# Interdisciplinarity and Design Conceptualisation: A Design Research Approach to the Early Stages of New Product Development

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Thesis submitted to Faculdade de Engenharia da Universidade do Porto in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Leaders for Technological Industries under the MIT-Portugal Program

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**September, 2016**

## abstract

Industrial design and mechanical engineering have a long history of tensions in new product development, which only become greater with increased complexity and diversity of knowledge associated with the products. Furthermore, an analysis of the history of these two disciplines shows that it is technology that mediates this relation. In other words, technology, that historically divided industrial design and mechanical engineering, it is now responsible for their methodological reconciliation. Academically, literature sustains that innovation is grounded in the integrative combination of the knowledge associated with society and technology. Industrially, there are also examples of global companies that are already applying, systematically, this interdisciplinary approach. Therefore, the main objective of this thesis is to study how new products are created in an interdisciplinary context, focussing in industrial design and mechanical engineering. The emphasis is on the conceptual stage of the design process, as the literature advocates its major impact in the whole process, and regards it as the least studied stage. Hence, this research considers a design case focused in this conceptual stage.

This research was conducted in the context of a project for new aircraft configurations for commercial aviation, aiming to give new insights to the area of collaborative approaches to the conceptual stage of new product development. The most challenging discussion arising from this analysis is to understand how, and whether or not to structure this conceptual stage. In this regard, the position of the studied consortium is that it is important to positioning itself towards a more structured approach, in order to better integrate different disciplines in the same project. This position resulted in the definition of a hypothesis for this thesis along these lines. Then, and following the chosen methodological approach, experimental studies were conducted to test this hypothesis in an isolated environment. Therefore, this study proposes a clear vision of what industrial design and mechanical engineering should be doing in the conceptual stage of the design process, and the decisiveness of technology in integrating them. Also, this study supports the idea that interdisciplinary knowledge should be combined in a structured way in this conceptual stage. The perception of these problems reinforces then the importance of trust and communication between the different actors, in order to conceptually integrate these disciplines and to innovate.

## keywords

Industrial Design
Mechanical Engineering
Design Conceptualisation
Collaborative Design
New Product Development

# resumo

Há muito que o Design Industrial e a Engenharia Mecânica apresentam uma tensão interdisciplinar no desenvolvimento de novos produtos. Esta tensão aumenta em correlação com a complexidade e diversidade de conhecimento associadas ao produto a desenvolver. Analisando o desenvolvimento histórico destas duas disciplinas, é possível perceber o papel mediador da tecnologia. Ou seja, a tecnologia, que historicamente separou o design industrial e a engenharia mecânica, é agora responsável pela sua aproximação metodológica. Academicamente, a literatura tem vindo a sustentar que apenas com a integração combinada de conhecimento associado à sociedade e à tecnologia se criará inovação. Em termos industriais, há já exemplos práticos de empresas globais que empregam esta abordagem integradora e interdisciplinar de uma forma sistemática. Deste modo, o objetivo geral deste estudo é o de refletir sobre o desenvolvimento de novo produto em contexto interdisciplinares, com enfoque na Engenharia Mecânica e no Design Industrial. Esta análise enfatiza a fase de conceptualização do processo de design, uma vez que a literatura advoga o seu impacto decisivo na totalidade do processo, e a considera como a menos estudada.

A investigação sustenta-se num estudo de caso que versa novas configurações para a aviação comercial, e oferece novas contribuições para o estudo de abordagens colaborativas para a fase conceptual de desenvolvimento de novo produto. Neste âmbito, a discussão mais premente para a fase de conceptualização do processo de design refere-se à estruturação, ou não estruturação, da mesma. A este respeito, a posição do consórcio em estudo é clara, posicionando-se no sentido de estruturar esta fase conceptual, por forma a integrar positivamente diferentes disciplinas dentro de um mesmo projeto. Esta posição resultou na definição de uma hipótese para esta tese alinhada com a posição do

caso em estudo. Seguindo a lógica metodológica escolhida, conduziram-se estudos experimentais num ambiente isolado para que a referida hipótese fosse testada. Deste modo, este estudo propõe uma visão clara das atividades do design industrial e da engenharia mecânica na fase de conceptualização, e o papel decisivo da tecnologia para a sua integração. Igualmente, este estudo sustenta a ideia de que o conhecimento interdisciplinar deve ser combinado de uma forma estruturada na referida fase conceptual. A perceção geral destes desafios, reitera a importância da confiança e da comunicação entre os diversos atores, num processo de inovação que integre conceptualmente diversas áreas de projeto.


## palavras-chave

Design Industrial

Engenharia Mecânica

Conceptualização em Design

Design Colaborativo

Desenvolvimento de Novo Produto

*Trez vezes ao leme as mãos ergueu,*
*Trez vezes ao leme as reprendeu,*
*E disse no fim de temer trez vezes,*
*"Aqui ao leme sou mais do que eu:*
*Sou um Povo que quer o mar que é teu;*
*E mais que o mostrengo, que me a alma tema*
*E roda nas trevas do fim do mundo,*
*Manda a vontade, que me ata ao leme,*
*De El-Rei D. João Segundo!"*

**IV. O Mostrengo**
Fernando Pessoa
*Mensagem (1934)*

## acknowledgments

Não foi fácil chegar a estes parágrafos, com todos os avanços e recuos que caracterizaram esta curta odisseia, mas eis-me perante eles. Cabe-me então agradecer a quem, de uma ou de outra forma, permitiu que esta demanda chegasse a bom porto.

Ao Professor Nuno Correia, por todo os ensinamentos, apoio e flexibilidade desde o mês de Setembro do ano de 2012. Sem a sua iniciativa, visão e enquadramento com o projeto newFACE, este trabalho não teria sido de todo possível. Adicionalmente, um agradecimento especial a todo o consórcio do projeto newFACE pela simpatia e disponibilidade com que me receberam nos seus trabalhos. À Professora Inês Secca Ruivo pela afabilidade e franqueza com que aceitou colaborar nesta investigação. Creio que nunca as novas ferramentas de comunicação se tenham justificado tanto. Agradeço também ao Professor Jorge Lino, que tendo sido envolvido por último nesta investigação, prestou uma orientação sempre assertiva e academicamente orientada.

Um agradecimento aos habitués do Design Studio pela sua camaradagem, e em especial à Carla Monteiro pela amizade, paciência e disponibilidade. A sua capacidade linguística e estética foi sempre uma mais valia. Agradeço também a todos os que de uma forma voluntária aceitaram participar nas sessões de Setembro e Outubro de 2015, e em especial aos que nelas colaboraram por afinidade.

Agradeço também à criatividade e voz rouca de Tom Waits, que foi sempre um bálsamo nos momentos de maior aperto.

Aos meus pais, Anália e António, por tudo.
À minha irmã, Catarina, porque sim.
À Tânia, por ser quem é,

*Pushing through the market square, so many mothers sighing*
*News had just come over, we had five years left to cry in*
*News guy wept and told us, earth was really dying*
*Cried so much his face was wet, then I knew he was not lying*
*I heard telephones, opera house, favourite melodies*
*I saw boys, toys electric irons and T.V.'s*
*My brain hurt like a warehouse, it had no room to spare*
*I had to cram so many things to store everything in there*
*And all the fat-skinny people, and all the tall-short people*
*And all the nobody people, and all the somebody people*
*I never thought I'd need so many people*

*A girl my age went off her head, hit some tiny children*
*If the black hadn't a-pulled her off, I think she would have killed them*
*A soldier with a broken arm, fixed his stare to the wheels of a Cadillac*
*A cop knelt and kissed the feet of a priest, and a queer*
*Threw up at the sight of that*
*I think I saw you in an ice-cream parlour, drinking milk shakes cold and long*
*Smiling and waving and looking so fine, don't think*
*You knew you were in this song*
*And it was cold and it rained so I felt like an actor*
*And I thought of Ma and I wanted to get back there*
*Your face, your race, the way that you talk*
*I kiss you, you're beautiful, I want you to walk*
*We've got five years, stuck on my eyes*
*Five years, what a surprise*

*We've got five years, my brain hurts a lot*
*Five years, that's all we've got*
*We've got five years, what a surprise*
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*Five years*
*Five years*
*Five years*
*Five years*

**Five Years**
David Bowie
*The Rise and Fall of Ziggy Stardust and the Spiders from Mars (1972)*

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# list of acronyms

**COM** Commercialisation

**DRM** Design Research Methodology

**DS** Descriptive Study

**FFE** Fuzzy Front-End

**NCD** New Concept Development

**NPD** New Product Development

**OEM** Original Equipment Manufacturer

**OI** Open Innovation

**PMI** Project Management Institute

**PS** Prescriptive Study

**RC** Research Clarification

**R&D** Research and Development

**RQ** Research Question

# 1 INTRODUCTION

Design is a historical development (Horváth 2004). Accordingly, the activities of design are considered of the same age of mankind itself, aimed at the early human basic needs of food and shelter (Manzini 1989, Valls 2003, Torrent and Marín 2005, Cross 2008, Bürdek 2010, Weck, Roos, and Magee 2011). Designing and making are generally considered as two of the most relevant human activities (Pye 2007). In its broadest sense, design is a natural human activity, and generically it is materialised in all the objects that surround us (Marcus 2002, Dubberly 2005, Cross 2006).

Conversely, this context makes it difficult to clearly define design, as it increased in technical complexity, and in social sophistication. Currently, it is possible to empirically understand design, but it is difficult to put a clear finger on its boundaries (Marcus 2002, Le Masson, Hatchuel, and Weil 2011). Still, all products we commonly use today are design objects, and they were the result of at least two centuries of an ever increasing human ability to control or reconfigure the environment (Heskett 1980, Marcus 2002, Foundation et al. 2010). The instrument of this transformation was the emergence of the mechanised industry, in which the industrial design and mechanical engineering disciplines saw a decisive leap forward in their professionalization. It is this study, of the relation between these two disciplines, which is the main purpose behind this research. Currently, design is thought as an activity that has an effect on nearly every space of human life. In general terms, design refers to those activities that actually generate a new product from a need, idea or technology, to the full documentation needed to complete realise it (Blessing and Chakrabarti 2002, Blessing and Chakrabarti 2009). Also, it is widely accepted that the disciplines of industrial design and mechanical engineering play a combined and decisive role in this new product development (NPD) process. Nevertheless, the generic design term is sometimes used as a polysemy.

## 1.1 RESEARCH OPPORTUNITY AND MOTIVATION

Design is a complex and total phenomenon, as it is responsible to integrate different systems. People, processes, knowledge, tools, methods, as well as economics should be positively combined in order to the organisation to function (Blessing and Chakrabarti 2002). In the post-World War II period, the multi-dimensional and complex problems of planning and design, fostered collaborative and interdisciplinary work (Bayazit, Esin, and Ozsoy 1981). Presently, the increased complexity in the social and technological dimensions attributes an increasing importance of having diversified design teams (Stempfle and Badke-Schaub 2002, Dym et al. 2005, Cross 2011). Therefore, a tremendous collaborative effort composes design today, with a large number of actors from different areas wanting to have a say in design decisions (Marcus 2002, Collin 2009). This increased collaborative effort is the result of a blurring in the boundaries of different project disciplines, in the conceptual stage of the design process (Horváth 2004, Sanders 2006). This blur mainly occurs in the conceptual stage of the design process, in which all innovators are united and focused in the final user (Borja de Mozota 2003).

The conceptual stage of any design process is very creative, and the integration of different sources of knowledge therein makes it complex. Hence, management literature started to show an increased interest in this conceptual stage in the early 1990s, coining this stage as the Fuzzy Front-End (FFE) (Khurana and Rosenthal 1997, Verganti 1997, Khurana and Rosenthal 1998, Smith and Reinertsen 1998). Interestingly, research in design is now currently focussing in the FFE as well, with an emphasis on experiential rather than physical or material affairs (Sanders 2006, Sanders and Stappers 2008). Currently, literature considers that allocating more resources in this field will lead to better products with higher economic returns (Cagan and Vogel 2013). Others like Wormald *et al*, suggest that it will be critical for design education to better understand how to successfully operate in the FFE, as global companies are increasingly having strategic options in this stage (Wormald 2011). Despite its importance, the FFE process remains a comparatively under-studied research topic (Koen et al. 2001, Koen, Bertels, and Kleinschmidt 2014a, b). To address this research opportunity, this thesis is grounded in a Research & Development (R&D) project for new aircraft configurations for commercial aviation, a relevant demonstration ground, covering different knowledge bases. As is also stressed under the Open Innovation (OI) paradigm, the consortium behind this R&D project involved a collaborative and open approach between the companies (Leen and Lubben 2013). However, assuming collaborative design approaches in the FFE is complex, and OI research gives little attention to this conceptual and open collaboration (Jorgensen et al. 2011, Enkel and Heil 2014). Therefore, this thesis aims to give new insights on the combination of disciplines in the conceptual stage of NPD.

## 1.2 DISAMBIGUATION OF THE TERM DESIGN

As discussed, the term design does not hold the same meaning for everybody. The popularisation of this term over the last two decades has made it commonplace, and now it almost admits an autonomous existence (Bonsiepe 2007). Occasionally, design might evoke a fashion or an attractive image, or it may also suggest creativity. For a minority it evokes the activities covering the form and function of industrial products. This last notion, of form and function of industrial products, is behind what we now understand as industrial design (Lorenz 1991, Walsh 1996). Nevertheless, this notion of industrial production may overlap, and literature sometimes considers the disciplines of industrial design and mechanical engineering, as having a shared domain of activity (Maldonado 2012). In the same line, Schön (1983) defined design as a reflective practice, in which the branches of industrial and product design belong to the wide family of engineering (Schön 1983).

Currently, industrial design is also an important link between creativity and innovation, in order to shape ideas to reach usefulness and attractiveness for users or consumers. It is a creative activity deployed to a specific and practical end, and it is rooted in the production of material goods (Cox 2005, Koskinen et al. 2011). Consequently, literature proposes industrial design as a total phenomenon, as within this process it directly connects with a wide range of other disciplines (Best 2010, Maldonado 2012). Therefore, industrial design activities normally coordinate, integrate, and articulate all the elements and disciplines that contribute to the development of new products (Maldonado 2012). Nevertheless, in this role of integrating different, yet related, project disciplines, tensions may occur between the disciplines as different actors attempt to define their specific space (as will be discussed in Chapter 4). Therefore, a review of the definitions from academia and practitioners on industrial design and mechanical engineering is pertinent:

*Mechanical Engineering is concerned with the responsible development of products, processes, and power, whether at the molecular scale, or at the large scale of large, complex systems.*

Massachusetts Institute of Technology (MIT), 2015

*Mechanical engineering is all about taking science and using it to produce things. It's about translating theoretical research into practical solutions and applications, which are used by society.*

The Institution of Mechanical Engineers (IMechE), 2015

*Industrial Design teaches students to use critical thinking and the design process itself to bring new value to companies, communities and citizens.*

Rhode Island Design School (RISD), 2015

*Industrial Design is the professional service of creating products and systems that optimise function, value and appearance for the mutual benefit of both user and manufacturer.*

Industrial Designers Society of America (IDSA), 2015

The above definitions present clear similarities between professional and academic perspectives on the same discipline, and clear differences between the different disciplines. Mechanical engineering is generally proposed as the use of science to create tangible products and processes for society. Conversely, industrial design is defined as a critical and valuable process of creating new products that optimise the production and the user satisfaction. While mechanical engineering is focused in science, technology, and energy, industrial design is more focused in processes, value, and ultimately the user. However, and as described in the above definitions, these disciplines aim to create value with the industrial products. Accordingly, recent studies in NPD show that a good general design can lead to more successful products, increased competitive advantage and financial performance (Goffin and Micheli 2010). In its broadest sense, design is a key asset to innovation, as it involves the generation of new concepts and new knowledge (Kimbell 2011). Nevertheless, as engineers and industrial designers use different scientific journals, rely on different epistemologies, and are related to different disciplines, interdisciplinary research incompatibilities may appear. The challenge is then to go beyond the professional traditions, in order to understand the continuum of industrial design and mechanical engineering in the design process (Le Masson, Dorst, and Subrahmanian 2013). In other words: to understand how these two disciplines interact in this continuum, where different practices and practitioners co-exist, but are apprehensive about the loss of identity in working together, forms the first challenge of this research.

## 1.3 RESEARCH QUESTIONS

As described in the previous sections, this research is focused in the conceptual and collaborative development of new products. Currently, literature argues that the boundaries of the different disciplines involved in the design process are blurring (Sanders 2006, 2010). Besides, these interdisciplinary relations are more pertinent in the conceptual stage, as the real leverage of new ideas and competitiveness in the whole process happens therein (Backman, Börjesson, and Setterberg 2007, Schweitzer and Gabriel 2012, PMI 2013, Gassmann and Schweitzer 2014). The general objective for this research is then to reflect on the interdisciplinary relation between industrial design and mechanical engineering, in the conceptual stage of the design process. Notwithstanding the importance of other relevant disciplines in the NPD process, such as marketing, economics and sociology, this thesis is focussed on the interaction between these two disciplines. To address this research generic objective, this study was broken down into two main Research Questions (RQs):

1. ***How does product design develop new products in an interdisciplinary context, and what tensions arise from that?***

This question addresses the issues of the interdisciplinary collaboration between different project disciplines. For this thesis the main purpose is to understand the relation between industrial design and mechanical engineering, which currently presents an increasing level of complexity. Therefore, three specific RQs were born related to this general question:

a) What is the origin of industrial design and mechanical engineering?
b) What are the differences and similarities between industrial design and mechanical engineering?
c) What types of knowledge support these two disciplines?

2. ***How should the conceptual stage of product development be approached in an interdisciplinary context?***

This question addresses the issues of the conceptual stage of the design process, perceived by the literature as the least understood period. Connected to this, two specific RQs appeared:

a) What is the importance of the conceptual stage in the overall design process?
b) How to integrate and manage different sources of knowledge in the conceptual stage of new product development?

The answers to these general and specific RQs were found resorting mainly to qualitative techniques, by means of the research approach chosen, and briefly explained in the following section.

## 1.4 RESEARCH APPROACH

The adopted research philosophy contains important assumptions about the way in which the researcher views the world. Accordingly, questions of method are secondary when compared to questions of paradigm (Saunders, Lewis, and Thornhill 2009). In design research, the research paradigms often hinge on the underlying views of positivist science or the construction of knowledge (Kimbell 2011). The conceptual design stage is inherently generative and inquisitive, requiring the designer to continuously question in order to innovate (Dym et al. 2005). Therefore, for this study a constructivist approach is taken, as it seeks to establish the meanings of a specific design phenomenon from the views of different participants (Creswell 2014). In terms of methodology, this research builds on the methodological paradigm proposed by Blesssing and Chakrabarti (2009): the Design Research Methodology (DRM). This creates a foundation with a degree of standardisation and helps to clarify the research approach. The design research approach in general, and the DRM in particular will be extensively analysed in Chapter 2.

The transformation of industrial design into an industrial discipline, brought responsibilities that only recently design studies begun to address (Friedman 2008). Accordingly, research through design was considered as less straightforward, when compared to scientific research (Frayling 1993/4). As design research is still understood as a recent discipline, there is some uncertainty about its value and nature (Buchanan 2001, Cantamessa 2003) However, design research is becoming increasingly recognised and visible, reflecting the complex and multidimensional nature of design itself (Cash 2012). Also, design research aims to analyse design phenomenon holistically, above the disciplinary manifestations, by applying both aggregation and abstraction (Horváth 2004). The interdisciplinary tensions in NPD were mentioned as the main challenge for this research. Generally, the first reason to engage in a design research approach is that it provides a productive perspective for theory development (Edelson 2002). The constructivist philosophy of this study is thus underlined.

### 1.4.1 Research objectives

The specific RQs present a number of different elements required to answer the two main questions. As such, the RQs were broken down into a series of objectives to be addressed separately, as follows:

i. To understand the emergence of industrial design and mechanical engineering (Chapter 3)
ii. To review and compare the knowledge base associated with each discipline, and its importance for NPD (Chapter 4)
iii. To recognise and critically compare the processes leading to the general creation of new products, and understand the importance of the conceptual design stage (Chapter 5)

iv. To understand the importance of an interdisciplinary and structured approach in the conceptual design stage (Chapter 6)

v. To conduct experimental studies in order to validate the hypothesis postulated in this study (Chapter 7)

## 1.5 THESIS STRUCTURE

**Chapter 2** details the research paradigm and the methods taken. Also, the DRM that structured this research is extensively detailed.

The design phenomenology, which includes history, taxonomy and technology, is one of the sub-disciplines of design research (Archer 1981, Cross 2006). Therefore, **Chapter 3** presents a historic retrospective on the disciplines of industrial design and mechanical engineering. Also, within this chapter the perceived integrative role of technology between these two disciplines is outlined.

To understand the knowledge that creates usable and desirable products is an area of intense design research (Buchanan 2001). Accordingly, **Chapter 4** analyses the knowledge base behind industrial design and mechanical engineering. Also, the importance of new knowledge for the creation of new products is discussed and underlined.

A design research approach must exploit the design process as an opportunity to enhance the researchers understanding of teaching and learning, and in terms of the educational systems (Edelson 2002). The design praxeology, which studies the practices and processes of design, is one of the sub-disciplines of design research studies (Archer 1981, Cross 2006). Over **Chapter 5**, this sub-discipline of design research studies will be the focus of research. Therefore, within this chapter a critical analysis to some design models is performed, with a focus in their common conceptual stage.

Literature argues that there is a gap in the study of collaborative approaches applied to the front end. Accordingly, **Chapter 6** presents a combined analysis of the Open Innovation (OI) paradigm and the FFE stage. Also, the design case that sustained this thesis is detailed in this chapter, as it deals with these research areas.

One area that is of increased importance within design research is that of empirical studies, as they provide insight into many areas of design whilst supporting theory building as well (Cash et al. 2012, Cash 2012, Le Masson, Dorst, and

Subrahmanian 2013). The proposal of a design theory relies in the interdisciplinary and integrative nature of design, and in the strong relationship between empirical and theoretical approaches (Friedman 2003, Le Masson, Dorst, and Subrahmanian 2013). Therefore, and following the DRM guidelines, **Chapter 7** presents the results of a design experiment conducted within an isolated environment. The hypothesis to test in this experiment was based in the literature review, and in the immersion with the design case.

Finally, **Chapter 8** provides a discussion on the general findings of this research, the felt limitations over it, and it identifies areas for further development as well. Also, it presents suggestions for further research in the areas of empirical design studies and methodological research.

# 2 RESEARCH METHODOLOGY

Design was formally acknowledged as an individual activity in the second half of the 19th century (Bayazit 2004, Horváth 2004). Nevertheless, only in the second half of the 20th century researchers started to look at design as a topic of research (Edelson 2002, Blessing and Chakrabarti 2009). The historical and professional development of the design activities will be covered in Chapter 3. Traditionally, science and design are distinguished one from another (Bonsiepe 2007). However, there is a current interest in understanding the best way to integrate these two different worlds. Besides, research in design has been playing an important role in the evolution of the design profession itself since the period after the World War II (Bonsiepe 2007, Koskinen et al. 2011). Therefore, understanding how design and research cooperate is the starting point of this chapter.

## 2.1 DESIGN RESEARCH OVERVIEW

In the traditional theory-testing paradigm, design and research are considered as distinct processes that take place sequentially, and design is often not considered as a learning opportunity. Conversely, in the design research paradigm the boundaries between design and research are eliminated (Edelson 2002). The elimination of these boundaries is the dynamic result of the increasing complexity of new technologies embedded in products (Horváth 2004). Therefore, there is a current interest in what is the best way to integrate the fields of design and research (Koskinen et al. 2011), and design research may materialise this. It incorporates the same types of outcome-based evaluation that characterises the traditional theory testing, yet simultaneously recognising design as an important approach in its own way (Edelson 2002).

Iterative circles of generating ideas and confronting them with the community characterise both design and research (Horváth 2004). Historically, one of the pioneers in field of design research (Archer 1981) presented a reasonable classification for that relation. Table 1 summarises the ten areas proposed by Bruce Archer.

**Table 1 |** design research breakdown (Archer 1981)

| | |
|---|---|
| **Design History** | The study of what is the case, and how things came to be the way they are, in the design area |
| **Design Taxonomy** | The study of the classification of phenomena in the design area |
| **Design Technology** | The study of the principles underlying the operations of the things and systems comprising designs |
| **Design Praxeology** | The study of the nature of design activity, its organisation and its apparatus |
| **Design Modelling** | The study of the human capacity for the cognitive modelling, externalisation, and communication of design ideas |
| **Design Metrology** | The study of measurement in relation to design phenomena, with special emphasis on the handling of non-quantitative data |
| **Design Axiology** | The study of worth in the design area, with special regard to the relations among technical, economic, moral, social and aesthetic value |
| **Design** | The study of the logic of discourse on matters of concern in |

| | |
|---|---|
| **Philosophy** | the design area |
| **Design Epistemology** | The study of the nature and validity of ways of knowing, believing and feeling in the design area |
| **Design Pedagogy** | The study of the principles and practices of education in the matter of concern to the design area |

Additionally, three sub-disciplines were proposed for the design research field as follows:

1. Design phenomenology, which includes design history, taxonomy and technology
2. Design praxeology, which includes design modelling and metrology
3. Design philosophy, which includes design axiology, epistemology and pedagogy (Archer 1981)

A slightly different taxonomy was proposed by (Cross 2006), which renamed design philosophy field as design epistemology. Despite the differences between these three sub-disciplines, overlaps among them may happen. This research covers two sub-disciplines of the design research area, namely the design phenomenology and the design praxeology.

Generally, design research is a systematic enquiry whose goal is to develop, articulate, and communicate new knowledge and useful theories (Archer 1981, Edelson 2002, Bayazit 2004, Cross 2006, Chakrabarti 2010). Therefore, a good design research approach should produce knowledge that can be applied elsewhere, and should make the design process more efficient to develop more successful products (Chakrabarti 2010, Koskinen et al. 2011). Because design knowledge partially grows from practice, design knowledge and design research may overlap (Friedman 2003). Nevertheless, the recent character of the design research may produce some uncertainty and controversy about its value and nature (Buchanan 2001, Cantamessa 2003, Cross 2006). Also, design research is very much in vogue in the learning-sciences community, but faces obstacles in the broader research community (Collins, Joseph, and Bielaczyc 2004). In order to eliminate these obstacles on the general research community, design research relies in three different sources of knowledge to create its own theory: people, processes and products (Cross 2006). This diversified knowledge base reflects the complex and multifaceted nature of design research (Cash 2012). In order to attribute a degree of standardisation to this thesis, the research structure will be based in the Design Research Methodology (DRM) (Blessing and Chakrabarti 2009). The DRM and its application over this research will be discussed extensively in the following section. Also, basing the current study in an existing model helps to clarify the general research approach.

As abovementioned, design knowledge grows in part from practice. Therefore, this study is based in a specific design case, from which emerged both the topics to be covered and the research activities. Literature considers this approach as a clinical research, which will be explained in the following sub-section.

### 2.1.1 Clinical research

From the perspective of the type of problem addressed, research may be clinical, applied or basic. Clinical research is directed toward an individual case, it is focused in the problems faced by designers, and it uses the case study method as well (Buchanan 2001, Friedman 2003). As this study uses a single design case as case study, the clinical research approach was selected.

The case study is the favourite method in examining contemporary events, and it is often the more recognised type of research by designers and design educators (Buchanan 2001, Yin 2009). Case studies are normally focused with one particular design project at a time, and researchers observe the progress either contemporaneously or post-hoc (Cross 2001a). Therefore, a single case study is often used when it represents an unique case (Saunders, Lewis, and Thornhill 2009). The unique strength of this approach is its ability to deal with a full variety of evidence, such as documents, reports, observations and interviews (Yin 2009). Herein, the research attempts to observe and record all the relevant events shaping the course of action (Buchanan 2001). For this study, the relevant data, such as meeting records, excel-sheets, sketches, mind-maps and 3D drawings, were saved in a File Transfer Protocol (FTP) server, which facilitated the access to data. The researcher attended more than half of the monthly meetings held, from September 2012 to April 2015, had access to the FTP server and took part in two of the three one-week workshops. The design case supporting this case is detailed in Chapter 6.

## 2.2 METHODOLOGY

In order to contextualise the methods applied in this research, there are three areas that need to be pondered in this chapter. Firstly, to define a philosophical basis allows a particular paradigm to be developed. Then, defining a theoretical structure links the specific work to the wider research context and supports the identification of the appropriate approach. Finally, developing a methodological approach based on theory supports the specific research methods used (Cash 2012). These areas are covered in the following sub-sections.

### 2.2.1 Research philosophies

Research philosophy term relates to the development of knowledge and its nature. Also, from the research "onion" illustrated in Figure 1, the choice of the research philosophy is precisely the first step to take when in any research work (Saunders, Lewis, and Thornhill 2009).

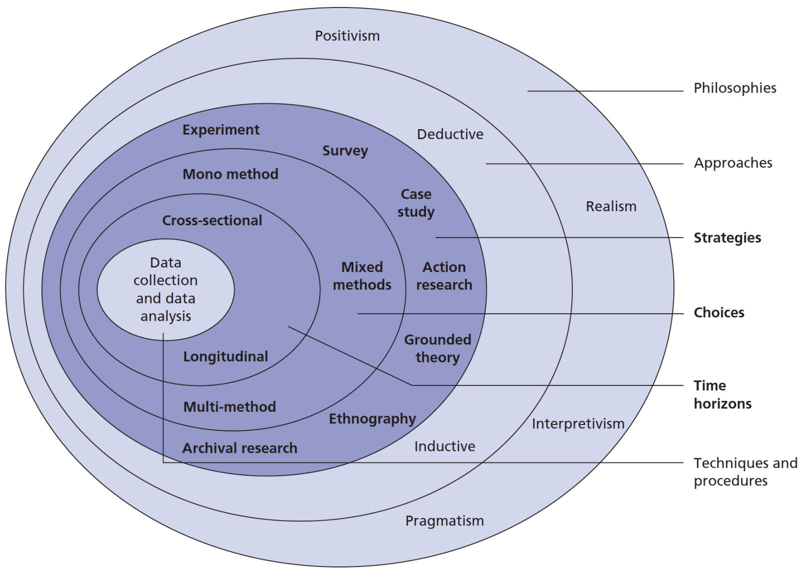


**Figure 1 |** the research "onion" (Saunders, Lewis, and Thornhill 2009)

The role of the research philosophy to take is to guide and structure the broad worldview of the researcher (Cash 2012). Nonetheless, literature present different taxonomies for the existing research paradigms. Regardless the different taxonomies, four main research paradigms are traditionally highlighted. Table 2 synthesises these four different research paradigms and their ontologies. The paradigm term is used to further explore the research philosophy notion. It can be defined as a way of examining social phenomena, from which understandings can be gained and explanations attempted (Saunders, Lewis, and Thornhill 2009).

**Table 2 |** research paradigms and their ontologies (Saunders, Lewis, and Thornhill 2009)

| **Positivism** | **Realism** | **Interpretivism** | **Pragmatism** |
|---|---|---|---|
| External, objective and independent of social actors | It is objective. Exists independently of human thoughts and beliefs or knowledge of their existence (realism), but is interpreted through social conditioning (critical realist) | Socially constructed, subjective, may change, multiple | External, multiple, view chosen to best enable answering of research question |

Instead, (Creswell 2014) choose the term worldview, as a general philosophical orientation about the world and the nature of the research that is to be conducted. Table 3 presents four different worldviews and their major elements.

**Table 3 |** philosophical worldviews and their major elements (Creswell 2014)

| **Postpositivism** | **Transformative** | **Constructivism** | **Pragmatism** |
|---|---|---|---|
| Determination | Political | Understanding | Consequences of actions |
| Reductionism | Power and justice oriented | Multiple participant meanings | Problem-centred |
| Empirical observation and measurement | Collaborative | Social and historical construction | Pluralistic |
| Theory verification | Change-oriented | Theory generation | Real-world practice oriented |

Worldviews are traditionally based on discipline orientations, researchers' orientations, and past research experiences (Creswell 2014). Therefore, as the descriptions of the design research traditionally hinge between the positivism and the constructivism (Kimbell 2011), the choice should be between these two. Constructivism, often combined with interpretivism, is typically seen as an approach to qualitative research (Creswell 2014). Thus, as this present research will be mainly conducted with qualitative research methods, the constructivist worldview is the selected one. Also, its general association with the interpretivism paradigm underlines its subjective character. A key element in collecting data by this method is to observe the participants' behaviours during their engagement in specific activities (Creswell 2014). These activities and their structure will be detailed in the following sub-sections.

### 2.2.2 Theory

There are two main types of analysis, the inductive and the deductive. Table 4 summarises the major differences between the referred approaches.

**Table 4 |** deduction and induction emphasis (Saunders, Lewis, and Thornhill 2009)

| **Deduction emphasis** | **Induction emphasis** |
|---|---|
| Scientific principles | Gaining an understanding of the meanings human attach to events |
| Moving from theory to data | A close understanding of the research context |
| The need to explain causal relationships between variables | The collection of qualitative data |
| The collection of quantitative data | A more flexible structure to permit changes of research emphasis as the research progresses |
| The application of controls to ensure validity of data | A realisation that the researcher is part of the research process |
| The operationalisation of concepts to ensure clarity of definition | Less concern with the need of generalisations |
| Researcher independence of what is being researched | |
| The need to select samples of sufficient size in order to generalise conclusions | |

Despite the identified differences, it is perfectly possible to combine deduction and induction within the same research. Besides, there are advantages in proceeding this way (Saunders, Lewis, and Thornhill 2009). Therefore, a combined approach was chosen and multiple qualitative research methods were combined, built on the four steps of the DRM. Accordingly, an inductive approach is firstly taken to build a hypothesis, and then a deductive approach is taken to test this same hypothesis.

### 2.2.3 Methodological approach

A design research approach aims at the development and validation of knowledge, methods and tools that can improve the design process. Therefore, design research needs to develop and validate knowledge systematically, and this requires a methodology (Blessing and Chakrabarti 2002). Accordingly, the DRM was developed in order to help design research become more effective and efficient (Blessing and Chakrabarti 2009). The specific objectives behind the creation of the DRM are presented in Table 5.

**Table 5 |** specific objectives of the DRM (Blessing and Chakrabarti 2009)

| |
|---|
| To provide a framework for design research become more effective and efficient |
| To help identify research areas, projects and programmes that are most likely to be academically and practically worthwhile and realistic |
| To allow a variety of research approaches and methods |
| To provide guidelines for more systematic planning of research |
| To provide guidelines for more rigorous research |
| To help develop a solid line of argumentation |
| To provide new methods and pointers to existing methods to carry out the stages of the research process |
| To help select suitable methods and combinations of methods |
| To provide a context for positioning research projects and programmes relative to other design research |
| To encourage definition on the applied research |

Generally, the DRM provides effectiveness and rigour to design research, aims at developing a solid line of argumentation, and helps on the selection of suitable methods. The DRM consists of four successive and related stages, which are illustrated in Figure 2.

