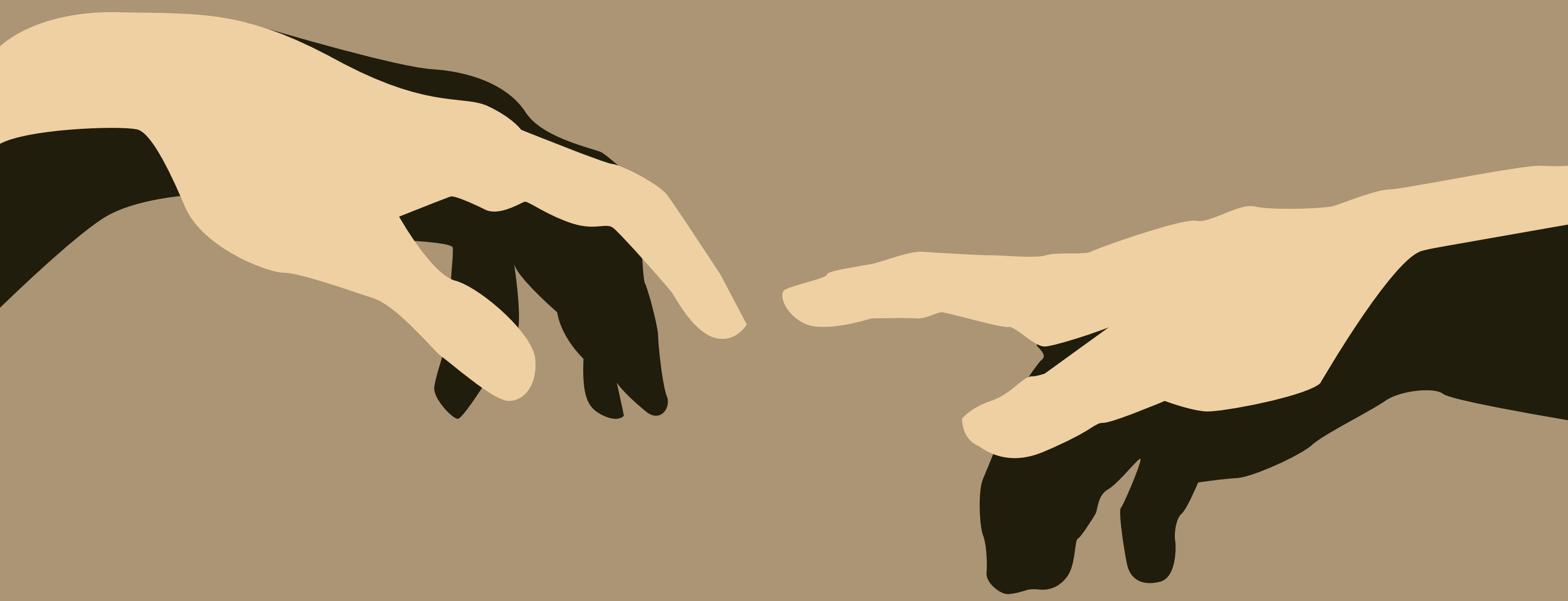
Psychological	**Physiological**	**Behavioral**
Mantelet 2006 Mougenot 2008 Bongard-Blanchy 2013 Gentner 2014	Kim, 2012	Rieuf 2013

Table 45: LCPI thesis also tackling Kansei related studies

Cette recherche peut également être positionnée dans le cadre des activités de recherche de la LCPI. Ce doctorat s'intègre dans un groupe d'études récentes qui étudient différentes façons de prendre en compte le processus Kansei des utilisateurs (c'est-à-dire un processus affectif centré survenant lors d'une interaction avec un produit) dans le processus de conception. Notamment, Bongard-Blanchy (2013) et Gentner (2014) ont été les premiers à aborder explicitement la notion d'expérience utilisateur.

Ce groupe d'études utilise trois types de mesures du processus Kansei: les mesures psychologiques (questionnaires et entretiens), les mesures physiologiques et les mesures comportementales (cinétiques) (voir Tableau 1). La recherche présentée dans cette thèse se concentre principalement sur les mesures psychologiques, mais aussi sur les mesures comportementales. Ces mesures ont les caractéristiques d'impliquer des sessions de conception participatives avec les utilisateurs, d'inclure des échantillons multi-sensoriels, et d'évaluer les réactions des utilisateurs lors de l'interaction avec les produits.

FRENCH VERSION



«I do not believe in things,
I only believe in their connection»
George Braque

Je ne crois pas aux choses,
Je ne crois qu'à leur lien»

1.3 Histoire de la collaboration industrielle et de la recherche

La division Kansei Design de TME travaille en collaboration avec la LCPI d'Arts et Métier ParisTech depuis 10 ans.
La collaboration a débuté lorsque Carole Bouchard, professeure au laboratoire CPI, et Carole Favart, directrice générale du département de design Kansei de TME, se sont rencontrées. Cette rencontre a débouché sur un partenariat à long terme fondé sur des bases solides, alimenté pendant 10 ans par 10 étudiants à la maîtrise et deux doctorants. étudiants, tel que présenté à la figure 4.

La présente recherche est le deuxième doctorat de la LCPI. étude entreprise dans la division Kansei Design de TME. Le premier a été la recherche d'Alexandre Gentner (2014), qui a travaillé sur l'expérience utilisateur, et plus particulièrement sur un modèle d'informations de conception Kansei parmi les équipes de conception, soulignant la valeur ajoutée de la représentation multi-sensorielle précoce résultant des activités de conception centrées sur l'expérience. . Le travail de Gentner sera discuté plus tard dans cette thèse.

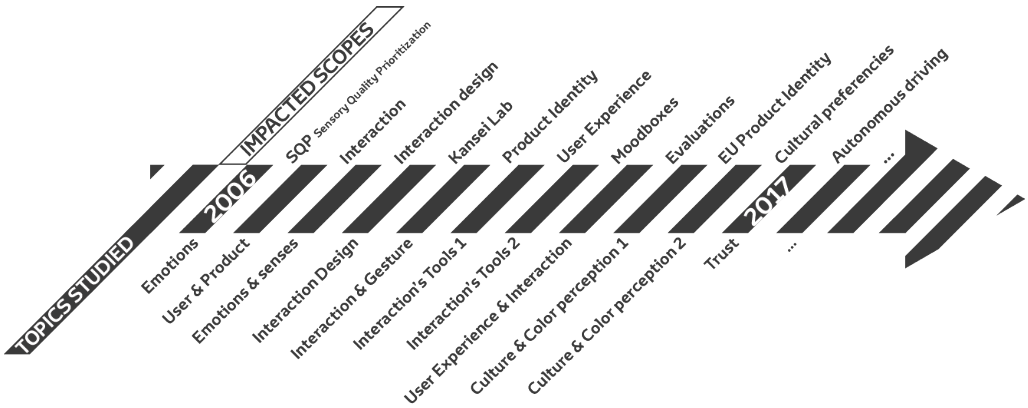
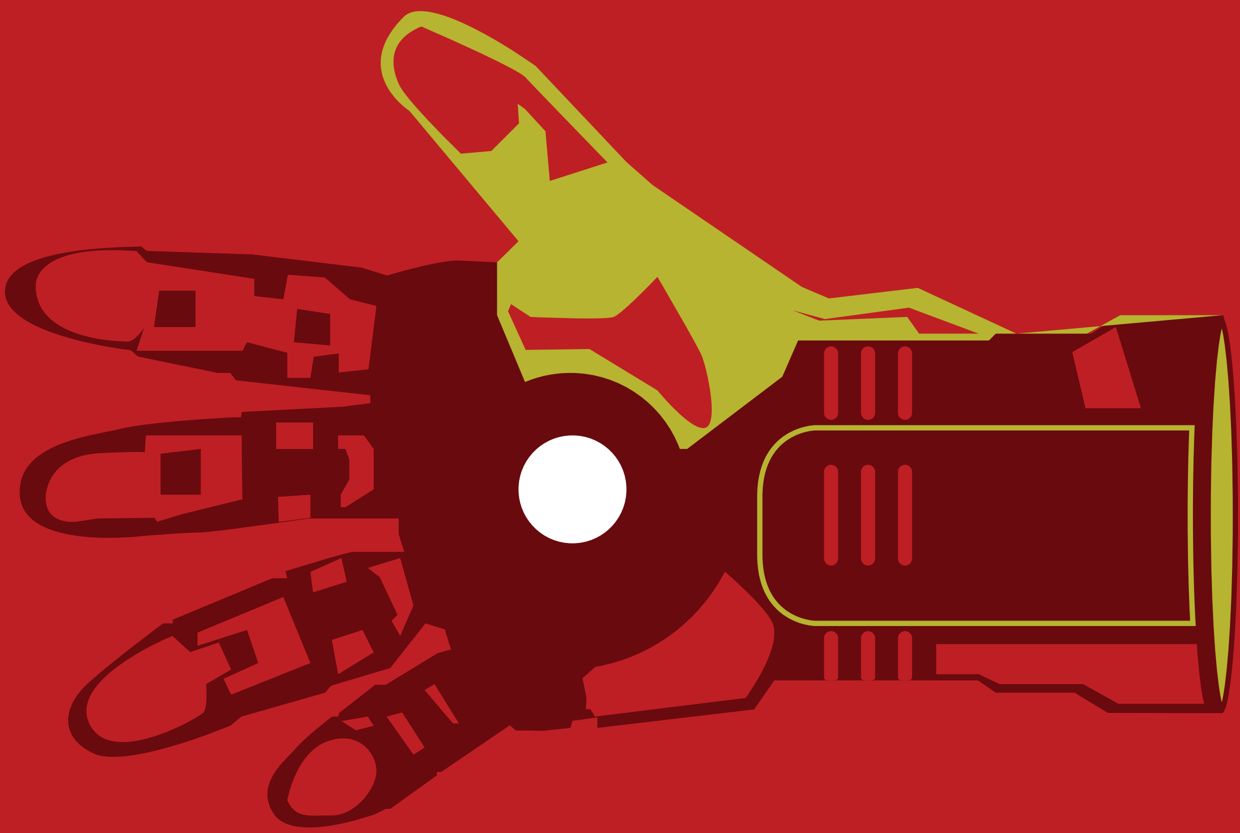


Figure 97: Past project between TME-KD and LCPI

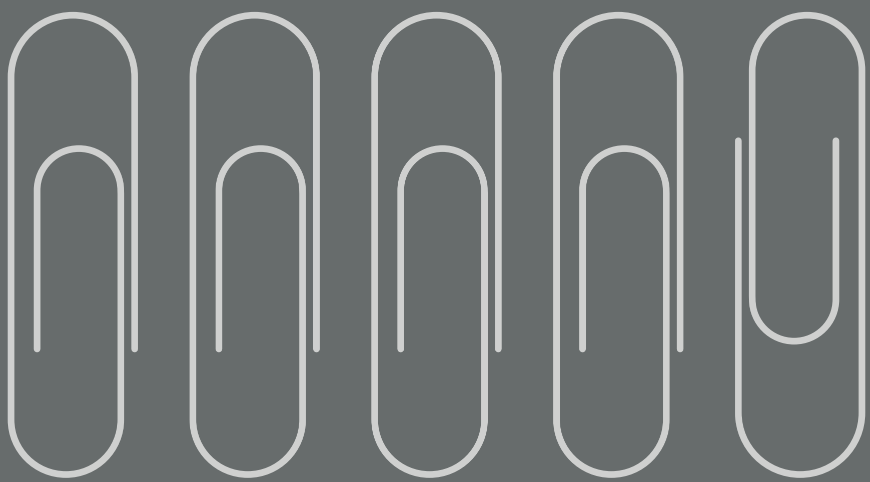
Pour retracer l'histoire de cette collaboration, il faut remonter à 2006, lorsque le premier étudiant à la maîtrise a initié la collaboration. Il a commencé par une étude sur les émotions, et sur ce qui allait être nommé, quelques années plus tard, la priorisation de la qualité sensorielle (SQP). L'étudiant du deuxième master a étudié la notion d'interaction entre l'utilisateur et le produit, conduisant un an plus tard à une étude sur les sens pour relier les émotions et les interactions. Ce jalon dans la collaboration a amené le nom du laboratoire Kansei à la division. En 2010, quatre ans plus tard, une étude a débuté sur l'association entre les visions du design émotionnel et de l'interaction. Cette étude a porté sur le concept de territoire identitaire, incluant pour la première fois une collaboration sur la notion d'expérience produit. Cette étude a conduit à la matérialisation de différents outils, tels que MoodBoxes. Les trois études suivantes, au cours des trois années suivantes, ont porté sur l'interaction, y compris une étude sur le geste, et deux sur les applications et les outils de conception interactive. En 2014, une étude a été menée sur le lien entre ce qui a déjà été présenté comme expérience de l'utilisateur et la conception de l'interaction, conduisant à l'amélioration des modèles théoriques sur lesquels la division travaille. Les deux études suivantes ont porté sur l'impact des influences culturelles sur l'interaction, et plus particulièrement sur la perception des couleurs et les préférences. Ainsi, la collaboration a commencé avec les émotions et SQP; magnifié vers Kansei Design; puis développé à la notion complète d'expérience utilisateur; et enfin axé sur le cœur de l'expérience utilisateur, la portée de l'interaction. Récemment, des études ont porté sur des piliers particuliers de l'interaction, tels que la culture et la perception. Suite à cette collaboration, la prochaine étude poursuivra un autre aspect de l'interaction et de l'expérience utilisateur, à savoir la notion de confiance dans la conduite autonome.