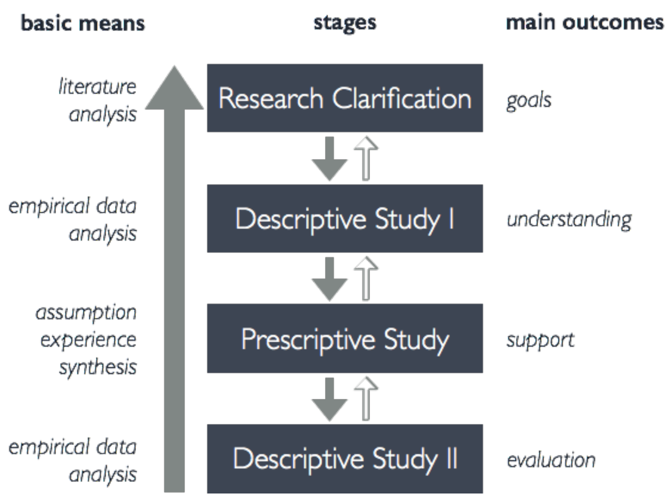


**Figure 2 |** the DRM; adapted from (Blessing and Chakrabarti 2009)

The bold arrows among the different phases show the process flow, while the light arrows represent the iterative character associated (Blessing and Chakrabarti 2009). The basic means used in each stage, and the main outcomes are represented as well. The following sub-sections will briefly detail each stage proposed in the DRM, and their application in the current research.

#### 2.2.3.1 Research Clarification (RC)

The RC stage contextualises the research, and identifies the main research problems, and the relevant disciplines and areas to be covered (Blessing and Chakrabarti 2009). The method selected for this clarification was a literature review, complemented with a first involvement in the design case supporting this thesis. Generally, the literature review is an early activity. However, it was necessary to continue searching in the literature throughout the whole research. Also, critically reviewing the literature provides the foundation on which general research is based, and a continued review could be necessary (Saunders, Lewis, and Thornhill 2009). A detailed breakdown of this review is materialised in Chapters 3, 4, and 5.

#### 2.2.3.2 Descriptive Study I (DS I)

In the DS I the objective is to describe the existing situation, and highlight the problems. Blessing and Chakrabarti (2009) also emphasise that this stage aims at understanding the relevance of the research topic. In this case, the selected issue was the link between the design case and the gap found in the literature discussing the lack of collaborative design studies focused in the FFE. In this sense, a hypothesis was then advanced, a model for the FFE was outlined (Chapter 5), and a comparative test between this industrial environment, and an isolated one, was outlined. Besides, this design case was retrospectively analysed, by means of a short questionnaire, and its results were matched with the literature and with the observations made (Chapter 6).

#### *2.2.3.3 Prescriptive Study (PS)*

The objective of the PS is to use the understanding obtained with the previous phases in order to improve the existing situation. The general idea is to achieve results of the supporting evaluation (Blessing and Chakrabarti 2009). For this case, the selected issue was a design experiment that aims at testing the postulated hypothesis. This design experiment is outlined in Chapter 7. Therein, instead of an inductive approach as before, this approach is mainly deductive.

#### *2.2.3.4 Descriptive Study II (DS II)*

The DS II aims at evaluating the assumptions behind the previous PS, and to validate the overall research (Blessing and Chakrabarti 2009). In this case, the DS II assessed whether the findings achieved with the aforementioned stages can be generalised, and the limitations or extension of these generalisations. The ontologies defined to assess the prescriptive study were based in the literature, and in the outcomes of the design case analysis. Also, the conducted analysis was matched with a short questionnaire distributed to the participants of the design experiment. The DS II is materialised in Chapters 7 and 8.

## 2.3 SUMMARY

This chapter has detailed the research methodology that sustains the overall analysis, by detailing the steps of the referred DRM. These steps were:

1. Research Clarification (Chapters 3 and 4)
2. Descriptive Study I (Chapters 5 and 6)
3. Prescriptive Study (Chapters 6 and 7)
4. Descriptive Study II (Chapters 7 and 8)

Also, the actual relevance of having a design research approach was outlined, under the paradigm of constructivism.

# 3 A HISTORICAL PERSPECTIVE ON THE DEVELOPMENT OF DESIGN AND ENGINEERING

The bulk expressions of design were born connected to the early activities of Men (Valls 2003, Torrent and Marín 2005, Bürdek 2010). Yet, with the advent and growth of the mechanised industry, over the last two centuries, the human ability to control or reconfigure its surroundings substantially increased. The industry proliferation allowed a torrent of artefacts, beyond the human basic needs of food and shelter, to satisfy the needs and wills of a growing consumerist society (Heskett 1980, Foundation et al. 2010). As history reveals, mankind early achieved its referred basic needs, and technology (once *ars*, *techné* and later *ingenia*) has been playing a vital positioning in the society development. This decisive role of technology applies to both the practical applications of scientific knowledge and to large social enterprises (Nye 2006, Dolza 2009). As the history of society is also the history of technology, a technique to define them both is in terms of their shared evolution (Schewe 1994, Nye 2006, Sanz et al. 2009).

As referred, present research aims at reflecting on the interdisciplinary relationship between industrial design and mechanical engineering, in the conceptual stage of the design process. To attend this challenge, both industrial design and mechanical engineering are historically analysed, as historical analyses aim to interpret the development and activity of Men (Kirby 1990). However, present chapter doesn't pretend to be a mere historical analysis of industrial design and mechanical engineering. Instead, it aims to outline the perceived role of technology in the dialogue between these two disciplines.

This chapter is an extended version of the paper "Design and Technology: A Historical Perspective on the Mediating Role of Technology between Industrial Design and Engineering" published in The International Journal of Design in Society (Volume 10, Issue 2, 2016). This paper was also presented in the 9th International Conference on Design Principles and Practices held in Chicago (12-14 March 2015).

## 3.1 THREE PERIODS HIGHLIGHTED

Notwithstanding the tremendous leap forward occurred with the Urban Revolution, or the recognised technical advances achieved by the Classic Civilisations, this historic retrospective covers three remarkable and consecutive periods of technological developments. Firstly, the *Renaissance*, a period marked by the first notion of globalisation, in which decisive communication systems, for engineering and industrial design, were developed. Secondly, the *Industrial Revolution*, an era marked by the mechanisation, the division of labour and the emergence of the first professionalised engineering societies. Lastly, the *dawn of the 20th century*, a marking period for contemporary society in which modern industrial design emerged.

### 3.1.1 Renaissance

The Renaissance was a period of tremendous engineering accomplishments, which started in Italy in the late 14th century and was spread throughout the rest of Europe until the 17th century. It is mostly known as a highpoint for the humanism and arts; however, several simultaneous achievements of engineering (e.g. the city of Venice) are, in somehow, overlooked (Kirby 1990, Bjerklie 1998, Foundation et al. 2010). Accordingly, decisive communication systems, for engineering and industrial design, were developed in this marking period: the linear perspective, the technical drawing, and the printing press. Also, the design of ships was particularly improved in Portugal and Spain, setting the stage for the European exploration of Africa and the Americas (Foundation et al. 2010).

In the late 1430s Johannes Gutenberg created the printing press with movable type and the spread of this technology completely changed the European cultural landscape. Figure 3 presents one hypothetical reconstruction of Johann Gutenberg's Printing Press.

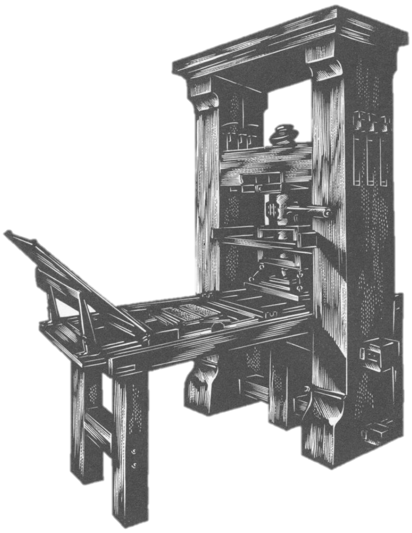

**Figure 3** | Johannes Guttenberg's printing press representation (http://www.libraries.rutgers.edu/rul/libs/scua/depol_images/jdp9.shtml)

This single technical achievement revolutionised the literacy levels, the communication of information, and the amount of available information was increased accordingly (McClellan and Dorn 2006, Foundation et al. 2010). With the printing press, the schematic representation of useful mechanisms, previously an exclusive of valuable hand-manuscripts, was then easily reproducible (Dolza 2009). Therefore, the printing press marked a transition period for society.

Of similar importance were the development of both the linear perspective and other methods of technical drawings, such as the exploded and rotated views. These drawing techniques made it possible to study the mechanical systems, without the need of creating three-dimensional models. Therefore, the ability to communicate new ideas and new concepts was also improved. Filippo Brunelleschi was the man behind the development and understanding of the perspective in about 1420. Below figure (Figure 4) illustrates one of the Filippo Brunelleschi's perspective experiments at the *Battistero di San Giovanni* at Florence, Italy.

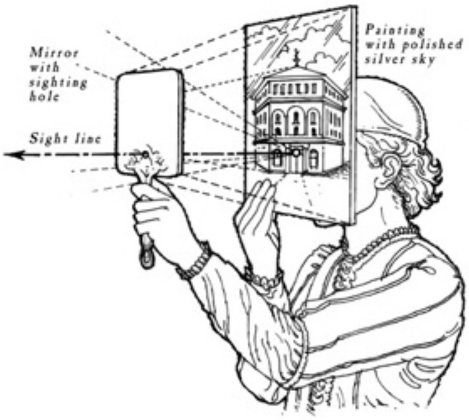


**Figure 4** | Filippo Brunelleschi optical instrument
(https://storiadellarteallempedocle.wikispaces.com/space.template.percorso+storico+della+prospettiva)

Despite Brunelleschi to be considered as the inventor of the perspective, other Renaissance inventors, such as Leon Battista Alberti, had also state some relevant theories in this domain. Concerning the cutaway techniques, the credits of their creation are attributed to Mariano di Iacopo (Bjerklie 1998, Foundation et al. 2010). Nonetheless, the most important symbol of the Renaissance was Leonardo da Vinci. Literature considers Leonardo as the first known designer, yet, his practical objects, ingenious and mechanisms tell us more about a futurist, rather than a designer with aesthetical concerns (Bjerklie 1998, McClellan and Dorn 2006, Bürdek 2010, Foundation et al. 2010).

Currently, it is possible to observe a revival of interest in Iberian science and technology of this period (Unger 2011). In 1291 Ugolino and Vadino Vivaldi departed from Genoa heading to the Indian lands, but, as soon as they passed the Pillars of Hercules, currently the straits of Gibraltar, they vanished. Conversely, two centuries later in 1498, Vasco da Gama arrived in Calcutta and the Modern Age began (Law 1987, Rodrigues and Devezas 2009). Consequently, galleys were excluded as basically Mediterranean and caravels acquired fame with the early Portuguese and Spanish voyages of discovery (Elbl 1985, Edwards 1992). The first reference to the caravel appeared in the *Foral de Vila Nova de Gaia* of 1225, but several authors believe that this ship's career started around 1420 (Elbl 1985, Devezas and Modelski 2006, Rodrigues and Devezas 2009). With a weight lesser than 100 tons and having about 25 meters from stem to stern, the caravels were built in the carvel-building method. In this constructive method, builders set up the keel first, then the frames, and lastly, tacking on the hull planks to those frames. Figure 5 illustrates an actual replica of the Vera Cruz caravel, used by the Portuguese in the discoveries period.

**Figure 5** | an actual replica of the Vera Cruz caravel (http://pt.wikipedia.org/wiki/Vera_Cruz_(caravela))

This constructive technique had the advantage of producing lighter ships and with less skill required from the carpenters in the shipyard. Also, the form of the hull means that if there were damage to the outer planks there was no threat to the integrity of the ship, only to the water tightness (Law 1987, Devezas and Modelski 2006, Unger 2011). The caravel, combined with the generalisation of magnetic compass in Christian Europe, and the invention of the *Volta* technique, were decisive for the Portuguese success through the 15th century (Law 1987, Devezas and Modelski 2006). The magnetic compass, the dead reckoning and the *portolano* chart, took out some of the guesswork in a long-distance navigation, and improved the knowledge of position. With the *Volta* technique, ships were no longer forced to stay close to the coast. Therefore, the Cape Bojador, the classic point of no return, was no longer the obstacle it had previously been (Law 1987). Figure 6 represents the Indian sailing route: the red line represents the outward route, and the green line represents the way back route.

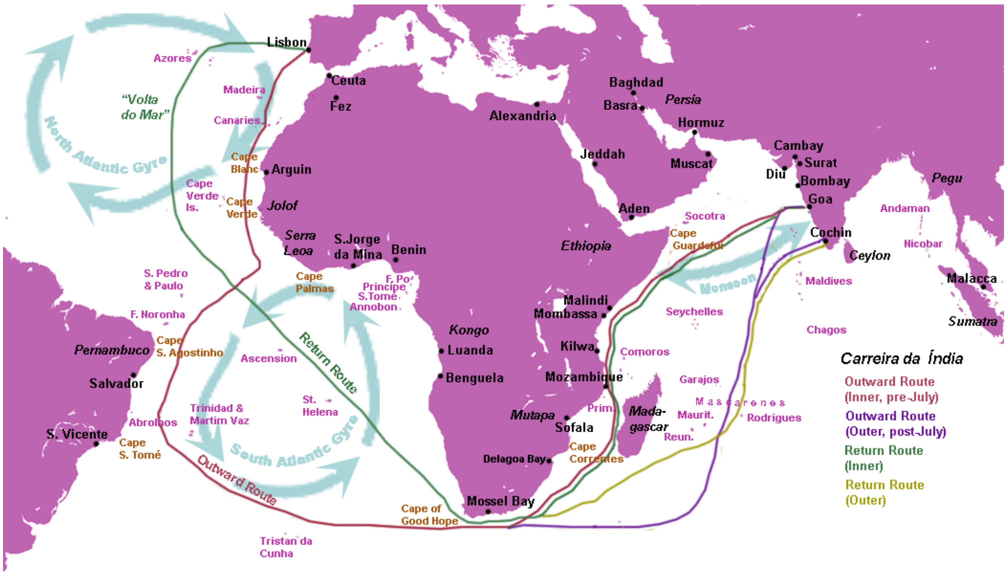


**Figure 6** | the representation of *Carreira da Índia* (http://pt.wikipedia.org/wiki/Império_Português)

Over this period, Portugal and Spain were magnets for Italian technology, talent and investment. Also, the Iberian countries were the birthplace of skilled people and ideas soon exported to France, England and the Low Countries (Unger 2011). Concerning the Portuguese expansion, some historians consider it as one of the initial phases in building a worldwide history. It marked two very important transitions in the formation of a global system: the creation of a global network, and the rise of some scientific commitment in the system-building effort. Actually, the Portuguese helped to launch the globalisation by the dawn of the 15th century, in a process that lasted 150 years. For the first time in history, a global reach system was built, far more complex and involving a network of basic technical and technological innovations, that synergistically turned into establishment (Devezas and Modelski 2006, Rodrigues and Devezas 2009). Congruently, this first globalisation was the result of several technical innovations that were based in one of the first commitments between technique and science. Hence, the seeds to a global technological revolution were launched.

### 3.1.2 Industrial Revolution

The early 18th century was marked by revolutions in the production methods and in the patterns of consumption that affected the history of the manufactured products. In the growing cities of Florence, Venice, Nuremberg, or Bruges, new materials and processes were increasingly being developed. The productivity was then increased and a confidence in the achievement of material comfort emerged, connected to the desire for social mobility and individual fulfilment (Heskett 1980, Raizman 2003). Therefore, the roots for what we now know as Industrial Revolution were being seeded. The Industrial Revolution was a technological and socio-cultural period of transformation, which was started in England in the late 18th century, and later expanded throughout Europe and the U.S. (Hauffe 1998, Valls 2003, Torrent and Marín 2005, McClellan and Dorn 2006). Literature considers that Thomas Savery's engine, developed in 1702, marked the opening of this distinctive period. However, it was an improvement of this early apparatus, developed by Thomas Newcomen in 1712, that led to the first steam engine (Kirby 1990). This subversive machine is illustrated below (Figure 7).

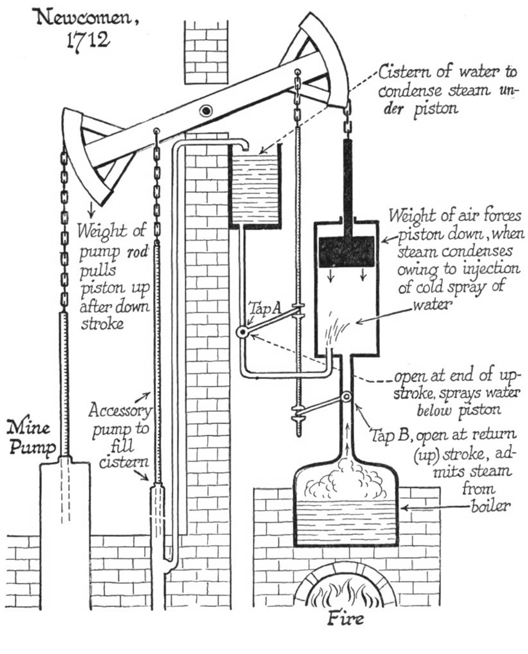


**Figure 7** | Newcomen's steam engine (http://railroad.lindahall.org/essays/locomotives.html)

The steam engine has been considered as the most influent technological development of the Industrial Revolution, as it completely changed its course. Also, it marked a profound social revolution (Carnot 1824). Starting with the Newcomen's early apparatus, passing through the innovative and widely adopted James Watt engine of 1765, and ending with the disruptive Trevithick's railroad locomotive of 1801 (Figure 8). Many steam-engines were created as a result of high doses of intuition, tinkering and lucky strikes, instead of applied scientific knowledge itself (Kirby 1990, McClellan and

Dorn 2006). Besides, only in 1777 Johann Beckmann (a German economist) firstly coined the term *technology*, as the science of technique or the doctrine of men performing something technical at their best (Devezas and Modelski 2006, Rodrigues and Devezas 2009).

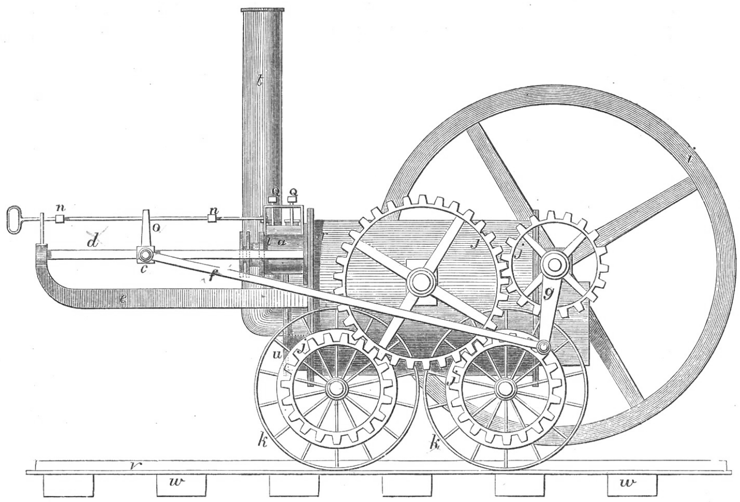

**Figure 8** | Trevithick's Tramroad Locomotive (http://railroad.lindahall.org/essays/locomotives.html)

Science and technology were separate entities throughout this evolutionary period. Yet, the transition to the 19th century was marked by a paradigm change with the foundation of the *École Polytechnique* in Paris. This institution was focused in standardising engineer's training, under the principle of an alliance between science and technique. The French culture established the need to reconcile science/technology and the mathematical/scientific training as central to modernise the country. Conversely, the British approach emphasised the technique as the means for the economic development (Dolza 2009). Nonetheless, early in the 19th century, British governors reorganised the technical knowledge, as a new sociological relation between technology and science, and paved the way for the age of the engineer (Hauffe 1998, Torrent and Marín 2005, McClellan and Dorn 2006). Then, the initial resistance to steam was forsaken and this source power was widely adopted as the main source power. Advances in metallurgy, improvements in inland transportation, such as roads, canals and railroads came attached to the steam engine (Kirby 1990). Additionally, the establishment of the first engineering societies[1] and the development of the necessary standards to distinguish engineers, were marks of engineering becoming a scientific field (Foundation et al. 2010). Consequently, early in the 19th century, the gulf between design and production became most acute, as the distinctive characteristic of the industrial production was, precisely, the division of labour (Heskett 1980). Within this new context, the single worker was no longer forced to craft and shape objects himself; instead, it was the factory owner or the engineer who made the decisions in a compete industrial environment (Hauffe 1998, Council 2007). Also, the steam engine freed thousands of men and horses from the hard physical labour (Kirby 1990).

Later in the 19th century, the U.S. took the leadership in the scientific production, thanks to the work of Frederick Taylor over the last two decades of that century. Taylor studied the work-processes, seeking the best way to perform the industrial tasks. Their studies marked the beginning of the scientific management, often called *Taylorism*. Taylor's theories of productive efficiency were aimed at increasing productivity among workers, and were behind the first assembly lines (Heskett 1980, Hauffe 1998, Gorman 2003, Raizman 2003). Also, these theories served as one impetus for the development of the field of ergonomics, already in the 20th century (Gorman 2003). These technological progresses resulted in new methods of production, new equipment and new functions, yet, renewed aesthetics and human factors were not part of the picture (Hauffe 1998, Cagan and Vogel 2013). Therefore, literature considers that the emergence of industrial design, as a professionalised discipline, was linked to the need for smooth the aesthetic and cultural chaos that pervaded. This chaos was the result of the sudden passage from craft production to massive and mechanised operations (Valls 2003).

Thereby, the word *design* currently changes its meaning when the word *industrial* is added (Torrent and Marín 2005). Literature has been assuming that the referred gulf between design and production is critical to understand industrial in its actual context. Accordingly, modern industrial design is the result of the quick division of labour and mechanised production triggered early in the 19th century (Hauffe 1998, Bürdek 2010, Raizman 2003, Council 2007). This period witnessed a great leap forward in the manufacturing and in the subsequent consumption, accompanied by a political climate that was favourable to this trend. As such, industrial design faced a highpoint in this

[1] The first of these was the American Society of Civil Engineers in 1852. The American Society of Mechanical Engineering (ASME) was founded in 1880 (Foundation et al. 2010)(https://www.asme.org/about-asme/engineering-history).

rushed period, as the attribution of entirely new geometries gave a wide space for "shaping" (Torrent and Marín 2005, Maldonado 2012). Nevertheless, with this expansion reform and regulation became mandatory.

The central issue in the 19th century was, possibly, the apparent conflict between technology, industrialisation, commercialisation, democratisation, and the quest for standards (Raizman 2003). Therefore, the second half of the 19th century was marked by the activities of different and emerging reform movements. The activities of these reform movements, combined with initiatives highlighting the importance of applied arts, warned society for the need to apply cultural and artistic features to the produced goods (Hauffe 1998, Raizman 2003). Nonetheless, the negative effects of the Industrial Revolution went beyond this aesthetic scope, as it affected society in general. The cities' overcrowding, the worker depersonalisation and the general loss of taste were considered a social wound (Hauffe 1998, Valls 2003, Torrent and Marín 2005, Bürdek 2010). Though, this aesthetic and social mess woke up the critical spirit of many individuals, who faced extraordinary moments of historical clarity. Consequently, several movements rose in England and Germany aimed at overcoming the referred negatives effects of the industrialisation. This position against the machine and the mass production systems was assumed by notable writers, artists and intellectuals of the 19th century (Maldonado 2012). The challenges in assimilating the mechanised production were evident in the poorly designed products exhibited in the Great Exhibition of 1851. Yet, some exceptions came from the U.S, such as, Goodyear's rubber products, Colt's revolvers and McCormick reapers' (Walgate 2003, Maldonado 2012). Still, the inferior designs exhibited there originated several writings from the intellectuals John Ruskin and William Morris. These two notables placed the issues of design and production within a new ethical framework, linking arts, crafts with the social reform. William Morris championed the traditional crafts production, not only with his strongly conviction of the superior quality for the produced goods, but also for the honourable and well-paid employment that he thought crafts should ensure. The writings of John Ruskin's also linked aesthetics with work conditions (Gorman 2003); once again, the dialogue between technology and society arose. Accordingly, many art guilds, including the Arts & Crafts Exhibition Society founded by Morris, Ruskin, and others, were modelled by these theories. Besides, the *art nouveau*, the famous *Deutscher Werkbund* and the remarkable design school *Bauhaus* were also influenced by the theories of Morris and Ruskin (Hauffe 1998).

During the tumultuous period of the late 19th century, Christopher Dresser's name emerged, and he is traditionally considered as the first professional European industrial designer. He was able to work with a varied number of manufacturers, and designed with silver plate, cast iron, furniture, ceramics and glass, as well as textiles, carpets and wallpaper (Gorman 2003, Classics 2009a). The images below (Figure 9 and Figure 10) illustrate two different products designed by Dresser using different raw materials.

**Figure 9** | teapot designed by Christopher Dresser, 1878

(http://www.vam.ac.uk/content/articles/t/christopher-dresser-teapots/)

**Figure 10** | ceramics tableware designed by Christopher Dresser, 1870

(http://www.vam.ac.uk/content/articles/t/christopher-dresser-teapots/)

Dresser was the most inventive designer of his time (Classics 2009a). He was interested in a very close collaboration between design and manufacturing, with a close attention to the ease of manufacture and subsequent use. Conversely, some of his referred and notable cotemporaries completely rejected this possibility (Heskett 1980, Walgate 2003, Raizman 2003, Museaum and Council 2004). Hence, the interdisciplinary collaboration was already a topic in the late 19th century. Besides, the discussion around the collaboration between the design practice and the potential of the machine shaped the emergence of the industrial design. Dresser championed industrial design as a professionalised discipline, by means of this total commitment with the mechanised production and his confidence in technology. He paved the way for future designers in the early 20th century (Museaum and Council 2004). Hence, the hesitation towards the technological developments marked the young industrial design discipline, while some voices completely rejected technology, some others embraced it in their methods and practices.

### 3.1.3 The dawn of the 20th century

The steam engine remained as the prime mover in industry and in transportation until the end of the 19th century. Later, with the development of diesel and gasoline internal-combustion engines by German engineers, a new main mover appeared which created the automobile and the tractor (McClellan and Dorn 2006). The emergence of effective transportation systems, early in the 20th century, was a large factor of political, economic and social evolution. Also, the diffusion of knowledge was increased (Kirby 1990). Changes in transportation were accompanied by revolutions in other industries, such as, electrification, domestic technologies and entertainment. The way in which people live, commute and interact was transformed.

In the United States, where modern meant massive and industrialised, engineering assumed vigorously the leadership in changing the social and industrial landscapes. Therefore, the life of an increased middle class was affected (Hauffe 1998, Foundation et al. 2010). Regarding industrial design, its separation from the applied arts was not already resolved in the beginning of the 20th century. As abovementioned, the discussion around industrial design started in the Great Britain, in the late 19th century. Instead, in the beginning of the new century, the discussion between applied arts and production was mainly based in Germany, the homeland for the modern industrial design (De Fusco 2005, Bürdek 2010). In Germany the discussion was centred in the relationship between design and mechanised processes. Conversely, in the U.S., where no handicraft tradition existed, this same discussion didn't raise (De Fusco 2005, Torrent and Marín 2005). The American launch as an industrial and metropolis power was tightly connected with the machine formula. Therefore, since the early beginning, and in an opposition to the German approach, the complete mechanisation was sought even in the more complex crafts (Torrent and Marín 2005).

Notwithstanding the clearly different mind-sets, Germany, in general, admired the new American model, its productivity, and considered it as an example to follow.

Consequently, over the first three decades of the 20th century, the German industrial design was strongly influenced by the American industrial methods (De Fusco 2005). Accordingly, an aesthetic reform for the machine occurred in Germany powered by the belief that a more unified approach to design was of national interest (Raizman 2003, Valls 2003, De Fusco 2005, Torrent and Marín 2005). Therefore, the *Deutscher Werkbund* was founded in Germany, in 1907, aiming at raise the quality of the German productions, defining the standards for industrialisation, crafts and aesthetics. This institution sought to balance economic, artistic and moral objectives, reconciling the increased consumption trend with the cultural references (Hauffe 1998, De Fusco 2005).

According to Raizman (2003), somewhere in-between the American and German approaches laid precisely the design reform. This reform sought to balance the rationalisation of industrial production, and the individuality of the designer, with the desires of the increased consumerist society. The dichotomy between the individualism of any designer, the normalisation over the industrial production and the market remains as relevant issue today. Thus, the early 20th century was a marking period for the industrial design discipline that we know today. In this sense, some prominent cases over this period were selected, detailed and comparatively analysed.

## 3.2 CASES UNDER STUDY

Three cases were selected for the referred comparative and detailed study, due to their different expressions of technology, industrialisation, society and their combined poise in the early 20th century. The focus is on the referred industrial powers of that time, the Germany and the United States. Starting with the highly successful industrial case of the *Ford Motor Company*, to its contemporary and notable *AEG* phenomena, and ending with the controversial Bauhaus' director Hannes Meyer, a detailed analysis is presented. This analysis aims at grasping the role of technology in the cases under study, and simultaneously compares its role to contemporaneity.

### 3.2.1 Ford Motor Company

Henry Ford, the man behind *Ford Motor Company*, was one of the most powerful and influential individuals of this time (Gorman 2003, De Fusco 2005). Idealising a car for all, the successful Model T passed from 10.607 units produced in 1908 to 300.000 units in

1913, with the introduction of the assembly lines. It was the first time in the automobile industry that the assembly lines were used (De Fusco 2005). With this newly introduction, the assembly time dropped from 12 hours to about 90 minutes. Eventually, Ford ended up building a Model T every 24 seconds (Classics 2009b). Figure 11 illustrates Ford assembly lines in 1913.

**Figure 11** | Ford assembly lines in 1913 (https://www.college.columbia.edu/core/content/ford-assembly-line-1913)

With the illustrated assembly lines, the working hours decreased from 9 hours per day to 8 hours per day, and a third shift was also introduced (Classics 2009b). Besides, the parts were being produced in a different place from the one where they were assembled; this helps explain the quick reduction of the production time. This displacement was an essential factor for the current mass production system (De Fusco 2005). Simultaneously, the organisation, the appearance and the management of the Ford factories' were subject of the general public interest (Gorman 2003).

Apart from the mass production of goods, the industrialisation occurred in the industrialised nations, in-between the two world wars, created a new capitalist society with a large working class (Hauffe 1998). Therefore, in order to attend the increased demand for consumer goods, Henry Ford democratised the car industry. A starting price of 850 US dollars in 1908 for the Model T was reduced to 260 US dollars in 1920, due to the new productive and commercial systems. Also, Henry Ford believed that the workers should use the products they were producing, the salaries were then raised, and the workers involved in the net profit of the company accordingly. In 1914 Ford was paying 5 US dollars per day to his workers, twice the salary paid by his competitors (Classics

2009b). This social approach, combined with the standardisation production, has been known as *Fordism* (De Fusco 2005).

Notwithstanding the use of the recent productive and management technologies, no real improvements happened in aesthetics. Model T was thus clearly influenced by the $19^{th}$ century carriage. Besides, Ford refused to considerably change the Model T over its production period, and only small changes were done to resist to the passage of time (Heskett 1980, De Fusco 2005). Comparing Ford Company with its contemporary *Werkbund*, Ford considered aesthetics as a secondary asset. Therefore, the design in Ford was mainly related to standards, technique, function and formal stability (De Fusco 2005). The model T was based in the geometry of the traditional horse carriage, it was produced in a standardised way, and aesthetics was sacrificed. Nevertheless, the advantages of Ford's standardisation were strongly appreciated by contemporary German industries, such as, Siemens and AEG, two electrical goods companies founded in the late $19^{th}$ century (Heskett 1980). Ford believed that technology should serve society and tried to put individual transportation available for the working class, yet, his industrial peers rebelled against this initiative. With the optimisation of the production technology, the automobile should be available for as much people as possible.

### 3.2.2 AEG

As abovementioned, AEG was strongly influenced by Ford's production system; yet, these two companies were grounded in substantially different premises. Everything that AEG proposed, debated and disseminated was done in terms of its own design phenomenon. Therefore, AEG is considered as one of the most successful cases in industrial design history (De Fusco 2005). Created in 1887, from a previous company dedicated to light bulb's production, AEG felt a casual fact that impacted tremendously in the company. It was established, by the German legislation, that all electrical goods should be covered, in order to avoid severe electrical accidents. Initially, this initiative had no formal results but gradually they commenced to appear (Torrent and Marín 2005), and with great impact to industrial design.

Contrary to Ford Company, which laid its Model T in the traditional horse carriage, AEG produced entirely new products with a wide space for formal inventiveness. This circumstance was a turning point for the company and for the modern industrial design itself (De Fusco 2005, Torrent and Marín 2005). In a complete contrast with Ford's philosophy, AEG was producing a wide array of new electrical products.

Thus, in order to reinforce the company's individual representation, Peter Behrens was hired in 1907. Behrens was engaged as an artistic adviser, with responsibilities in company's products, graphics and even buildings. From 1907 to 1914 Behrens designed catalogues, price lists, electrical equipment, as well as worker apartments, fair booths and factory buildings (Heskett 1980, Hauffe 1998, Torrent and Marín 2005). Through Behrens work, AEG become the first company in the world with a total corporate identity; a precedent without successors for a long time (Hauffe 1998, De Fusco 2005). Besides, with a simple line of brand-new electrical kettles (Figure 12), produced in 1909, a major innovation happened.

**Figure 12** | electrical kettles designed by Peter Behrens (http://www.wikiwand.com/de/Peter_Behrens)

In the above-represented kettles, the standard components rooted in the American system productive were exploited, and the possibilities of combining them were used to provide a firstly general product-range. Technology was combined with a high aesthetical value and the resulting products were distinguished and perceived as of extreme quality (Heskett 1980, De Fusco 2005). The innovative factor of these new industrial products allowed AEG to combine standardised production with aesthetical concerns, as no similar formal tradition existed before.