Dans le cadre de cette collaboration, deux Ph.D. les candidats ont étudié l'expérience utilisateur et la conception d'interaction avec la division Design de Kansei. Le premier est Gentner (2014), dont le travail sera décrit plus tard dans cette recherche. Le second est l'auteur actuel. Gentner travaille toujours sur le développement et l'intégration d'outils et de méthodologies pour l'évaluation et la création d'expériences utilisateur et d'interactions dans les phases initiales.



«I guess I would say that interaction design is making technology fit people». David Kelley

«Je suppose que je dirais que la conception d'interaction c'est rendre la technologie adaptée aux gens»



«Creativity is to discover a question that has never been asked. If one brings up an idiosyncratic question, the answer he gives will necessarily be unique as well»

Kenya Hara

«La créativité est de découvrir une question qui n’a jamais été posée.
Si l’on pose une question idiosyncrasique,
la réponse qu’il donne sera nécessairement aussi unique»

-
3 QUESTION DE RE-CHERCHE ET HYPO-THESES
-

Ce chapitre traite de la question centrale soulevée par l'état de la technique. On propose ensuite de répondre à cette question en examinant trois hypothèses.

3.1 Question de recherche

1. Même si le modèle d'information de conception (i) montre clairement que l'interaction est au cœur de l'expérience utilisateur, il n'y a pas de compréhension formalisée de l'impact de l'expérience utilisateur sur l'interaction (ou de l'interaction sur l'expérience utilisateur). Ce manque de connaissance sur la relation entre interaction et expérience utilisateur, sur leur influence réciproque, nous conduit à poser la question suivante:

Comment la relation réciproque entre expérience utilisateur et interaction devrait-elle être formalisée et enrichie?

2. Même si l'état de la technique présentait un modèle d'information de conception (i) et trois dimensions (d), structuré en huit domaines (a), nous ne pouvions pas trouver de connaissances sur l'impact de ces dimensions (d) sur l'utilisateur. réponses affectives et cognitives (informations de conception liées à l'interaction (i)) dans la communauté de recherche. Ce manque d'information nous amène à la question suivante:

Comment les trois dimensions (d) (environnement, cible et source) influencent-elles l'information de conception (i) du modèle (réponses affectives et cognitives des utilisateurs) lorsqu'un utilisateur interagit avec un artefact?

3. Alors que l'état de l'art soutenait que l'approche métaphorique peut être un outil puissant, et pourrait être utilisé dans la conception initiale, nous n'avons pas pu trouver de connaissances sur le lien entre l'approche métaphorique et le processus de conception dans la communauté de recherche. Ce manque d'information conduit à la question suivante:

Quel niveau de conception (lev) est le mieux adapté pour soutenir la génération d'interaction en utilisant l'approche métaphorique dans la conception précoce?

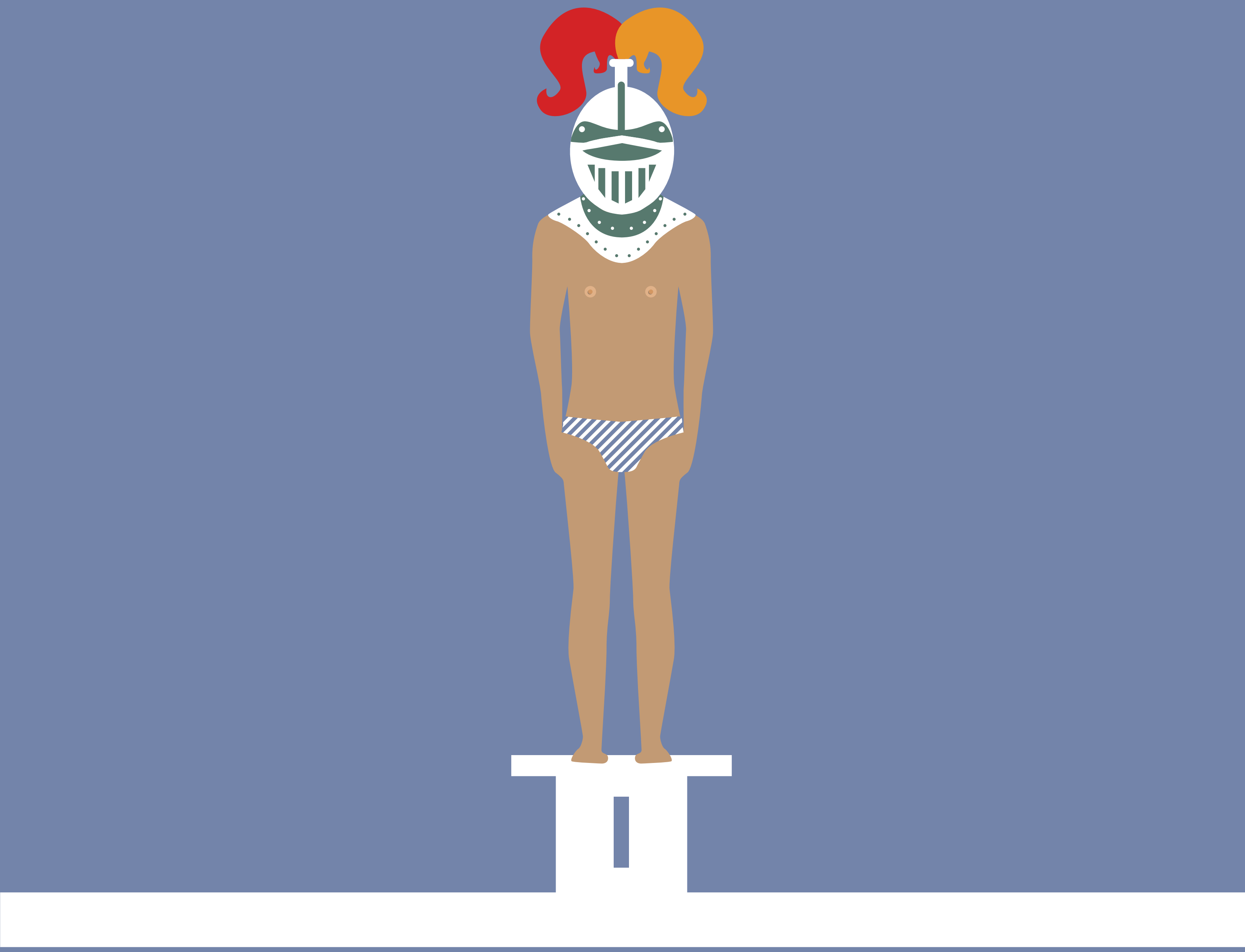
Ces trois questions sont résumées dans la question centrale suivante:

-

Comment une compréhension de l'interaction homme-produit peut-elle améliorer conception de l'expérience utilisateur?

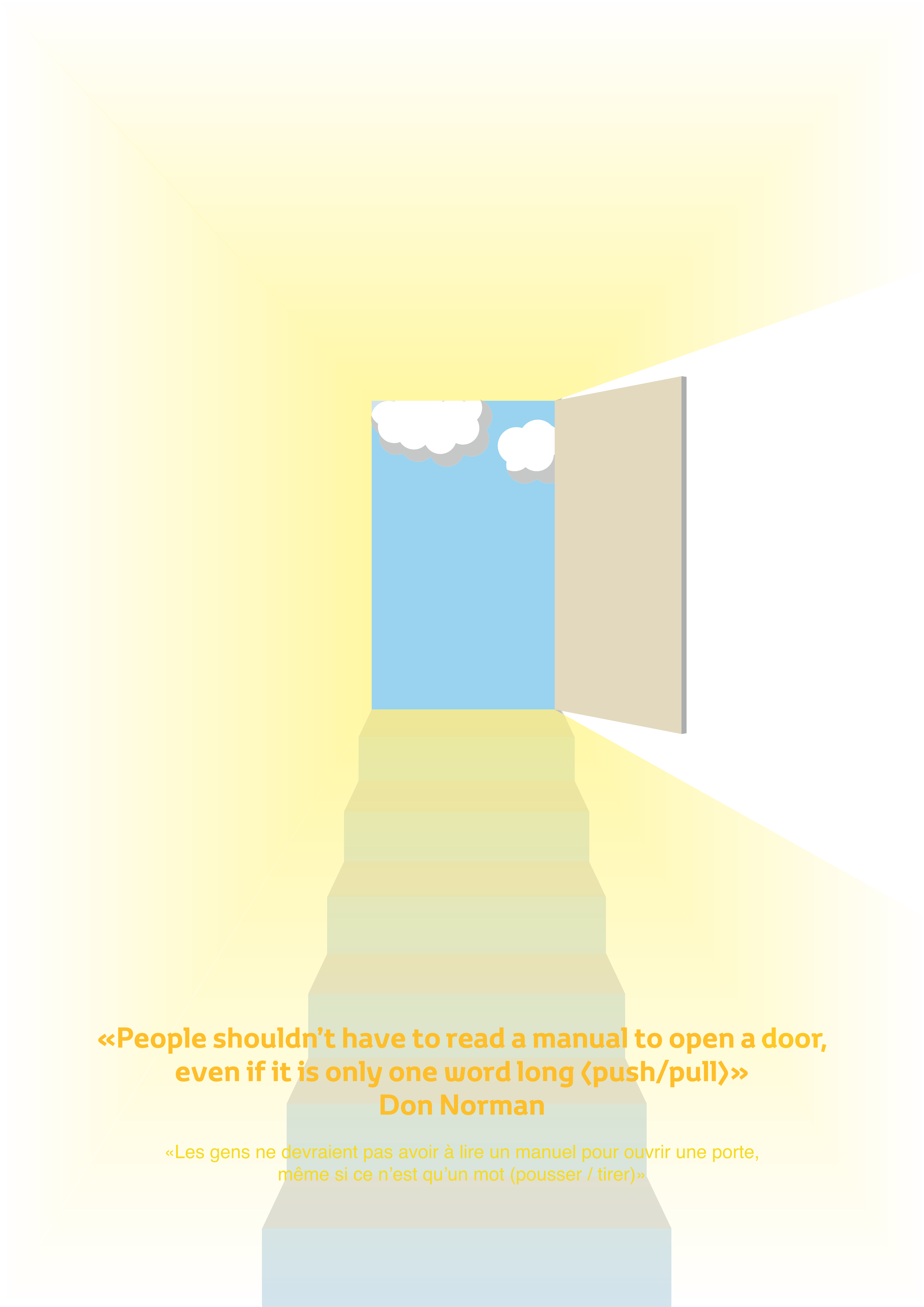
-

Cette question a été conçue pour mettre en évidence trois problèmes, à savoir le lien direct entre l'interaction et l'expérience de l'utilisateur; la notion de conception et de conception de l'interaction dans le domaine de l'expérience utilisateur; et la création d'outils et de méthodologies pour réussir.
Le but de notre recherche est de fournir une meilleure compréhension de la relation entre l'expérience utilisateur et l'interaction, afin de soutenir les premières phases de conception, à la fois la conception et l'évaluation des interactions et des expériences utilisateur.