### 3.2.3 Hannes Meyer

Hannes Meyer (Figure 13) was the *Bauhaus* school director, from 1928 to 1930, and a new era emerged during his regency. Meyer believed that arts should have no involvement with the design process, and supported a more pragmatic approach, aligned with the Henry Ford philosophy. Accordingly, Meyer had a vision for the Bauhaus that privileged standards, norms and functions. This vision pointed to the creation of highly functional and standardizable products, accessible to a wider social spectrum (Torrent and Marín 2005, Droste 2007, Secca Ruivo 2008).

**Figure 13** | Hannes Meyer around the time he became second rector at Bauhaus (http://thecharnelhouse.org/2013/08/10/hannes-meyer/)

Over Hanne's Meyer regency, Bauhaus' workshops were changed in order to achieve the standardisation and a small easy-assembly line was also developed, aligned with the American system. Standardisation, normalisation and massive production became the newly Bauhaus' work guidelines (Droste 2007, Bürdek 2010). Therefore, the echoes of the American system were felt in both the German industries and design schools. However, Meyer's main objective was to produce highly aesthetic icons gifted of utilitarian characteristics, in a clear opposition with the American system that lacked in aesthetic concerns. Also, Meyer's formal language was clearly influenced by the Russian *Constructivism* movement and its concerns with standardisation and materials (Torrent and Marín 2005, Droste 2007). He considered design work as a collaborative experience, often exemplifying with the importance of choosing the suitable associates in architecture, his area of graduation (Schnaidt 2013). After Dresser's theories and practices, the collaborative character of the design activity was thus emphasised again by Hannes Meyer.

Nevertheless, Meyer's rigid attitude, combined with his excessive technicality and his assumed communism, attracted him enemies. Then, he was accused to politicise the school and its students, causing him to be boycotted and later forced to abandon. Notwithstanding the short period of Meyer's administration, he had a tremendous impact in the students. The impact of Meyer's beliefs was felt in the industrial design evolution itself, namely in the compliance with user and consumer needs (Torrent and Marín 2005, Droste 2007, Secca Ruivo 2008). Accordingly, it is assumed that Meyer's political convictions led him to use technology to favour society, searching a social balance through the products in use.

### 3.2.4 Comparative analysis

It is generally accepted that the American system strongly influenced German industry and academia, the homeland of the modern industrial design. However, contemporary industries from the two sides of the Atlantic, such as AEG and Ford, were grounded in different premises. On the one hand Ford, aimed at the automobile optimisation, supported in the enhancement of productive technologies. On the other hand, AEG exploited the recent developments, in both the productive systems and in electricity, to create novel and appealing products for an increased consumerist society. Therefore, AEG used the vast German applied arts tradition to introduce its new products in the market, a non-existent tradition in the U.S. Also, AEG succeeded with no compliance with the user needs, and it was then able to innovate in both the technological and aesthetical landscapes. This relationship between Ford and AEG approaches is illustrated below (Figure 14).

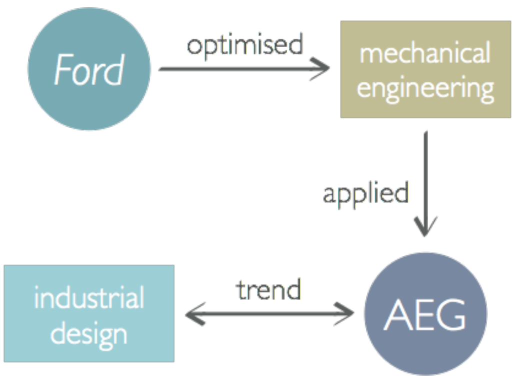


**Figure 14** | Ford and AEG relationship

Ford aimed at the automobile and productive technology optimisation; instead, AEG used the recent productive and electrical technologies (engineering conquers) to create entirely new products. This twofold approach created a new trend and the industrial design was industrially championed. Therefore, (Cagan and Vogel 2013) argue that the generation of breakthroughs is based in the successful combination of aesthetics and technology. Traditionally, this combination is perceived as having value in the market, and AEG might have been a good and early example of this successful combination. Thereby, Ford and Meyer shared a pragmatic vision of the industrial production, but Meyer considered aesthetics as a quality indicator. Also, Meyer pioneered the compliance with the user needs.

## 3.3 A COMBINED EVOLUTION

The accelerated pace of technological change towards the 19th century marked the history of industrial design and the history of mechanical engineering (Hauffe 1998, McClellan and Dorn 2006). The majority of the products we commonly use today where shaped throughout this conflicting period (Maldonado 2012). Even the airplane, a conquer of the engineering of the 20th century was firstly idealised late in the 19th century (Torrent and Marín 2005). It was clearly innovative era, in which the first professionalised engineering societies appeared, and the scientification of the mechanical practices started.

From the tinkering, experimentation and intuition of valuable craftsmen, marks of the early mechanisation period, a shift occurred to the engineer era in less than a century. The solution to the social problems of the man-machine interaction, the first notions in managing human and technical resources, and the application of scientific knowledge were engineering achievements. However, a tremendous aesthetic and cultural confusion pervaded: ornamentation was used deprived of any tradition, and several historical trends were illogically combined. The bad taste proliferated throughout society, and this aesthetic chaos raised the critical spirit of important intellectuals. Consequently, reformers and reform movements raised in the later 19th century in both Great Britain and Germany, with echoes over the U.S as well. Within these reformers, revolutionary voices raised against the machine and the mechanised production, proposing a return to the handiwork. Equally, other voices wanted to embrace the mechanised production and combine it with the applied arts tradition, inside a context of good taste and historicism. Therefore, from this dichotomy industrial design emerged as a professionalised and recognised discipline.

The process of emergence of these two professional activities was not as sudden as it might appear. Instead, it was a result of a slow and evolving process orientated with many theories and speculations developed with the first signs of mechanisation, late in the 18th century. This evolving process, was aimed to the definition of aesthetic and cultural criteria applicable to industrial production (Valls 2003). Figure 15 synthesises and sequences the emergence of mechanical engineering and industrial design as individual and professionalised disciplines.

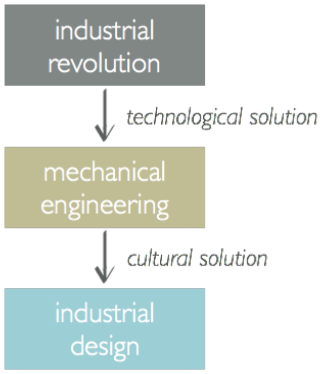


**Figure 15 |** mechanical engineering and industrial design emergence

From the point of view of the researcher, mechanical engineering was seeded in the first social and scientific response for the vast social problems and disasters. These bad happenings were brought by the massive and uncontrolled production of the Industrial Revolution. Conversely, industrial design has its roots in the struggle against the aesthetic and cultural naivety that occurred in the era of the engineer. As abovementioned, technology and society have evolved together; thus, this combined conflict between technology and society is outlined in Figure 16.

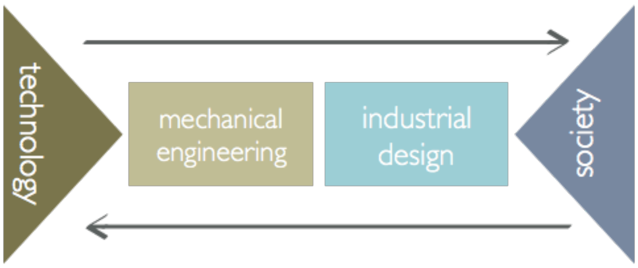


**Figure 16 |** technology and society

Also, engineering and industrial design might mediate the perceived evolutionary tension between society and technology. Literature argues that engineering historically pushed technology, as it took advantage of the technological developments of each period and made them tangible to society. Instead, industrial design strategy was directed to the social acceptance of the referred tangible technological developments into society (Borja de Mozota 2003, Sanz et al. 2009). Also, engineering is responsible for the innovation with breakthrough technologies, while design is responsible to innovate in processes that lead to the adaption of these innovations in tangible materialisations to society (Nye 2006). Therefore, the perceived technology mediating positioning, between engineering and design, in society is illustrated in Figure 17.

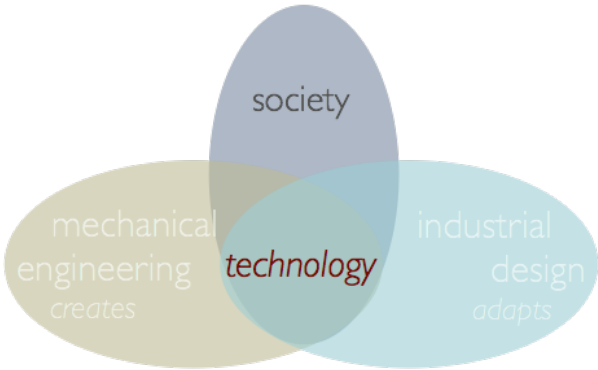


**Figure 17** | the mediating positioning of technology

Concerning the AEG case, one of the most successful cases in industrial design history, it is possible to find a similar pattern to the one represented above. AEG took advantage of the developments in the technological paradigm, and adapted them in the creation of new products for a growing consumerist society. Therefore, this company was able to create radical innovations, as it was producing, a century ago, what was never been produced before. Besides, AEG started from existing knowledge and exploited the recent technological possibilities. Literature considers that AGE created new meanings perceived as having value (Best 2010, Norman and Verganti 2011, Cagan and Vogel 2013). Conversely, Henry Ford and Hannes Meyer also believed that technology should be used in favour of the society; yet, Henry Ford underestimated aesthetics and bet in maximising technology. Contrary to Henry Ford, literature now claims that the successful integration of style and technology results in the creation of breakthrough products. In these breakthroughs, style refers to the sensory elements that communicate the desired meanings, and technology refers to the core function that drives the products (Cagan and Vogel 2013). Therefore, a combined approach between the technological and social landscapes is decisive for the innovativeness of new products.

## 3.4 CONCLUSIONS

Historically, the technical inventions of the Renaissance, with its first commitment with science, paved the way for the technological developments of the Industrial Revolution. Notwithstanding the tremendous engineering accomplishments of the early and Classic civilisations, mechanical engineering as a professionalised discipline emerged in the $19^{th}$ century. The *mathematisation* of sciences rooted the profession of engineer. Instead, industrial design rose in the rejection of technology and mechanised production, with rising up of the values associated with crafts production. Also, the increasing separation between design as conception, and its subsequent production, had a decisive impact into the modern industrial design.

Technology played a decisive role in the development of mechanical engineering and industrial design disciplines, and its permanent conflict with society based the reform and regulation of the design practice. Notwithstanding the roots of the industrial design, the post-industrialisation period revealed individual designers and companies that nicely integrated the technological advances, with social, cultural and aesthetic concerns. Besides, in the discussion between technology and society relied the social evolution. Historically, the first signs of technology divided mechanical engineering and industrial design. Nevertheless, technology is now responsible for their reconciliation, fostering radical innovations with technologies and meanings into new products. This emerging area of research will be extensively analysed in the Chapter 4. Among the three cases under study, AEG was considered as the most successful case in this relationship between technology, engineering and industrial design. This company was considered as an exciting moment in the design history, and it was an engineering success as well. Early in the $20^{th}$ century, AEG was able to combine style and technology; key factors in current industrial differentiation.

# 4 INTERDISCIPLINARITY IN NEW PRODUCT DEVELOPMENT

Knowledge is usually thought as a mental state, and Men in their social activity produce knowledge that should be considered as a social product as any other (Bhaskar 2008, Wilson 2014). Hence, it is not right to consider knowledge as independent from its production, and from the people who produce it, as cars, armchairs or literature. It has its own craftsmen, technicians, standards and skills, and it is subject to change as other commodities are (Bhaskar 2008). One definition of knowledge it that it is information that can change something or somebody, either by placing the ground for action or by making an individual, or institution, capable of different or more effective actions (Huggins and Johnston 2010). Regardless the discipline, knowledge is normally generated and accumulated through the action of doing something and evaluating the results (Owen 2007). However, the impact of knowledge on the general economic life only gained a systematic recognition in the second half of the 20th century. Accordingly, it is currently considered as an important strategic resource for New Product Development (NPD) companies as well (Ford and Woudhuysen 2012, Jayaram and Pathak 2012).

In the current dynamic, fast-changing and global economy it is necessary to pay attention to knowledge creation processes, as equally relevant to the learning and competence building processes (Asheim and Coenen 2005). Additionally, literature considers knowledge as one of the basic resources for the development of real innovations (Casanueva, Castro, and Galán 2013). The question of creating new knowledge, and even enhancing the existing one, assumes a particular relevance in a NPD context (Ford and Woudhuysen 2012). Accordingly, an area under intensive design research deals, precisely, with considering what kinds of knowledge bear on the creation of new products, that are useful, usable and desirable (Buchanan 2001). Regarding the early stages of NPD, the one under analysis, new concepts have to be adopted and adapted therein, through upstream and downstream knowledge sharing and enrichment. This adoption and subsequent adaptation have a significant influence in the concept effectiveness, and in the subsequent product development performance *per se* (Alblas and Jayaram 2014). Notwithstanding the widely recognised importance of knowledge creation and management for the early stages of NPD, only leading corporations are reshaping their management in order to increase these skills (Bergman, Jantunen, and Saksa 2004). Currently, apart from the traditional twofold tech-push/market-pull sources of knowledge for NPD, a third source of knowledge is emerging. It reconciles both knowledge on technological opportunities (Verganti 2008, Dell'Era, Marchesi, and Verganti 2010), with the increased association to the immaterial elements that new products face (Alting et al. 2007). Therefore, the relevance of this combined analysis on the different sources of knowledge creation, and sharing, in the early stages of NPD is underlined in this chapter.

This chapter is an extended version of the paper, "Transdisciplinary knowledge for innovation - Blurring the design disciplines boundaries'", presented in the 4th PhD Design Research Forum – UD5 Periphery and Promised, held in Porto (19-20 October 2015).

## 4.1 THE KNOWLEDGE BASES MODEL

Generally, the innovation processes of companies are strongly shaped by their specific knowledge base (Asheim and Coenen 2005). Therefore, an alternative taxonomy for knowledge, which explicitly takes into account the content of the actual interactions occurring in the collaborative design approaches was introduced: the knowledge bases model (Martin and Moodysson 2011, Manniche 2012). This taxonomy distinguishes between three epistemologically different types of useful knowledge bases:

1. Synthetic (engineering/instrumental)
2. Analytical (scientific/theoretical)
3. Symbolic (artistic/creative) (Manniche 2012)

The main characteristics of these different knowledge bases are summarised in Table 6.

**Table 6** | main features of the synthetic, analytical and symbolic knowledge bases (Manniche 2012)

| | **Synthetic** | **Analytical** | **Symbolic** |
|---|---|---|---|
| **Purpose of knowledge creation** | Designing or constructing instrumental solutions to specific human problems | Theoretically understanding natural or social systems, confirming or rejecting dominant scientific laws or defining new ones | Creating sociocultural meanings and interpretations of artefacts and their use |
| **Approaches to reasoning** | Inductive processes commencing with observation of specific instances and problem-solving needs | Deductive processes based on formal, abstract models, generalisation and codification | Creative processes based on open-ended, divergent thinking, going beyond conformity and conventions, and usually involving personalised commitment of participants |
| **Typical target of innovation** | Change of functional attributes of products, processes | Improvement of cognitive/theoretical models for products, | Change of aesthetic, semiotic value-laden features of products, |

| | | | |
|---|---|---|---|
| | or organisations | processes or organisations | processes or organisations |
| **Typical learning method** | Learning by doing and by interacting with customers and suppliers | Learning by searching and researching | Learning by interacting with customers and by buzzing within professional creative communities |
| **Type of knowledge created** | Mainly tacit, context-specific practical knowledge but important codified component | Mainly codified, highly abstract and universal knowledge | Strongly tacit, context-specific, semiotic content |
| **Institutional context of knowledge sourcing** | Market and supply-chain networks<br>Company R&D | Science and education systems<br>Company R&D | Company sources<br>Consumer culture<br>Creative business services<br>Policy discourses |
| **Geographical context of learning/knowledge sourcing** | Mainly regional and national | Mainly global | Mainly local/regional but importance of global and cultural trends |
| **Typical management challenge** | How to avoid lock-ins in out-dated technological paradigms | When do we need further understanding of a topic and when can we proceed to practical test and application? | How to capture subjective values of organisational stakeholders and consumers and how to align the business accordingly? |

The following paragraphs will analyse each knowledge base highlighted in Table 6. Typically, the synthetic knowledge base has the form of novel combinations of the existing knowledge, rather than the creation of new-knowledge itself (Moodysson, Coenen, and Asheim 2008, Manniche 2012). It is grounded in company's internal learning, or learning by doing, and it is based in interactions with markets and networks of companies as well. Often, it involves customers, suppliers and institutions for applied research (Manniche 2012). In this paradigm, connections between academia and industry are relevant, but they occur in the area of applied research and development, and less in basic research (Martin and Moodysson 2011). From Table 6, it is possible to highlight the purpose of synthetic knowledge in designing for specific and tangible human problems, its inductive and problem-solving approach, and the learning by doing character. In terms of innovation target, synthetic knowledge generally aims to change the functional attributes of products, processes or organisations.

The analytical knowledge base prevails in activities with a highly relevant scientific approach, and where knowledge creation is often based on formal models, codified science, and rational processes (Moodysson, Coenen, and Asheim 2008). Therefore, it constitutes the traditional core attribute of universities, research institutions, and R&D departments in companies (Asheim and Hansen 2009, Manniche 2012). Additionally, companies with R&D departments rely on knowledge that is generated in academia or in research institutions. Thus, the linkages between industry and public research organisations are extremely important therein, and occur more frequently than in other types of industries (Martin and Moodysson 2011). From Table 6, the deductive processes based on abstract models, the generalisations and the codifications are underlined. These processes, when aligned with the general purpose of the improvement of theoretical models, and its impact in products, processes, or organisations, assume an increased relevance as well.

The symbolic knowledge base deals with the creation and communication of cultural meanings, symbols, ethics and aesthetics. This taxonomy was recently introduced, in order to account for the increased importance of sociocultural production (Martin and Moodysson 2011). The usefulness of this knowledge base is mainly supported in sociocultural embedded perceptions of meaning, instead of scientific evidence or instrumental functionality (Manniche 2012). Despite the symbolic knowledge to be crystallised into material products, its impact in the consumer, and its economic value, arises from its intangible character and its aesthetic quality (Martin and Moodysson 2011). Accordingly, and from Table 6, it is possible to emphasise the purpose of creating symbolic interpretations for the artefacts in use. Also, the innovation target in symbolic processes lies in the change of aesthetics, and in the introduction of semiotic features into products, processes or organisations.

Literature identifies a wide number of job functions that are clearly dominated by one of these three knowledge bases. Also, it classified them according to the knowledge base they draw upon (Asheim and Hansen 2009). This job identification is represented in Table 7.

**Table 7** | occupational groups within the three different knowledge bases (Asheim and Hansen 2009)

| Synthetic Knowledge Base | Analytical Knowledge Base | Symbolic Knowledge Base |
|---|---|---|
| Architects, engineers and related professionals | Physicists, chemists and related professionals | Writers and creative or performing artists |
| Physical and engineering science technicians | Mathematicians and statisticians | |
| Computer associate professionals | Computing professionals | |
| Optical and electronic equipment operators | Life science professionals | |
| Ship and aircraft controllers and technicians | College, university and higher education teaching professionals | |
| Safety and quality inspectors | | |
| Life science technicians | | |

Notwithstanding this list of specific disciplines for specific knowledge bases, most activities comprise more than one knowledge base. Also, the degree to which a certain knowledge base prevails varies considerably between companies, and their different types of activities and occupations (Martin and Moodysson 2011). Engineering and architecture, e.g., are two overlapping categories and thus will influence the empirical results for the synthetic category (Asheim and Hansen 2009). Architects drawn on both the synthetic and the symbolic knowledge bases; on the other hand, some fields of engineering cover both the synthetic and the analytic knowledge bases. This engineering spanning, among the analytic and the synthetic knowledge realms, will be discussed later in this chapter. Regardless industrial designers not be listed in Table 7, a similar pattern might be traced between this discipline and architecture. Thus, despite the intrinsic synthetic character of any design discipline, industrial designers deal with the symbolic realm as well. This combined approach for the industrial design discipline will be extensively discussed later in this chapter.

### 4.1.1 Tacit and explicit knowledge

The different knowledge bases differ in various respects, such as the degree of formalisation, the context-specificity of knowledge and the dominance of either the tacit or the codified knowledge content (Martin and Moodysson 2011). The most common way to analyse the relationship between knowledge characteristics and the effects of location of innovation has evolved around the question of whether knowledge is codified or tacit (Moodysson, Coenen, and Asheim 2008). The first can be written down, and it is easily transferred over time and distance. The later is embedded in people and organisations, being specific to the specific context of each organisation (Martin and Moodysson 2011). Michael Polanyi was the first author to stress that the majority of the existing knowledge cannot be put into words. Thus, he firstly posited the existence of a tacit dimension (Polanyi 1966). The classical and the basic notion is that tacit knowledge is by definition difficult to materialise and strongly context specific. Therefore, it is difficult to share this knowledge over distance, being most successfully transferred through direct interaction. This clearly understandable tacit/codified dichotomy is often criticised for a narrow understanding of knowledge, learning and innovation. The underlying assumption is that under this opposition, the tacit knowledge transfer can exclusively occur on a local scale. Conversely, many studies aiming at understanding the flows of tacit knowledge identify a relatively low degree of local knowledge exchange, when compared with global flows of knowledge (Martin and Moodysson 2011).

Another, and similar, existing taxonomy divides the knowledge creation processes in tacit and explicit. The tacit knowledge had already been described, while the explicit knowledge refers mainly to facts or discrete quantities of information (Casanueva, Castro, and Galán 2013). It is argued that a company only creates real new knowledge through the interaction of both the tacit and the explicit/codified knowledge bases (Esterhuizen, Schutte, and du Toit 2012). When it comes to the creation and utilisation of knowledge, the most relevant forms of innovations are mixed in this respect. Therefore, the two types of knowledge should be perceived as complementary rather than substitutes of each other (Polanyi 1966, Johnson, Lorenz, and Lundvall 2002, Martin and Moodysson 2011, Casanueva, Castro, and Galán 2013). Accordingly, companies with NPD teams have responsibilities in integrating these different knowledge creation processes, to create and deliver radical breakthroughs (Kleinsmann, Buijs, and Valkenburg 2010, Manniche 2012). Nevertheless, an independent analysis to these two contexts is necessary, as there is a clear difference between their features and their channels of transfer. Besides, they present different structural and relational characteristics when inserted in collaborative and open contexts. (Casanueva, Castro, and Galán 2013). Open Innovation (OI) is a relevant issue for this thesis, and will be extensively detailed in Chapter 6.

The knowledge integration processes are perceived as important and promising in the context of NPD, but an effective strategy is desirable in order to achieve superior development performance (Jayaram and Pathak 2012). However, the challenges associated with this knowledge management process vary depending on the characteristics of the companies, and the innovative character of their products as well. Regardless the importance of knowledge integration, tacit knowledge is sometimes considered as vital in the innovation process, and it is often the source of innovation and competitive advantage (Mu, Peng, and Love 2008). The tacit dimension is sometimes perceived as the differentiating character between the winner and the looser companies. Therefore, the tacit knowledge base is a relevant knowledge category, as many professional and research practices rest on behavioural patterns and are embedded in personal action. However, all knowledge relies on cycles of knowledge management moving from tacit knowledge, to explicit, and finally to tacit again (Friedman 2008), as illustrated in Figure 18.

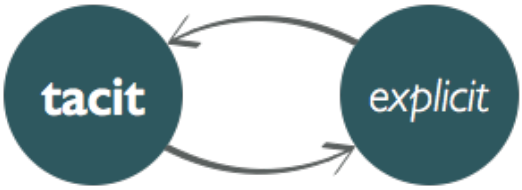


**Figure 18** | cycles of knowledge; adapted from (Friedman 2008)

As referred, tacit knowledge is relevant to all fields of practice. Therefore, confusing tacit knowledge with general design knowledge is not correct. Design knowledge is multifaceted, combining the formal scientific knowledge (explicit), with tacit human knowledge (Friedman 2003, Horváth 2004, Friedman 2008). Therefore, in order to create new knowledge and new design theory these two knowledge bases should be combined, and their professional activities should be merged as well.

### 4.1.2 Industrial design and engineering knowledge bases

Traditionally, the analytic and the synthetic aspects were the core of general design knowledge. Hence, the logic was analysing and then synthesising the elements of form, function, materials, and the way to design, produce and use. Nevertheless, with the increased presence of new products in society, culture, and daily life, the paradigm changed. Therefore, there is a concern with placing products in their situations of use, whilst simultaneously there is a concern with the way individuals feel and interact with these same products (Buchanan 2001). The symbolic and non-tangible dimension is gaining then an increasing relevance. Therefore, current challenge lies in how to manage both the tacit and the explicit knowledge bases, and in how to create new capabilities for collaborative design. However, to make this organisational knowledge creation in such a multi-company context, the process should be facilitated and planned in a structured way (Bergman, Jantunen, and Saksa 2004). Again, the idea of having structured planning for the design management process is emphasised.

Historically, managing the knowledge processes evolved from technology-push to market-pull, and from an interactive model to a collaborative and transdisciplinary knowledge approach (Bergman, Jantunen, and Saksa 2004). Consequently, mechanical engineering and industrial design should play a decisive role in the creation of this new and transdisciplinary knowledge. This twofold approach is sustained with the increasing relevance of integrating tacit and explicit knowledge. Charles Owen (2007) drew a map to use both content and process factors that may explain the different knowledge bases of a variety of disciplines. As exemplified in Figure 19, two axes define this map. The Analytic/Synthetic axis classifies fields by process, and separates the maps into left and right haves. Instead, the Symbolic/Real axis divides the map into vertically halves, according to the content and the realm of activity. Fields in the upper half are concerned with the abstract and the symbolic worlds. Conversely, the fields in the lower half are concerned with the real world, and with the artefacts or systems in the physical environment (Owen 2007).

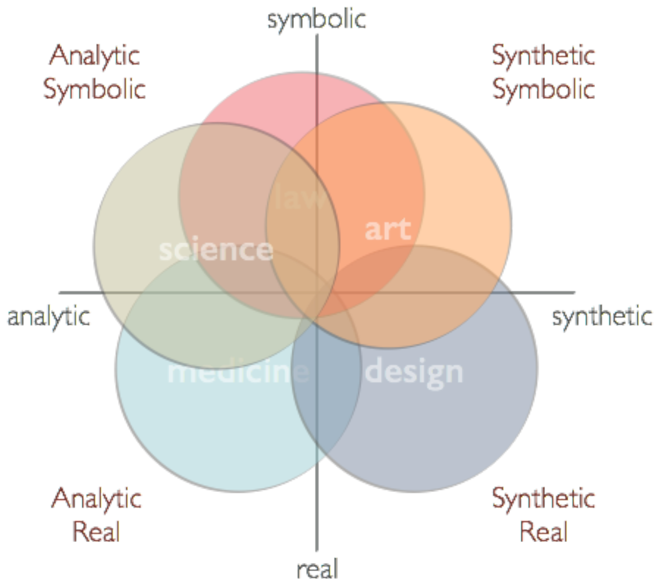


**Figure 19** | the knowledge differences exemplified; adapted from (Owen 2007)

The five disciplines represented in Figure 19 are highly recognisable, present well-defined processes, and well-understood differences. According to Simon (1996), analysis refers to the understanding and explanation of the natural world. Instead, synthesis refers to designing something in order to attain functional goals. Accordingly, when we move from the natural to the artificial, or man-made things, we are moving from analysis to synthesis (Simon 1996), and the above map is clear on this passage, However, the represented positioning is very subjective, as an absolute positioning is not of extreme relevance in this comparisons (Owen 2007). Also, the relative positioning provides a means for comparing the relationships of disciplines in terms of content and process. Therefore, design in the above mapping is highly synthetic and strongly concerned with real world subject matter, deals with communication and symbolism, and it has a symbolic character. Nevertheless, as general design requires analysis to synthesise information it has a slightly analytic character as well. Also, as a recently specialised field, design is placed in an opposite positioning to science (Owen 2007).

From Simon's (1996) point of view, the natural sciences are a body of knowledge that analyse specific phenomena in the world, and about the characteristics and properties they present. Conversely, we currently live in a world increasingly man-made and artificial, in which synthesis is behind these human creations. Therefore, the synthetic process appeared as the scope of the design effort, as design is traditionally concerned with how things ought to be (Simon 1996). Instead, science is concerned with how things are, and this opposing character explains the opposite positioning between science and design. This spanning, between science and design, helps to explain the decomposition represented below (Figure 20) for the mechanical engineering discipline and two of its sub-disciplines.

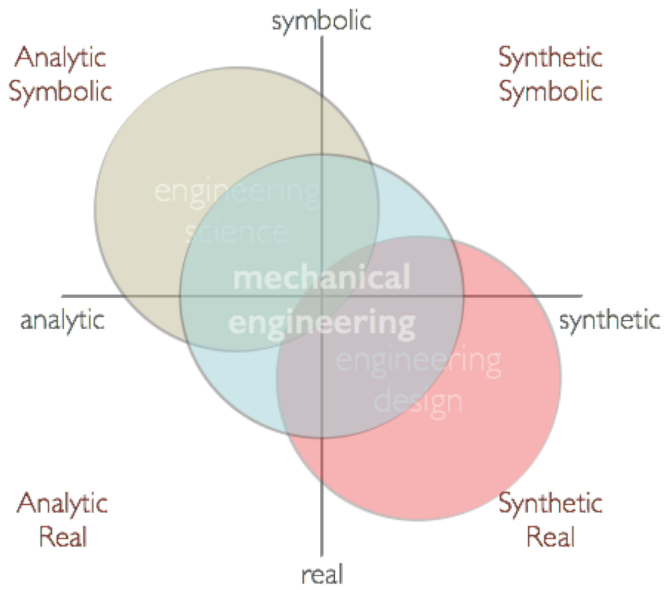


**Figure 20** | the engineering fields decomposed; adapted from (Owen 2007)

As illustrated in Figure 20, mechanical engineering is centred among the analytic and the synthetic domains, when we consider it as a whole (Owen 2007). Generally, the main task of engineering lies in the application of scientific knowledge and principles to the solution of technical problems (Utterback et al. 2006). It thus presents the engineering science sub-discipline, which is mainly analytic, and located in the left half. Also, mechanical engineering aims to optimise the scientific solutions, within the requirements and constraints set by material, technological, economic, environmental and social considerations. Inside the broad engineering field, the materialisation of the referred scientific and analytic knowledge into new products is the task of engineering designers. Therefore, the engineering design sub-disciplines is clearly located in the right half (Owen 2007, Pahl, Wallace, and Blessing 2007).

Generally, industrial design and mechanical engineering disciplines are applied to industrial products. Nevertheless, as these disciplines present quite different approaches and perspectives, tensions may arise between the two (Utterback et al. 2006). Thus, changing the disciplines in comparison, a new mapping that compares industrial design with mechanical engineering is proposed in Figure 21. This diagram is based in the same principles aforementioned (Owen 2007), and uses the same type of representation as well.

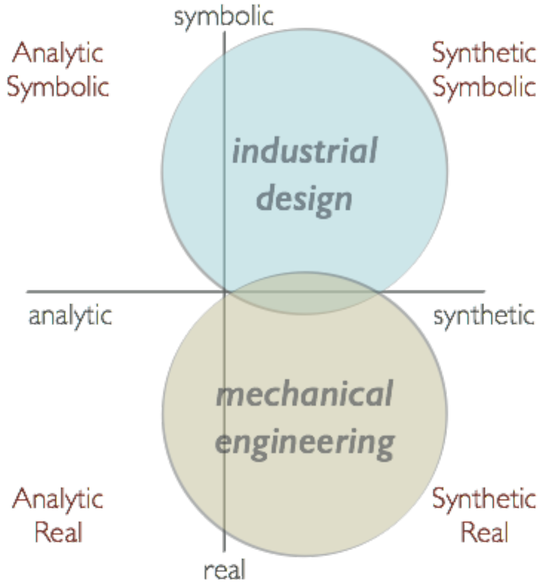


**Figure 21** | proposed positioning for the design and the mechanical engineering disciplines

Traditionally, the industrial designer is focused in understanding the user, its desires, and perspectives, while the engineer is concerned with the application of scientific knowledge and the characteristics of a specific technology (Utterback et al. 2006). When mechanical engineering is compared with industrial design, the last gains in symbolism, and the first gains in synthetic character and realism. Industrial design deals with the symbolic and bulk semiotic character of the industrially produced artefacts. Conversely, mechanical engineering itself, without considering it with sub-disciplines, deals with the materialisation and synthesis of the scientific knowledge. Mechanical engineering has thus an opposite positioning to science and its analytic processes. Considering the design disciplines as a whole, they should both be considered as synthetic in their process (Simon 1996). Therefore, industrial design and the mechanical engineering are localised in the right half, the one that characterises the synthetic processes.

From Simon's perspective, the world of design is the world of the artificial *per se* (Simon 1996). Accordingly, the values of design tend to be associated with human and environmental needs, created by or resulting from human actions (Owen 2007). In this sense, literature considers that design exists because of the need for form, and form, in its broadest sense, is able to create order in the process (Alexander 1973, Owen 2007). The creative activity behind the industrial design activity is precisely to determine the formal qualities of the industrially produced products. Accordingly, Figure 22 presents the illustrated need or goal of form in industrial design.

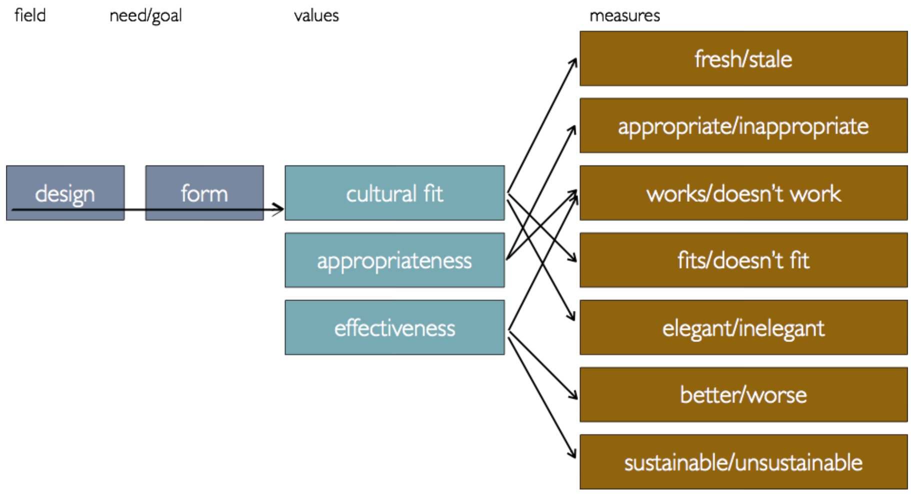


**Figure 22** | viewpoints and values for industrial design; adapted from (Owen 2007)

Notwithstanding these measures to be perceived as decisive for NPD, they are only examples and they do not represent the complete set of existing measures for industrial design. Firstly, *cultural fit* is associated with aesthetic issues. Then, *appropriateness* targets the wide range of physiological, cognitive, social and cultural human factors. Lastly, *effectiveness* gauges functionality and utility (Owen 2007). Accordingly, for *cultural fit* the suggested measures are fresh/stale, fits/doesn't fit and elegant/inelegant. For *appropriateness* the suggested measures are appropriate/inappropriate, and work/doesn't work. Finally, for *effectiveness*, the suggested measures are works/doesn't work, better/worse and sustainable/unsustainable measures. Extrapolating the design evaluation and viewpoints (Owen 2007), and comparing them with the analysis the knowledge base, a similar analysis is proposed in Figure 23 for mechanical engineering. The values and measures for this proposal were based in the work and principles of Owen (2007), and in the historical perspective in Chapter 3.

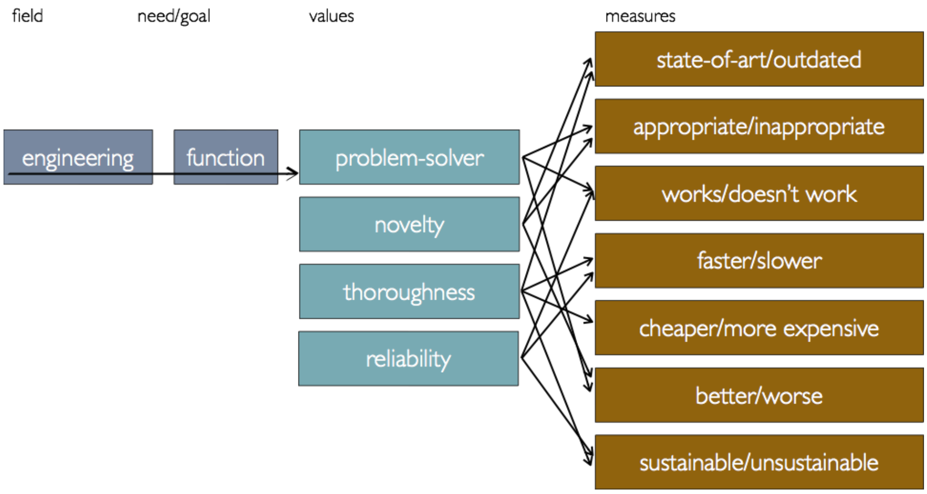


**Figure 23** | viewpoints and values for mechanical engineering

As it was stressed in Chapter 3, the roots of the mechanical engineering discipline lie in optimising the function, as historically, it has been mainly focused in functionality. Besides, engineers traditionally use technology to make the products function (Verganti 2009). As for industrial design, the represented values and measures do not cope with the global set of existing measures for mechanical engineering. However, they were selected due to their representativeness in both the engineering history and practice. Therefore, *problem-solver* is related with the problem-solving character of the engineering disciplines. Then, *novelty* deals with the technological character of any engineering innovation. Thirdly, *thoroughness* handles with the meticulous, rigorous and enhanced character of the engineering solutions. Lastly, *reliability* copes the trustworthiness and safety expected for the engineering objects. Accordingly, for the *problem-solver* the appropriate/inappropriate, the works/doesn't work, and better/worse are the expected measures. Then, for *novelty* value, the state-of-art/out-dated, the better/worse, and the appropriate/inappropriate are the proposed measures. Thirdly, for the *thoroughness* value the recommended measures are the state-of-art/out-dated, the cheaper/more expensive, and the sustainable/unsustainable. Lastly, for reliability the works/doesn't work, the faster/slower, and the sustainable/unsustainable measures are suggested. However, the difficulties in clearly border these two disciplines, and activities, became evident in the literature (Horváth 2004, Best 2010, Ertas 2012, Maldonado 2012) as soon as the technological and sociocultural complexity increased. This positive overlap between industrial design and mechanical engineering will be discussed in the next sections.

## 4.2 TRANSDISCIPLINARITY

Generally, design is considered as a total phenomenon, as it operates in relation to a wide range of other disciplines and external conditions, such as culture, society and technology (Best 2010, Maldonado 2012). Accordingly, a massive collaborative effort composes design, in its broadest sense, with many people from different disciplines taking design decisions (Marcus 2002). Nevertheless, this need for collaboration only recently gained the current significance, and it is now firmly established in more disciplines beyond the design itself. The roots for this collaborative topic are in the increased specialisation, formalisation, and the already discussed professionalization of the diverse branches of knowledge (Collin 2009). Frequently, the terms used to explain the collaborative efforts, such as interdisciplinary, multidisciplinary and the recent transdisciplinary, are used as essentially synonymous (Collin 2009, Fawcett 2013). However, the last two decades of designing large-scale and complex systems have demonstrated the inefficiency of either inter- or multidisciplinary approaches. These traditional approaches do not promote the necessary collaboration and synthesis to go beyond the existing disciplinary boundaries. Therefore, they are failing in the generation of creative and innovative solutions for the current large-scale and complex problems, both in social and technological landscapes (Ertas 2012). Then, transdisciplinarity gained importance, and it is generally understood as a process or activity that produces, integrates, and manages different knowledge in the scientific, social and technological areas. Also, it has evolved from special types of problems, which ask for the integration of different knowledge bases (Scholz et al. 2006) and systems.

Historically, the integration of research methods and techniques, across disciplines, has been of great interest in the cultural studies, the social sciences, and the health science since the post WWII period. Despite the multidisciplinary and interdisciplinary capacity of cross disciplines boundaries, their goals remained within the basis of the same disciplinary research (Ertas 2012). Then, in 1973, an OECD report on environmental education, firstly posited the transdisciplinary designation (Scholz et al. 2006). Transdisciplinary discussion was early grounded in the basic principles of complexity, multiple levels of reality, and the logic of the integrated and combined *middle* (Thompson Klein 2004). It was initially defined as a state of knowledge production that occurs when a common set of axioms prevail, related to, but lying beyond and complementing the traditional disciplines (Scholz et al. 2006). Also, since the 1970s, several definitions on transdisciplinarity were postulated, which attributes some uncertainty to the term. Nonetheless, the majority of the definitions combine several terms as follows: collaboration, shared knowledge, unity of knowledge, distributed knowledge, common knowledge, integration of knowledge, new knowledge generation, integrate disciplines, beyond disciplinary knowledge, and complex problems (Ertas 2012). Hence, knowledge is precisely one of the most cited terms when dealing with transdisciplinarity, whether in creating it or integrating it, which attributes an increased value to studies coping this approach.

Currently, the trend for the different project disciplines lies in a blurring of the boundaries in the conceptual stage of the design process. The general impression is that this border is blurring as a consequence of many more wanting to be involved as early as possible in the design process. Also, there is a global discontent at multiple borders in-between the different disciplines (Sanders 2006, 2010). Accordingly, Ertas (2012) argues that the elimination of the disciplinary boundaries is one of the fundamental characteristics of transdisciplinarity, when the objective is to stronger exploit disciplinary collaboration. This author exemplified with the development of a wind turbine fan, as illustrated in Figure 24. Therein, three different engineering disciplines work with researchers from the social sciences, natural sciences and humanities. The main objective was to understand the impact on the environment, and in the neighbouring communities to better guide the project (Ertas 2012).

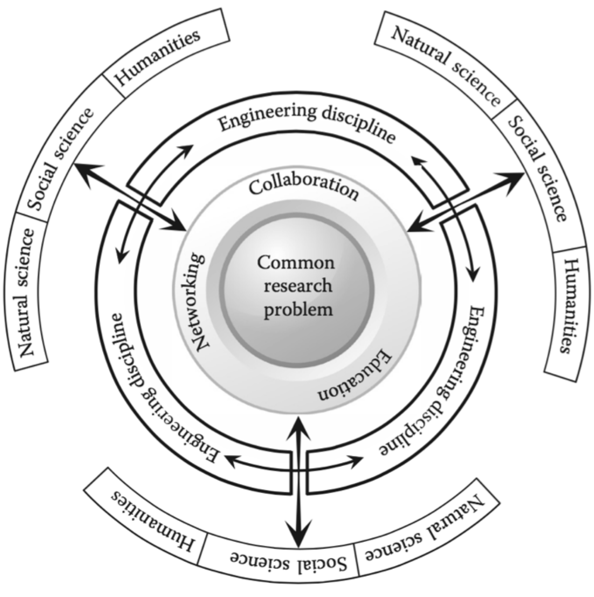


**Figure 24** | transdisciplinary process (Ertas 2012)

As shown in Figure 24, the transdisciplinary processes involves crossing the boundaries between the different disciplines working in a multidisciplinary context. Accordingly, the interactions between different disciplines and different companies are also considered sources of knowledge (Mu, Peng, and Love 2008). Currently, NPD companies are facing the complex challenge of combining technological and science-based knowledge (technology-push), with knowledge about future user situations and markets (market-pull). The general idea is that a narrow focus on technology involves the risk of developing products that are difficult to penetrate into the market. Conversely, a simple focus on users and their expressed wishes can potentially become extremely conservative for a NPD situation (Alting et al. 2007). Therefore, the combination of knowledge bases is the best option.

As referred, this thesis is focused in the conceptual collaboration between industrial design and mechanical engineering. Therefore, it is possible to trace a parallel between this research and the systemic, holistic and integrative characteristics of the transdisciplinary approaches. An emerging paradigm that may explain the benefits of a transdisciplinary approach between these two disciplines is technology epiphanies. A technology epiphany results in the identification of the more powerful and successful new meanings in products, enabled by new technologies (Verganti 2011b). This paradigm will be minutely analysed in the following section.

## 4.3 TRANSDISCIPLINARY EPIPHANIES

As abovementioned, literature has traditionally identified a twofold source of knowledge for the NPD processes. In this twofold vision, the first deals with the availability of new technologies, and the later deals with the understanding of the user needs (Dell'Era, Marchesi, and Verganti 2010, Verganti and Öberg 2013). Historically, the first has been clearly related with the engineering disciplines and the later more related with industrial design. It was Giovanni Dosi (1982) who firstly coined that the theories of technical change might be classified into two broad categories: market-pull, and technology-push. The first points to market forces as the main determinant of technical change, and the later defines technology as an autonomous, or quasi-autonomous, factor in the short run (Dosi 1982). Traditionally, the market pull is the main source of innovation, as NPD processes are a direct consequence of the explicit needs expressed by the customers or consumers. Instead, in the technology-push approach, innovation stems from the development and research activities of companies that develop new technologies, allowing the creation of new products. Therein, the central role of companies is the development of new technologies that subsequently drive its innovation process (Dell'Era, Marchesi, and Verganti 2010, Altuna, Dell'Era, and Verganti 2012). Nevertheless, an analysis conducted to global and innovative companies, such as Alessi, Apple, Artemide, Bang & Olufsen or Kartell, showed signs of weakness of this twofold approach. Conversely, non-measurable data is gaining importance inside these analysed companies. Accordingly, these companies are now following a third strategy, known in the literature as design-driven innovation (Verganti 2008, 2009, Dell'Era, Marchesi, and Verganti 2010, Battistella, Biotto, and Toni 2012), or design-inspired innovation (Utterback et al. 2006). In this new paradigm, beyond the availability of new technologies and the explicit user needs, a third source of knowledge is added. This third source comprises the creation of new languages and new meanings embedded into the new products (Utterback et al. 2006, Verganti 2009, Verganti and Öberg 2013). This third vector of innovation is sill an unexplored area, and it aims at introducing new meaningful experiences to the user. Besides, it is a change in the purpose for which the products are used, instead of starting with the "what" or "how" question, it all starts with "why" (Verganti and Öberg 2013). The referred three dimensions of innovation are illustrated in Figure 25.

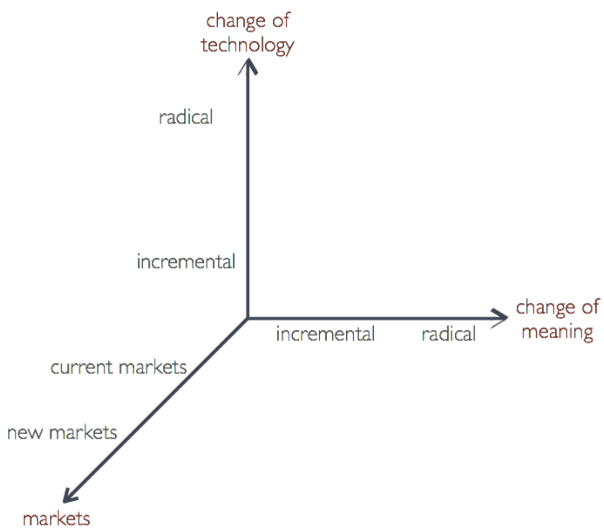


**Figure 25** | the three dimensions of innovation; adapted from (Verganti and Öberg 2013)

The meaning vector illustrated in Figure 25, when translated into solutions (the traditional "what" question), may include either the utilitarian and the functional needs, or the sometimes-neglected emotional and symbolic needs. The "why" question brings products a wider perspective, beyond the visible and tangible functions. Also, it is important to highlight that innovation of meanings can be based on existing or in new technologies (Verganti and Öberg 2013). This notion of meanings embedded in products gained interest in the last three decades and deserves a short analysis. Furthermore, despite their clear resemblances, both the design-driven innovation and the design-inspired innovation approaches will be briefly analysed in separate.

### 4.3.1 Meanings in products

Products are now understood as having associated meanings (Krippendorff 2006). This, widely acknowledge as product semantics since the 1980s, recognises that market competition is driven by a semantic dimension. The general idea is that people buy and use products for non-tacit and non-tangible reasons, that include both the functional utility and the immaterial use-satisfactions of the user (Verganti 2011b). The product semantics theory systematically inquiries how people attribute meanings for the artefacts they use. It also defines a methodology for designing artefacts in the view of the meanings that users could attribute to them. This theory has been attracting marketing and management attention, pursuing the idea that these meanings could add value to industrial products (Krippendorff 2006). As abovementioned, this semantic or tacit dimension is sometimes considered as the differentiating factor between companies thriving and disappearing.

Currently, companies are increasingly looking for new products that are not only functionality superior, but also capable to create an emotional link with their users (Utterback et al. 2006). Normally, to attend this challenge it is addressed how individual users understand the products they are using, and how they interact with them in their own terms, and in their own reasons. Yet, as products are not steady goods, these considered meanings might change throughout their use (Krippendorff 2006). As represented in Figure 25, innovation in meanings (the sematic dimension) might be more or less radical (as are innovation in technologies or markets). Accordingly, a product may adopt a language and deliver a message that is aligned with the current sociocultural models, or it can develop and create new trends (Utterback et al. 2006). Therefore, instead of searching for an appealing and state-of-art engineered product, users might look for a combination of these two aligned with a satisfaction feeling. However, as for the technological innovations, that call for changes in the technological paradigm, radical innovations of meaning demand profound changes in socio-cultural models as well (Utterback et al. 2006). Despite the associated challenge, a positive integration between different sources of materialised, and non-materialised, knowledge is again reinforced.

### 4.3.2 Design-driven innovation

In the design-driven innovation approach, innovation stems from a third knowledge source, one that combines knowledge about user-needs with new technological opportunities. This strategy aims at radically change the emotional and symbolic content of products, through a strong understanding of wider changes in society, culture and technology. Nevertheless, it is a largely unexplored area of research (Verganti 2008). Few authors and few companies are openly discussing or presenting this area of research.

The design-driven innovations, introduced by the referred global companies, didn't come from the market; instead, these companies were able to create entirely new markets (Verganti 2009). In this trend, there is a belief that innovation stems from the knowledge about product languages, about the knowledge that can be used to deliver a new message to user, and about the user sociocultural context (Altuna, Dell'Era, and Verganti 2012). Companies relying in a design-driven philosophy step back from users and take a broader perspective. Also, these companies are not following trends, but they make new proposals to market aiming at creating new trends. However, companies that are very successful at design-driven innovations are not open to a strong research over their innovation processes. Their knowledge and procedure is tacit and almost invisible, with no predefined steps. Instead, they rely in immersion and close contact between all the participants (Verganti 2009). Figure 26 describes the three modes of innovation postulated by the design-driven innovation approach.

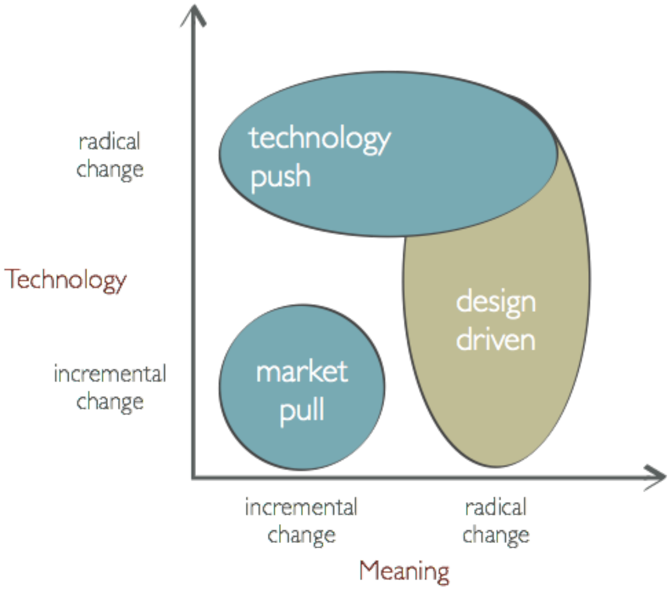


**Figure 26** | design-driven approach as the radical change of meanings; adapted from (Verganti 2009)

In the design-driven approach, innovation starts from the understanding of subtle and unspoken dynamics in sociocultural models. Also, this approach proposes radically new meanings and languages that often imply a change in the sociocultural regimes. Secondly, in the market-pull approach, innovation starts from the analysis of user needs, and the subsequent search for the technologies and languages that can actually satisfy them. Lastly, the technology-push approach is the result of the dynamics associated with the scientific and technological and technological research (Verganti 2011b). As the design-driven innovation requires extensive learning, companies using this path have a long history of appreciating the value of design (Chang, Kim, and Joo 2013). Consequently, many observers wrongly refer to Apple as a user-centred company. Yet, Apple instead of following user needs pursues innovation in technologies to make new proposals to society (Verganti 2009). Design-driven innovation doesn't start with users' insights, but it is pushed by the vision companies have about emerging breakthrough meanings and product languages (Verganti 2008). Therefore, design-driven innovation is closer to the technology-push approach rather than the market-pull strategy (Verganti 2011b). Therefore, the overlap between these two approaches is of extreme importance, and will be discussed ahead in this section.

### 4.3.3 Design-inspired innovation

The design-inspired innovation taxonomy is considered as a triad knowledge source for the innovation process as well. Generally, it requires creativity of a higher order, whether the products are professional tools, machinery for production or consumer goods or services. It is considered as a synthesis of technology with the users experiences (Utterback et al. 2006). As for design-driven innovation, three sources of knowledge are essential in this approach: knowledge about user needs, knowledge about technological opportunities and knowledge about product languages (Utterback et al. 2006). The integration of these three types of knowledge is illustrated in Figure 27.

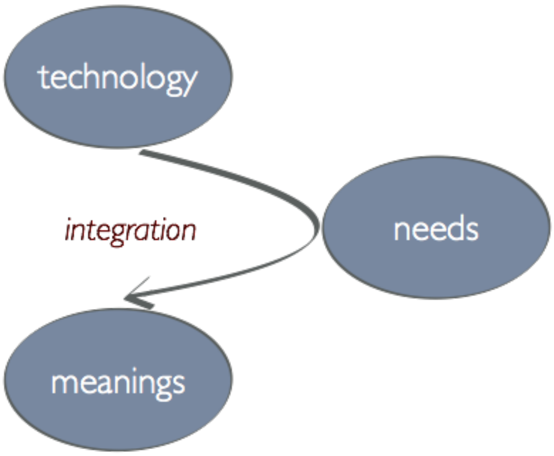


**Figure 27** | design-inspired innovation as the integration of technology, needs and language; adapted from (Utterback et al. 2006)

The first dimension, technology, is based on the technological development that provides the utilitarian function. The second dimension, language, concerns sense and the already mentioned meaning; it is the "why" of any product (Verganti 2009). Lastly, the third dimension deals with the inputs from the market. Wrongly, the classic dialectic of *Function versus Form* leads designers to relegate the language dimension only to the aesthetic appearance of products. The general idea presented in Figure 27 is that good design should combine meanings embedded in products, as well as their function and the user needs. In this combined approach, any balance between technology, market and meaning is unique and differentiated. The Apple's iPod is considered as the finest example of this triad (Utterback et al. 2006). The distinctive character of this distinctive product will be discussed in the following sub-section.

There are several similarities between the design-driven innovation and the design-inspired innovation approaches, and they are based in the same three dimensions of innovation, as represented in Figure 25. Therefore, this research mainly uses the design-driven taxonomy due to the higher amount of bibliographical references using this designation.

## 4.3.4 Technology epiphanies

As abovementioned, one area that admits a particular interest for analysis and detailed research is the overlap between the technology-push and the design-driven approaches (Verganti 2011b). This referred overlap, represented in Figure 28, is at the heart of some of the most successful products in many product development companies, such as Apple, Philips or Nintendo (Verganti 2009, 2011a). The result of this overlap is considered as a technology-epiphany, and three products from these three companies will be detailed ahead.

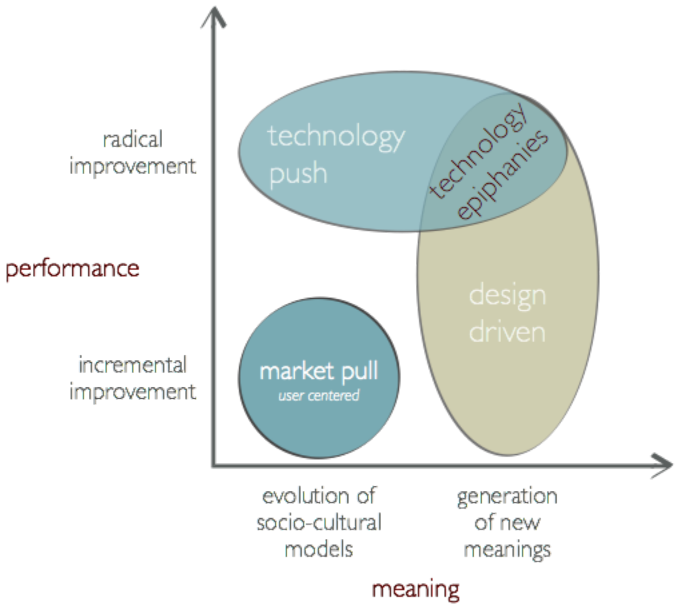


**Figure 28** | the overlap between the technology-push and the design-driven approaches; adapted from (Verganti 2009)

In conventional product development, companies look for new technologies that will better serve the existing needs of their customers. Instead, to create a technology epiphany, companies should turn to interpreters rather than users themselves, in order to address needs that customers many not realise they have (Verganti 2011a). One of the most famous cases of a technology epiphany is probably the Apple iPod (Figure 29), firstly introduced in 2001 (Verganti 2009). As previously discussed, the design-inspired innovation defendants normally mention the iPod as an example as well.


**Figure 29** | first generation iPod (2001) (http://www.webdesignerdepot.com/2009/01/the-evolution-of-apple-design-between-1977-2008/)

Apple is a well-cited company in the technology epiphanies paradigm (Verganti 2009, Chang, Kim, and Joo 2013). For the iPod production (the most famous epiphany) Apple didn't invest in a technological substitution, as MP3 players were already introduced in 1997. Instead, Apple seized the opportunity offered by the digital audio encoding to create a radically new meaning, allowing people to produce their own personal music. The iPod is not simply a portable music player, as it comprises an entire and seamless experience developed by Apple. This new experience is materialised in the iTunes software application, and in the iTunes Store, a new business model for selling music (Verganti 2009). This integrated and new music experience made it easier for people to discover and buy new music and organise it into their own personal playlists. Also, it delivered a new alternative to piracy that was threatening to destroy the music industry early in this millennium (Verganti 2011a). Simultaneously, the iPod has been delighting its costumers due to the simplicity and elegance of its design (Utterback et al. 2006, Verganti 2009). Therefore, technological new products as the iPod act as framing devices enabling a more distinctive experience of auditory embodiment. Besides, this disruptive product casts light upon the meaning and significance of others sharing the same environment (Bull 2010). Nevertheless, these epiphanies do not have to be the outcome of eureka moment, instead, they can be systematically produced by either the new technologies' suppliers, or the companies that incorporate them in their portfolio (Philips 2011).

*Innovation is key in business. But new ideas and technologies are not enough on their own. Being the first with a new meaning or application for a product that creates a new space in the market is critical to success.*

Philips Design (2015)

Philips started to produce technology epiphanies in the early 1990s, and invested systematically in this strategy since 2001. This company is one of the examples of having a methodological approach in the technology epiphanies paradigm. Currently, Philips Design is focused in delivering new visions enabled by new technologies, and that could become more meaningful to users than the existing products. Since the introduction of computed tomography (CT) and magnetic resonance imaging (MRI), respectively in the early 1970s and 1980s, radiologists demand for powerful machines. The general idea is to improve the quality of images and reduce the time of the exams (Verganti 2011a). Philips Ambient Experience for Healthcare (AEH) is an example of a successful design in creating new meanings, according to the positive reaction of the hospitals and patients that already experienced it (Philips 2011). Figure 30 illustrates one example of this new meaning in the AEH project.


**Figure 30** | AEH's kitten scanner (Verganti 2011a)

In this example, the AEH's kitten scanner helps children overcame their fears of the real machine, using toys to interact with a playable machine. Also, this project created children-friendly medical environments to peace their anxiety, that revealed highly successful (Verganti 2011a). Therefore, to create technology epiphanies, Philips Design creates new visions of exploiting the limits of new technologies. Inside this company, designers have a holistic design approach, research based methods, and interdisciplinarity (Philips 2011).

The Nintendo Wii, illustrated below (Figure 31) is another example of a technology epiphany. Nintendo, cleverly applied micro-electro-mechanical systems (MEMS) accelerometers, and transformed the experience of playing with game consoles from passive immersion in a virtual world into active physical entertainment (Verganti 2011a).


**Figure 31** | Nintendo Wii (https://en.wikipedia.org/wiki/Wii - /media/File:Wiimote-in-Hands.jpg)

This game console was launched in 2006, and rapidly conquered market leadership in 2007. Also, the strongest competitors, Sony (PlayStation) and Microsoft (Xbox), felt the need to develop themselves this new way of gaming and immersion, launching, respectively, the Move and the Kinetic systems in 2010.

Design management has been focused on how design can act as a differentiator in mature industries. Yet, this paradigm signifies that there is a relevant and unmapped field of how design can act at its conceptual stage, when a breakthrough technology emerges. Accordingly, the research of how radical innovation of meanings may be design-driven, how it interacts with breakthrough technologies, and then creates the technology epiphanies, is a relevant and promising area for research (Verganti 2011b).

### 4.3.5 Comparative review

Thereby, a transdisciplinary approach in the conceptual design stage allows the creation of new knowledge that can positively impact in the success of the new product. A conceptual overlap between industrial design (symbolic) and the mechanical engineering (real) knowledge bases (Owen 2007) benefits the creation of entirely new meanings. Therefore, a holistic overlap between the symbolic and the real domains of activity may result in a transdisciplinary epiphany, as illustrated in Figure 32. Also, literature argues that technology is now more close to design-driven innovation than the traditional market-pull data.

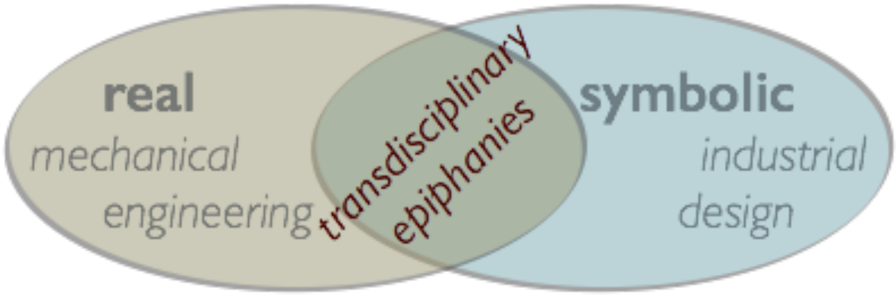


**Figure 32** | transdisciplinarity epiphany between engineering and industrial design knowledge bases

As mentioned, the general objective of this research is to understand the sensitive and conceptual relation between industrial design and mechanical engineering. Hence, the real and the symbolic taxonomies for the domain of activity (Owen 2007) were used to comparatively classify these two disciplines. Besides, and using the already mentioned taxonomies, the above outline is proposed (Figure 32). Accordingly, a transdisciplinary epiphany occurs when a shared and new knowledge, resulting from synthesis of symbolic and real knowledge bases, is created in NPD contexts.

## 4.4 CONCLUSIONS

Knowledge is a key asset for any company, and to produce new products new knowledge should be produced accordingly. In the case of NPD companies the importance of knowledge increases, as different knowledge bases should be positively combined. A review of the literature showed that mechanical engineering and industrial design disciplines are synthetic in their process. Nevertheless, industrial design gains in symbolism, and the values and units of measure of these two disciplines were argued to be different, yet intersecting.

Collaborative design approaches, due to the access of a diversified knowledge base, were considered a key factor in the success of design-driven companies. Generally, collaboration between different actors provides different technological solutions, that free their creativity from as many constraints as possible (Dell'Era, Marchesi, and Verganti 2010). Nevertheless, without an effective management of these networks of innovation, knowledge may flow more freely out of each company that productively into it. Thus, companies need to evolve and to be in constant renewal of their mind-set to meet the changing needs. Otherwise, locking companies into non-updated networks might hinders the creation of new knowledge and innovation (Huggins and Johnston 2010). An analysis to this notion of collaboration in cross-functional contexts will be extensively discussed in Chapter 6. The following, Chapter 5, presents a review of the existing models for the design process, focussing in its common and conceptual stage.

# 5 CONCEPTUAL DESIGN PROCESSES

A positive energy in fostering interdisciplinary collaborations characterises the current design landscape (Dubberly 2005, Sanders 2010). Therefore, and as already mentioned, literature considers design as a total phenomenon, as it operates in relation to other disciplines and knowledge (Best 2010, Maldonado 2012). This diversified knowledge increases the current complexity of the design problems, and the social and scientific knowledge required to address them increased accordingly (Ertas 2012). This increased complexity, in both the social and scientific landscapes, placed the ground for a collaborative and cross-functional approach as a recognised key to solve this intricacy (Thompson Klein 2004).

Notwithstanding the relevance of other disciplines for NPD, such as economics, sociology or marketing, the conceptual relation between mechanical engineering and industrial design is the purpose of this research. To create new products, or to improve the existing ones, the design process should be improved accordingly (Dubberly 2005). However, and despite the importance of the overall design process, the early and conceptual stage is currently the object of the main action. This early stage was coined as Fuzzy Front-End (FFE) in the 1990s (Smith and Reinertsen 1998), and its significance is the result of an increased preoccupation with innovation. Also, the diversified array of practitioners waiting to have a voice in design process attributes the current significance for the FFE (Sanders 2006, Sanders and Stappers 2008, Sanders 2010). Notwithstanding the vastness of design models, literature is inconclusive with an optimal solution; the existing consensus is that there is no set best practice. Other consensus is that different design problems admit different design methods and tools (Council 2007, Best 2010, Crawford and Di Benedetto 2010). Therefore, throughout this chapter a comparative and critical analysis to some design models, from engineering and industrial design, is done. Also, a synthesis for the conceptual stage of the design process is proposed.

This chapter is an extended version of the paper "Transdisciplinarity and Design: Comparative Review and Synthesis for the Design Process", presented in the 8th International Conference: Senses & Sensibility Conference held in Lisbon (5-7 October 2015). This same paper was selected for the special edition of the Radical Designist, A Design Culture Journal (UNIDCOM/IADE).

## 5.1 DESIGN METHODOLOGY

Historically, the exploration of design methods and processes started at Bauhaus school, in the early 20th century. Therein, attitudes to industrial design were radically changed, and a methodological foundation for design education was established (Bayazit 2004). This new approach to design, revolutionised contemporary industries as well, and many external products were accordingly redesigned (Council 2007); Bauhaus was a highly influential school. Mostly, design theories and methods weren't elicited from either purely formal research or descriptive studies of the practices of designers. Instead, they were related with a specific rationalisation of the design activity in their historical and cultural context (Le Masson, Hatchuel, and Weil 2011). After Bauhaus closure by the Nazis, in 1933, the majority of its staff moved to US, UK or Soviet Union, and their foster institutions were strongly influenced by this new coming academic staff.

Later, in the post-war period, the novel scientific methods and techniques, used to develop the inventions of WWII, attracted many designers. Accordingly, the design work took a great leap forward, as it became evident that the product should no longer be the only core of the design task. Therefore, human needs started to be increasingly considered as well (Cross 1993, Bayazit 2004). Besides, it was primarily after the WWII that the idea of a design theory and practice, common to architecture and engineering, emerged as a field of research (Le Masson, Hatchuel, and Weil 2011). Later, in 1962, the first conference on the design methods subject took place in London. The engineers Bruce Archer and John Chris Jones, that were very interested in product design, were among the conference organisers (Cross 1993). This conference led to the emergence of design methodology as a subject or field of research (Bonsiepe 1992).

Nevertheless, in the early 1970s, a great decadence of design methodology research happened, due to the difficulties in addressing the emerging and wicked problems of that period. Later in this decade, a change came accompanied by the belief that for accomplish a complete knowledge, different methods and points of view need to be accepted (Bürdek 2010). Therefore, the design methodology field of research was strongly developed in the 1980s, especially in the engineering disciplines and in some branches of the industrial design. This development resulted in a series of books of engineering and design methods (Cross 1993, 2001b, Bürdek 2010). Regardless the lack of confidence in its practical implementation, design methodology thus became a mature academic field in the 1990s (Cross 1993). Also, one the first attempts of the design methodologists was the development of new and systematic design procedures (Dubberly 2005).

Generally, the design methodology field of research is based in the assumption that underlying the design process there is a common structure. It is a strongly process oriented field of research, with a normative and abstract approach, that aims at optimising and developing the design process (Bonsiepe 1992, Kroes 2002). Therefore, design methodology should provide guidelines for the process rather than guidelines for the product (Edelson 2002). Currently, it is expected that the design methodology could be able to foster inventiveness and holistic understanding. Also, it should be compatible with the concepts, methods and findings of other disciplines, and ease the planning and management of the increased teamwork. Finally, this area of research should foster and guide the ability of designers, encourage creativity, whilst simultaneously drive the need for and objective evaluation of the results (Cross 2008). Notwithstanding the wide array of proposed models for the design process, many design practice still appears to proceed in an unsystematic way (Cross 2001a). Therefore, a systematic and comparative analysis to the design process, and to its models, assumes an increased relevance.