«Recognizing the need
is the primary condition for design»
Charles Eames

«Reconnaître le besoin
est la condition première de la conception»


«People shouldn’t have to read a manual to open a door,
even if it is only one word long ‹push/pull›»
Don Norman
«Les gens ne devraient pas avoir à lire un manuel pour ouvrir une porte,
même si ce n’est qu’un mot (pousser / tirer)»

-

5 CONTRIBUTIONS

-

Ce chapitre traite des contributions académiques et industrielles de cette recherche.

5.1 Contributions Academiques

Ce chapitre rassemble les résultats académiques de cette thèse et montre comment ils contribuent à la recherche et à la pratique du design. Quatre éléments sont présentés: Le modèle de l'information de conception, la taxonomie des produits interactifs, le processus de conception à travers les paradigmes physiques et numériques, et les différents principes.

5.1.1 Modèle d'information de conception

Le modèle d'information de conception (déjà présenté comme un résumé de l'état de l'art, et présenté à la figure 60 comme un rappel), cartographie les différentes composantes de l'expérience utilisateur, mettant en évidence la zone d'interaction et indiquant toutes les informations de conception cela doit être pris en compte dans l'approche interactive de la conception ou de l'évaluation des expériences et interactions des utilisateurs au cours des premières phases de la conception. Ce modèle est une variante des modèles d'Ortiz Nicolàs et Aurisicchio (2011), et Gentner (2014): La différence et l'amélioration résident

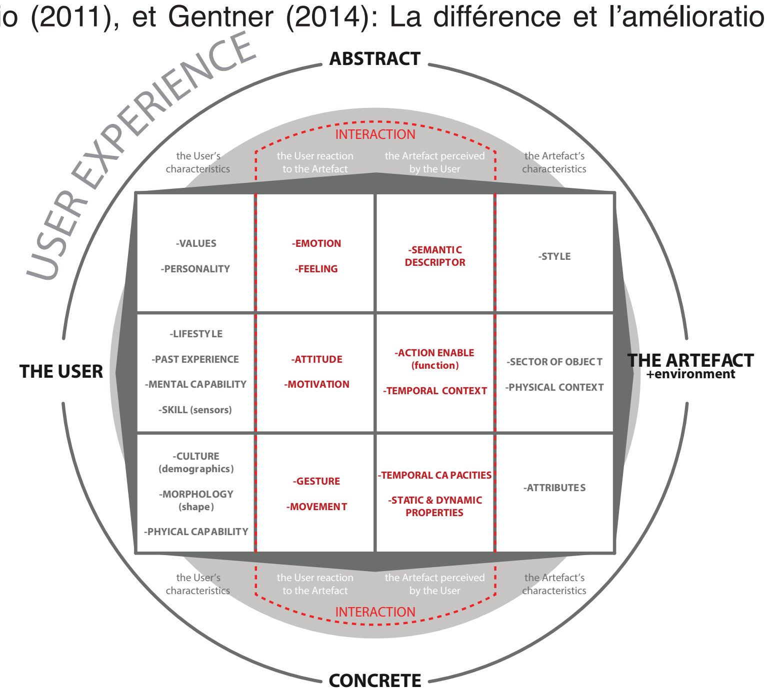


Figure 98: Model of Design Information

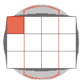
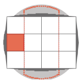
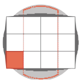
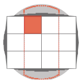
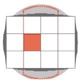
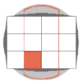
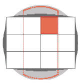
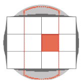
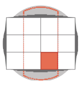
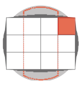
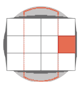
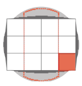
POSITION ON MODEL	RELATED COLUMN	CATEGORY NAME	DESCRIPTION	EXAMPLE	REFERENCE
	User's characteristics	**Value**	These words represent final or behavioural values.	Ambitious, open-minded	Nurkka 2008
		Personality	Words to illustrate the user mind in general	Enthusistic, vibrant	Govers & Mugge 2004
		**Lifestyle**	Combination of values of the user	Work hard and play hard	
		Past Experiences	Previous experiences lived by the User	I already played with it	Parrish 2008
		Mental capability	User's capability in intellectual notion	Number of command he can remind	
		Skill	based on user's personal capacities and skills;	driver licence	Overbeeke et al 2002
		**Culture**	The culture of a user covers his/her age, gender, nationality, function, and organisational affiliation	Young (20-29) Europeans	Gero 2010
		Morphology	Related to the outward appearance of the user	Body shape, structure, handicap	
		Physical capability	Action enable by the physical capabilities of the user	Able to reach something at 2 meters	Overbeeke et al 2002
	User's reaction to the Artefact	**Emotion**	Targeted emotion to be felt by the user	Joy, surprise, interest	Russel 1980 Plutchik 1980
		Feeling	User's generals sensations	Pain, mood	Lang 1995
		**Attitude**	characteristics of the user in his relation;	discovered, learn	Lalmas, O'brien & Yom-Tov 2013
		Motivation	The different motivational degrees affecting user's behavior	motivated by fun, motivated by somebody putting pressure	Deci & Ryan 2000
		**Gesture**	Movement of a part of the user's body used as input	Hand and body movements	Moussette 2012
		Movement	the reason of the gesture	move to play, move to explore	Krippendorff 2006
	Artefact perceived by the User	**Semantic descriptor**	Adjectives related to meaning and characteristics.	Playful, romantic, traditional	Dias 2013 Hassenzah 2000
		**Action enable**	Function, usage	Create, relax, communicate	Lund 2001 Brooke 1996
		Temporal context	Notion of time in the interaction	Narrative description of an interaction	Lin and Cheng 2011
		**Temporal capabilities**	based on product characteristics	feedback, active touch; visual feedback, pressure, grape	Maes 2009
		Static & dynamic properties	Static: vision, shape, texture, tactual, olfactory Dynamic: Auditory, Visual changes, force feedback, vibration feedback, olfactory feedbacks	opacity changing, shape changing, light signal, fast rythm	Camere, Schifferstein 2015
	Artefact's characteristics	**Style**	Characterization of all levels together through a specific style.	Edge design	Dias 2013
		**Sector of object**	Object or sector being representative for expressing a particular trend	Tennis, wearable computing	Kim et al 2012
		Physical context	Physical elements surrounding the product	In a modern living room	Forlizzi 2007
		**Attributes**	Attributes of the product, as concrete characteristics	80 kg; Ral 9010; wood;	Minge 2013

Table 46: Design information description

dans l’accent mis sur les informations de conception liées à l’interaction.

Ce modèle contribue à la compréhension de l’expérience utilisateur et de l’interaction à travers une représentation formalisée. Il décrit à la fois les informations relatives aux interactions entre utilisateurs et artefacts et l’expérience, ainsi que les informations relatives à ce que nous devrions prendre en compte lors de la conception des interactions précoces et des expériences utilisateur. Les différentes cases des informations de conception sont décrites dans le Tableau 21.

Ce modèle peut être utile à la fois dans le monde académique et dans le monde industriel: il permet de cartographier et d’identifier les informations de conception liées à l’expérience utilisateur et à la conception de l’interaction. Ce modèle peut également être utilisé pour évaluer l’interaction et l’expérience utilisateur afin de mettre en évidence les défis de conception, comme le montrent les différentes expérimentations. Enfin, ce modèle peut également être utilisé comme un moyen d’identifier l’implication des personnes dans les différentes phases du processus de conception. Ce faisant, il peut aider à organiser et à structurer les équipes de conception en fonction des informations de conception utilisées.

Avec la croissance extrême de l’évolution des technologies, l’intelligence des artefacts et l’humanisation des artefacts, on peut imaginer que le modèle pourrait être inversé: Au lieu de diffuser l’information de conception de l’utilisateur à l’artefact, , et d’autres informations de conception très axés sur l’homme, nous pourrions imaginer l’inverse. L’artefact peut être conçu avec une personnalité, des valeurs, une culture, des émotions, des sentiments, etc. Ainsi, nous imaginons que nous pouvons facilement changer les deux éléments principaux

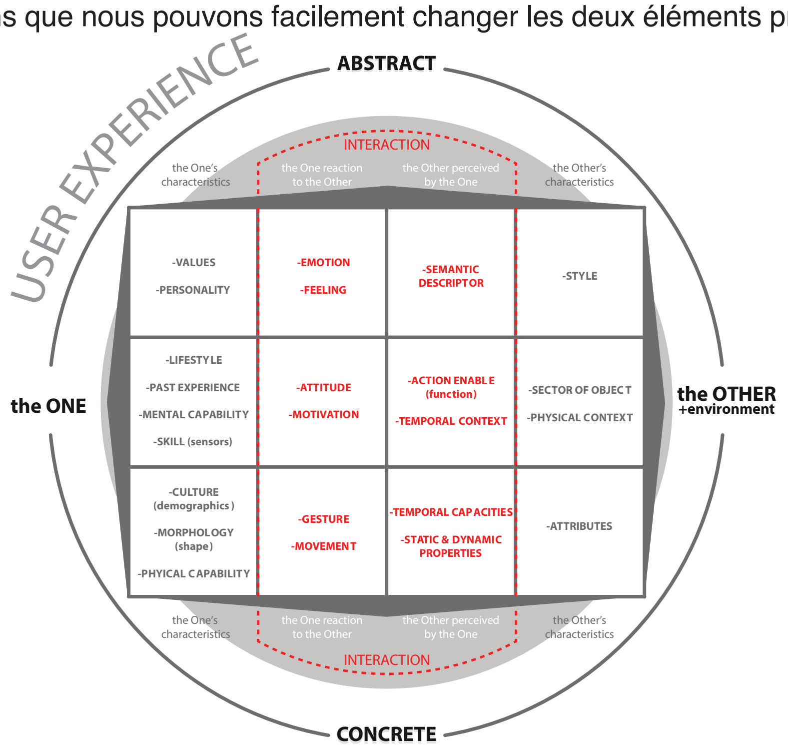


Figure 99: Model of design information: variation

(user-artefact). De cette façon, nous invitons les concepteurs à concevoir l'artefact différemment en tant qu'être humain, lorsque l'élément interagit avec l'utilisateur. Ainsi, nous proposons une variation de notre modèle, non plus de l'utilisateur à l'artefact, mais de l'un à l'autre, où l'un peut être l'utilisateur ou l'artefact, selon la façon dont les gens veulent utiliser le modèle (voir Figure 61).

5.1.2 Taxonomie des produits interactifs

La classification des interactions en termes de perception de l'utilisateur des dimensions physiques et numériques (d), de l'environnement (d), de la cible (d) (propriétés du produit) et des sources (d) (références perçues) a développé une taxonomie des produits interactifs. 62). En utilisant cette taxonomie, nous avons souligné le lien entre les interactions physiques et numériques, nous amenant à une contribution prouvant que les interactions expérientielles (indépendantes de l'environnement) sont plus significatives lorsqu'elles sont conçues avec des principes physiques et numériques (d): avec des sources numériques (d), ou des cibles numériques (d) combinées avec des sources physiques (d). Ceci établit une nouvelle étape dans la compréhension de la conception d'interaction en utilisant des propriétés physiques et numériques dans le cadre de l'expérience de l'utilisateur, et dans la compréhension des métaphores dans la conception d'interaction.