### 5.1.1 Design process

The study of the design process is a complex area for research (Edelson 2002). Commonly, the design process is considered as the series of activities and methods that together aim at solving design problems. Also, the understanding of the design process is an initial requirement to achieve reliable solutions (Council 2007, Kumar 2013), and the quality of the process determines the quality of new products as well. Therefore, if we wish to improve the products, we should improve the design process accordingly (Dubberly 2005).

Rather than a predefined series of orderly steps, the design process can be described as a system of related activities that together form the continuum of innovation (Brown 2008). Accordingly, recent models for the design process assume alternative shapes and present a holistic approach (Dubberly 2005), in order to foster the inventiveness all-along the process. Regardless its vastness, it is possible to advance that literature on this subject is inconclusive; the only consensus is that there is not set best practice. Actually, many design models are proposed, varying in the scale and nature of the problem addressed, and it has been accepted that different design problems admit different design methods (Council 2007, Crawford and Di Benedetto 2010). Additionally, different project disciplines admit different processes and methodologies, depending on their objectives and desired outputs (Best 2010). Nevertheless, understanding the design process as a whole is an initial requirement to achieve a reliable solution. Besides, any organisation should understand the specific activities and methods it can deploy at different points throughout the process (Kumar 2013). Thereby, both engineering and industrial design models will deserve a critical and comparative analysis. The focus is on its conceptual stage, as it is believed that this is a common stage, regardless the discipline.

## 5.2 DESIGN MODELS COMPARATIVE REVIEW

It is generally accepted that the accuracy of the design process normally determines the quality of the products as well (Dubberly 2005). Accordingly, throughout the last two decades, there were many attempts to model the design process (Cross 2008). To attend the current challenge of analyse the conceptual relation between mechanical engineering and industrial design, design models spanned throughout these two disciplines are presented and analysed in this section. Additionally, a SWOT analysis to the different presented models is done in order to better compare them. As abovementioned, the focus of this critical and comparative analysis is on the conceptual stage of each model.

### 5.2.1 Bruce Archer

Bruce Archer, one of the organisers of the first conference on Design Methods in 1962 (Cross 1993, Margolin 2010), published his first design model in 1963. It was the first attempt to break the design process into linear stages (Council 2007). A representation of this model is illustrated in Figure 33.

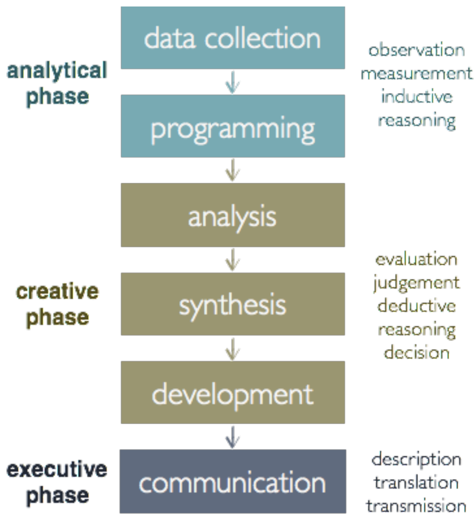


**Figure 33** | Bruce Archer's design model; adapted from (Council 2007)

Three main stages are clearly highlighted: the analytical, the creative and the executive. The generative stage in this model ends in the *synthesis* step, comprising more than half of the entire model. Interestingly, *communication* is considered as the final step, due to the general idea that the project must pass to an internal and executive decision. Yet, Nigel Cross (2008) considers this model to be swamped in the fine detail of numerous tasks and activities that are necessary in all practical design work. As referred, a SWOT analysis is conducted to all the presented models and the SWOT to Archer model is represented in Table 8.

**Table 8** | SWOT analysis in the model from Archer

| Strengths | Weaknesses | Opportunities | Threats |
|---|---|---|---|
| The first model | Numerous tasks and activities | Three main clear stages | No iterations are considered |
| It tends to suggest a common structure | Linear process | Generalizable and highly influential | |
| This model is concerned with new ways of working | | | |

From Table 8, a common structure might be easily generalizable: analytical, creative and executive stages. However, this model presents a simple and linear structure, admitting no iterations. Also, from the early beginning of the design methods research the continuous adoption of improved ways of work was recommended.

### 5.2.2 Bruno Munari

The linear model from Archer, and some of his 1960s peers, was immediately and widely accepted. However, in the 1970s Bruno Munari sustained that no model should be considered as absolute or definite. Instead, any design model should be considered as a changeable and iterative tool (Munari 2006). Also, Bruno Munari (2006) considered industrial design as a clear problem-solving discipline, as illustrated in Figure 34.


**Figure 34** | Bruno Munari's design model; adapted from (Munari 2006)

Considering current perspectives, Munari's approach is somehow obsolete, as both linearity and a mainly problem-solving approach are being questioned in their innovativeness (Best 2010, Sanders 2010). This model triggered is then by a problem, or a need, and it is composed of nine steps. It is relevant to notice that the conceptual stage in this model comprises approximately six steps, ending with the *experimentation* step.

**Table 9** | SWOT analysis in the model from Munari

| Strengths | Weaknesses | Opportunities | Threats |
|---|---|---|---|
| Focus in the problem-solving | Numerous tasks and activities | Its creator considered it an incomplete contribution | Highly focused in the problem-solving approach |
| Individual contributions are accepted | Despite admitting iterations, linearity is advised | Improvements are accepted | |

From Table 9, the problem-solving approach might be very restrictive according to the current perspective. Nevertheless, the ability to accept individual contributions is a positive attitude for a continuous improvement.

### 5.2.3 Bernhard Burdek

From Burdek's perspective, the design process could be modelled as an information and manipulation system (Bürdek 2010). Accordingly, Figure 35 illustrates this considered information, and manipulation, in-between all the steps composing its model.

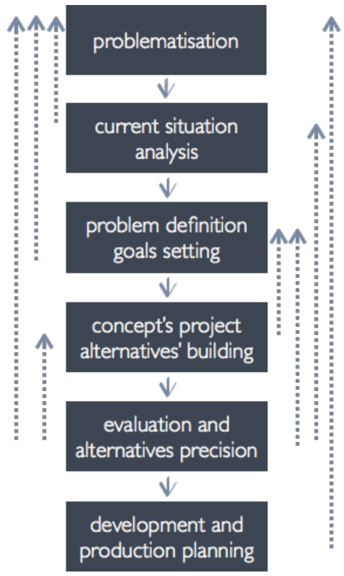


**Figure 35 |** information model for the design process; adapted from (Bürdek 2010)

The model from Burdek (2010) conceives the design process as system to decode information. This model is characterised by many feedback possibilities and iterations. Besides, these feedback and iteration loops allow preventing linearity, previously advised as means to solve problems. This information system aims at handling the continuous introduction of new data and technological novelties throughout the process, and the possible caused delays (Bürdek 2010).

**Table 10** | SWOT analysis in the information model from Burdek

| **Strengths** | **Weaknesses** | **Opportunities** | **Threats** |
|---|---|---|---|
| Many iterations are admitted | Numerous tasks and activities | Problem-finding is not considered, despite the admitted iterations | Too many details may confound the designers |
| Information and evaluation over all the steps | | An information system is proposed in the whole model | |

From Table 10, it is possible to highlight the continuous iteration and evaluation in all steps composing this model. This is the result of the considered continuous information system for the design process. However, the amount of activities considered might swamp the process, as argued by (Cross 2008).

### 5.2.4 Nigel Cross

Nigel Cross (2008) divided descriptive models from the prescriptive ones. The first usually identify the significance of generating a solution early in the process, while the later aims at persuading designers to adopt improved ways of learning. Accordingly, the first attempt from Archer (Figure 33) is considered as prescriptive (Cross 2008). A prescriptive approach idealises the design process, and it prescribes the steps the designer should follow (Mc Neill, Gero, and Warren 1998). Conversely, Cross (2008) developed a simple descriptive model for the design process (Figure 36), based on the essential activities performed by the designer (Dubberly 2005). Accordingly, authors advising the descriptive approach, argue that the process that designers actually follow is different from the idealised and prescriptive one (Mc Neill, Gero, and Warren 1998). Figure 36 illustrates de descriptive model from Nigel Cross.

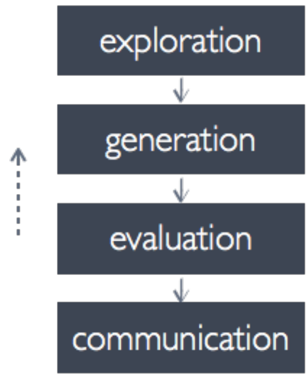


**Figure 36** | descriptive model for the design process; adapted from (Cross 2008)

In a descriptive approach, Nigel Cross (2008) considers the solution-focused nature of design to be clear, as a simple solution is early developed. Therein, after some initial context *exploration*, the project arises from the *generation* of an initial idea or concept. Then, the design proposal is exposed to *evaluation* against the criteria of the design brief. The process ends with *communication* of the concept ready to the subsequent development (Cross 2008). There is a clear intention to reduce the number of steps, as Nigel Cross (2008) believed that a larger number and their corresponding activities might be risky for the smooth running of the process.

**Table 11** | SWOT analysis in the descriptive model from Cross

| **Strengths** | **Weaknesses** | **Opportunities** | **Threats** |
|---|---|---|---|
| Focus in the problem solving | Iterations only between evaluation and generation steps | An easily generalizable model | Solutions might be developed too early |
| Iterations are advised | | Highly focused in the conceptual stage | |

From Table 11, it is possible to state that communication is a transition step between the conceptual stage and the development one. Yet, new concepts are considered to be as developed early in the overall process.

## 5.2.5 Michael French

From Frenchs' perspective, design begins with a need and ends with a set of drawings and information that enable a materialisation (French 1999). Accordingly, these two elements, need and information, respectively start and finish his model, which is represented in Figure 37. Also, the model from French admits a descriptive character as well.

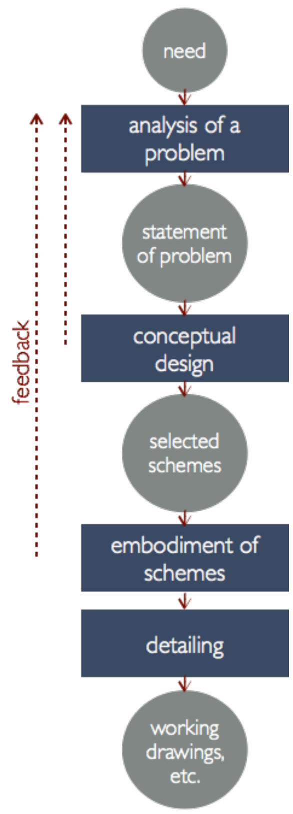


**Figure 37** | block model for the design process; adapted from (French 1999)

In Figure 37, the circles represent steps reached and the rectangles represent work in progress. Firstly, the problem analysis consists of identifying the need to be satisfied. It is a small but important stage in the overall process that ends with a problem statement. Then, the conceptual design is the stage that makes the greatest demands from the designer, and presents the most space for general improvements. Besides, different disciplines should be brought together therein, to take the most important decisions for the overall process. Thirdly, the concepts are worked up in greater detail, and if there is more than one solution a final choice should be made. For this stage, the outcome is commonly a set of drawings. Lastly, the quality of the detailing work should be good in order to avoid delays, extra costs or failures (French 1999). It is possible to get the absence of a clear evaluation stage, and this is explained by the proposed continuous evaluation in all the four steps.

**Table 12** | SWOT analysis in the block model from French

| **Strengths** | **Weaknesses** | **Opportunities** | **Threats** |
|---|---|---|---|
| The more creative stage is iterative | Only needs are considered for starting the process | Conceptual design stage is highlighted as the most important | The opportunities in both new technologies and markets are not considered |
| Evaluation is considered as intrinsic to any stage | | A collaborative approach for the conceptual stage is advised | |

From Table 12, it is possible to highlight the perception that the conceptual design stage is considered as the most important. Also, it is advised a collaborative approach for this stage, the idea behind the general objective of this research. Equally relevant is the notion of a continuous evaluation to foster innovative outcomes.

## 5.2.6 Gavin Ambrose and Paul Harris

These two authors clearly reinforce the iterative characteristics of the design process. However, it is argued that any process is linear in nature (Ambrose and Harris 2009), as proposed in Figure 38.

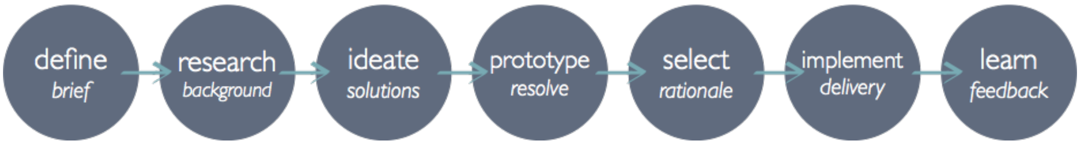


**Figure 38** | design-thinking process; adapted from (Ambrose and Harris 2009)

Ambrose and Harris (200) are aligned with Munari (2006), who has advised a certain order to coordinate the whole process. Still, Ambrose and Harris (2009) emphasise the iterative and creative character of the general design process. Revisit earlier segments of the process, rework and iterate on them is considered as essential. Also, it is considered that design-thinking should be present in each step composing the design process (Ambrose and Harris 2009).

**Table 13** | SWOT analysis in the design thinking model

| **Strengths** | **Weaknesses** | **Opportunities** | **Threats** |
|---|---|---|---|
| Creativity is inherently considered | Some conservatism for a model considered as iterative | Revisiting, iterating and reworking is advised | Despite the iterative characteristics, linearity is advised |
| | A strict path is implied | | |

From Table 13, it is possible to highlight the inherent creative and iterative character considered for the design process. Nevertheless, this model presents a linear and clearly sequential shape.

### 5.2.7 Pahl, Wallace and Blessing

These three authors consider a problem-solving approach for the design process as well. Accordingly, they believe that any process is triggered by a problem, and the outcome is thus expected to be a solution for this same problem. This problem-solving process is illustrated in Figure 39.

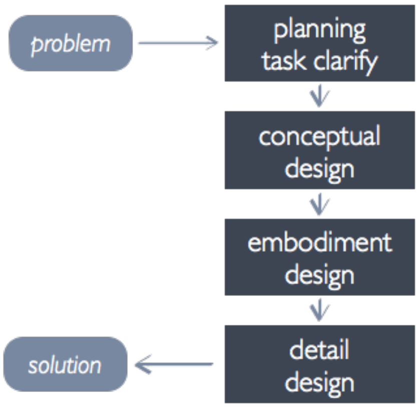


**Figure 39** | Pahl, Wallace and Blessing's design model; adapted from (Pahl, Wallace, and Blessing 2007)

Regardless its structure, the challenge in defining a clear borderline between the four identified stages is underlined. Besides, their systematic approach aims at keeping the iteration loops as small as possible, in order to make the design work effective and efficient (Pahl, Wallace, and Blessing 2007). The conceptual stage represents half of the entire process, and the importance of the abstraction is emphasised for the early stages.

**Table 14** | SWOT analysis in the model from Pahl, Wallace and Blessing

| **Strengths** | **Weaknesses** | **Opportunities** | **Threats** |
|---|---|---|---|
| Stages are very clear | No iterations are admitted | The difficulties in create boundaries between the different steps | Mainly problem-solving |
| A solution concludes the process (problem-solving based) | Linearity is advised | | |

From Table 14, it is possible to highlight the strict and linear approach proposed for the effectiveness of the process. Also, the challenge in borderline each stage composing the process is underlined as well.

## 5.2.8 Borja de Mozota

Brigitte Borja de Mozota (Borja de Mozota 2003) identified three types of design processes: the analytical, the iterative and the visionary. However, whether analytical, iterative or visionary, the design process follows a similar path, with the same stages composing it (Figure 40).


**Figure 40** | Borja de Mozota's model for the design process; adapted from (Borja de Mozota 2003)

Despite the referred similarities in their path, the iterative processes are considered as the real producers of breakthroughs (Borja de Mozota 2003). It is assumed that the analytic stage comprises steps one and two, the synthetic stage comprises steps three and four, and the final stage comprises steps five and six. Notwithstanding the perceived creative character of this model, the more creative and conceptual stage ends with step three, with its choice of ideas, concepts and style.

**Table 15** | SWOT analysis in the model from Borja de Mozota

| **Strengths** | **Weaknesses** | **Opportunities** | **Threats** |
|---|---|---|---|
| Iterative processes are considered essential for radical innovations | Concepts to be found early in the process | Three main stages can be translated from this model | Iteration loops are not represented |
| | | Easy to generalise a common structure | |

From Table 15, and despite the advised iterative character for the design process, no iteration loops are represented, which assumes a threatening character. Nevertheless, the three clear generic stages in this model are well sustained, and are very promising for generalisations.

### 5.2.9 Vijay Kumar

From the perspective of Vijay Kumar, any design process should move iteratively through different modes of activity to deliver real breakthroughs (Kumar 2013). Therefore, Kumar proposed a non-linear and iterative model for the design process, as illustrated in Figure 41.

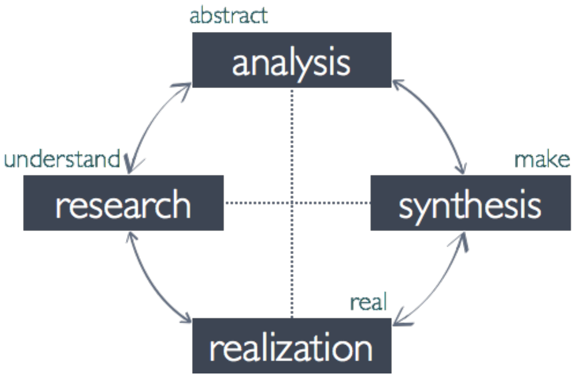


**Figure 41** | Kumar's iterative model for the design process; adapted from (Kumar 2013)

Thereby, the design process should move back and forth through modes of activity. Detailing each step presented in Figure 41, *research* is about knowing the reality. *Analysis* is about trying to create appropriate mental models. *Synthesis* is about generating new concepts with previous abstract models. Lastly, *realisation* is about implementing tangible offerings. Also, Kumar considers the design process as non-linear and iterative, supporting that more iterations might generally lead to more successful innovations (Kumar 2013).

**Table 16** | SWOT analysis in the model from Kumar

| **Strengths** | **Weaknesses** | **Opportunities** | **Threats** |
|---|---|---|---|
| Highly iterative | Highly subjective | Focused in the conceptual stage | Difficulties in closing the loop |
| Design and technology driven | | More iterations to more successful innovations | The proposed iteration between the final and the initial stages |

From Table 16, it is possible to notice the highly iterative character of this model, and the difficulties in closing the loop. However, (Kumar 2013) considers the amount of iterations as decisive for successful innovations, and emphasises the importance of both design and technology to the conceptual stage of the process.

### 5.2.10 Elizabeth Sanders

Elizabeth Sanders (Sanders 2006, 2010) developed a non-linear model for the design process as well. Besides, the FFE is clearly highlighted in this model, as illustrated in Figure 42. The FFE is a term coined in the 1990s (Smith and Reinertsen 1998), and its significance is the result of an increased preoccupation with innovation. Also, the diversified array of actors wanting to have a voice in the design process attributed the current relevance to the FFE (Sanders 2006, 2010, Sanders and Stappers 2008).

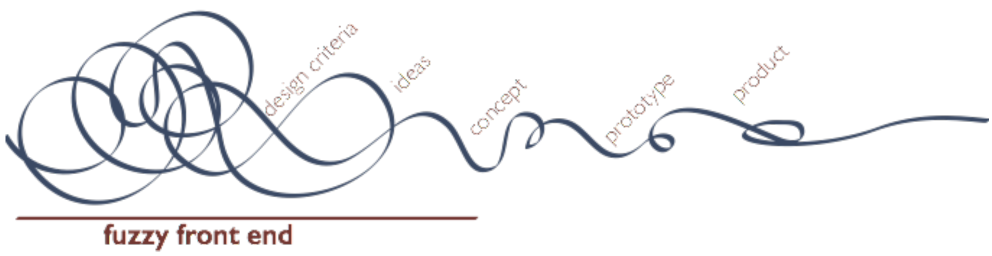


**Figure 42** | generative model for the design process; adapted from (Sanders 2010)

In recent years, the FFE received an increased interest by the design community This early stage is mainly focused in new ways of understanding, and emphasising, the wills and dreams of society, and thus has received this increased interested (Sanders 2006). Accordingly, the amount of time, resources and iterations applied at this conceptual stage. Also, different areas of expertise, including mechanical engineering and industrial design, should be early assigned to the process (Sanders 2010). Therefore, a collaborative approach for the FFE is supported.

**Table 17** | SWOT analysis in the model from Sanders

| Strengths | Weaknesses | Opportunities | Threats |
|---|---|---|---|
| The generative space of the early stages is underlined | Highly abstract model | The conceptual stage represents half of the entire process | The amount of loops may swamp the process |
| Wide space for iterations | | An early compromise between mechanical engineering and industrial design | |

From Table 17, it is possible to highlight the highly abstract character of this model, and the iterations perceived as decisive and positively generative. Nevertheless, this positive impact of these iterations only happens early in the process, diminishing through it. Also, the notion that the two disciplines in analysis should be assigned to the FFE is of extreme importance.

### 5.2.11 Kathryn Best

Kathryn Best argues that design is an iterative, cyclical and non-linear process. Her model is based in the creative process, and thus some creative aspects common to all project disciplines were identified (Best 2010). The steps outlined with Figure 43 synthesise Best's general model for the design process.


**Figure 43** | the creative model for the design process; adapted from (Best 2010)

Notwithstanding the design process to be considered as iterative and non-linear, a linear shape was proposed in this analysis; Kathryn Best didn't graphically materialise her model. The iterative model, (Ambrose and Harris 2009), was the basis for the model illustrated above. Therein, it all starts with immersion in a set of problematic issues considered as interesting. Then, ideas are mixed, and unusual connections might be made; and, thirdly, the achieved concepts might be combined. Fourthly, the most promising insights are evaluated and considered as worth, or not, pursuing. Lastly, these final insights are turned into something. Throughout the process designers can work individually in moments of reflection and analysis, as well as in collaborative teams, leading to sudden insights and important decisions (Best 2010). Therefore, both individual work and collaborative are supported, but the collaborative work is argued for the decision-making process.

Notwithstanding the common steps in all the project disciplines, Best (2010) considers that disciplines still use different processes and methodologies, depending on their objectives. Also, it is suggested that several design consultancies try to create different models for differentiation purposes (Best 2010).

**Table 18** | SWOT analysis in the model from Best

| **Strengths** | **Weaknesses** | **Opportunities** | **Threats** |
|---|---|---|---|
| Inspired in the creative process | Different models for different problems | From the creative process a common structure might be generalisable | Difficulties in proposing one single model |
| The process should be iterative and cyclical | | Collaborative work to burst sudden insights and to decide | Different models for companies' differentiation |
| | | All the project disciplines are considered as having common steps | |

From Table 18, it is possible to highlight the creative characteristics of the design process, and the advised successive iterations to reach the best solution. Of extreme important for present research is the notion that collaborative work burst new visions and important decisions. However, alternative models for alternative design problems, and for different companies were discussed, and generalisations were not advised.

### 5.2.12 Milton and Rodgers

These two authors argue that the development of new products may start with either an idea or an opportunity. Despite the way in which process starts, it ends with a physical artefact (Milton and Rodgers 2013), as illustrated in Figure 44.

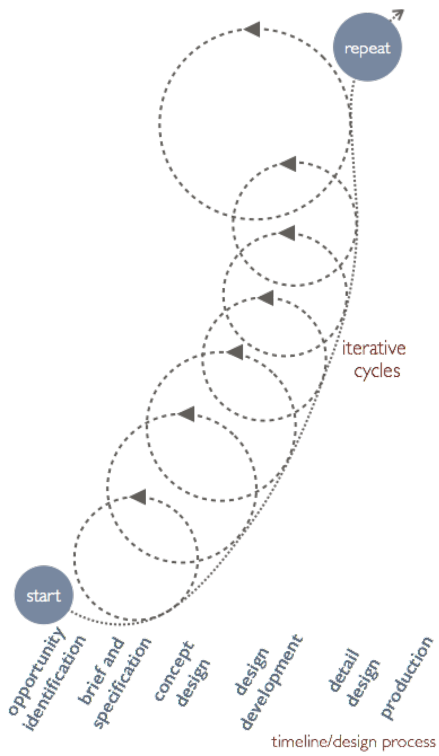


**Figure 44** | iterative design model; adapted from (Milton and Rodgers 2013)

Each iterative cycle represented in Figure 44 includes four distinct steps: *understand*, *observe*, *visualise*, and *review*. These steps are normally performed before repeating the cycle to collect extra data, or moved into the next step of the process. Also, it is argued that design research is now highly focused in the FFE, in order to explore the desires and needs of the end users. Nevertheless, a similar research throughout the remaining stages of the design process is advised (Milton and Rodgers 2013). To this continuous research, the arrows and the dashed circles represent a continuous evaluation and analysis in all steps of the process.

**Table 19** | SWOT analysis in the iterative model

| **Strengths** | **Weaknesses** | **Opportunities** | **Threats** |
|---|---|---|---|
| A highly iterative model | It is assumed that some stages may not even happen | Evaluation happens in any stage | The FFE is considered to be a "fashion" research topic |
| Opportunity to restart at any stage | | Ideas and opportunities start the process | The narrow focus on the FFE is unadvised |
| Continuous evaluation | | The process should be considered as a whole | |

From Table 19, it is possible to highlight the advised interactivity and continuous evaluations throughout all steps composing the process. However, it is argued that the FFE is now a fashion research topic of design research, and that the other stages are thus neglected in somehow.

### 5.2.13 New Concept Development

The FFE topic, its origins and relevance for the design process were briefly introduced in this chapter. Accordingly, the New Concept Development (NCD) model was developed and proposed as an iterative and circular model for this conceptual stage (Koen et al. 2001), as represented in Figure 45.

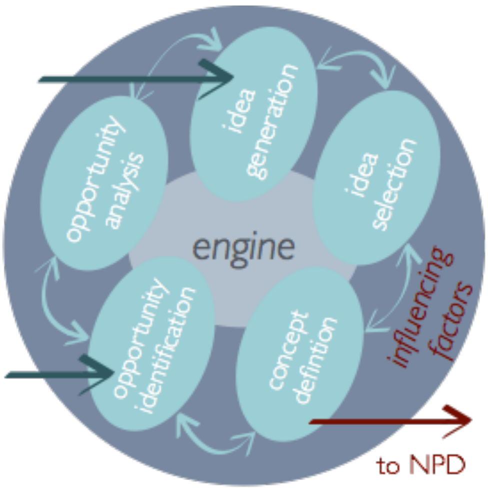


**Figure 45** | new concept development model; adapted from (Koen et al. 2001)

As illustrated with the green arrows, both idea generation and opportunity identification might trigger the process. Also, five iterative steps, or key elements, compose this model, which ends with *concept definition* and the subsequent passage to the development stage *per se*, represented with the red arrow. The circular shape means that ideas and concepts are expected to iterate. Therefore, it is an iterative course between the five key elements, instead of a linear process. The engine comprises the organisational attributes, the development teams and the interdisciplinary collaborations (Koen et al. 2001), thus admitting and increasing relevance for this research. The contextual factors are related with the organisational capabilities, the world and the enabling sciences, technologies and social issues involved (Koen et al. 2002). Nevertheless, literature argues that this model is highly abstract and difficult to apply to industry (Gaubinger and Rabl 2014).

**Table 20** | SWOT analysis in the NCD model

| Strengths | Weaknesses | Opportunities | Threats |
|---|---|---|---|
| An iterative model for conceptual design | An highly abstract model | The relevance of this model has been widely accepted | Difficulties in directly apply this model to industries |
| Both ideas and opportunities can trigger the overall process | | The engine lies in collaborations between different disciplines | |

From Table 20, it is possible to highlight the proposed double approach to start the process: both ideas and opportunities can trigger it. Also, the engine relevance lies in the interdisciplinary collaborations, a decisive research topic for this general study. Conversely, this model is considered as highly abstract and of difficult implementation.

## 5.3 SYNTHESIS AND PROPOSAL

From the previous analysis, it is possible to highlight the general interest and debate over the FFE topic, as literature considered the development steps *per se* as already established and well documented in the literature. Accordingly, the proposed and synthesising model reflects only the conceptual stage of the design process, which is sometimes wrongly treated as a single step inside the overall design process. This early stage is distinguishable from later stages, as it is concerned with understanding generically the problem, rather than making specific decisions about the solution (Mc Neill, Gero, and Warren 1998). Figure 46 illustrates the model proposed.

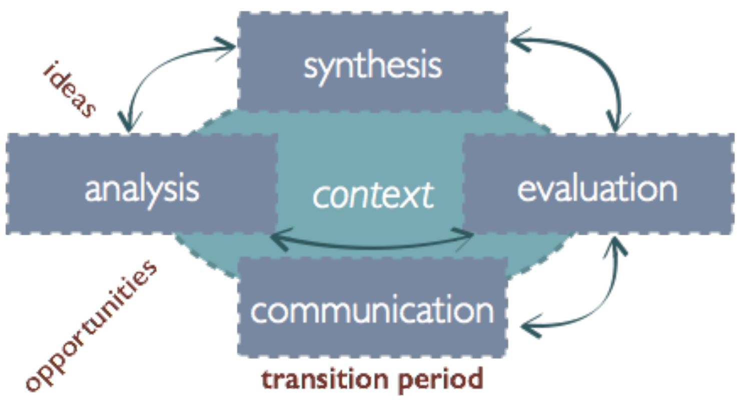


**Figure 46** | proposed model for the conceptual design stage

In the literature, there is a general belief that designing progresses move in cycles of analysis-synthesis-evaluation activities (Cross 2001a). Therefore, and resulting from the presented analysis, a common structure to the conceptual design stage is proposed as follows: *analysis*, *synthesis*, *evaluation* and *communication*. Firstly, analysis deals with understanding the sociocultural context, the market, and the technological environment. Also, ideas and opportunities are identified therein. Secondly, synthesis deals with matching the identified opportunities with ideas for new conceptualisations; it is a highly abstract stage in which different sources of knowledge are merged. Thirdly, evaluation deals with the assessment of the most promising concepts, and might comprise the prototyping and testing of developed models. Finally, communication is considered as a transition period, as the final outcomes have to be approved and developed internally or externally, depending on the NPD context. Besides, in order to maintain a creative path, every step should admit assessment activities in order to move to next step or iterate to the previous one.

To foster creativity and innovative outcomes, iteration loops were inserted in-between each stage composing the model, and an additional loop was inserted between *evaluation* and *analysis*. This last loop was inserted in order to reset the process if needed. As represented, no iterations are admitted between the communication and the analysis steps, as the loop should be closed, in order to no compromise the whole project. Also, iterations should be fostered in-between all the steps and the context or environment in which the project is undergone. Besides, the dashed lines serve to illustrate this continuous interacting intention, aligned with the referred difficulties in border all the steps composing the process (Pahl, Wallace, and Blessing 2007). A constant interaction between all the steps and their socio-cultural and technological context might foster transdisciplinarity since the beginning of the project to the communication of the final concept.

As illustrated in Figure 46, both individual or groups ideas, and the identified market and technological opportunities may trigger the process. Literature argues that technological innovations start with the identification of both the technological possibilities and opportunities. Design innovations go even beyond that, as they aim at understanding society and making new proposals, by means of new meanings and new technologies embedded into new products (Kumar 2013). Accordingly, understanding where these two processes interact, is the key to achieve the already mentioned holistic and transdisciplinary success. The technology epiphanies paradigm, discussed in Chapter

4, already demonstrated the increasing reconciliation between the design-driven innovation and the technology-push approach.

## 5.4 CONCLUSIONS

Notwithstanding the variety of design models, this chapter underlined the importance of the conceptual stage for the overall process. Therein, uncertainty and iterations were shown as facing a highpoint, when compared to the subsequent stages. The analysed variety of design models might be explained by the diversity of design problems, and the extension of design criteria to be solved early in the process. Nevertheless, the main discussion in design research is now focused in a collaborative approach for the FFE, due to its perceived impact in the overall process. Therefore, the proposed synthesis aimed at fostering a holistic and interdisciplinary collaboration, since the conceptual stage of the design process. Also, the continuous interaction with the sociocultural and technological environments, identified in this synthesis, underlined this general idea.

The transdisciplinary topic and its relevance for NPD were extensively discussed in Chapter 4. Hence, the FFE topic and its impact in the overall design and innovation process will be thoroughly discussed in Chapter 6. Also, the importance of a collaborative and cross-functional approach therein, will be underlined by means of the portrayal and insights of the design case that supported this thesis.

# 6 OPEN INNOVATION IN THE FUZZY FRONT-END

Companies are now prone to conceptually collaborate by means of collaborative design approaches. Nevertheless, managers still claim the absence of truly innovative ideas (Gassmann and Schweitzer 2014). The intensified competition aligned with the increased pace of technological change requires companies to be in constant renewal. Throughout this change, companies have realised that staying alone to obtain the knowledge needed to develop new products is no longer the best option (Enkel and Heil 2014). Therefore, management literature emphasises the potential of collaborative networks of product development, and these networks became a top priority for product development companies (Mishra and Shah 2009, Jorgensen et al. 2011, Simon and Tellier 2011, Leavy 2012).

Hereupon, the Open Innovation (OI) paradigm appeared, based in the assumption that companies should use both internal and external knowledge, as well as internal or external paths to market. Currently, this is almost a prerequisite in order to better conduct New Product Development (NPD) projects (Leen and Lubben 2013).

Therefore, and given the importance of new products to companies, a continued improvement of the processes leading to the development of successful products is critical (Carbone 2011). Thereby, literature generically divides the innovation process in three stages, with the full involvement of top management only happening in the later steps. Furthermore, highly defined processes and clear procedures with well-documented responsibilities and tasks characterise the referred later steps. Nevertheless, the real leverage in bringing up new ideas and improving the competitiveness of the overall process lies in the already mentioned Fuzzy Front-End (FFE) (Verganti 1997, Backman, Börjesson, and Setterberg 2007, Schweitzer and Gabriel 2012, PMI 2013, Gassmann and Schweitzer 2014).

This chapter is an extended version of the paper "Cross-Functional and Collaborative Concept Development: A Design Research Approach in the Aeronautical Sector", submitted to The Design Journal (Taylor & Francis). Also, this chapter presents results of the paper "A Cross-Functional Approach for the FFE: Highlights from a Conceptual Project", presented at the ICED 2015 Conference held in Milan (27-30 July).

## 6.1 OPEN INNOVATION

Traditionally, companies developed their new products internally. Therefore, most companies pursued a closed innovation strategy, with limited interactions with the outside environment. In this closed innovation approach, a company generates, develops and commercialises its own ideas. It was a dominant philosophy for leading industrial corporations throughout the 20$^{th}$ century (Chesbrough 2003). Nevertheless, in a study conducted by Henry Chesbrough in the 1990s, he concluded that this model of companies doing things on their own was reaching its limits (West, Vanhaverkebe, and Chesbrough 2006). Consequently, a paradigm shift occurred. The reasons attributed to this change were related with the increased mobility of highly skilled workers, and the growing availability of venture capital. This venture capital was directly aimed to the creation of new companies capable of capitalise the new and emerging knowledge (Chesbrough 2003, West, Vanhaverkebe, and Chesbrough 2006). Therefore, the past closed strategies were abandoned, and companies are now increasingly acquiring external knowledge to complement their own. Consequently, the majority of the current complex artefacts are the direct result of collaborative interactions as, often, is not possible to find this diversified knowledge internally. The use of strategic alliances for the development of new products thus became prevalent in high-tech industries (Ma et al. 2012, Oliveira and Alves 2014). Besides, the current global economy and the increasing transparency of knowledge creates the perfect path for the OI paradigm (Lindegaard and Kawasaki 2010). This designation, coined in 2003 by Henry Chesbrough, sustains that a company should use both internal and external ideas. Additionally, companies should use internal and external paths to market, in order to accelerate the innovation process (Chesbrough 2003, Leen and Lubben 2013). This trend assumes that useful knowledge is widely distributed and even the most capable R&D organisations must be open to leverage external sources of knowledge. Therefore, this open approach should be a core process in the innovation strategy of companies (Chesbrough, Vanhaverbeke, and West 2006). The NPD companies are not exception for this trend.

Thereby, the OI topic is now a highly relevant subject in the innovation management research, and its basic premise lies in opening up the traditional innovation process (Chiaroni, Chiesa, and Frattini 2011, Huizingh 2011). Ideally, and despite the referred open approach, it is important to go beyond than just involving others in the whole project. Hence, the contribution from outside environment must be significant and holistic (Lindegaard and Kawasaki 2010). Within OI approaches, projects can be launched from either internal or external sources of technology, and new technologies can enter the process at various stages. Also, the outcomes of the development projects can go to market in many ways and at many times (Chesbrough 2006), as represented in Figure 47.

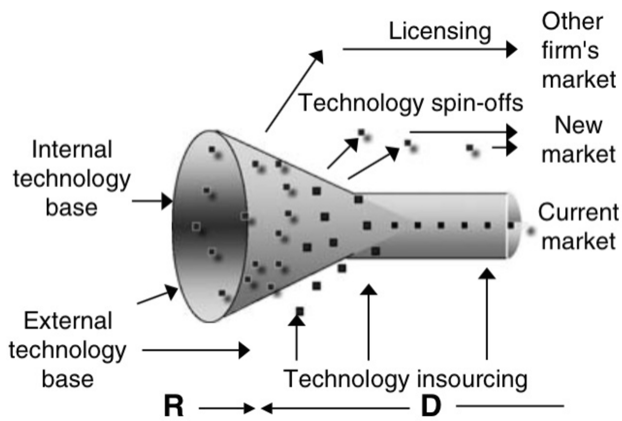


**Figure 47 |** Open Innovation paradigm (Chesbrough 2006)

When inserted in an OI context, companies firstly scan the external technological environment and only then the project is triggered. As represented in Figure 47, if any new external knowledge is available throughout the project, companies can embed it at any time (West, Vanhaverkebe, and Chesbrough 2006). Therefore, literature argues that the borders between companies and their external environment is becoming more porous, enabling innovation to easily move between the company and its surroundings (Chesbrough 2003). Generally, the OI approach is the alternative that allows companies to positively collaborate, and it allows academia and its start-ups to create truly fundamental innovations to the current challenges (Fitzgerald 2015). Due to the current relevance of this new paradigm of innovation, a brief comparison between the OI and the traditional approach is presented in the following sub-section.

### 6.1.1 Traditional Innovation VS Open Innovation

As aforementioned, the past approaches to innovation were naturally closed, with several differences to the actual and open context. Table 21 highlights the major differences between the OI trend and their precedent theories.

**Table 21 |** the differentiating points of the OI approach; adapted from (Chesbrough 2006)

| |
|---|
| 1. Equal importance given to external knowledge, in comparison to internal knowledge |
| 2. The centrality of the business model in converting R&D into commercial value |
| 3. The purposive outbound flows of knowledge and technology |
| 4. The abundant underlying knowledge landscape |
| 5. The rise of innovation intermediaries |
| 6. New metrics for assessing innovation capability and performance |

Firstly, Table 21 highlights the equal importance that is attributed to either internal or external knowledge, even in robust knowledge companies. Additionally, it is argued that the evaluation criteria for the innovation performance should be renewed. Nevertheless, to have a clear and defined OI strategy a match between the overall strategy, and the individual strategies of each company composing the network should exist (Lindegaard and Kawasaki 2010).

Despite the relevant contributions, it is far to say that the OI approach *per se* truly makes an enduring contribution in understanding the whole innovation process (Chesbrough 2006). However, literature has been showing an increased interest in this paradigm, and some research suggests this activity to be a fruitful path for academic studies. Furthermore, the importance of team-learning has been noted as a critical aspect for product success (Carbone 2011) and few studies have analysed the FFE in a collaborative and cross-functional context. Hence, present research assumes a relevant contribution, as it is focused in collaborative approaches to the conceptual stage of the design process. The next section will then extensively analyse the FFE topic, the natural environment of this study.

## 6.2 FUZZY FRONT-END

Notwithstanding the absence of a generally accepted model for the design process (as discussed in Chapter 5), the conceptual stage is one of its common branches. Despite being considered essential decisive in the innovation process as well, the conceptual stage is still the least studied (Bullinger 2008). Conceptualisation and specially the idea *per se* are fundamental to the emergence of new products, and this importance presents a twofold approach. It is critical to project management research, as any new project aims to crystallise new ideas into a well-defined concept and, ultimately, a new product. Also, and due to its creative characteristics, design research has been changing its focus and efforts to the conceptual stage of the design process as well (Sanders 2006, 2010).

In this conceptual stage, ideas are generated, ranked, and selected for further development. Besides, the idea generation *per se* is considered as the indispensable core in the entire process (Smith 1998, Harmsen 2013). Conversely, conceptualisation is sometimes considered as a single step inside the design and innovation process and its study is, in somehow, disregarded. Nevertheless, it is clearly a decisive, iterative and complex stage with a wide space for further studies (Koen et al. 2002). Also, it is considered as the first stage of any innovative process (Bullinger 2008), and management literature generally sequences the innovation process as follows:

1. Fuzzy Front-End (**FFE**)
2. New Product Development (**NPD**)
3. Commercialisation (**COM**) (Deppe et al. 2002, Dornberger and Suvelza 2012, Riel, Neumann, and Tichkiewitch 2013, Markham 2013)

In the above list, the FFE is clearly the least well-known and acknowledged item. However, the difficulties in establish a best practice for the design process emphasise the importance of an extensive research in the FFE as a promising way of improving innovativeness (Council 2007).

Many projects fail due to mistakes or inadequate management over their initial and conceptual stages (Dornberger and Suvelza 2012). Conversely, it is possible to find the least expensive opportunities in improving new product's time-to-market therein (Smith and Reinertsen 1998). As abovementioned, to successfully conduct NPD projects the diversified knowledge of different companies should be early integrated and combined (Carbone 2011, Leen and Lubben 2013). However, literature is still sparse in the study of open approaches applied to the conceptual stage of the innovation process (Jorgensen et al. 2011, Enkel and Heil 2014). This gap in the literature presents an increased relevance for this overall research.

In the 1990s, (Smith and Reinertsen 1998) termed the early stages of the innovation process as the Fuzzy Front End (FFE), with the term *fuzzy* referring to the intangible nature of this particular stage (Jorgensen et al. 2011). Also, the word *fuzzy* indicates the diffuse, creative, dynamic and unstructured activities typical in this early stage (Bullinger 2008). However, when it comes to the creation of new products and technologies, literature considers that it all starts in the FFE (Elverum, Welo, and Steinert 2014). Historically, the importance of the FFE activities was empirically validated in research studies conducted by the Japanese automotive industry in the late 1990s (Verganti 1997). Notwithstanding the perceived importance of the FFE to the overall innovation process, it still is a comparatively under-examined topic (Koen et al. 2001, Koen, Bertels, and Kleinschmidt 2014a, b). The framework illustrated with Figure 48 is behind the perceived neglect over the FFE study.

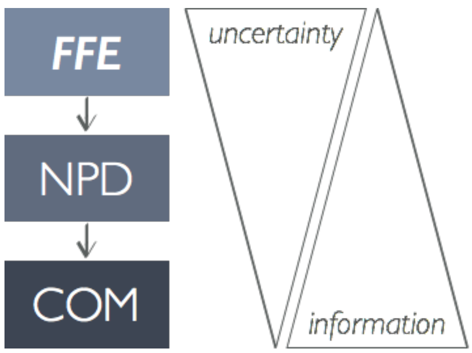


**Figure 48 |** levels of uncertainty/information during the innovation process; adapted from (Deppe et al. 2002)

As the Project Management Institute (PMI) highlights, risk and uncertainty are greatest at the beginning of any project (PMI 2013). However, throughout the innovation process the uncertainty decreases as the level of available information increases (Figure 48). The FFE is clearly the least recognised stage, and no other stage has the same levels of uncertainty, ambiguity and complexity (Deppe et al. 2002, Mootee 2011). Nevertheless, this initial uncertainty is something to be embraced, instead of feared, as without uncertainty no novelty happens (Ford and Woudhuysen 2012), and research on this subject should go even deeper.

Presently, there is no generally accepted definition for the FFE. However, literature generally considers the FFE to start when ideas or opportunities are identified, ending with a decision on whether or not to start a development project (Elverum, Welo, and Steinert 2014). This early stage has a decisive impact in the fate and results of the innovation projects, as allocating more resources therein normally lead to better-executed products (Cagan and Vogel 2013). Also, the appropriate funding, the proper use of the available human resources and the promotion of essential intangible skills are indispensable in the FFE. Therefore, addressing these problems since the project beginning might result in the reduction of the risk of failure in NPD projects (Dornberger and Suvelza 2012). The actual relevance of this stage and the main proposed models for it will be highlighted in the following sub-sections.

### 6.2.1 Relevance of the Fuzzy Front-End

The dynamic and often unstructured characteristics of the FFE assign challenges to its effective management (Kim and Wilemon 2002). Nonetheless, FFE largely determines not only the outcome of the innovation process, as the associated costs, timeframe and required resources. Also, important decisions for the entire project are taken in the FFE, as it is clearly the most influencing stage in the entire innovation process. Figure 49 represents the level of influence, costs, and information throughout the entire innovation process.

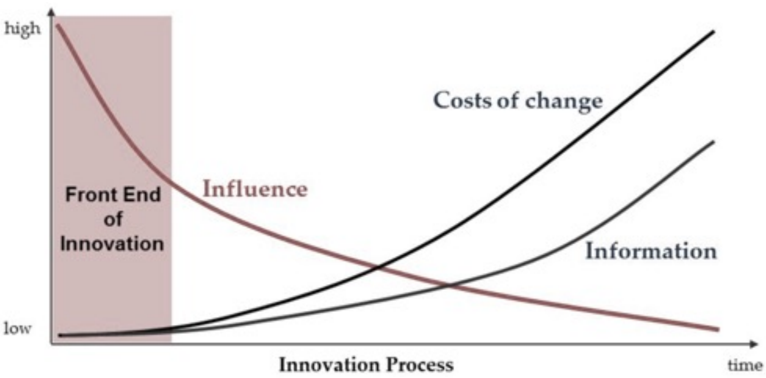


**Figure 49 |** information, costs of change, and influence over the innovation process (Herstatt and Verworn 2001, Dornberger and Suvelza 2012)

As illustrated in Figure 49, the FFE admits the highest influence in the innovation process, with the lowest costs of change. Also, the more inwards with the process, the more money is needed (Cagan and Vogel 2013). As abovementioned, the FFE starts with low levels of information, helping to explain the reason to many companies fail in this early stage. Besides, managers are now stressing the practical need of acting more systematically in the FFE (Riel, Neumann, and Tichkiewitch 2013). The systematic approach of Philips towards the technology epiphanies paradigm, discussed in Chapter 4, is a successful example. Therefore, research aiming at systematically and generally structure the FFE activities, is considered as missing (Verworn 2009, Riel, Neumann, and Tichkiewitch 2013). Also, the referred highest level of uncertainty in the FFE, and the lack of strategies to an effective idea management, assign an increased importance on this systematic study (de Brentani and Reid 2012).

As illustrated in Figure 48, the FFE precedes and influences the NPD. However, while the NPD best practices were already extensively analysed and studied, a similar study for the FFE is considered as missing (Koen et al. 2002). Also, literature argues that methodologies used in NPD won't work in the FFE (Khurana and Rosenthal 1997, Koen et al. 2002). Therefore, in order to emphasise the major characteristics and differences of the FFE and the NPD stages, a comparative analysis is presented in Table 22.

**Table 22 |** generic comparison between traditional FFE and NPD (Koen et al. 2001, Kim and Wilemon 2002, Koen et al. 2002, Dewulf 2013)

| | FFE | NPD |
|---|---|---|
| **State of an idea** | Probable, fuzzy, easy to change | Clear, specific, difficult to change |
| **Nature of work** | Experimental, often chaotic | Disciplined, structured and goal |

| | | |
|---|---|---|
| | | oriented |
| **Features of information** | Qualitative, informal and approximate | Quantitative, formal and precise |
| **Funding** | Variable | Budgeted |
| **Commercialisation date** | Unpredictable | High degree of certainty |
| **Revenue expectations** | Often uncertain | Predictable |
| **Degree of formalisation** | Low | High |
| **Activity** | Both individual and team to minimise risk | Multi-functional development team |
| **Management methods** | Unstructured, experimental, creative | Structured, systematic |
| **Damage if abandoned** | Usually small | Substantial |
| **Measure of progress** | Strengthened concepts | Milestone achievement |

Analysing Table 22, the experimental work, the uncertain revenues, and the unstructured management methods are highlighted as the causing points of the fuzzy character. Literature argues that these points stress the need for an intensive and detailed study over the FFE (de Brentani and Reid 2012). Wrongly, some companies might argue that the FFE stage does not require funding, due to the conceptual nature of the work to be done (Markham, 2013). However, funding is a significant issue, especially in large-scale engineering FFE projects. The social, technical, and organisational complexity of these projects, caused by the involvement of different companies, assign them several risks of schedule and cost overruns (Lucae, 2013). A proper and well-established funding plan is therefore essential in complex NPD projects. Also, multidisciplinary work is not solely considered as taking place in the FFE stage, individual work is stressed as well. For the FFE, the multidisciplinary work is mainly considered in order to minimise and share the risks over a cross-functional team. Additionally, literature argues that the more interdisciplinary work conducted in the FFE the more successful this stage will be, due to the degree of concept refinement to be further in the following stage (Markham 2013). This last identified issue underlines the relevance of the present and generic study.

### 6.2.2 Models for the Fuzzy Front-End

The term fuzzy might wrongly suggest that the early stage of the innovation process is unclear. However, literature argues that the creative problem solving shouldn't be necessarily chaotic (Gaubinger and Rabl 2014). The frame of reference in the FFE argues that, its actual descriptions, aim at the development of a widely accepted model to reduce the referred uncertainty (Nobelius and Trygg 2002). The first comprehensive study for the FFE was proposed in the 1990s (Khurana and Rosenthal 1997), and proposed a systems view for this conceptual stage, as illustrated in Figure 50.

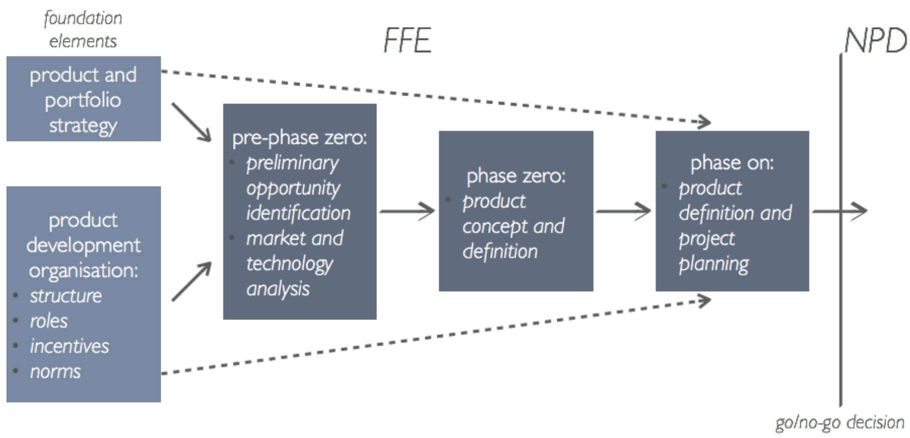


**Figure 50 |** model for the FFE; adapted from (Khurana and Rosenthal 1997)

In this model, it is simultaneously considered the overall strategy together with relevant inputs, such as ideas, market analysis, and technological opportunities. Thus, understanding the interrelationships between all the activities is equally important as the activities themselves (Khurana and Rosenthal 1997). These authors considered both the multidisciplinary, or interdisciplinary, relationships as particularly significant for the FFE. Detailing each phase, companies normally start a new project when they firstly found an opportunity (pre-phase zero). Then, if the newly defined opportunity is worth exploring, a small group is assigned to work on the product concept definition and planning; sometimes suppliers can be included as well (phase zero). Lastly, companies evaluate the business and technical feasibility of the new product, confirming the product definition and planning for the NPD phase (phase one).

Later, in order to create a common language and shared vocabulary for the FFE, (Koen et al. 2001) developed the New Concept Development Model (NCD), analysed in Chapter 5. These two models personify the two conflicting approaches for the FFE, the sequential and iterative. However, due to pros and cons of these two approaches, many researchers are searching for a combination of them, in order to find a structure for this stage (Gaubinger and Rabl 2014). While the model from Khurana and Rosenthal (1997) lacks in flexibility and iterations, the NCD model is considered as highly abstract, which makes difficult its application in industry. Therefore, the proposed model for the conceptual design stage, detailed in Chapter 5, tried to overcome these referred limitations in order to be easily materialised.

### 6.2.3 Current discussion

Currently, there is a permanent and vivid discussion on whether or not this early stage should be formalised or left unstructured (Backman, Börjesson, and Setterberg 2007, Markham 2013, Elverum, Welo, and Steinert 2014). Managing the FFE is a continuous conflict between creativity and systematisation, as too much structure might kill creativity, while scant structuring might negatively affect the FFE performance (Gaubinger and Rabl 2014). Also, Markham (2013) considers that one of the benefits of implementing a structured approach in the FFE is the control of costs and the elimination of unauthorised use of resources. Management literature considers this relationship, between the degree of structuration and levels of performance, to have an inverted U-shape. As illustrated in Figure 51, extreme creativity and excessive structure may have negative effects in the FFE performance (Enkel and Heil 2014, Gaubinger and Rabl 2014).

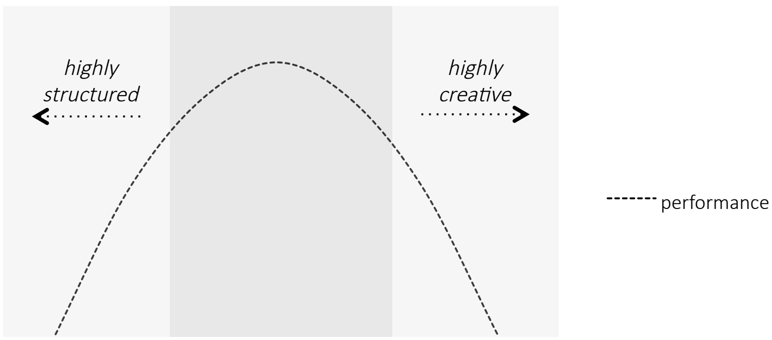


**Figure 51 |** levels of structure and creativity over the FFE performance

The correct balance between the degree of structuration and planning, aided by newly and creative tools for conceptualisation, is one of the objectives behind this study. Generally, literature considers that the term *fuzzy* wrongly suggests that the FFE should be unstructured and chaotic. Yet, creative problem solving and problem seeking processes do not require chaotic conditions, and they can be subject of certain structures and regularities (Gaubinger and Rabl 2014). As represented in Figure 51, a balanced approach between creativity and formality might present the desirable results. According to Kumar (2013), recognising and understanding that innovation can and should be planned is the first and critical step. Besides, a transdisciplinary and planned collaboration can contribute to reduce the technical and market uncertainties, and the ambiguities of the FFE (Schweitzer and Gabriel 2012). This belief might be behind the establishment of many multi-companies and multi-discipline networks.

Generally, literature considers that companies must energise the FFE in order to speed up the whole process, and also states that making the most in the FFE is essential to create real breakthroughs (Smith and Reinertsen 1998, Cagan and Vogel 2013, Gassmann and Schweitzer 2014). Also, external as well as internal sources of ideas should be exploited on a single and continued base in the FFE (Bullinger 2008). These assumptions are aligned with the OI philosophy, and thus underline the importance of these two research areas in the design project supporting this thesis.

## 6.3 DESIGN CASE

Value should be added when a design research program is conducted (Koskinen et al. 2011). Accordingly, the case under study has an international scope, with five different companies composing this network (A to E). Besides, the project was financially supported by the Portuguese Agency for Innovation (F). Company A was the project leader, with responsibilities in the methodology development, guidelines, expected deliverables and guidance in the different project stages', according to companies' knowledge. Companies B-E accepted the plan developed by company A, and, as argued by (Markham 2013), this structured approach in the FFE was aimed to control costs and use of the resources. The description of the different companies involved is presented below (Table 23).

**Table 23** | consortium description

| | |
|---|---|
| **Company A** | An industrial design company<br>It is focused on structuring methodologies for product development and industrial innovation |
| **Company B** | A research and technology organisation in the field of mechanical engineering<br>It is an interface institution of University of Porto, for advanced and mechanical manufacturing technologies |
| **Company C** | Integrates a group with a strong expertise in product design and engineering, computer simulation, prototyping, manufacturing tooling, moulds and automation system |
| **Company D** | An aeronautical Original Equipment Manufacturer (OEM)<br>It represents the main company of the group, with all the capabilities of the value |

| | |
|---|---|
| | chain, from concept, engineering, production and maintenance |
| **Company E** | It belongs to the OEM group, specialising in the manufacture of large composite parts and assembly of complex aero-structures |
| **Company F** | It is the Portuguese Agency for Innovation |

As presented in Table 23, this consortium admits different backgrounds and skills in order to handle with the complexity of the project under study. While Company A is focused in the needs and desires of the passenger, companies B-E have a more technological scope, and are focused in the aircraft requirements and operations. Also, company D admits a strong client focus and knowledge, which encompasses all the passenger issues door-to-door as well.

Literature argues that people, trust and communication are fundamental within an open and collaborative approach in NPD projects (Mu, Peng, and Love 2008, Lindegaard and Kawasaki 2010, Leen and Lubben 2013). Thus, the higher the trust between partners, the better the outcomes of knowledge and technology transfer (Mu, Peng, and Love 2008). Not only did these companies have a successful history of previous collaborations, as most of the individuals involved had worked together before, in most of these collaborations.

In order to create real value around collaborative projects, strategic intentions must be common to all actors (Munksgaard et al. 2012). Strategy has precisely an increased relevance in the FFE, as the bad results over the NPD process are result of bad orientation happening therein (Crawford 1984, Crawford and Di Benedetto 2010). This premise guided Crawford through his initial studies on NPD activities in the 1980s (Crawford 1984). Hence, to understand how a network of companies can strategically collaborate, Table 24 highlights four different strategic intentions for a NPD network.

**Table 24** | four different strategic intentions for NPD networks (Munksgaard et al. 2012)

| | **Existing process** | **Evolving process** |
|---|---|---|
| **Existing structure** | *<u>(1) Current relationships</u>* | (2) Changed relationships |
| **Evolving structure** | (3) New relationships | (4) Changed network positions |

The case under study fits in the first case (the one that is underlined), as all companies have already worked together, and also with similar positions in different NPD projects. However, company E is a new arrival to the ensemble, as no previous collaboration history existed and it brings new considerations and motivations to the consortium (although inside a group context). Suitably, the project under study aimed to develop new configurations for commercial aviation, with a combined focus in both the eco-efficiency and passenger' needs. Existing studies already covered these aspects, yet individually. Therefore, a combined approach, on both interior needs and exterior prerequisites for aeronautical systems, attributed a distinctive character to this project. This way, the team early-identified difficulties in integrating the array of issues covered by a civil aircraft development, such as safety, sustainability and passenger experience, as an inhibiting factor for innovation. This conclusion is aligned with the major OEMs previously identified gaps and concerns.

As abovementioned, in order to provide guidance, timelines and deliverables for each stage of the project, company A defined a detailed work plan early in the project. Despite the perceived strict structure, Company F considered the plan as holistic and flexible enough to reconcile the interior passengers' needs, with the demand for eco-efficiency. Company F acted as a stakeholder, as the current models for the FFE do not address the need, source, importance or sufficiency of funding (Markham 2013). Hence, Chesbrough identified two types of organisations focused in funding R&D projects (Chesbrough 2003), as follows:

1) Innovation investors, who want some portion of future revenues
2) Benefactors, who are focused on the early stages of research discovery.

For this case, company F acted as a benefactor, as it was focused in the results of the research process instead of product development *per se*. Thus, the project was accepted with research and development plans funded for three years. Throughout these three years, monthly meetings took place, with a defined agenda and deliverables for each month, aligned with PMI recommendations (PMI 2013). The monthly meetings happened in the facilities of different companies, and were scheduled one month in advance. Additionally, three major one-week workshops were held. From the first, three major user groups of customers were created using the personas tool, capable o transforming data from the market into a model, and extensively described ahead. From the second workshop, a list of concepts was evaluated and the most promising three were selected. From the last workshop, the needs for each concept were highlighted and assessed, and concepts perceived as relevant for future collaborations were decided upon. The assessment sessions of the third workshop used no specific tool, and were conducted in an open meeting. To collect information from the market many tools were used, such as benchmarking, brainstorming, personas, mind mapping and scenarios. However, the most relevant and distinctive were the personas and the scenario techniques. These two techniques will be analysed in the following sub-section.

### 6.3.1 Context factors and personas tool

Notwithstanding the weight of the personas tool, the market and the technological scenarios were decisive to construct a general and shared future context. According to (Dornberger and Suvelza 2012), the scenario technique allows the analysis of different possible variants of the reality in the future. More than predict the future, design scenarios allow designers to raise questions and issues about it (Milton and Rodgers 2013). Therefore, company D initially shared several documents that it considered crucial, and that would help in the forecast activities for the future of air travel. Some of these documents were developed by a civil aviation flight reservation platform, and are of public release[2]. These documents were distributed to the consortium, before the first workshop, with the objective of creating a shared thinking between the individuals involved in the planned working sessions.

The main conceptualisation technique used in the first workshop was the personas tool. It is a tool capable of transforming data from the market into a subject or a model (Dornberger and Suvelza 2012). Since their introduction by Cooper, the personas tool has been integrated in the design process of many global and prominent firms, such as Microsoft or Sony. Yet, the existing literature on this subject fails to reach consensus on the benefits of incorporating personas into the design process (Miaskiewicz and Kozar 2011). Developed in 1992 by Alan Cooper, personas aims to develop a precise description of the user and what he wishes to accomplish. Despite not being real people, personas represent groups of users, with targeted demographic use, throughout the whole design process (Cooper 2004, Milton and Rodgers 2013). Besides, they are considered as particularly useful during the conceptual stage of the design process (Milton and Rodgers 2013). In the project under analysis, the identified personas represent the archetypes of actual passengers, and also airliners, for the commercial segment. For all the identified personas, the objective is to capture the set of final users for the concepts under development. Also, these personas were considered until the project closure, as suggested

[2] http://www.amadeus.com

by the literature (Cooper 2004, Milton and Rodgers 2013). The list of personas resulting from the first workshop is represented in Table 25.

**Table 25** | the initial personas used in the case study (Consortium)

| Major Groups | Distinctive Groups |
|---|---|
| ***Commercial Persona*** | Committed flyer |
| | Young spirit |
| | Hyper value |
| | Active senior |
| | Bulk-on |
| | Happy family |
| ***Executive Persona*** | Utility |
| | Corporate user |
| | Money maker |
| | Celebrity |
| | Very happy family |
| | Sky emperors |
| ***Airline Persona*** | Low fare |
| | Value for money |
| | Charter |
| | Traditional |
| | Out of the mind |
| | Premium |
| | Regional |
| | Green |

The individuals participating in these sessions where then divided in three groups, with one representative per company. The objective was to hypothesise market requirements and demands for each persona. Simultaneously, a list of future relevant technological drivers was developed, in order to help on these personas characterisation. Then, it was decided to create a blog, using *Tumblr*[3], to share inputs about new and relevant technological opportunities found in websites, magazines, or newspapers. The researcher did blog updates on a weekly basis in-between the first and the second workshops.

From the initial list of personas, represented in Table 25, assessments were then done, in order to highlight the most promising ones for the draw-storming sessions. From

[3] A freeware blog platform

this list of 20 personas, combinations were arranged and a shorter list of 14 personas was highlighted. Later, a discussion was taken around the representativeness of each persona, and 8 personas were considered as generally representative, even for the remaining 6. Company A took draw-storming sessions to create visual concepts for these 8 personas, and the remaining companies then discussed and evaluated them. Due to confidentiality issues, only the first list of personas was presented, as it was already publicly shown. Later, in the second workshop, a detailed evaluation and selection was conducted for each concept. Then, the project team selected the most promising three concepts based on feasibility, market coverage, and perceived innovative character. Each concept received a designation according to its market and shape, as follows:

1. Utility
2. Boxwing
3. V-Tail

Between the second and the third workshops, one-year passed in which the concepts were iteratively developed. The most challenging characteristics were the definition of sizing, propulsion, aerodynamics and geometry of each concept, in order to develop the first 3D models. Additional discussions on structures, interiors and operations were taken for each concept as well. The researcher was not involved as initially within this one-year period. For the assessment sessions of the third workshop, Companies D and E brought mind-maps with technological forecasts for the next four decades. A mind-map is a visual representation of hierarchical information, and it is a good method to create visual representations of words and ideas (Milton and Rodgers 2013). Then, and as argued by Cooper (2004), the specific details of each persona, both in personal or professional terms, were highlighted and matched with the concepts, and it was decided to create an individual storytelling. Likewise, it is the researcher's opinion that the three concepts, resulting from the overall development project, were strongly shaped in the personas discussion and workshop. Each concept was finally materialised in scaled models, which were already presented publically. These models are illustrated in Figure 52, Figure 53, and Figure 54.


**Figure 52** | Utility concept


**Figure 53** | Boxwing concept

**Figure 54** | V-Tail concept

These scaled models were firstly exhibited in a national event, organised by the consortium, which occurred in May 2015. Later, in June 2015, the same models were exhibited in an international air-show, and were positively welcomed. A storytelling video was also created explaining the objectives for each concept, and for the persona behind it. Finally, in order to get a retrospective evaluation from the individuals involved in the whole project development, a questionnaire was created and distributed. The questionnaire structure and results are outlined in the following sub-sections.

### 6.3.2 Questionnaire

The questionnaire (Appendix A) was conducted after the public presentation of the results of the project. It consisted of 23 questions logically distributed, with two types:

1) 18 multiple-or one-choice questions
2) 5 open-ended questions (respondents were asked to give their personal opinions)

Nevertheless, before distributing the final questionnaire to all respondents, a short introduction was made to the four companies represented in one of the monthly meetings attended. This brief introduction specified the main objectives behind this research activity, and a first bulk version was distributed by e-mail to the participants, as proposed by Milton and Rodgers (2013). Only one contacted company didn't reply to this introductory e-mail, but the three other respondent companies gave a positive feedback for a wider distribution of this questionnaire. Then, all the five companies were contacted to explain the questionnaire objectives, with 10 people selected to answer this questionnaire. It was possible to obtain 9 responses (response rate of 90%).

Regardless the small sample, it would not make sense to share the questionnaire with a larger number of people. Each company involved some other elements to collaborate in specific phases of the project; yet, these individuals didn't have a global perspective of the project. The questionnaire was conducted in the Google Docs platform and the responses were confidential, but people were asked to inform the researcher about its completion. Only 2 responses were obtained without any accompanying notification. In order to make the respondents comfortable with the questionnaire no question was considered as mandatory to conclude it. This way, 2 of the respondents did not fully complete it.

### 6.3.3 Questionnaire results

From the first multiple-choice question, which asked the reasons behind the commitment in a project as this, opinions diverged. The results obtained are illustrated in Table 26.

**Table 26 |** the main reasons to be involved in the project

| Hypothesis | Number of respondents |
|---|---|
| Interest in the topic | 7 |
| Previous experiences with the same elements of the team | 6 |
| Future collaborations in other projects | 5 |
| Knowledge sharing between the team | 4 |

Despite the knowledge characteristics attributed to this project to have a low rate, 7 respondents later considered the knowledge brought by the five companies as decisive to the overall project. Instead, only 2 respondents considered that a smaller consortium would achieve, approximately, the same results. Aligned with the expectations for future collaborations, comes the expected development of the three final concepts. In this question, the questionnaire revealed divergent opinions as well (multiple-choice question), as illustrated in Table 27.

**Table 27 |** the expected development of the three concepts

| Hypothesis | Number of respondents |
|---|---|
| The three concepts are promising for further development | 2 |
| Two concepts are promising for further development | 3 |
| Only one concept is promising for further development | 4 |

Therefore, only 2 of the 9 respondents considered the overall project as capable of being further developed; the majority believes that only one concept deserves to be materialised in a new project or new product. Conversely, 8 respondents expect to collaborate again with the entire consortium, and only 1 conceives a future collaboration with only two of members of the consortium.

As abovementioned, this project was aimed to reconcile the interior demands and needs of the passenger (user) with better efficiencies in energy and environment (technology). The opinions over the creation of value in this project, either in technology and passenger focuses diverged as well (multiple-choice question), as represented in Table 28.