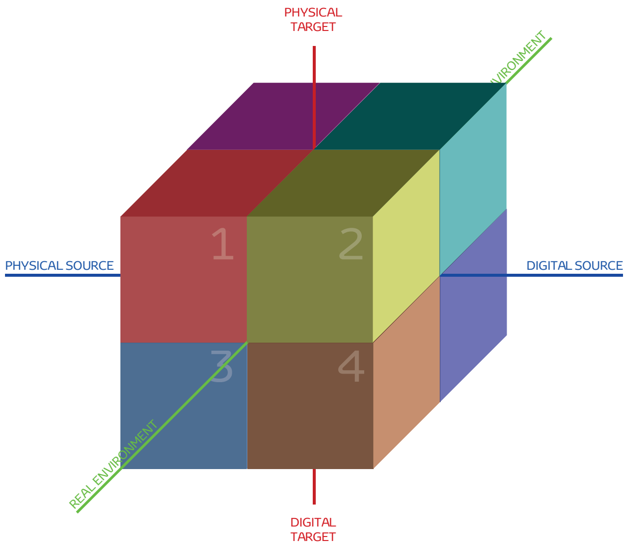


Figure 100: Taxonomy of interactive products

La taxonomie développée pourrait aider à cartographier les typologies de produits interactifs dans un espace en trois dimensions. Nous encourageons la communauté de recherche à acquérir et améliorer le cadre de cette taxonomie, afin de préciser les zones les plus fines dans chaque zone mise en évidence. Le tableau 22 résume et décrit ces domaines.

5.1.3 Approche métaphorique du processus de conception

Dans cette recherche, nous avons démontré que l'approche métaphorique

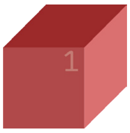
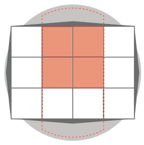
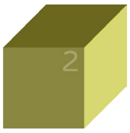
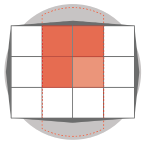
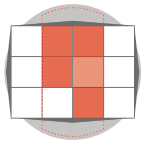
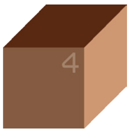
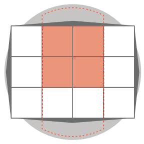
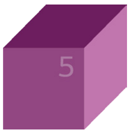
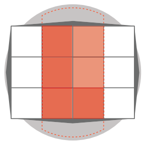
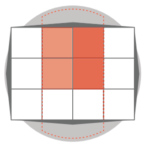
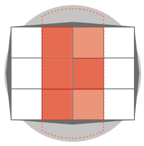
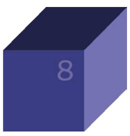
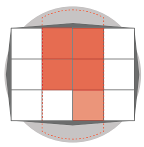
3 DIMENSION(d) & 8 AREAS (a)		-PRIN-CIPLES (p)	DESIGN INFORMATION(i)	
AREAS(a) FROM THE INTERAC-TIVE TAXONOMY		*5 PRIN-CIPLES(p)*	*% OF IMPACT ON THE THEORETICAL MODEL(i)*	*COMMENTS*
	1-Real en-vironment; Physical target; Physical sources	Movable Transformable Graspable Manipulable Malleable		This full physical and real typology of products are more related to abstract notions like emotion, semantics, behavior and action enablement.
	2-Real en-vironment; Physical target; Digi-tal sources	Programmable Transformable Connectable Personalizable Movable		This kind of physical targets that use digital sources have been characterized as very powerful for abstract notions; mainly for emotion, semantics, and behavior.
	3-Real en-vironment; Digital target; Physical sources	Graspable Manipulable Movable Malleable Spacia-lize-able		This area, about digital targets that uses physical sources, covers a wide scope of the design information boxes. Only the sensory related part is less covered than the other. This is a part that can be improved with better physical sources.
	4-Real en-vironment; Digital tar-get; Digital sources	Transformable Programmable Personalizable Connectable Replicable		This area, covers both the abstract design infor-mation (emotion and semantics) and the middle part of the theoretical model (behavior and action enablement). Nevertheless what is covered is not strongly impacted.
	5-Virtual environ-ment; Physical target; Physical sources	Movable Manipulable Transformable Graspable Ubiquit-able		Unfortunately only one video has been related to this area. Thus, the average result might not be significant enough. Nevertheless it seems to impact mainly the left part, dedicated to user reactions.
	6-Virtual environ-ment; Physical target; Digi-tal sources	Transformable Personalizable Manipulable Spatialize-Able Connectable		This area seems to impact mainly the right part, dedicated to user perception of the product. The user part might be improved with more physical engagement of the user (immersive environ-ment).
	7-Virtual environ-ment; Digital target; Physical sources	Manipulable Movable Malleable Graspable Spatialize-Able		This typology strongly covers the left part of the model, dedicated to user reaction to the product, and to the design information related to action enablement. The perceiption of the product might be improved with more meaningful semantic notions. Additionally, the static and dynamic pro-perties could be improved with physical sources.
	8-Virtual environ-ment; Digital tar-get; Digital sources	Programmable Personalizable Replicable Connectable Voidable		This full digital and virtual area has been as-sessed as more related to abstract and middle design information. Nevertheless, this impact is not very strong.

Table 47: Description of the eight ereas

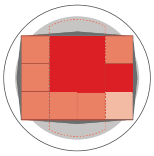
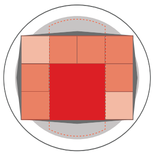
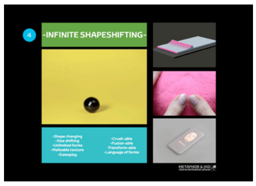
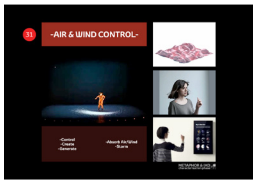
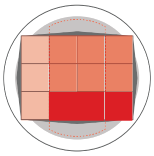
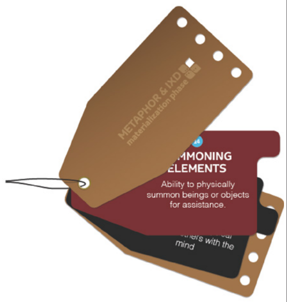
LEVEL	DESIGN INFORMATION	DETAILS	FORMALIZATION
Theorization It underlies needs, emotions and associated practices.		The theorization's level(lev) is tackling more abstract Design Information(i). We also highlighted that the Design Information(i) of 'semantic descriptors' is the most important one at this level. Furthermore, the experiementation 3 showed that the theorization's level(lev) is oriented toward quantity more than quality of generated solutions.	
Characterization It addresses the things people can do through an interactive product.;		The characterization's level(lev) is covering Design Information(i) that are interaction-related in the middle of the model. Furthermore, it covers both abstract and concrete Design Information(i). The characterization's level(lev) is more balanced in terms of generated solutions: the quality predominates on quantity.	
Materialization It addresses acting through an object on an operational, sensory-motor level (turn a button, play on an interface…), and makes given functionality accessible in an aesthetically pleasing way.		The materialization's level(lev) is oriented towards concrete elements such as' gesture and movement'; 'static and dynamic properties' and 'attributes' of the product. Additionally, the quality of the materialization's level(lev) has been assessed as stronger than the quantity of generated solutions.	

Table 48: Design Levels(lev) description

peut être utilisée à différents niveaux de la phase de génération du plan d'interaction: le niveau de théorisation, le niveau de caractérisation et le niveau de matérialisation. En effet, l'utilisation de l'approche métaphorique peut être utile à chaque niveau, car nous avons prouvé que cette approche implique des informations de conception qui augmentent l'expérience utilisateur significative. De plus, nous avons mis en évidence la complémentarité de ces trois niveaux. Chaque niveau implique différentes informations de conception. Ceci conduit notre recherche, non pas vers la question «quel niveau était adapté à l'utilisation de l'approche métaphorique», mais vers «quelles sont les spécificités de chaque niveau en utilisant l'approche métaphorique».

Suivant cette approche, nous avons formalisé un outil de conception d'interactions et d'expériences utilisateur basé sur les trois niveaux (voir Tableau 23).

Nous encourageons la communauté à utiliser cette approche métaphorique pour: formaliser de nouveaux outils, améliorer celui que nous avons formalisé, améliorer la compréhension générale de l'approche métaphorique dans la conception d'interaction, et finalement, améliorer et explorer son utilisation dans le processus de conception.

GENERAL NAME	PRINCIPLE	DETAILS
Haptic related	Transformable	From one state to another
	Movable	From one place to another
	Graspable	Take with hands
	Manipulable	Handable
	Malleable	Deform the shape
Space Related	Asynchronize-able	Real time / time differences
	Ubiquit-able	Different places in same time
	Spacialize-able	Proximity/depth
Pixel Related	Programmable	Plan of sequential actions
	Personalize-able	Adapt to people and things
Virtual Related	Gravityless	Independent from gravity
Computer Related	Distributable	Shareable
	Fusible	From 2 to 1 element
	Voidable	Ctrl Z
	Replicable	Ctrl C+ ctrl V
Numbers Related	Connectable	To other elements
	Universalizable	For all

Table 49: Design Principles description

5.1.4 A Set of Principles

Le quatrième élément mis en évidence est la notion de principes (p). Ces principes ont été soulignés dans cette recherche comme un moyen de différencier les produits interactifs en termes de paradigmes physiques et numériques. Ces principes peuvent être utilisés pour mieux définir et comprendre la perception des utilisateurs des produits interactifs. De plus, ces principes peuvent être utilisés comme un défi de conception pour le développement précoce de produits interactifs.
Cette liste de principes peut être améliorée et étendue avec de nouveaux mots-clés liés aux capacités physiques ou numériques. Nous encourageons la communauté à renforcer cette liste et à la mettre en œuvre dans le processus de conception (voir le tableau 24).

5.1.5 Conclusion sur la contribution académique

Quatre éléments académiques majeurs ont été mis en évidence afin de contribuer au progrès de la communauté de recherche en ce qui concerne la compréhension et l'amélioration de l'interaction et de l'expérience de l'utilisateur dans la conception précoce. Ces éléments ont été présentés comme des améliorations sur les théories, les méthodologies et les outils existants. Ils