**Table 28 |** perceived value created with this project

| Hypothesis | Number of respondents |
|---|---|
| A combined value was created as planned (the social component prevailed) | 7 (2) |
| No added value was created to the technological and social paradigms | 2 |

As represented in Table 28, 7 respondents considered that this project created value in both the social and technological landscapes. Also, among these respondents, 2 considered that the social component prevailed over the technological one. Nevertheless, no respondent considered that this project had created isolate social or technological value.

As companies have different knowledge bases, 7 respondents admitted the existence of different understandings and perspectives over the project. Also, the design management role and holistic vision of Company A were highlighted. Despite the different perspectives over the project, 8 respondents believe that a balance between the different disciplines in collaboration existed. Also, 6 respondents considered these different perspectives as decisive for the project development. Regarding these different perspectives, 5 respondents identified the existence of clear contradictions throughout the project. However, only 2 of the respondents clearly identified these contradictions. On the one hand, the dichotomy user/requirements was highlighted; and, on the other hand, the dichotomies efficiency/velocity and shape/comfort were underlined. Nevertheless, the most diverging point lies in the number and characteristics of the monthly meetings taken during the project (multiple-choice question). These results are presented in Table 29.

**Table 29 |** characteristics of the monthly meetings

| Hypothesis | Number of respondents |
|---|---|
| Decisive | 5 |
| Insufficient | 2 |
| Excessive and pointless | 1 |
| Not answered | 1 |

Interestingly, 1 respondent that considered the meetings insufficient in number advised the adoption of virtual meetings, to reduce the associated costs. When the respondents were asked to identify the major innovations brought by this project (open-ended question), the opinions naturally diverged as well. These results are presented Table 30.

**Table 30 |** major innovations brought by the project

| Hypothesis | Number of respondents |
|---|---|
| The structured and combined methodology | 5 |
| The Utility concept | 3 |
| The three final concepts | 1 |
| The personas tool | 1 |
| The concepts selection process | 1 |

| | |
|---|---|
| Not answered | 2 |

Besides, 7 respondents considered these innovations to be impossible to achieve without the collaboration of the entire consortium. The other 2 considered that these same results could have been achieved with the specific knowledge of a small number of companies. The most converging point was the opinion about the previously structured and defined methodology; 8 respondents considered it as adequate and only 1 found it excessively structured. Besides, 5 respondents considered this same methodology as decisive for the overall project course, and 6 considered it to have a decisive character in obtaining the external funding. Also, in the opinion of 7 respondents the initially set-up plan was met.

Literature considers that cross-functional collaborations are unique in character, and present challenges in broadly conclude and generalise from them (Schweitzer and Gabriel 2012). Nevertheless, some major common opinions were traced and summarised in Table 31.

**Table 31 |** major consensus in the questionnaire

| **Propositions** | **Number of Respondents** |
|---|---|
| Expectations in collaborate again with the entire consortium | 8 |
| Adequacy of the previously structured methodology for concept development | 8 |
| Balance between the different disciplines in collaboration | 8 |
| Importance of the knowledge brought by the five companies involved | 7 |
| Value created in both the technological and social landscapes | 7 |
| Existence of different perspectives over the project | 7 |
| Capacity to meet the initially set-up plan | 7 |
| Decisiveness of these different perspectives | 6 |
| Decisiveness of the referred methodology in obtaining the funding | 6 |
| Previous experiences are important to new collaborations | 6 |

As the total of respondents was 9, a minimum of five matches represents a majority. However, as the questionnaire was not fully completed, a minimum of six similar answers was considered for Table 31. The expectations in collaborate again with the consortium, the adequacy of the used methodology, and the achieved balance between the companies were the most converging points; 8 respondents considered the three.

### 6.3.4 Design case discussion

As initially referred, short attention has been given to the FFE in an OI context. As well as the difficulties in managing cross-functional collaborations, the presented case study has the *fuzzy* character associated with any FFE. The entire project had a conceptual and explorative scope, as it was aimed to the development of new concepts for hypothetical further development. Generally, companies adopt a shared focus in the FFE when they want to enhance their knowledge sharing, and their innovative skills (Enkel and Heil 2014). Nevertheless, only 4 respondents considered participating in this project as a means for a knowledge sharing approach. Simultaneously, literature argues that trust and communication between partners are the fundamentals of any NPD network (Mu, Peng, and Love 2008, Lindegaard and Kawasaki 2010, Leen and Lubben 2013). Therefore, it is important to highlight that the results of this project led 8 respondents to think in collaborate again with the entire consortium. Also, 6 respondents considered that the previous experiences with the same elements of the same companies were decisive.

From this study initial objective, on whether or not to structure and plan conceptual projects, the results of the questionnaire were clear: 8 respondents emphasised the benefits of an initially structured plan in cross-functional contexts. Yet, the remaining respondent highlighted the excessively structure of the previously defined plan. This divergence is aligned with the abovementioned continuous conflict between creativity and systematisation (Gaubinger and Rabl 2014). On the other hand, literature normally neglects funding as a relevant issue in the FFE research as well (Koen et al. 2001, Kim and Wilemon 2002, Koen et al. 2002, Markham 2013). However, 6 respondents considered that the previously structured methodology was decisive in obtaining the external funding. Notwithstanding its conceptual character, the project followed a set of steps, with well-defined guidelines and deliverables, as for the NPD projects *per se*. This methodology was considered as having a distinctive character by 4 respondents, and was considered as valuable for Company F to fund the project. Conversely, the planning, usefulness and characteristics of the monthly meetings were diverging points, as opinions spanned from their insufficiency to decisiveness. Besides, virtual meetings were suggested for future projects, in order to reduce the associated costs of commuting between companies' facilities in a monthly basis.

As abovementioned, company A has a design perspective, while companies B-E have an engineering approach. Nevertheless, 7 respondents considered that a balance between the different knowledge bases was achieved, and only 2 considered that the social scope prevailed over the technological one. Company A was the project planner and leader; thus, the researcher was expecting this social prevailing to be more considered inside the respondents. Also, 5 respondents admitted the existence of clear contradictions in this project, but only 2 identified them in a very low response rate. The open-ended characteristics of this question might be behind this low response rate. The identified contradictions spanned from the passenger focus and comfort, to the aircraft requirements, speed and shape. Therefore, these contradictions are very relevant for the present research, but this low response rate makes generalisations difficult.

Finally, the achieved concepts were not considered as equally promising, and only 2 respondents considered them as promising for future developments. Besides, 3 respondents considered two concepts as promising, and 4 respondents considered that only one concept is worth developing. This is aligned with the 2 respondents that considered the achieved three concepts to be driven by less than five companies, which attributes a different degree of involvement to companies. Also, 2 respondents considered the combined and structured methodology and its tools, namely the personas, as attributing distinctive character to the project.

## 6.4 CONCLUSIONS

There is a gap regarding the application of collaborative approaches to the conceptual design stage, and this study gave new insights to this area of research. From this research specific objective, of understanding the importance of an interdisciplinary and structured approach for the conceptual design stage, the results of this case were clear. Correspondingly, 8 respondents considered the previously structured methodology as decisive, and 5 respondents considered it as the major innovation produced by the project. Regardless the unique character of this case study, it is possible to advance that in cross-functional collaborations an initial and integrative plan would help the diversified perceptions towards the developing project. Nevertheless, from the conducted observations it might be said that the perspective of the project leader (company A) prevailed in specific occasions, unlike the results of the questionnaire. Therein, only 2 respondents considered the social perspective as having prevailed over the technological one. Nevertheless, open projects might be useful for companies in this consortium, as they help to maintain a continued innovation strategy, a decisive factor for companies to remain competitive.

Funding is sometimes neglected in the FFE research. Conversely, the project under analysis benefited from a financial support from a benefactor company. This benefactor perceived value in the collaborative and cross-functional team as it allowed the access to a diversified knowledge, and thus supported the project. Also, 6 respondents considered that the early-established commitment inside the consortium was decisive in obtaining the required funding. Therefore, a structured approach might be useful to obtain external funding as it increases the reference points of the funding institution. Following the DRM guidelines, the insights obtained with this empirical analysis will be the then tested in a non-industrial environment. Hence, an isolated design experiment was conducted with students and recent graduates of different disciplines involved in product development, and it is presented in Chapter 7.

# 7 EXPERIMENTAL STUDIES ON THE PROPOSED METHOD

As already mentioned, design researchers are increasingly recognising the importance of empirical studies. Accordingly, and following the Design Research Methodology (DRM) guidelines, an empirical design experiment with students and recent graduates, covering different disciplines, was conducted. Generally, the design experiments are developed as a means to test and evaluate educational designs based on principles derived from prior research (Collins, Joseph, and Bielaczyc 2004). Therefore, over the last four decades, researchers have used design experiments to explore the working practices and performances of individual designers and design teams (Cross 2011, Cash et al. 2012). However, there is a current challenge of improving the quality of these empirical studies (Blessing and Chakrabarti 2009). As such, both experienced and inexperienced designers, or design teams, have been studied by means of empirical studies

(Cross 2011), to validate the results. The study presented in this chapter pretends to give additional insights to this area of research. As design is a social activity, designers in industrial environments generally work in teams or in permanent contact with others (Dwarakanath and Blessing 1996). Also, design education should be focused in teaching design students how to better function in design teams (Dym et al. 2005), in order to better prepare them to industrial environments. Hence, as the research supporting this experiment was focused in interdisciplinary design teams, this design experiment follows a similar and collaborative strategy.

The model of teamwork in design is relatively recent, and had its origins in the scope and complexity of many design tasks. Simultaneously, the need of multiple expertise and division of labour reinforced the use of design teams (Goldschmidt 1995). Therefore, the last two decades of both design research and practice were increasingly focused in the understanding of how designers try to solve design problems in a collaborative way. Generally, literature proposes systematic approaches to design to optimise results; yet, empirical research revealed that designers rarely follow methodologies normatively prescribed (Stempfle and Badke-Schaub 2002). Nevertheless, it is now more interesting to understand how planned and unplanned actions are handled within a team, even if literature considers that teamwork is prone to the emergence of several conflicts between the team members (Cross 2011). The standard to improve the quality of these empirical studies has been the development of large-scale statistical studies. However, these studies are very time/resources consuming, which is not always appropriate and are barely used in design research. Therefore, the technique that has been widely used is the small-scale studies (Cash et al. 2012). Although small-scale studies could not substitute large-scale validation, they are useful to understand new trends, and can give different insights into design situations (Cash 2012). Accordingly, a small-scale design experiment was conducted, and this chapter analyses it.

Literature argues that any experiment starts with the formulation of a hypothesis (Saunders, Lewis, and Thornhill 2009, Cash et al. 2012). The hypothesis behind this experiment had its roots in the extent literature review, and was partially validated in the design case discussed in Chapter 6, as follows:

1. ***A structured approach in the conceptual design stage benefits the interdisciplinary dialogue***

To test this hypothesis different teams were given the task of discuss future aircraft concepts, aligned with the study presented in Chapter 6. Therefore, two main objectives rose from the advanced hypothesis:

1. To understand the benefits of an interdisciplinary approach in the conceptual stage of the design process
2. To test a proposed model for this stage (Chapter 4)

Accordingly, five design teams were asked to discuss, generate, and evaluate new concepts for future aircrafts, in order to test the referred hypothesis and achieve the listed objectives. Objective 1 means that all teams were asked the same thing, with no distinctions made depending on the different backgrounds, to fade possible disciplinary boundaries. Objective 2 means that the proposed model for the conceptual stage of the design process (Chapter 4) should be tested and evaluated. This chapter is an extended version of the paper "Interdisciplinarity and Design Conceptualisation: Contributions from a Small-Scale Design Experiment", presented in the 20th DMI: Design Management Institute Conference held in Boston, MA (28-29 July 2016).

## 7.1 EXPERIMENTAL SETUP

In NPD projects, it is a common practice to initiate a new work, or a new task, with a collective ideation session, or with a brainstorming session (Goldschmidt 1995). However, and when compared to a traditional brainstorming session, an ideation session is a more structured technique. It brings together people with different backgrounds and encourages building on each other's ideas (Kumar 2013). This was precisely the main objective behind this experiment, to eliminate the perceived disciplinary boundaries, and explains the choice of this method. Table 32 summarises the way to proceed in order to conduct an ideation session.

**Table 32 |** how to create an ideation session; adapted from (Kumar 2013)

| **1. Plan the ideation session** |
|---|
| Define what is to be achieved |
| Prepare guidelines describing rules of engagement, how teams should interact, structure their time, and assign the tasks |
| Create a plan with a goal statement, a compact schedule, and arrange an inspiring space |

| | |
|---|---|
| **2. Select the participants** | |
| Involve the right combination of people for the sessions | |
| **3. Organise insights, principles, and frameworks to guide ideation** | |
| Define how to present these insights, and how they should be used during the sessions | |
| Organise them as reference materials for the ideation sessions | |
| **4. Create a comfortable environment for the sessions** | |
| Create an environment that is conducive to creativity | |
| Provide a space the teams can work comfortably | |
| Make sure the basics are covered (sticky notes, pens, paper, e.g.) | |
| **5. Start the session and facilitate activities** | |
| Facilitators play an important role | |
| **6. Generate Concepts** | |
| The focus should be on producing as many concepts as possible | |
| Confine the ideation time (45minutes-2hours) | |
| **7. Capture and Summarise** | |
| Each concept is captured or summarised in a single page | |
| Compile all concepts into output documents that can be later shared | |

The seven steps proposed by Kumar (2013) were generically followed and are detailed in the following section, as the procedures varied depending on the team. As abovementioned, this experiment consisted of five teams, each made up of three participants. All the teams were given the same briefing (Appendix B) containing data on three main topics, as follows:

1. Three personas (utility, celebrity and commercial)
2. A social and technological context (sustainability, connectivity, personalisation, experience, comfort and mobility)
3. Alternative aircraft configurations (blended wing-body, flying wing, box wing, canards, oblique flying wing, tandem wing, twin boom, double fuselage, v-tail)

These elements were collected from the design case presented in Chapter 6. Also, this briefing specified the objectives for the design experiment, and encouraged the participants to be as creative as possible. No feasibility issues were discussed, due to the complexity of the aeronautical topic. Despite the focus on the external configurations, care was also taken to include user insights to encourage a holistic idea generation process. Also, the short duration of the experiment, only two hours, necessarily called for specific user insights to avoid the risks of a non-fulfilment of the exercise. Firstly, all design activity was focused in the briefing, with no physical artefacts for the participants to interact with. This lack of physical interaction was done to allow the monitoring of the design activity, making it easier to manage and review. Secondly, the facilitator was not allowed to answer the participant's questions concerning ideation *per se*, only questions concerning the general experience were answered. This reduced the possible variations between the different teams as well as possible personal and research insights from the experiment controller. The role of the facilitator was to present the briefing documents for the participants, and to manage the progress of the experiment. As the researcher and the facilitator were the same individual, it was important to take as much notes as possible during the different sessions.

As referred, the teams were given two hours for the whole experimental task. They were both asked to develop as much ideas as possible, to assess them, and to present the final results. Table 33 details the equipment used in the experiment.

**Table 33 |** generic breakdown of experimental equipment

| Equipment | Description |
|---|---|
| Video | 1 camera |
| Audio | 2 microphones (one external for the camera, and the one from the laptop) |
| Notes and Sketching | A4, A3 paper, and 4 different colour pens and markers (the usage of these different colours varied depending on the teams)<br>Sticky Notes |
| Computer | Access permitted to the Internet (the accessed feed was then reviewed) |

It is important to highlight that, depending on the team, the access to the different colour pens was conditioned. These experimental details will be explained in the following section. Also, all the five teams had a computer with the sent briefing, and with permanent access to Internet, to any further research they wanted to take. Figure 55 illustrates one of the five teams during its ideation session.

**Figure 55 |** example of one of the teams during its session

Literature argues that a key factor in the design and analysis of the empirical studies is the characterisation and measurement of the ideation effectiveness. It also proposes four different criteria to measure ideation effectiveness:

1) Novelty of the ideas generated
2) Variety of the ideas generated
3) Quality of the ideas generated
4) The effectiveness of these ideas (Shah, Smith, and Vargas-Hernandez 2003, Cash 2012)

Firstly, novelty measures how unusual or surprising an idea is, when compared to others. It is important to note that not every new idea is novel, as it can be considered unusual only in some degree. Then, variety measures the explored space during the idea generation process. The generation of similar ideas indicates low variety, and reduces the likelihood of came up with better ideas in other areas. In this context, quality measures the feasibility of and idea and how close it is to congregate the design requirements. Finally, quantity is the amount of ideas generated (Shah, Smith, and Vargas-Hernandez 2003). Unfortunately, no expert in the aeronautical sector was able to analyse the data, and thus the quality measure was not considered for this study.

Additionally, ontologies obtained from the design case were selected as means to qualitatively assess the different sessions. Ontology is a term used to refer to the shared understanding of a specific domain of interest. Also, it necessarily entails a specific view of the environment, with respect to a given problem (Uschold and Gruninger 1996). In this study, the ontologies considered for the assessment of the sessions, were directly related with the initial briefing, as follows:

1) Personas
2) Context Factors
3) Configurations

These three topics were presented in the briefing distributed to the different teams, and were used as criteria to comparatively analyse them. Additionally, the team behaviour, or the coordination between the different elements, was analysed and assessed.

### 7.1.1 Team formation

Three teams were selected by direct and personal invitations, while the two other teams were composed of volunteers of the Master's Program in Product and Industrial Design at the Faculty of Engineering, University of Porto. Notwithstanding the referred personal effort in the formation of three teams, the selection criteria were previously well established, according to the objectives behind the experiment. Therefore, and as suggested in Table 32, different backgrounds were selected, to test the hypothesis and to reach the experimental objectives.

From the literature, it seemed necessary to have the activities well planned in order to fit the project in the available time, whether working alone or in a team. Therefore, to understand how planned and unplanned actions are handled within a team, gained in interest (Cross 2011). Accordingly, the experiment consisted of different ideation sessions to test different situations. All participants had academic or professional experiences in development disciplines, and in brainstorming sessions. Also, different combinations of academic and professional backgrounds were tested in this experiment.

### 7.1.2 Team size

A second key decision was team size. Usually, larger teams tend to take longer to reach a decision and require a clear, and *a priori*, leadership to be effective. Instead, smaller teams show higher levels of tension, but normally do not settle quickly on a single idea. This referred dichotomy behind small-teams attributes them several advantages when facing a creative problem-solving approach (Cash et al. 2012). Besides, the amount of resources and time to prepare and analyse will be greater the higher the team, as initially discussed. Accordingly, Table 34 summarises the advantages and disadvantages of having 1-5 elements per team.

**Table 34 |** team size advantages/disadvantages matrix (Cash et al. 2012)

| **Team size** | **Participants needed** | **Recording method** | **Advantages/Disadvantages** |
|---|---|---|---|
| 1 | 5 | Concurrent verbalisation | A single strong/weak participant may affect results<br>Not a suitable representation of industrial teams that are normally three or more people in this situation |
| 2 | 10 | Listen to discussion | A single strong/weak participant may affect results<br>Two people removes the need for verbalisation as their discussion can be easily recorded |
| *3* | *15* | *Listen to discussion* | *Strong/weak participants are balanced amongst other team numbers*<br>*Participant discussion is easy to follow*<br>*No parallel discussions possible* |
| 4 | 20 | Listen to multiple discussions | Strong/weak participants are balanced<br>Greater idea generation potential<br>Multiple parallel discussions may be hard to follow<br>Lots of people required |
| 5 | 25 | Listen to multiple discussions | The same drawbacks and benefits of having 4 people per team<br>Yet, literature suggests they would also require formal team leadership to be most effective |

From the data presented in Table 34, and despite the greater idea generation potential of greater teams, three elements were chosen (represented in italic). While teams of one or two wouldn't be representative due to lack of discussion, teams of four and five would complicate the data analysis for one single person. However, the use of small teams can be seen as a drawback, as they are not representative of real industrial situations, with many persons normally involved in one project (Cash et al. 2012). Hence, generalisations from academic teams to industrial design teams have be to done with caution. Still, literature argues the need for the laboratory studies usage for the sake of the methodological rigorousness (Stempfle and Badke-Schaub 2002). This was precisely the guiding principle of this experiment, to methodologically validate a specific worldview.

## 7.2 EXPERIMENTAL PROCEDURE

The intention of this experimental procedure was to give each team comparable activities, but simultaneously to allow the analysis of different test conditions. Accordingly, the five teams were given the same main tasks:

1. To generate as much as ideas as possible for new aeronautical concepts
2. To combine, or select, from these ideas the three considered as more promising

Additional information was provided to three of the five teams, namely a structured guideline for the two hours of the session. The description of the different teams, and their composition, is outlined in Table 35.

**Table 35 |** teams setup

| Team | Elements | Comments |
|---|---|---|
| **A** | 26 year old PhD candidates, with a design background (x2)<br>50 year old design professor | Team A had a structured approach for the session<br>The PhD candidates were colleagues of the researcher<br>They firstly contacted the 3rd element in the session<br>This element has a long professional experience<br>3 Female |
| **B** | 19 year old mechanical engineering students (x3) | Team B didn't use any structure<br>An open exercise<br>Three colleagues in the second year of the mechanical engineering bachelor<br>3 Male |
| **C** | 22 year old student (design background)<br>25 year old student (mechanical engineering background) | Team C have a structured approach for the session<br>Colleagues in the 2nd year of the masters program in product and industrial design<br>The older element has a master in mechanical engineering as well |

| | | |
|---|---|---|
| | 26 year old student (mechanical engineering background) | 2 Male/ 1 Female |
| **D** | 30 year old product design<br>31 year old architect<br>31 year old electric engineer | Team D didn't use the proposed structure<br>An open exercise<br>Long-time friends<br>Friends of the facilitator/researcher as well<br>Less than five years of professional experience<br>2 Female/ 1 Male |
| **E** | 21 year old student (design background)<br>22 year old student (mechanical engineering background)<br>22 year old student (design background) | Team E had a structured approach for the session<br>They are recent colleagues in the masters program in product and industrial design (1st year)<br>2 Male/ 1 Female |

Prior to the study, all participants received by e-mail the basic information outlining the size of the teams, the length of time involved and the objectives for the study. Also, the briefing sent contained relevant information on different topics, such as market, context factors, and possible configurations.

As represented in Table 35, there are four academic teams and one non-academic team. Accordingly, the sessions for teams A, B, C and E took place in the same room of the Faculty of Engineering, University of Porto (DEMec). Instead, the session for the team D happened outside the academic environment. Three teams (A, C and E) have a structured approach for the two hours session, and only two teams (A, B) are composed by elements of similar background. This was done to test, and comparatively analyse, the different conditions proposed as objectives for this experiment. Accordingly, teams A, C and E had their session divided into four phases, aligned with the model proposed in Chapter 4.

**Table 36 |** the subdivision of the sessions for teams A, C, E

| Phase | Characteristics | Time |
|---|---|---|
| Analysis | It is expected that the team discusses the data in the briefing | 15' |
| Synthesis | It is expected that the team starts to discuss and conceive as much ideas as | 60' |

| | | |
|---|---|---|
| | possible | |
| Evaluation | It is expected that the team assesses the ideas and choose the most promising three | 30' |
| Communication | It is expected that the team details the chosen three concepts | 15' |

Before the session, teams A, C and E were briefed on the expected structure for the session. It was noted to these teams that the time intervals indicated in Table 36 are the maximum available time per phase. Accordingly, if the teams felt comfortable with the achieved outcomes, they are allowed to call the facilitator and move on to the next phase at any time. Teams B and D were informed that they could coordinate and organise the two hours session as they preferred, but that the objectives were to generate as many ideas as possible, and to select the most promising three. As argued by Kumar (2013), the overall ideation session should take two hours, with the most creative phase occupying half of it (one hour). Participants were not aware of this division until after the session, and thus each session started with a small introduction.

### 7.2.1 Analysis

As referred, after a five-ten minutes introduction, in which the facilitator explained the objectives and the conditions for the experiment, as well as answered to any existing doubts, the sessions started. Teams A, C and E received A4 paper, sticky notes, and blue pens, while teams B and D could use all the available material since the session beginning. The absence of restrictions concerning the material usage for teams B and D maintained throughout the experience. Also, a notebook with the received briefing and with access to Internet was made available for the entire session. For the structured team, phase 1 is expected to have fifteen minutes duration. Teams B and D had no structure, and the four phases detailed subsequently do not apply to them.

### 7.2.2 Synthesis

For phase 2, teams A, C and E received black markers, and the initially distributed blue pens were removed from the table. No additional comments were made, only a refreshment of what was expected to happen in the following sixty minutes. Either the already used A4 papers or the sticky notes remained in the table.

### 7.2.3 Evaluation

For phase 3, the same teams received green markers, and the black markers were removed. Only small comments remembering that this phase is expected to have a selection of the three most promising concepts were done. As for the phase 2, either the already used A4 papers or the sticky were not removed from the table. This phase was expected to lasts thirty minutes.

### 7.2.4 Communication

For phase 4 no restrictions were made concerning the material usage, and three A3 papers were distributed. The facilitator remembered the teams to draw or annotate their chosen ideas on single sheets of A3 paper, one idea per sheet. They were specifically told that the idea must be understood based on this piece of paper alone. This phase was expected to lasts fifteen minutes.

### 7.2.5 Final notes

The facilitator was the same in the four sessions, and his behaviour was passive, he was there only to manage the session, to observe and to take some notes. The different teams had no contact among them; in fact, they were composed of people that are not familiar to each other. Also, the different sessions were not conducted consecutively; they were planned according to their elements availability. Except from team A, the order in which the sessions were carried out was randomised. Team A was initially idealised as the really the first team, in order to obtain some feedback on the limitations of the session. Accordingly, the suggestion of making available different colours for the sticky notes was accepted.

Also, a short questionnaire was distributed to all teams after each session. The idea was to have additional insights on the experiment through the eyes of the different elements involved in it. The assessment of the different sessions, whether with structure or without it, suggestions and limitations encountered, and the briefing effectiveness were issues in this questionnaire as well.

## 7.3 RESULTS AND DATA HANDLING

Each of the five sessions produced video and audio recordings, as well as many sketches or notes, three final ideas/concepts per team, and three questionnaires per session. For teams A, C and E, notes at different phases were differentiated by changing the colour of the participants' pens at the start of each phase. This allowed the notes to be aligned with the different recordings, and also let the researcher separate initial ideas from latter additions. For teams B and D, this differentiation didn't happen.

The criteria used to assess the teams' performance were the total number of ideas (aircraft and passenger focus), the variety of ideas, and the novelty of these ideas. Also, the connections made with the given data, namely in market, context and possible configurations, were comparatively analysed. Finally, the way in which each team behaved was comparatively evaluated as well. Regardless the major qualitative focus of the overall experiment, a quantitative assessment was performed to capture the amount of discussed ideas per team. Care was taken to guarantee that each idea was only counted once, as the same ideas was often discussed, noted, and later recalled again. The following sub-sections will minutely detail the assessment of the different sessions, based in direct transcriptions from the audio and video analysis. For the qualitative study the assessment was conducted as follows:

a) ---+ (Weak)
b) --++ (Sufficient)
c) -+++ (Good)
d) ++++ (Very good)

The results will be then comparatively discussed in order to obtain any conclusion or possible generalisations. Concerning the briefing elements, it was directly said to all teams that they are not obliged to follow them, and that they could build their own market or context. Nevertheless, the way the teams used the data was comparatively analysed as well, as these data represented the only common elements to all teams.

### 7.3.1 Team A

As detailed in Table 35, Team A is composed by elements having a design background, despite the higher professional experience of the older element. Therefore, this team was asked to be as creative as possible, and simultaneously to follow the proposed strategy for the conceptual design phase.

**Table 37 |** evaluation of team A session

| | | | |
|---|---|---|---|
| **Briefing** | Personas | ++++ | "At the end we'll have 3 completely different aircraft"; "An aircraft for each persona" (7'/phase 1)<br>"The personas should serve as inspiration, not as restriction" (2'/phase 2)<br>"Let's take another look to our personas" (45'/phase 2) |
| | Context Factors | -+++ | "Pedal in the wing in order to accumulate energy" "Those who pedal more seat in the window" (40'/phase 2); "Energy efficiency, more active persons" (40'/phase 2); "New technologies can allow personalised seats" (55'/phase 2) |
| | Configurations | ---+ | "The interior will influence the exterior" (6'/phase 2); "In which way these passenger ideas will influence the external configurations? In no way…" (20'/phase 2); "We should think on the exterior…" (57'/phase 2) |
| **Quantity** of ideas | Passenger | ±20 | |
| | Aircraft | ±18 | |
| **Variety** of ideas | | -+++ | "External camera to take photos" (2'/phase2); "a transparent dome" (8'/phase 2); "natural materials" (55'/phase 2); |
| **Novelty** of ideas | | -+++ | "Individual seats through the wings" (4'/phase1); "shared taxi in the post-flight" (20'/phase 2); "central body, and then two individual aircrafts" (35'/phase2) |
| **Methodology** | Analysis | 15' | Yet, the analysis of the briefing still continued in the following phase |
| | Synthesis | 57' | Clearly, the most creative part of the session It ended with a generic idea of the final outcomes |
| | Evaluation | 28' | A clear assessment phase, in which some ideas were ranked and combined as expected |

| | | | |
|---|---|---|---|
| | | | Also, some new ideas came up with this referred combination |
| | Communication | 15’ | Tasks easily distributed, and only one team element prepare the final concepts |
| **Team Interaction** | | ++++ | Very interactive and creative session, with clear objectives and tasks assigned |
| **Session Completion** | | ++++ | The four phases were clear<br>Three different concepts were presented |

The given personas were the starting point for the session, and guided the agenda of team A. As this team has a design background its discussion was mainly in the passenger and the ideas appeared accordingly. However, the team was able to cover and discuss different areas during the ideation process. Also, the context factors were discussed point by point, and the “experience” of flying was mentioned many times throughout the session. Accordingly, the flight experiences of the elements of this team served as a basis for many discussion periods. Aligned with the design background of the team, the thinking process was always from the inner space of the aircraft to its outer space. This team opted to not use the Internet research, and the given configurations were only slightly reviewed. The analysis and the synthesis phases were clearly iterative.

Interestingly, team A was the only to leave the table and took advantage of the entire room. Figure 56 illustrates the third phase (evaluation) in which the elements of team A attached the created concepts to the wall. This task was done in order to have a generic overview of the concepts, to combine, and to assess them.

**Figure 56 |** team A performing during the evaluation phase

In this phase, this team came up with a keyword for each of the concepts that were materialised in sketches. This team was the one to produce a larger number of sketches in the second phase (synthesis), with 17 pages drawn in black (the colour used for this phase). Also, some notes in these sketches were then made in the following phase in green (the colour used for the evaluation phase), and as represented in Figure 56. This combined attitude attributed a distinguished character to team A, from all the five teams that composed the design experiment. As discussed in Chapter 4, the evaluation phase is decisive in the design process and increases its creative character, due to the unusual connections that can be made (Best 2010). Finally, it is important to highlight that this team tried to organise itself since the beginning, and the different tasks to perform were naturally distributed.

### 7.3.2 Team B

As described in Table 35, young mechanical engineering students composed team B. Accordingly, this team was asked to be as generative as possible, and to use the two hours in the way they feel more comfortable.

**Table 38 |** evaluation of team B session

| | | | |
|---|---|---|---|
| **Briefing** | Personas | --++ | "The persona 1, and the persona 2 can be covered by a single concept" "Otherwise, we can try to make a plan that covers all the three personas" (2') "So, we can have 6 concepts: long trips (fast and slow), short trips (slow and many people) (…) the recreational (zeppelin and glider)" (10') |
| | Context Factors | --++ | "Sustainability is covered, personalisation also, experience and comfort are covered as well, we miss in mobility and some others…" (1h23') |
| | Configurations | ---+ | The web research started immediately at the 3rd minute of the session |
| **Quantity** of ideas | Passenger | ±2 | |
| | Aircraft | ±44 | |
| **Variety** of ideas | | -+++ | "Zeppelin" (7') "Ionic engine"(25'); |

| | | | |
|---|---|---|---|
| | | | “modular aircraft (30’); “a Titanic with memoire”(31’); “photovoltaic ink” (43’) |
| **Novelty** of ideas | | ++++ | “LEGO aircraft” (46’); “a magnetic catapult” (1h3’); “Magnus effect” (1h19’) |
| **Methodology** | Analysis<br>Synthesis<br>Evaluation | 1h32’ | These three phases were intuitively iterative with no clear borders<br>Each new idea was immediately assessed<br>Accordingly, many ideas immediately felt in the session |
| | Communication | 25’ | The team started to draw the final concepts in silent<br>Only two elements interact in this phase<br>Yet, each final concept is discussed |
| **Team Interaction** | | -+++ | A very quiet and productive session<br>Some moments of parallel tasks |
| **Session Completion** | | -+++ | Three new concepts were clearly achieved<br>No real assessment of the concepts |

In a complete opposition to the previous team, the Internet research almost triggered the experiment of team B. Many documentaries, news, and research previously conducted were referenced by its elements. Having an engineering background, this team mainly discussed the aircraft requirements and the passenger was somehow neglected. Nevertheless, they produced 12 pages of sketches before the final phase of the session, using the different available materials (Teams B and D had no restrictions on that). Initially, the personas kept the attention, but before the first hour this team decided to leave them and create a new segment of market, the recreational flights, as illustrated in the below part of Figure 57.

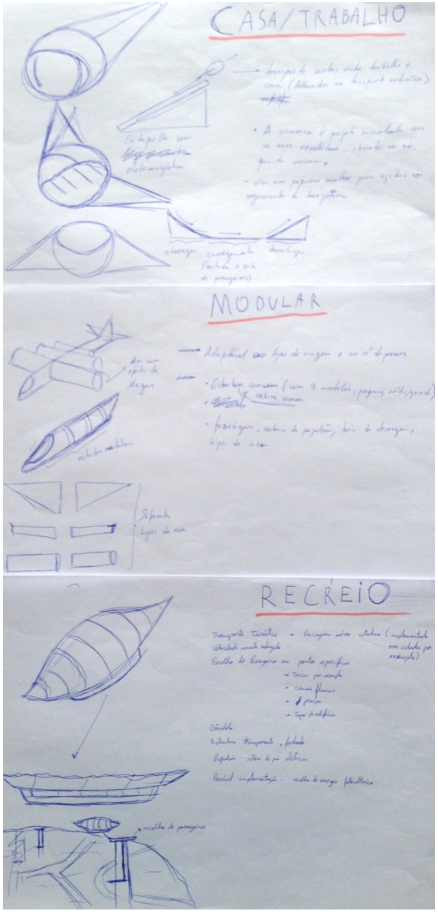


**Figure 57 |** the final elements of Team B

Also, the context factors deserved a closer attention after the first twenty minutes of the session. The analysis and the synthesis were clearly iterative, and it is difficult to trace a clear evaluation phase. Interestingly, many videos covering mechanical properties, laws and opportunities were watched by team B. However, the absence of a clear assessment phase, and the different media used, made some apparent and promising ideas to be forgotten.