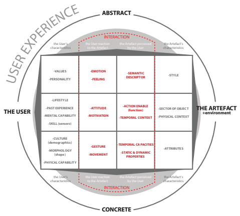
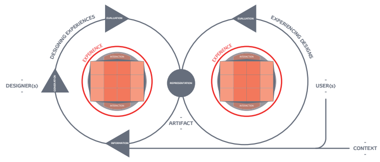
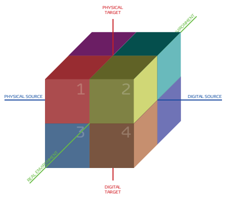
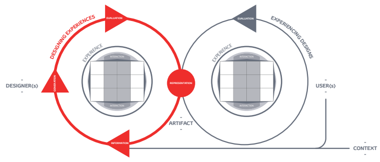
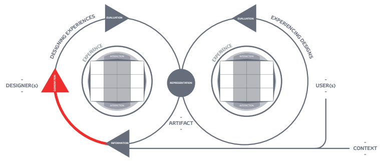
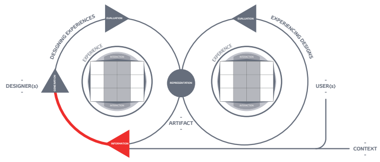
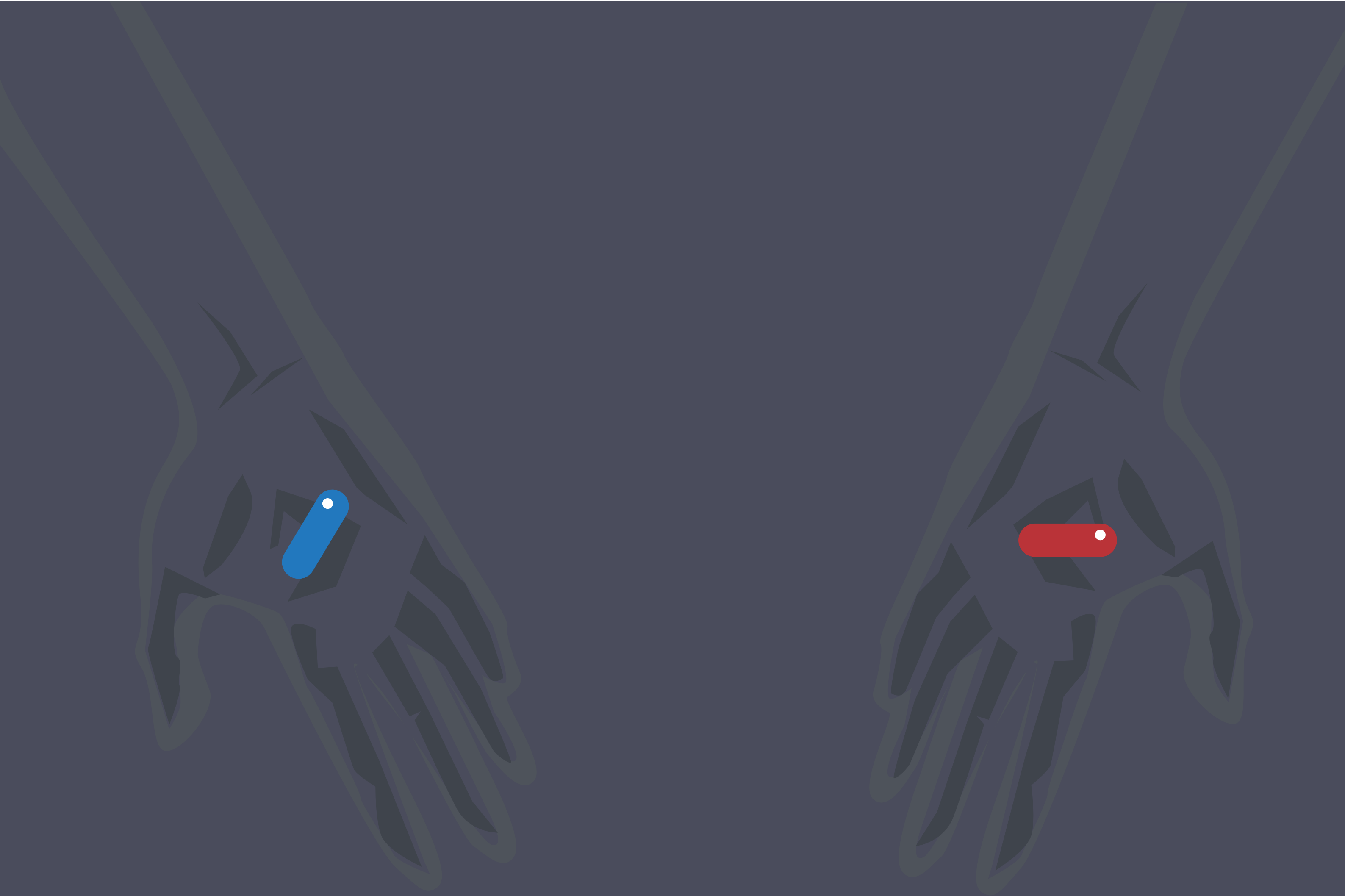
SUMMARY OF ACADEMIC CONTRIBUTIONS			
NAME, DESCRIPTION & CHAPTER		**REPRESENTATION**	**POSITION WITHIN THE DESIGN PROCESS**
Model of design information: Model of User Experience and Interaction, where design information are displayed from user to artifact (horizontal axis), and from abstract to concrete (vertical axis)	5.1.1		
Taxonomy of interactive products: 8 areas of interactive products, displayed through three axis: environment; target and source.	5.1.2		
Metaphorical approach: The use of metaphor for designing Interactions and User Experiences.	5.1.3		
Principles: Product principles consisting of keywords mostly related to what the interactive product enables the user to do.	5.1.4		

Table 50: Summary of academic contributions

ne constituent pas une fin en soi, mais constituent un pas en avant dans la recherche qui peut être améliorée, augmentée et même détournée à des fins plus larges.

Ces éléments supportent le processus de conception. La dernière colonne du tableau 25 (Résumé des contributions académiques) présente la contribution au processus de conception. Les contributions académiques ont abouti à quatre contributions différentes, mais potentiellement complémentaires, au même processus de conception.



«The main goal is not to complicate the already difficult life of the consumer»
Raymond Loewy

«L’objectif principal n’est pas de compliquer
la vie déjà difficile du consommateur»

5.2 Contributions Industrielles

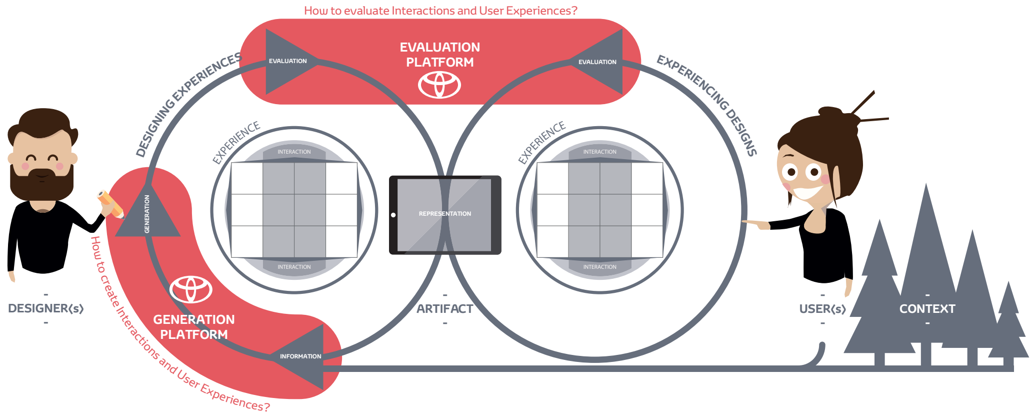


Figure 101: Representation of the Evaluation and the Generation platforms according to model of litterature Review

Comme indiqué au début de cette recherche, la contribution industrielle vise à enrichir et améliorer la façon dont TME, et plus précisément la division Design de Kansei, évalue et génère des interactions du point de vue de l'expérience utilisateur.

Dans cette recherche, nous avons utilisé trois expérimentations pour développer différents outils et méthodologies qui soutiennent ce but. Depuis qu'ils ont été créés dans le cadre de cette recherche, ils ont été adoptés dans divers projets. De cette façon, ils ont également contribué à intégrer l'approche de conception de Kansei dans le développement de produits de Toyota.

Les études présentées dans cette recherche ont permis une meilleure compréhension et défini l'approche dans un contexte industriel. En plus de ces contributions théoriques, deux types de contributions industrielles pratiques peuvent être mises en évidence. Ils sont détaillés dans les sections ci-dessous. Le premier type correspond aux nouveaux outils supportant les activités de conception qui ont été créées. Le second type correspond aux nouvelles méthodologies de conception pour créer des interactions dans les premières étapes de la conception.

5.2.1 Développement de nouveaux outils

De nouveaux outils ont été créés au cours de cette recherche. Ils soutiennent tous des activités de conception centrées sur l'expérience, avec un accent particulier sur les informations de conception axées sur l'interaction. Comme indiqué précédemment, ces outils soutiennent et améliorent la manière dont les interactions sont générées et évaluées au début de la conception.

Les tableaux 26 et 27 résument les outils qui ont été développés, en relation avec l'expérimentation qui a soutenu leur création. Il présente également leur position suggérée dans le processus de conception. Comme expliqué, certains outils ont été créés afin de soutenir l'interaction au début de la conception. Par exemple, l'outil C (Kansei Kabin) prend en charge la représentation des idées lors des séances de brainstorming. L'outil J (SuperInteraction) favorise la création d'interactions, mais en introduisant de nouvelles notions abstraites

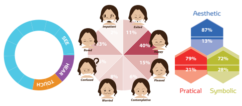
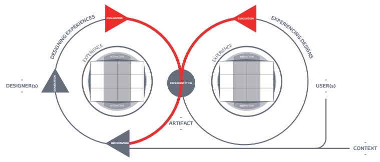
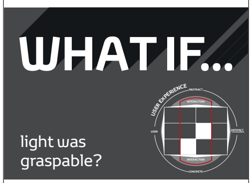
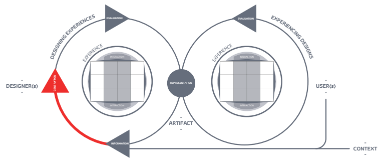
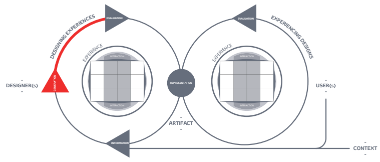
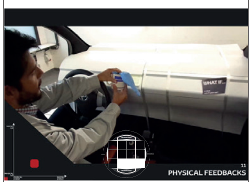
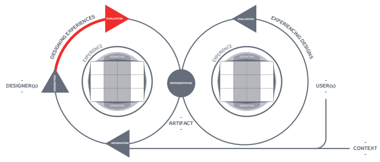
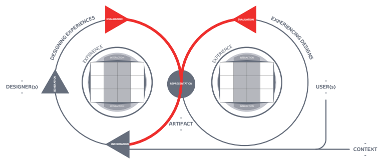
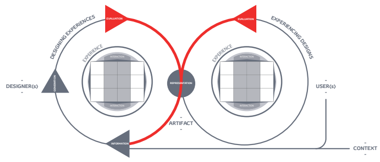
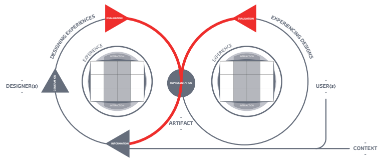
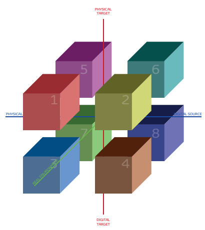
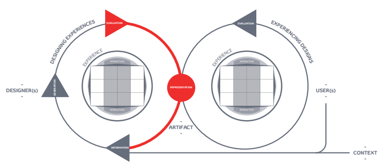
SUMMARY OF TOOLS: INDUSTRIAL CONTRIBUTIONS			
NAME, DESCRIPTION & EXPERIMENTATION		**REPRESENTATION**	**POSITION WITHIN THE DESIGN PROCESS**
A- Car's evaluation Evaluation criteria for assessing one component in cars.	Exp1		
B- Kansei Kards Cards for brainstorming. Tackling different design information, and involving different typologies of Interactive products.	Exp1		
C- Kansei Kabin Exp1 Half car augmented with sensors to formalize and record in-situe ideas, gestures, scenario and more.	Exp1		
D- Koncept Evaluation Methodology for evaluating ideas and concept. It is based on the physical and digital paradigm, and on design information.	Exp1		
E- Kansei Kabin Tool for evaluating low-tech prototypes in a controlled environment. Based on half a car with projection and sound system.	Exp1		
F- HMI Score Methodology for evaluating few components in a car. Based on objective and subjective measurement methods, translated into a simple score of HMI.	Exp1		
G- Kansei Kit Open tool for evaluation of components in car. BAsed on objective and subjective measurement methods. Can be improved by any list of keywords or components.	Exp1		
H- Kansei Klassification Evaluation method based on 3 axis for classifying interactive products. Not only automotive components can be assesed and classified into the 3D representation.	Exp2		

Table 51: Generated tools - part 1

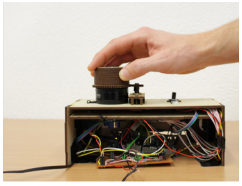
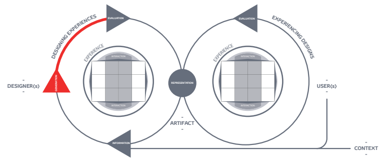
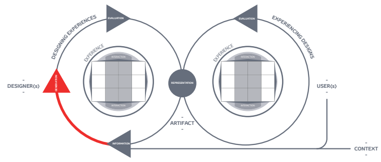
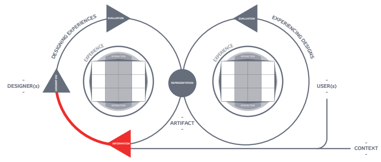
I- Kansei Knob Programmable knob to create the right sensation. Can also be used to look for the right shape, texture, material (...) of the knob depending of the turning feeling.	Exp3		
J- Superinteraction Set of metaphorical sources for creative session. Based on superhuman.	Exp3		
K- Scenario Kards Cards for setting up quickly a scenario of use. Based on context, type of driving, point of view of narrator...	Exp3		

Table 52: Generated tools - part 2

dans les «activités d'information» pour renforcer les «activités de génération». D'autre part, l'évaluation de l'interaction est soutenue par des outils tels que l'outil G (Kansei Kit), qui soutient à la fois les concepteurs et les utilisateurs (clients) dans l'évaluation des interactions en voiture. Ce faisant, il peut mettre en évidence les faiblesses et les nouveaux défis de conception qui alimentent l'activité d'information que les concepteurs utilisent lors des activités de génération.

5.2.3 Création de nouvelles méthodologies

Trois nouveaux types de méthodologies liées à l'interaction et à l'expérience utilisateur ont été détaillés et discutés en relation avec les expérimentations. Les méthodologies sont présentées ci-dessous du point de vue de la pratique de conception.

Méthodologie métaphorique

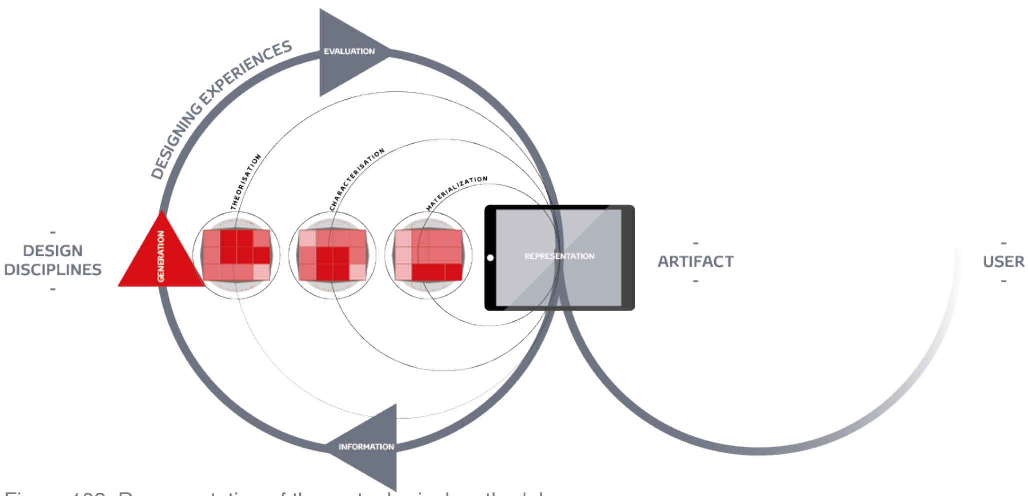


Figure 102: Representation of the metaphorical methodology

La première méthodologie développée par cette recherche est une méthodologie pour concevoir des interactions et des expériences utilisateur basées sur l'approche métaphorique.
La Figure 64 illustre que cette méthodologie s'inscrit dans le processus de conception complet. Plus spécifiquement, cette méthodologie soutient l'activité de «génération», telle que décrite par Bouchard (2003). Trois niveaux ont été présentés: Théorisation, Caractérisation et Matérialisation. Comme prouvé dans l'expérimentation 3, les trois niveaux supportent la conception de différentes informations. Trois variantes de l'outil ont été développées, basées sur les paradigmes physique et numérique. La figure 65 présente une version simplifiée de la façon dont les concepteurs peuvent choisir entre les différents niveaux de l'activité de génération. En

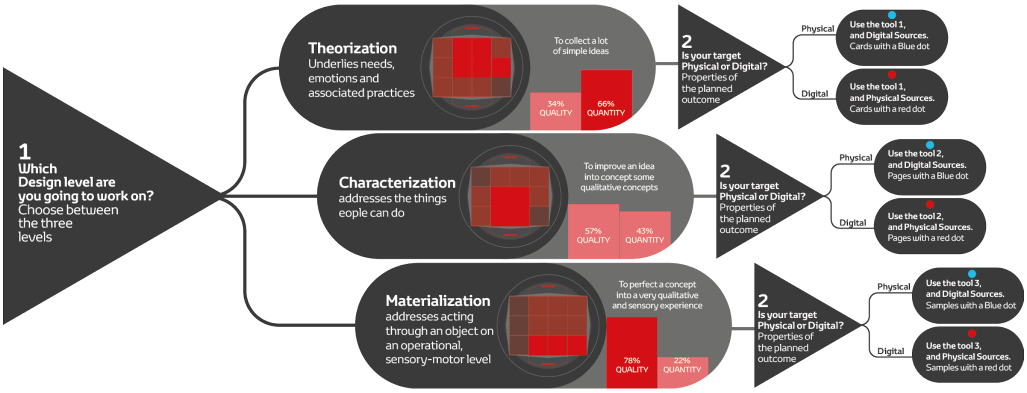


Figure 103: step by step instructions of the metaphorical methodology

outre, il clarifie également la façon dont les concepteurs doivent utiliser des sources physiques ou numériques en fonction de leurs propriétés cibles. Cela conduit finalement à l'une des variantes des six outils.
Cette méthodologie propose de nouvelles façons de concevoir l'interaction et les expériences des utilisateurs à travers les paradigmes physiques et numériques. L'approche surhumaine est une option que nous considérons inspirante. Néanmoins, de nombreux outils peuvent être créés en suivant les paradigmes physique et numérique.

Méthodologie des disciplines

En se concentrant sur les acteurs du développement de la conception, nous pouvons reconnaître différentes disciplines, comme présenté dans l'expérimentation 3. Considérant que différentes disciplines sont impliquées dans le processus de conception, et sachant que les équipes multidisciplinaires abordent un champ plus large d'informations de conception, une méthodologie a été développée. évaluer les disciplines et la portée des informations de conception. En effet, les hiérarchies linéaires que nous avons utilisées évoluent vers des organisations multidisciplinaires pour des réseaux plus flexibles. Ainsi, la méthodologie «orientée stratégique» développée consiste simplement à corréler les champs d'application des disciplines (personnes) avec les besoins des projets (en fonction du niveau auquel l'activité de génération sera abordée). En faisant cette comparaison, nous pouvons sélectionner et impliquer les bonnes disciplines pour créer une équipe de conception

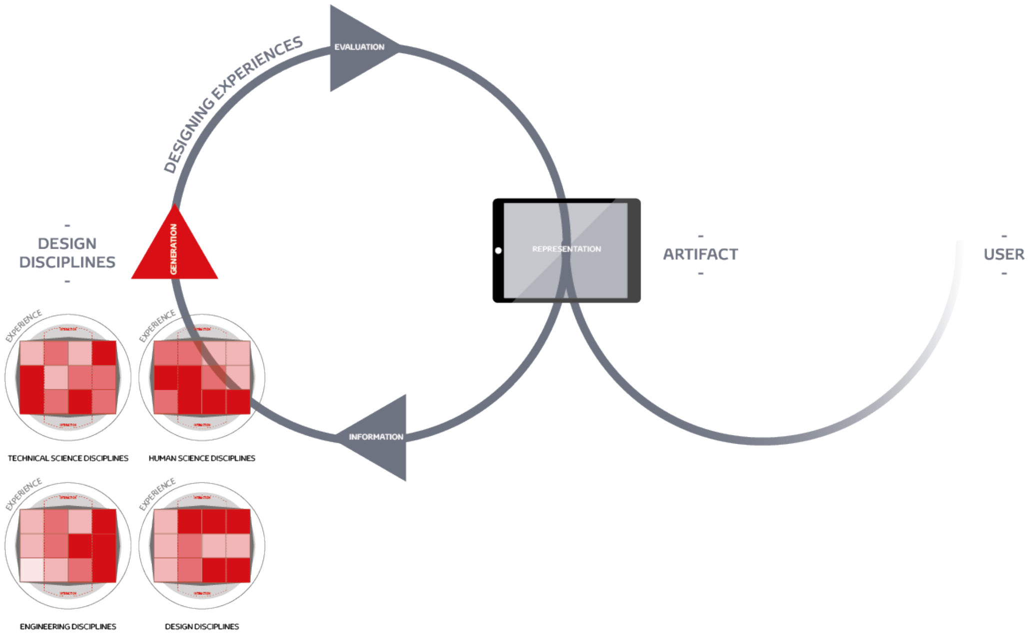


Figure 104: Representation of the Discipline methodology

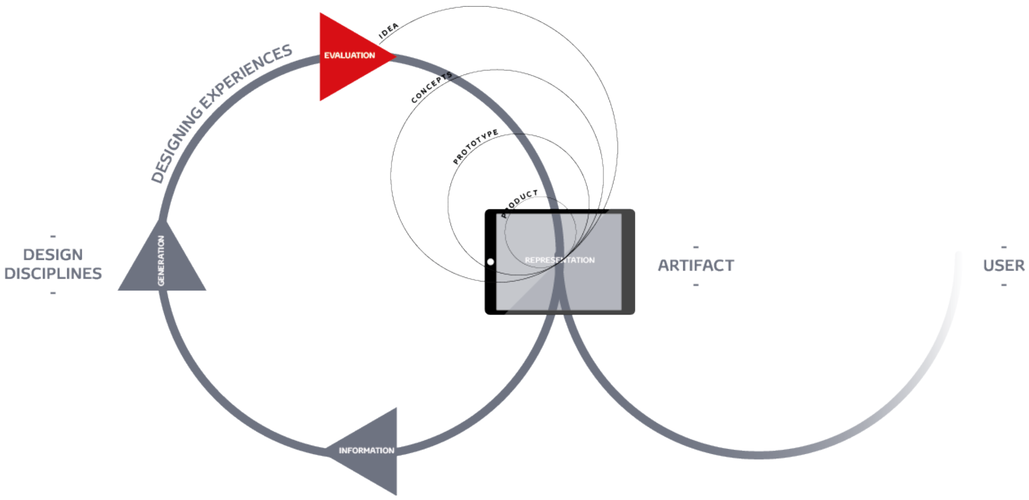


Figure 105: Representation of the evaluation methodology

adaptée. La méthodologie est basée sur un ensemble de questions qui alimentent le modèle théorique d'information de conception (voir Figure

66).

Méthodologie d’évaluation

La troisième méthodologie qui a été développée au cours de cette recherche concerne la capacité à évaluer des idées, des concepts, des prototypes et des produits basés sur les interactions et l’approche de l’expérience utilisateur. Des outils spécifiques ont été proposés pour répondre à différents besoins et différents niveaux d’évaluation (voir la partie précédente sur le «développement d’outils»). Cependant, la méthodologie développée vise à utiliser ces outils afin d’évaluer, en utilisant les mêmes critères, différentes idées, concepts, prototypes ou produits, afin de les comparer (voir Figure 67). En les comparant, nous pouvons potentiellement arrêter ou orienter différemment un projet avant les étapes finales. Il est intéressant de réduire le temps et les coûts.

En procédant à ces évaluations, nous pouvons distinguer quatre types de résultats, comme le montre la figure 68:

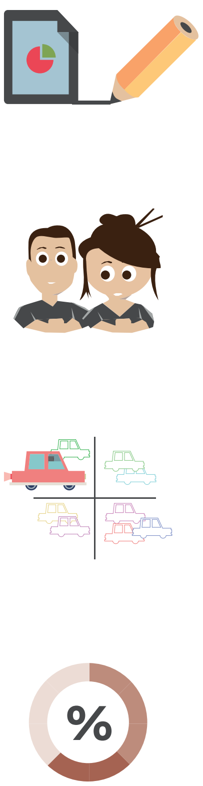


Figure 106: The four types of results

1. Mettre en évidence les défis de conception: Les évaluations sont utiles pour mettre en évidence les faiblesses et les nouveaux défis de conception. De cette façon, nous pouvons améliorer les projets grâce à de nouvelles activités de conception.

2. Définir les objectifs: Les résultats pourraient être utilisés pour définir si un projet est dédié à des objectifs spécifiques, et potentiellement renforcer la façon dont les produits peuvent correspondre à des objectifs spécifiques en ce qui concerne les nouvelles activités de conception.

3. Effectuer des analyses comparatives: Évaluer un projet (idée, concept, prototype ou produit final) par rapport à des concurrents afin de mettre en évidence les forces ou faiblesses potentielles qui doivent être renforcées ou améliorées par de nouvelles activités de conception. En outre, il peut également être utilisé simplement comme un moyen de positionner des projets en termes de produits concurrents (cartographie).

4. Mettre en évidence un score final: Enfin, ces évaluations sont également un moyen de donner une note simple aux interactions et à l’expérience utilisateur. Donner une note simple est utile pour mettre en évidence un résultat transversal et unifié.

5.2.4 Adoption de la contribution industrielle dans les activités de Toyota Motor Europe

Dans cette section, nous présenterons comment ces outils et méthodologies soutiennent différents types de projets du département Design de Kansei à TME. Cette discussion est basée sur le transfert de savoir-faire et de connaissances qui avait déjà eu lieu au moment de la rédaction de cette thèse, ainsi que sur une vision plus générale de la façon dont les contributions industrielles de cette recherche pourraient être incluses dans l'organisation.
Comme cette recherche suit une approche de recherche-action, elle peut être décrite comme un processus itératif impliquant des activités de recherche et de pratique. Les différentes contributions détaillées précédemment ont donc été créées en tenant compte à la fois de la pertinence académique et de l'utilité industrielle. La méthodologie métaphorique (expérimentations 1 et 3) a été organisée dans le cadre de vrais projets de développement de nouveaux concepts (travail sur Toyota New Global Architecture). Pour des raisons de confidentialité, l'accent a été mis sur la configuration, les outils, les méthodologies et la structure, plutôt que sur les aspects exacts et les activités de communication des représentations résultantes. De plus, nous avons utilisé la deuxième expérimentation pour améliorer notre compréhension de l'approche métaphorique.
La méthodologie de l'évaluation a d'abord été testée dans l'expérimentation 1, et améliorée dans l'expérimentation 2, avant d'être utilisée en évaluation réelle pour l'analyse comparative des voitures, l'établissement des objectifs et la résolution des problèmes de conception.
La méthodologie de la discipline a d'abord été testée dans l'expérimentation 2, et améliorée dans l'expérimentation 3. Les idées recueillies ont été discutées et partagées avec la direction pour une plus grande implication dans les organisations stratégiques.

L'adoption des outils et des méthodologies
Ayant été utilisées dans le cadre de la théorie des expériences, les méthodologies métaphoriques et d'évaluation ont de nouveau été utilisées dans de nouveaux projets de développement de concepts des marques Toyota Lexus. Cette intégration au sein du département de conception Kansei de TME comprend la réutilisation des outils associés pour les activités de production et d'évaluation. La valeur ajoutée des différentes contributions industrielles a également été reconnue par les membres de l'équipe de conception d'autres départements fonctionnels (ingénierie, planification de produits, stylisme, électronique), par la haute direction de TME, ainsi que par plusieurs ingénieurs de développement automobile. Des outils tels que les Kansei Kards, le score MHI et les Superinteractions sont maintenant même utilisés avec d'autres méthodologies que celle pour laquelle ils ont été créés.

Kansei Kards (et si) et Superinteraction ont été appréciés par la division impliquée dans de nouveaux projets de développement de concept pour leur capacité à transmettre des dimensions de conception abstraite au cours des activités de production. De plus, leur facilité d'utilisation a été appréciée par les

membres Toyota.
La méthodologie d'évaluation et les différents outils qui y sont liés ont été très appréciés par la direction de Toyota, pour les efforts déployés en se concentrant sur les dimensions subjectives. L'approche centrée sur l'humain a été mise en évidence comme un moyen de plus en plus décisif de différencier les marques, en mettant l'accent sur l'expérience utilisateur plutôt que sur les dimensions objectives des produits. La méthodologie d'évaluation avec le parcours utilisateur spécifique a été utilisée pour évaluer différents produits interactifs embarqués par différentes divisions de Toyota et de ses concurrents (technologie avancée / électronique / bruit et vibration / dynamique du véhicule). Cette méthodologie sera également utilisée dans les mois à venir pour évaluer les différences de perception entre différentes cultures. Toyota prévoit d'abord d'évaluer les perceptions japonaises, européennes et américaines des produits interactifs, correspondant aux trois centres de recherche et de développement Toyota, afin de mettre en évidence les défis de conception par culture.
Enfin, les différents outils et méthodologies générés développent et améliorent la structure de la division Kansei Design elle-même. La division vise à devenir de plus en plus «agile», avec des outils, des méthodologies et des compétences qui peuvent être utilisés à différents moments du processus de conception. Avec une organisation aussi flexible, l'ambition de la division est de s'éloigner du processus de conception habituel et de se positionner comme un satellite capable de fonctionner à différentes étapes du processus de conception.

«Design is a plan for arranging elements in such a way as best accomplish a particular purpose»
Charles Eames

«La conception est un plan pour organiser les éléments
de manière à accomplir au mieux un but particulier»

FRENCH VERSION

5.3 Résumé des contributions

Cette recherche sera conclue avec un aperçu des différentes contributions qui ont été mises en place. Ces contributions ont été organisées aux tableaux 28 et 29.

La première partie est descriptive et permet de détailler le contexte de cette étude: L'étude des interactions utilisateur-artefact à partir de l'approche de l'expérience utilisateur (liée à la construction à partir de l'état de l'art et des trois expériences). Aucun outil n'est lié à ces éléments, qui sont des aperçus plutôt que des méthodologies (voir les tableaux 28 et 29).
La deuxième partie est prescriptive. Il propose les trois méthodologies, avec des outils qui pourraient soutenir le processus de conception. Cette partie se concentre davantage sur l'application de la partie descriptive (voir les tableaux 28 et 29).

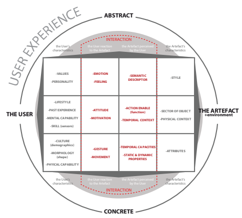
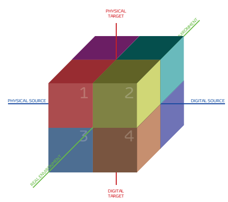
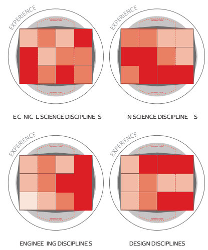
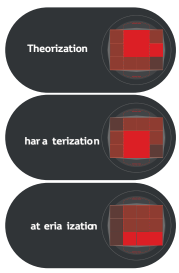
TYPE OF CONTRIBUTION	SUMMARY OF THE CONTRIBUTIONS		TOOL
Descriptive	Design information exchange during early design activities, foccussed on Interactions		Ø
	3 axes and 8 areas decribing a taxonomy of interactive products through the physical and digital paradigm		Ø
	Description of disciplines' scope of design informations		Ø
	Levels' description in early generation activities		Ø

Table 53: Contributions - Part 1

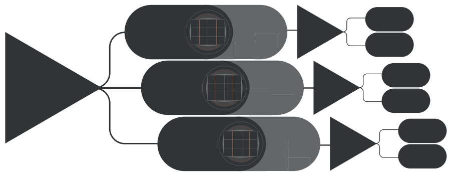
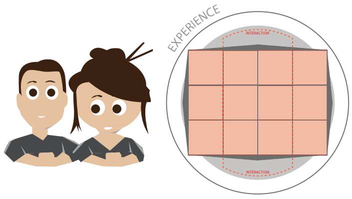
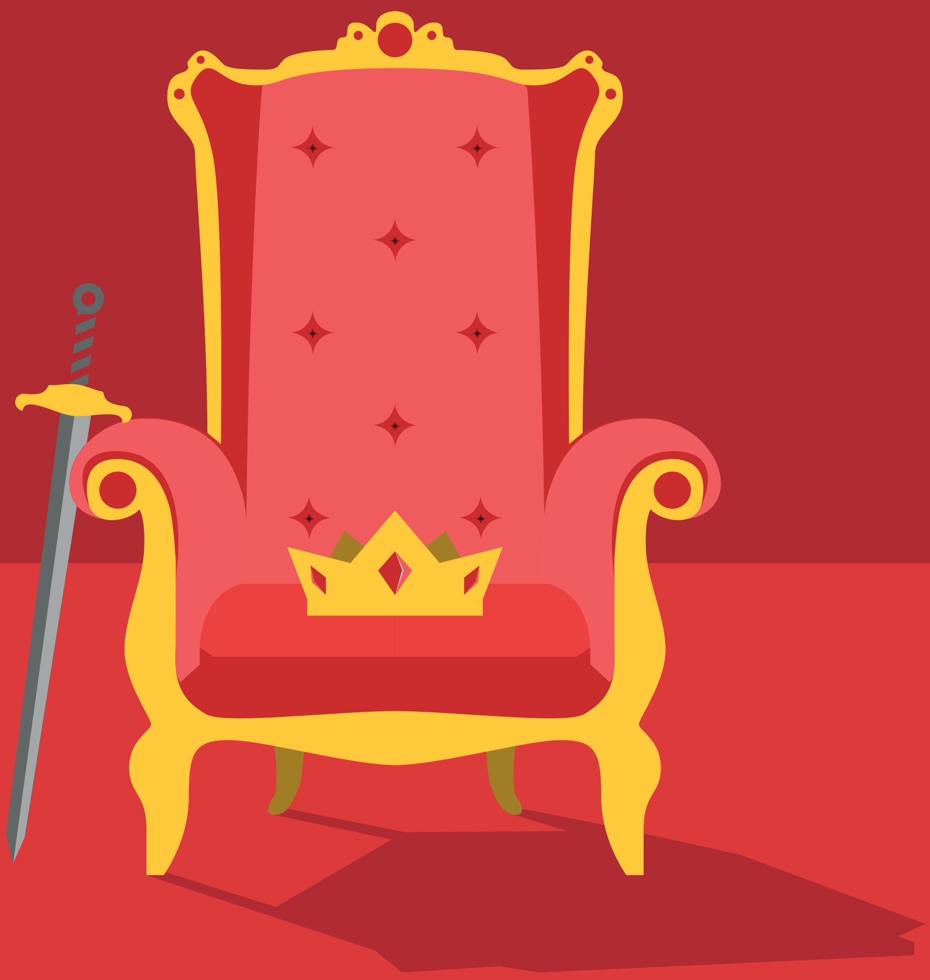
Prescriptive	Metaphorical approach of the physical & digital paradigm (+principles)		I H J B C K
	Evaluation method for assessing affective and cognitive perception of Interactive products/ concept/ idea		A D E F G H
	Managing method for assessing peoples and disciplines' design scope		G

Table 54: Contributions - Part 2

Ainsi, la recherche a abouti à différentes contributions qui pourraient être abordées par le contexte académique ainsi que par le contexte industriel. Nous encourageons les chercheurs et les concepteurs à explorer ces outils et méthodologies afin de simplement utiliser, améliorer ou même détourner leurs objectifs.



«There are 2 rules for success:
1. Never tell everything you know.»
Roger H. Lincoln

«Il y a 2 règles de succès:
1. Ne dites jamais tout ce que vous savez»

-

6 CONCLUSIONS ET PERSPECTIVES

-

6.1 Conclusions

Cette recherche est le fruit d'une collaboration de longue date entre le laboratoire CPI d'Arts & Métiers ParisTech et la division Kansei Design de Toyota Motor Europe. La recherche a débuté en 2015 avec le souhait de développer une approche originale qui pourrait encore s'insérer dans un flux logique avec des projets de recherche antérieurs (mémoire de master, thèse de doctorat et études internes) (Gentner, 2014). Le but de la recherche était de rassembler et de créer des connaissances et un savoir-faire qui pourraient soutenir le processus de design industriel dans la façon dont nous concevons les interactions du point de vue de l'expérience utilisateur. En outre, la recherche a commencé avec le désir de clarifier le lien entre les produits physiques et numériques d'un point de vue centré sur l'utilisateur et sur l'interaction.

Au cours des premiers mois de la recherche, les dimensions expérientielles appliquées à la conception de l'interaction sont apparues comme des notions clés, et les domaines de recherche connexes sont devenus des domaines influents de la revue de la littérature. Jusqu'alors, la portée des activités menées par Kansei Design Division, en collaboration avec le laboratoire CPI, était axée sur l'expérience utilisateur et l'approche de Kansei Design. L'orientation très axée sur l'interaction de cette recherche apporte une nouvelle étape dans la collaboration, menant à une prise en compte des réponses affectives et cognitives des utilisateurs-artefacts, et comment ces idées pourraient être utilisées dans le processus de conception précoce.
Lors de la définition du contexte théorique de cette recherche, il a donc fallu créer un lien entre les notions d'interaction du point de vue de l'expérience utilisateur (processus affectifs et cognitifs) et les dimensions physiques et numériques de l'artefact.
Basé sur ce domaine d'étude original, la recherche a discuté des activités de conception axées sur l'expérience, entreprises par les disciplines de conception afin d'améliorer le processus de conception industrielle pour l'évaluation et la conception des interactions. Ce domaine de recherche a été choisi parce qu'il a été observé que même si des outils et des méthodologies axés sur l'expérience soutenaient des activités de conception, l'adoption d'approches axées sur l'expérience industrielle orientées vers l'interaction utilisateur-artefacts, et plus

particulièrement les paradigmes physiques et numériques, et le processus de conception industrielle n'a été étudié que faiblement.

Les trois expérimentations de cette recherche ont exploré la manière dont nous pouvons générer et évaluer les interactions du point de vue de l'expérience utilisateur. À l'aide d'outils et de méthodologies nouvellement créés, nous avons exploré la façon dont les utilisateurs vivent les interactions, d'un point de vue physique et numérique, et comment ces idées pourraient influencer la façon dont nous concevons les premiers produits interactifs. Cette perspective nous a conduit à étudier l'approche métaphorique lors de l'évaluation et la conception des interactions. Ce faisant, nous avons exploré, formalisé et testé une méthodologie pour concevoir des interactions en utilisant l'approche métaphorique. Nous avons également évalué comment la nature de cette méthodologie peut influer sur la portée de l'information sur la conception au début de la conception. les disciplines de conception multiculturelles impliquées dans le développement de concepts; et le moment d'impliquer ce type de méthodologie du point de vue du processus de conception.
Dans chacune des trois expériences, les dimensions affectives et cognitives des interactions liées à la fois aux utilisateurs finaux et aux équipes de conception ont été un sujet majeur de discussion. La manière dont les interactions peuvent influencer les types abstraits de réactions affectives (émotions) et cognitives (sémantiques) a été discutée dans l'expérimentation 1 et plus largement (information de conception abstraite et concrète) dans l'expérimentation 2. Enfin, l'expérimentation 3 a détaillé comment une méthodologie pourrait aider aborder les dimensions affectives et cognitives de l'interaction au cours du processus de conception, en interrogeant les rôles des disciplines des concepteurs dans les équipes de conception multiculturelles.

En résumé, l'originalité de cette recherche réside dans les quatre points énumérés ci-dessous.

1. Domaines d'étude
Dans cette recherche, nous avons combiné deux grands domaines de recherche: le premier est l'approche centrée sur l'utilisateur de la psychologie cognitive (Atkinson & Shriffin, 1968, Helander & Kalid, 2006); et le second est l'approche centrée sur le produit de l'intelligence artificielle et du calcul (Schomaker et al, 1995, Andrist et al., 2014). Dans ces deux domaines, nous avons exploré l'expérience utilisateur (Ortiz Nicolas & Aurisicchio, 2011, Gentner, 2014), l'interaction (Krippendorff, 2006, Hassenzahl, 2010, Hekkert & Cila, 2015) et la perception (Saussure, 1916, Lakoff & Jonhson, 1980). Yanagisawa, 2016).

2. Interaction expérientielle
La vision de l'interaction était basée sur la perception de l'utilisateur au lieu des caractéristiques objectives du produit, afin de créer une interaction expérientielle au début de la conception. Cela a abouti, par exemple, à la taxonomie des produits interactifs.

3. Paradigme physique et numérique à travers les métaphores

La recherche a combiné les paradigmes physique et numérique en interaction (Ishii, 2012; Pine, 2009) avec l'approche métaphorique (Hekkert et Cila, 2015; Lakoff et Jonhson, 1980) pour concevoir des interactions au début du design.

4. Outils et méthodologies
L'ensemble des outils développés et des méthodologies dédiées à la création et à l'évaluation des expériences et des interactions des utilisateurs au début de la conception a été présenté à la fois comme une «façon de faire» et comme des «résultats» de cette recherche.
Cette recherche a finalement conduit à des contributions académiques et industrielles. En termes de premier, il a permis de formaliser l'interdépendance entre l'expérience utilisateur et les interactions, ainsi que de mettre en évidence une taxonomie formalisée des produits interactifs utilisant l'approche métaphorique des interactions physiques et numériques.
En ce qui concerne ce dernier type de contribution, les différentes expériences nous ont permis de proposer de nouveaux outils et méthodologies pour évaluer les interactions du point de vue de l'expérience utilisateur. De plus, la manière dont nous pouvons concevoir les interactions du point de vue de l'expérience utilisateur a également été abordée en utilisant l'approche métaphorique. Cela a abouti à une méthodologie composée d'outils qui soutiennent la façon dont nous pouvons concevoir ce que les utilisateurs vont percevoir et ressentir lorsqu'ils interagissent avec un artefact, avant que l'artefact lui-même ne se matérialise.

«The interface governs transformations from interior state to exterior relation»
Branden Hookway

«L'interface gouverne les transformations de l'état intérieur à l'extérieur»

6.2 Perspectives

Cette recherche a créé des moyens d'évaluer et de concevoir des interactions du point de vue de l'expérience utilisateur dans les premières phases du processus de développement de produits. Il a également contribué à mieux comprendre et formaliser l'interdépendance entre l'expérience utilisateur et les interactions, ainsi que l'impact des propriétés physiques et numériques sur les informations de conception.
L'approche métaphorique de l'interaction développée dans cette recherche a montré des résultats prometteurs, mais certaines de ses limites pourraient également être identifiées. Par exemple, le nombre de produits interactifs évalués ne permet pas de couvrir les huit domaines de manière égale. En ce sens, d'autres recherches devraient être menées sur l'impact des métaphores sur la perception affective et cognitive de l'utilisateur. De plus, sachant que les évaluations sont basées sur la perception de l'utilisateur, la validité des résultats collectés est très courte. L'impact de notions temporelles telles que la nouveauté ou la surprise doit être davantage exploré afin d'améliorer l'approche proposée. Logiquement, le modèle d'information sur le design peut également être amélioré et approfondi en termes d'impact de la temporalité (la manière dont les utilisateurs vivent leurs interactions), et en explorant l'impact de la culture sur les différentes réactions affectives et cognitives des utilisateurs. un artefact. En fait, nous pourrions envisager de nombreuses boîtes d'information sur la conception pour étudier l'impact sur l'expérience utilisateur complète, tel que présenté à la figure 69.

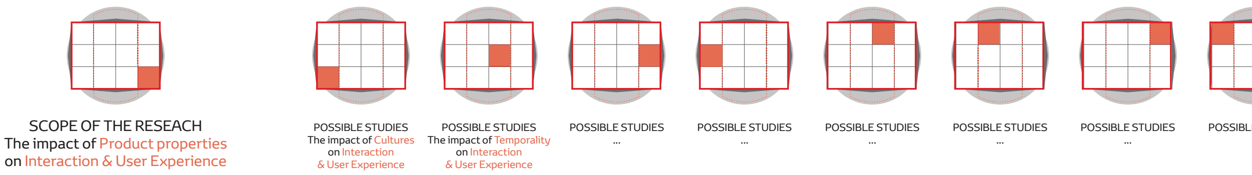


Figure 107: Possible futur studies according to theoretical model of design information (i)

Cette recherche visait à proposer au secteur industriel de l'industrie automobile un processus de conception et d'évaluation d'artefacts en utilisant l'approche de la perception humaine. Ce processus prend la voie inverse historique de la conception dans l'industrie automobile énorme et très axée sur les produits, basée sur nos conceptions de recherche pour les réactions affectives et cognitives. L'artefact est juste une manière matérialisée d'atteindre ces interactions et expériences utilisateur significatives, rien de plus. C'est pourquoi nous avons adopté l'approche métaphorique pour concevoir des interactions. Dans d'autres études, il serait très intéressant d'étudier comment cette approche métaphorique pour concevoir des interactions dans la conception précoce pourrait être utilisée. Ces études devraient répondre à des questions telles que: «Comment les sources métaphoriques peuvent-elles correspondre à une expérience globale?» Ou: «Dans quelle mesure la métaphore souhaitée peut-elle être perçue dans l'interaction utilisateur-artefact final?» Ou: «S'il existe un écart entre «métaphore intentionnelle» et «métaphore perçue», est-ce une information perdue ou est-ce une manière de souligner que la conception utilisant la métaphore est simplement indépendante de l’expérience des métaphores?

ELABORATION D'UNE METHODOLOGIE KANSEI,

À TRAVERS LES INTERACTIONS PHYSIQUES ET DIGITALES

RESUME :

L'expérience que les utilisateurs vivent est récemment devenue un facteur majeur de différenciation pour les entreprises de produits et de services (comme Toyota Motor Europe), les poussant à mener des recherches plus approfondies dans les domaines de l'expérience utilisateur et de l'interaction. Ces recherches amenent à une plus grande considération de la perception subjective plutôt que celle des propriétés objectives des produits.

Partant de cette approche de la **'recherche en design' à travers la perception subjective,** cette étude tente de comprendre et de formaliser les influences réciproques des interactions et des expériences utilisateur en définissant quels paramètres affectent les réactions subjectives. À partir de ces paramètres, cette recherche a isolé les propriétés physiques et digitales d'un produit dans le but de mettre en avant leurs **effets sur les réactions affectives et cognitives d'un utilisateur.**

Grâce à cette approche, cette recherche aboutit à des apports à la fois scientifiques et industriels: elle a rendu possible **la formalisation de l'interdépendance entre l'expérience utilisateur et les interactions**, la mise en place d'une t**axonomie des produits interactifs à travers l'approche métaphorique des interactions physiques et digitales** et enfin la matérialisation d'une **méthodologie et d'outils pour à la fois évaluer et créer des interactions à partir de l'approche expérientielle.**

Mots clés : (Kansei; Design d'Interaction; Experience Utilisateur; Metaphore; Psychology Cognitive)

ELABORATION OF A KANSEI DESIGN METHODOLOGY,

THROUGH PHYSICAL AND DIGITAL INTERACTIONS

ABSTRACT :

Users' experience with products recently became a major differentiation factor for products and services companies (such as Toyota Motor Europe), leading to deeper researches on both user experience and interaction. These researches preach for a deeper consideration of the subjective perception rather than artifacts' objective properties.

From this approach of '**design research' through the subjective perception,** this study intends to understand and formalize the reciprocal influence between Interaction and user experience, highlighting which parameters are affecting subjective reactions. From these parameters, this research isolated the artifact's physical and digital properties in order to highlight its effects on **user's affective and cognitive reactions**.

By doing so, this research resulted in both academic and industrial contributions. In terms of the former, it made possible to **formalize the interdependency between User Experience and Interactions**, to define **a taxonomy of interactive products through the metaphorical approach of physical and digital interactions** and to **materialize a methodology with tools for both evaluating and designing interactions from the User Experience perspective.**

Keywords : (Kansei; Interaction Design; User Experience; Metaphor; Cognitive Psychology)

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