### 7.3.3 Team C

With Team C, different backgrounds and experiences were combined, in order to firstly test the argued transdisciplinarity. Accordingly, this team was instructed to be as creative as possible, and simultaneously to follow the proposed guidelines for the session.

**Table 39 |** evaluation of team C session

| | | | |
|---|---|---|---|
| **Briefing** | Personas | --++ | "We should do a list with the most important characteristics of each |

| | | | |
|---|---|---|---|
| | | | persona" (2'/phase 1)<br>"Personas 1 and 2 are similar, yet the second needs more comfort" (3'/phase 2)<br>"Persona 3 is different from the remaining ones" (4'/phase 2)<br>"Now, I think its time to leave the personas…" (3'/phase 3) |
| | Context Factors | ++++ | "It would be interesting to cross the personas with the context factors" (1'/phase 1)<br>"Persona 2 needs quality, comfort, good service, good sound insulation" (2'/phase1)<br>"For P2 a sustainable choice is also important…In the US many have a Prius, it has to do with image" (10'/phase1) |
| | Configurations | --++ | "We are focusing too much in the interiors and in the service, and this is all based in the external…" "But it will helps!" (11'/ phase 1)<br>"Persona 1 will be close to a canard" (4'/phase 2) |
| **Quantity** of ideas | Passenger | ±6 | |
| | Aircraft | ±24 | |
| **Variety** of ideas | | -+++ | "UFO" (2'/phase 2); "MagLev" (8'/phase 2); "Panoramic View" (52'/phase 2); "The swallow!" (7'/phase 2) |
| **Novelty** of ideas | | --++ | "Catamaran" (47'/phase 2); "A glass bridge between the two parts" (49'/phase 2); "A system to activate transparency" (59'/phase 2) |
| **Methodology** | Analysis | 15' | A great focus in the personas and in the context factors |
| | Synthesis | 60' | Clear iterations with the previous phase<br>It ended with a clear discussion around the combination/selection of the most promising concepts |
| | Evaluation | 15' | Ideation continued |

| | | | |
|---|---|---|---|
| | | | Only one assessment discussion |
| | Communication | 15' | Each one proposed to develop a single A3 sheet |
| **Team Interaction** | | --++ | "Each one can make its own sketches, and then we'll see what happens" (9'/phase 2)<br>"Each one should do the sketches on their own" (12'/phase 2)<br>The discussions were smooth |
| **Session Fulfilment** | | -+++ | Three concepts were clearly presented<br>The evaluation phase was undervalued |

Team C initially tried to match the personas the context factors given. Then, an association between this first, and almost direct matching, and the given configurations were briefly tried. Regardless this initial great focus in the personas, in the evaluation phase the team started to leave them and chose to follow the ideas or concepts that they felt as most promising.

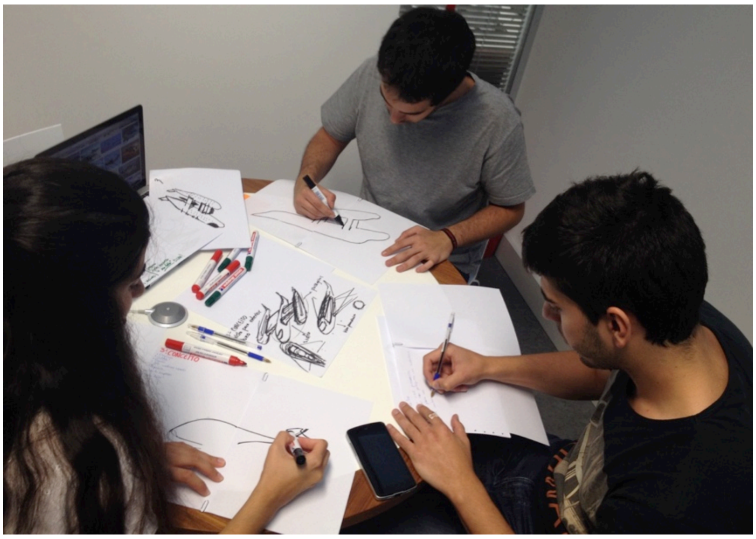

**Figure 58 |** team C performing during the communication phase

This team insisted in individual sketching with low degree of interaction and communication, as illustrated in Figure 58. As expected, the most productive phase was the second (synthesis), with 11 pages drawn in black. In some periods, the elements were conducting parallel tasks without a clear organisation and objectives. Therein, the analysis and the synthesis phases were clearly iterative, and in the evaluation phase only one concept was briefly discussed. Generally, the most promising concepts were already intuitively chosen in the second phase. Thus, team C only used 15 minutes to conclude the evaluation phase. Finally, the communication phase was very silent, as each element opted to develop its own concept after a volunteer selection. After the session the team referenced that this structured approach helped in the idea generation process. Also, it was considered that the personas played a decisive role in the initial focus.

### 7.3.4 Team D

As already mentioned, team D is the only with a non-academic character. Also, its session took place in a different place from the remaining ones.

**Table 40 |** evaluation of team D session

| | | | |
|---|---|---|---|
| **Briefing** | Personas | ---+ | "It might exist a commercial aircraft that we can adapt" (2'); "These kind of people likes exhibition!" (8'); "The category is private!" (1h21'); "We've only focused in the pop-star" (after session) |
| | Context Factors | -+++ | "Sustainability is now ubiquitous" (9'); "Materials have a tremendous influence" "They can also constraints the external configurations" (18'); "Customisation" (1h28') |
| | Configurations | --++ | "If we are discussing the external configurations, we have to approach the technical questions in a more serious way" (10') |
| **Quantity** of ideas | Passenger | ±5 | "The interiors were barely developed…" (1h32') |
| | Aircraft | ±26 | |
| **Variety** of ideas | | -+++ | "Solar aircraft" (10'); "Silicone wings" (17'); "Biomimetic" (33'); "Collect wings to reduced the space in the airports" (35'); "Pterosaurs" (42') |
| **Novelty** of ideas | | -+++ | "In the future, we might have aircrafts that can be easily transformable" (10'); "Hydrogen aircraft" (9') |

| | | | |
|---|---|---|---|
| **Methodology** | Analysis | 1h23' | "I think that we should, firstly, try to stipulate what we are looking for!" (1')<br>This first period was very iterative |
| | Synthesis | | "The shape is defined, let's think in the application of our three concepts" (56') |
| | Evaluation | - | No direct assessment was conducted |
| | Communication | 20' | The girls dominated this phase<br>This led to an additional web research from the engineer (1h35') |
| **Team Interaction** | | --++ | The team initially assumed its limitations in aeronautics<br>They both tried to draw |
| **Session Completion** | | ---+ | "A driver shaft, a model, and three options for this model" (46')<br>"The concept is the same!" (1h17')<br>"We are only doing a concept…" (1h24') |

Despite the absence of a structured approach, team D tried to organise itself since the beginning of the session. The context factors were minutely analysed and listed, but only the executive persona deserved a deep analysis. As for the remaining teams, the analysis and the synthesis phases were clearly iterative, and it is difficult to trace a clear assessment phase as well.

Interestingly, teams B and D, teams with an unstructured session, were the only teams to watch videos as part of their research. However, this array of consulted media created many blank periods in which the team felt clearly lost. As the elements of team D are long-time friends, they had an expected good interaction. However, when the male element (engineer) was urged to draw by the female elements (an architect and a designer) he felt very reluctant. Probably, the good sketching abilities of the female elements limited the engineer element with this specific task, and might have contributed to the small amount of sketches produced. If we not count with three final elements, this team only produced 4 pages of sketches.

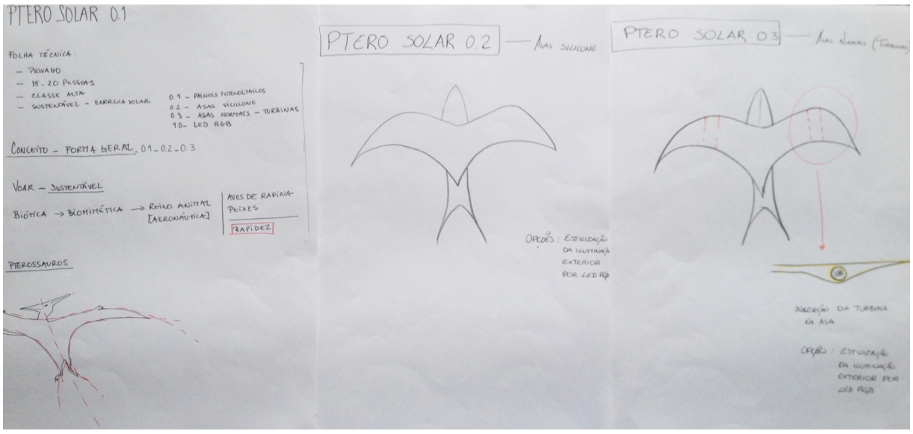


**Figure 59 |** the final elements of Team D

Finally, it is important to highlight that team C didn't present three different concepts at the end of the session. Instead, they delivered three options for the same concept, as illustrated in Figure 59. Therefore, the elements finalise this session with a clear sensation of disappointment and considered that they fail to meet the final goal of their session.

### 7.3.5 Team E

Regardless the time gap between team A and team E sessions, no direct contacts happen among all the 15 elements of the experiment. Accordingly, the surprise factor still existed in the elements of team E. This last team as approximately the same constitution of team C, except for the years of study, experience, and knowledge between them. Accordingly, these teams had the same objectives, a structured approach for different backgrounds, but the personal character of the different elements increased in importance.

**Table 41 |** evaluation of the team E session

| | | | |
|---|---|---|---|
| **Briefing** | Personas | -+++ | "Basically, the three final concepts will be one per each persona" (1'/phase 1) "Happy family might not be very interested in comfort" (2'/phase 1) "I'm trying to highlight the priorities for each one" "The three are completely different" (4'/phase 1) |
| | Context Factors | -+++ | "These are parameters that will help to choose things for the three personas" |

| | | | |
|---|---|---|---|
| | | | (4'/phase 1) |
| | Configurations | ++++ | "I'd move right now to technologies and configurations" (4'/phase 1)<br>"The configuration will then accompany the technology" (5'/phase 1)<br>"I don't believe that any of these configurations is really on production…" (10'/phase 1)<br>"Let's see if these configurations really exist!" "I think they are only proposals..." (41'/phase 2) |
| **Quantity** of ideas | Passenger | ±3 | "We didn't talk about the interior…"<br>"The interior is implicit" (24'/phase 3) |
| | Aircraft | ±15 | |
| **Variety** of ideas | | ---+ | "Fuel efficiency" (11'/phase 1); "Rocket powered aircraft" (28'/phase 2) |
| **Novelty** of ideas | | --++ | "Biomimetic" (20'/phase1); "an aircraft that flaps its wings!" (26'/phase 2);<br>"Different layers for the passenger seats" (38'/phase 2) |
| **Methodology** | Analysis | 15' | "Very few time for this phase…" "It creates too much pressure!" (10'/phase 1) |
| | Synthesis | 60' | "We are bending from the logic behind this exercise…" (16'/phase 2); "We should achieve a concept before starting to draw…" "We have no concepts until now!" (47'/phase 2)<br>Low levels of idea generation |
| | Evaluation | 27' | No direct assessment<br>"Concept could be the logics, all the line of though behind…" (5'/phase 3) |
| | Communication | 15' | |
| **Team Interaction** | | ---+ | "I have no opinion about this subject...[canard]" (13'/phase 2)<br>"Please read!" "I'm not reading because I was trying to discuss some ideas… and you only want to read!" "But you want to discuss opinions? I'd rather discuss information…" (45'/phase 2)<br>"We, designers, drawn, while you please |

| | | |
|---|---|---|
| | | read the requirements!" (46'/phase 2) |
| **Session Completion** | ---+ | "The idea is to present concepts!" (7'/phase 3); "We won't came up with anything…" (27'/phase 2); "We simply get lost…" (After the session) |

This team initially tried to directly connect the given configurations to the three personas. Besides, these configurations assumed a decisive importance, even limitative, throughout all the session. At the end of the analysis phase, the team criticised the lack of time for this task. Accordingly, and as expected, the analysis and the synthesis were clearly iterative and took half of the session.

Surprisingly, instead of ideas generation and subsequent discussion, one element chose to read several aeronautic requirements. This individual attitude conditioned the whole session, despite some advertisements of the remaining elements. Also, the passenger needs and wants were barely discussed; despite team the existence of two elements having a design background. To constrain even more the whole session, this same element wanted to understand the specific characteristics of each given aircraft configuration. Also, the simple notion of what a concept is was questioned as well. This team only produced the first sketches near to the end of the synthesis phase (47'), with only 6 pages of sketches in black. Therefore, it is possible to advance that this team didn't get the degree of abstraction desired for a generative session as this.


**Figure 60 |** the final elements of Team E

Finally, instead of concepts, the team presented new characteristics for the given personas, as illustrated in Figure 60. Accordingly, after the session they had a clear notion that they didn't carry the session as it was expected. Therefore, among the three interdisciplinary teams (C, D and E), only Team C was able to fully complete the experiment.

## 7.3.6 Questionnaire results

As already mentioned, a short questionnaire was distributed to teams after each session. Team A, as the first team to conduct the experiment, was chosen to validate the questionnaire. Accordingly, an initial bulk version was sent to its three elements in order to obtain feedback about the comprehensibility of the questionnaire. Opinions were obtained, and minimal changes to the questions initially posed were then made. This questionnaire (Appendix C) was mainly directed to the teams conducting a structured session (as teams A, C, and E). The second version (Appendix D), suitable to teams B and D, was an adaption of the original one.

As for the different sessions running, the results were very disparate. However, in the questions that aimed to evaluate the experimental procedure, common to all teams, the opinions were not as disparate. Table 42 presents these results.

**Table 42 |** the major consensus after the sessions

| **Hypothesis** | **Number of Respondents (A, C, E/ B, D)** |
|---|---|
| The given data (briefing) was enough | 13 (7/6) |
| The two hours duration of the sessions was sufficient | 11 (6/5) |

Interestingly, all the 6 elements of Teams B and D, teams that didn't follow the structured approach, considered the briefing as adequate for the proposed exercise. Concerning the duration of the session, 2 elements of Team E, the team that admitted more internal problems, considered the two hours' session as short. Also, 2 respondents from team C suggested a revision of the available time per each phase.

Concerning the proposed methodology, or its absence, the results were very interesting, and generalizable in some degree. The opinions of teams A, C and E spanned through the benefits of this methodology in integrating different perspectives, or in supporting the interdisciplinary dialogue, as represented in Table 43.

**Table 43 |** the methodology impact for teams A, C and E

| **Hypothesis** | **Number of Respondents (A/C/E)** |
|---|---|
| It supports the interdisciplinary dialogue | 7 (2/2/3) |

| | |
|---|---|
| It benefits an oriented creativity | 6 (2/3/1) |
| It integrates different perspectives | 5 (1/1/3) |

Therefore, 7 of the 9 elements of these teams considered that the structured approach was important in supporting a conceptual dialogue among different disciplines. It is important to remark that 5 of the 6 respondents from team C and E (teams combining different backgrounds), considered this as relevant. Besides, all the 3 elements of team E, the one with more tension, answered that the methodology supported the interdisciplinary dialogue and integrated different perspectives. Therefore, the proposed model revealed itself very useful for this conceptual and interdisciplinary exercise (Objective 2). Instead, when they were questioned about the hypothetical results of the same experience, but with no structured approach, the opinions diverged, as represented in Table 44.

**Table 44 |** the hypothetical results of a non-structured approach

| **Hypothesis** | **Number of Respondents (A/C/E)** |
|---|---|
| Different results would be achieved | 4 (1/1/2) |
| Similar results would be achieved | 3 (2/0/1) |
| Worst results would be achieved | 2 (0/2/0) |
| Better results would be achieved | 2 (1/0/1) |

As the above results demonstrate, the individual opinions towards the experiment clearly influenced the response to this questionnaire. Also, the respondents could choose more than one response for this question, and this might explain the different array of answers. Each team took a different path, even individual paths were taken inside the same team, and it is difficult to generalise from this. Interestingly, 1 respondent from team C considered that a non-structured approach would achieve scarce results due to the excessive freedom. As team B and D proved, this generic assumption makes no sense. Also, 1 respondent from team A considered that the results are always connected with the experience of the elements that compose the team. This element suggested that a combination of different backgrounds inside the same team would necessary achieve more creative results, as well. It should be noted that team A was not aware of how other sessions would be.

Also, the absence of a structured approach in sessions B and D did not seem to admit a broad consensus. Accordingly, the opinions of team B and D diverged, as represented in Table 45.

**Table 45 |** the absence of a structure for teams B and D

| **Hypothesis** | **Number of Respondents (B/D)** |
|---|---|
| A structured session will produce better results | 4 (1/3) |
| It limits the interdisciplinary dialogue | 2 (1/1) |
| It benefits the interdisciplinary dialogue | 2 (1/1) |
| It integrates different perspectives | 2 (1/1) |

Interestingly, all the elements of team D considered that a structured session would necessarily produce better results. The fact that this team clearly assumed its session failure may help to explain this trend. Besides, in the open-ended question that questioned the felt limitations during the experience this trend was reinforced. Among team B and D, 4 elements directly assumed that the absence of a structure for the session had a negative impact, as they felt initially lost. Also, 1 respondent of team B assumed that the absence of a structured methodology, for ideation and evaluation, made some promising ideas to be forgotten.

## 7.4 DISCUSSION OF THE RESULTS

Quantitatively, team A and B were those who managed to generate and discuss more ideas, as synthesised in Table 46. Interestingly, these two teams were built of elements with approximately the same background, despite the different degree of academic and professional experience. However, the qualitative character of this study and the overlaps in the different discourses, led the researcher to consider the number of ideas in approximation (±). As a consequence of their backgrounds, team A had a clear user focus, while team B was mainly focused in the aircraft and in its possible technologies. Besides, the technological issues proposed and discussed by team B were very distinctive and thus considered as very original.

**Table 46 |** comparative analysis of the sessions' assessments

| | | Team A | Team B | Team C | Team D | Team E |
|---|---|---|---|---|---|---|
| **Briefing** | Personas | ++++ | --++ | --++ | ---+ | -+++ |
| | Context Factors | -+++ | --++ | ++++ | -+++ | -+++ |
| | Configurations | ---+ | ---+ | --++ | --++ | ++++ |
| **Quantity** of ideas | Passenger | ±20 | ±2 | ±6 | ±5 | ±3 |
| | Aircraft | ±18 | ±44 | ±24 | ±26 | ±15 |
| **Variety** of ideas | | -+++ | -+++ | -+++ | -+++ | ---+ |
| **Novelty** of ideas | | -+++ | ++++ | --++ | -+++ | --++ |
| **Methodology** | Analysis | 15' (3) | 1h32' (12) | 15' (3) | 1h23'(6) | 15' (3) |
| | Synthesis | 57' (17) | | 60' (11) | | 60' (6) |
| | Evaluation | 28' (4) | | 15' (2) | - | 27' (3) |
| | Communication | 15' (3) | 25' (3) | 15' (3) | 20' (3) | 15' (3) |
| **Team Interaction** | | ++++ | -+++ | --++ | --++ | ---+ |
| **Session Completion** | | ++++ | -+++ | -+++ | ---+ | ---+ |

Team A and B were the teams that materialised more discussed ideas in sketches, as inserted immediately after the time spent per phase (number of pages produced) in Table 46. Also, teams A and B had *very good* or *good* team interaction, respectively. A common language, shared by elements with a similar background, clearly eased the communication of their sessions. Therefore, a good team interaction produces more ideas and consequently more ideas can be materialised into more sketches. Also, it is possible to admit that sketching represents a good way of communicate inside a team, to positively conduct an abstract exercise as this. Instead, among interdisciplinary teams (C, D and E), only team C was able to meet the objectives for the session. Comparatively, this team produced a higher amount of sketches in the synthesis phase, the most generative one. Therefore, immediately after the conclusion of their sessions, both team D and E directly assumed that they were not able to meet the session objectives.

Generally, the given personas and the context factors were the elements that started the discussion among the different teams. Still, team B, C, and D, chose to follow only one persona, or to create their own market segments in specific periods of their session. Instead, the given configurations did not deserve this approximate degree of importance for all teams. Curiously, only teams with an interdisciplinary composition (C, D, and E) took a deep analysis to these configurations, and in some cases tried to match them with the different personas.

The evaluation periods of time for team C and E are merely illustrative of the time spent by these teams at this phase. As abovementioned, team E didn't perform any direct assessment of the concepts, and the initial objectives for each phase were subverted in somehow. Accordingly, it was the team that presented more collective problems and that discussed the small amount of ideas. Team A was the only to undergone the evaluation phase as initially expected (Table 36). The dispersion of results illustrated in Table 44 and Table 45 reinforces that the discussion on whether or not to structure the FFE is far to be closed. Accordingly, Table 47 highlights the main findings and the perceived dichotomies on this design experiment.

**Table 47 |** main findings and dichotomies on the experiment

| **Findings** | **Dichotomies** |
|---|---|
| Teams with similar background (A and B) discussed a greater numbers of ideas | Teams A and B overlooked the given configurations |
| Teams A and B had a better group-spirit and fluidity in the session | Only team A conducted a clear evaluation phase |
| The market analysis generally initiated the sessions | Only teams B and E strictly followed the given personas |
| Interdisciplinary teams (C, D and E) analysed extensively the given configurations | Among teams C, D and E only the first accomplished the objectives |
| Good communication is decisive for the ideation sessions | Team D didn't achieve the expected outcomes |
| Teams using the proposed methodology (A, C and E) considered that it supported the interdisciplinary dialogue | Team E didn't accomplish the expected outcomes |
| Sketching is an important communication tool and benefits idea generation and discussion | Both teams D and E had two elements with a more creative background |

Team A and B discussed a larger number of ideas, and also generated a higher number of sketches. Sketching is considered as one of the oldest forms of communication, which reinforces the good group spirit and fluidity for these teams. Interestingly, these teams did not analyse extensively the given configurations, and conducted a more abstract session rather than data analysis (as team E). Team D and E, teams having industrial designers or architects involved, produced a smaller number of sketches and were not able conclude the session as expected. This underlines the importance of sketching as an interdisciplinary communication tool. Despite the *good* session fulfilment for team B and C, they didn't conduct a clear evaluation of the generated ideas or concepts, with many being left behind. From the opinion of the researcher, if they would have note or draw some of these forgotten ideas (synthesis), they would have the need to assess them subsequently (evaluation). Therefore, these sessions would gain in ideation and creativity, as more sketches would avoid these promising ideas to be forgotten.

Generally, teams using the structured approach considered that it was very helpful in supporting the interdisciplinary dialogue, even if team A was not interdisciplinary. Interestingly, one element of team A made the suggestion of having sessions combining different backgrounds, without knowing how the remaining sessions would be. It is important to emphasise that only team A, the team with more ideas and sketches, was able to conduct a clear and long evaluation phase. This fact reinforces the importance of this phase, to rethink, combine and evaluate, the most promising ideas or concepts.

### 7.4.1 Limitations of the design experiment

One of the limitations of this design experiment was the different degree of involvement of its fifteen elements. Probably, all the elements that undergone this experiment didn't have the exact profile required for an exercise as this. Also, the distributed briefing was clearly undervalued by some, which limited the quick beginning of some sessions. However, the volunteer level of the participants admitted these risks, and the researcher is very grateful to them.

Additionally, in future empirical studies as this, the obtained data should be distributed to different people in order to have a multiple analysis. Each researcher would make its own evaluation of the sessions, and the results would be then triangulated to ensure their validity. One of these extra researchers should be an expert in the topic, in order to evaluate the effectiveness of the discussed ideas. Concerning the topic to be discussed, aeronautics is very complex and some elements sustained their difficulties to cope with it. Therefore, future studies should use a less-complex theme for development.

## 7.5 CONCLUSIONS

To test the hypothesis behind this study (*A structured approach in the conceptual design stage benefits the interdisciplinary dialogue*), two objectives were posed: to understand the benefits of a interdisciplinary approach in the FFE; to test the proposed model for the conceptual stage of the innovation design process. These objectives served as basis to mount the experiment, which compared teams having this referred structure with others not having it. Also, the first two sessions gathered elements sharing the same academic background, while the remaining sessions mixed backgrounds with no distinctions among each transdisciplinary team. The hypothesis was partially validated, as teams testing the proposed and structured model (A, C and E) generally considered that it supported the interdisciplinary dialogue. There was a general feeling that this structured approach integrates different perspectives and give creativity a focus (see Table 43). Team D, which didn't use this model, admitted that the lack of this structured approach caused their failure in the session. Nevertheless, team E didn't have a proper interdisciplinary behaviour throughout the session nor accomplished the final expected results. Also, team D felt some disciplinary barriers in materialising some of the discussed ideas into sketches.

Sketching skills and sketching productivity were not to evaluate or compare throughout the different sessions. Nevertheless, the quantity of discussed ideas and produced sketches were directly related to the quality of the sessions, and to the relationships among their elements. Also, the higher the amount of sketches the better the discussion of ideas or concepts and their comparative assessment. Accordingly, even in the current digital era, sketching assumes a decisive and unique role in the interdisciplinary communication of project disciplines.

# 8 DISCUSSION AND CONCLUSIONS

This study had five main objectives, which were presented in Chapters 3-7. Therefore, the concluding remarks of each of these chapters are comparatively reviewed in this concluding reflection. It is also important to emphasise the decisiveness of the Design Research Methodology (DRM), which was detailed in Chapter 2. This research methodology was very relevant in the integration of the literature inputs, with the data obtained with the design case. This design case sustained the whole research, and the major findings obtained from it were materialised in Chapter 6. Also, the DRM was decisive in guiding the design experiment detailed in Chapter 7, which tested in isolation the main hypothesis behind this study.

## 8.1 DISCUSSION

In order to understand the professionalised emergence of industrial design and mechanical engineering (Objective 1), Chapter 3 presented an analysis of their historical development. It was argued that despite the unquestionable accomplishments of design, which created most of the recognisable products that define the present, industrial design and mechanical engineering emerged professionally in the 19th century. Furthermore, notwithstanding other visions and the general perception of technological development, the industrial revolution acted as trigger for these two disciplines. It was then demonstrated that the first technological manifestations historically separated mechanical engineering and industrial design. Striking examples of an initial reconciliation between the two, mediated by technology, were also advanced. Accordingly, the promising area for research that covers the overlap between the knowledge associated with industrial design and mechanical engineering supported Chapter 4.

In order to review and compare industrial design and mechanical engineering under analysis in detail (Objective 2), the knowledge base that supports the two was discussed in Chapter 4. It was argued that both industrial design and mechanical engineering are synthetic in their process, despite a higher symbolic character associated to the activities of the designer. Their different knowledge bases, epistemologies, and methods, would then gain in relevance when interactively combined in the design process. Accordingly, it was proposed that a transdisciplinary approach of two different realms of activity, symbolic (associated with industrial design) and real (associated with engineering), would benefit the creation of new meanings embedded in products. Herein, technology assumes an increased relevance, as it is now closest to the mentioned design-innovation trend than the traditional market-pull data. Technology, which historically separated mechanical engineering and industrial design, is responsible for their reconciliation. This reconciliation is already being applied systematically in several global and leading companies, and literature defined it as technology epiphanies. Additionally, the significance of a holistic and interdisciplinary approach in the early stages of New Product Development (NPD) was underlined.

In order to underline the importance of the conceptual design stage (Objective 3), Chapter 5 synthesised a critical analysis to several design models, spanned across engineering and industrial design. Despite the diversity of design models, this chapter underlined an early and common conceptual stage, the Fuzzy Front-End (FFE).

Accordingly, a model for this stage was proposed, grounded in the literature review and aiming to be tested later in the research (Chapter 7). This model intended to cope the iterative characteristics of this stage, and the difficulties in clearly borderline the different tasks and levels that compose it.

From the literature, it was felt that there is a research gap focused in the study of collaborative approaches to the referred FFE. Hence, to understand the importance of a structured approach therein, Chapter 6 presented the major findings of the design case that sustained this study. This case was conceptual and collaborative in nature and, as such, an opportunity to advance with research in this gap, presenting new insights to this area of research. The consortium, having submitted their view in questionnaires, considered that the integrative and structured approach used in this project was decisive, and provided a differentiation aspect of the work. Therefore, a structured approach for the FFE was considered as supporting the interdisciplinary dialogue therein. It should be emphasised that this consortium had already a history of previous collaborations in NPD, which helped the communication and organisation between the different actors. Finally, and following the DRM guidelines, this hypothesis was then tested by means of an empirical design experiment, in which different situations were tested. Hence, Chapter 7 presented the objectives and the organisation of this experiment, and comparatively discussed its results. Interestingly, the different conditions in test allowed for additional conclusions, and the results obtained with the design case were not necessarily translated in this experiment.

The results obtained with the design case (Chapter 6) showed that a structured and collaborative approach to the FFE would benefit the integration and communication of different disciplines. Nevertheless, additional design cases composed with different collaborations and topics were missed, as it was difficult to generalise from the results obtained with one single design case. From the design experiment (Chapter 7), and having in mind that team E didn't perform positively, it was possible to understand that the proposed model didn't necessarily guarantee a positive performance in the FFE. Nevertheless, it was generally considered that a structured approach in the FFE would benefit the interdisciplinary dialogue. As for the design case, beyond the impact of the organisation of each session, the individual attitudes and communication within each team admitted a great impact. Accordingly, whether a designer or an engineer, there is no structure that can handle with to the lack of individual attitude in abstraction, collaboration and conceptualisation. Interestingly, teams with a similar background (A and B) were those who performed better and those who discussed a larger number of ideas. Sketching assumed a relevant role for the interdisciplinary dialogue in the experiment, as teams performing better produced a larger number of sketches and discussed a larger number of ideas. Accordingly, it is possible to admit that this form of communication, assumes a decisive role in a conceptual and interdisciplinary design stage. The decisive role of sketching would then go beyond the technical drawing, typical of the development stages, as a tool of communication. Also, the analysed design case (Chapter 6) could have gained in creativity with sketching sessions among all companies, apart from the referred workshops of market analysis, concept evaluation, and needs assessment. It should be noted that the several sketching sessions were conducted in different phases of the project, but mainly internally at Company A (the design studio that led the project).

## 8.2 CONCLUSIONS

This thesis proposed a vision towards the origins of industrial design and mechanical engineering, and how and why the perceived tensions between these disciplines exist in NPD. Therefore, and trying to answer to Research Question (RQ) 1: *How does product design develop new products in an interdisciplinary context, and what tensions arise from that?* This study recommends a clear view of what these disciplines should be doing in the conceptual stage of the design process that goes beyond the vision on their origins. The different roles of mechanical engineers and industrial designers derive from their perspectives, namely the technology centred and user centred views, which decisively contribute to the innovative and creative outcomes in the FFE. Besides, the interdisciplinary integration of these two disciplines assumes a decisive guidance in the development of the whole project, and it is an important component in the technology epiphanies paradigm (as extensively discussed in Chapter 4). This paradigm encapsulates a whole new form of methodological and interdisciplinary collaboration. It was also possible to understand that the existing tension between industrial design and mechanical engineering is created by their overlap. Technology, through its importance in the historical development of these disciplines and its decisiveness in contemporaneity, was identified as the mediator between the two. The technology epiphanies paradigm is fundamental herein, as it explains the overlap between the design-driven innovation and technology-push as the radical breakthrough creator, instead of the traditional market-pull orientation.

The project that sustained this thesis was conceptual and interdisciplinary in nature, and therefore, as explained above was central in this study. Besides, literature revealed the increased relevance for studies covering the discussion on whether or not to structure conceptual and collaborative projects as this. Accordingly, a retrospective analysis and evaluation was conducted, in which the role of a previously defined structure was highlighted as important in mediating the interdisciplinary dialogue. With these results, and using the model proposed by this thesis (presented in Chapter 5), experimental studies were conducted to test the hypothesis (presented in Chapter 7). Accordingly, and trying to answer to RQ 2, "*How should the conceptual stage of product development be approached in an interdisciplinary context?* This study strongly supports the long proposed idea that interdisciplinary knowledge should be combined in the conceptual design stage. Furthermore, literature refers to the FFE as the most influencing stage in the overall design and innovation process, as the value of the overall project is created therein. Nevertheless, the discussion over the most relevant way of approaching this conceptual stage is not closed, notwithstanding the positive results of the design case, and of the experimental studies. Generally, there was an agreement that a structured approach in the FFE would help the interdisciplinary dialogue. As always, trust and good communication were also extremely important aspects, and possibly as important as the sustained structured approach. These results reinforced the current Open Innovation (OI) paradigm that is based in trust and communication to better collaborate. Nevertheless, the different experiments conducted showed the referred tensions by means of skewed attitudes towards the perceived usefulness of creativity: the orientation towards the user and, the technological content of products.

## 8.3 LIMITATIONS

One of the limitations felt in this research was the lack of an additional perspective from the social sciences. This research would have benefited with well-defined ethnographic roadmaps to attend the consortium meetings and workshops. The design experiment would then be prepared and analysed from a different and very relevant angle. Concerning the design experiment, additional teams should have tested the proposed method to have clear validation of the results, and of the method itself. However, it was not possible to conduct more similar sessions within the available time.

## 8.4 FURTHER RESEARCH

The variety of themes covered within this research, and the conclusions identified in this chapter highlight several areas for further research. These fall into two main areas: empirical design studies and methodological research.

### 8.4.1 Empirical design studies

There are several areas for further research concerning the design experiment outlined in Chapter 7. Firstly, to design, implement and analyse a different and higher-scale design experiment focused in an inter/transdisciplinary approach to the conceptual design stage. This new empirical study should admit different tiers of involvement. In the first tier, volunteers with approximately the same implicit disciplinary language would conduct a first ideation session, to feel comfortable with their skills and limitations. In a successive tier, but with the same degree of abstraction and creativeness, a second session will run with elements of different backgrounds, after the referred disciplinary immersion in the topic. Secondly, defining different themes for the experiment, some that fit in the elements' skills and others that are beyond them. The idea behind having different topics is to test the capacity to abstract and to conceptualise in teams. Thirdly, test the Concept Sketch method (Kumar 2013), that aims to materialise all ideas in sketches, and then compare its results with the outcomes of an ideation session under the same topic. Finally, developing rigorous coding strategies for the analysis of the different criteria associated to the conducted experiments.

### 8.4.2 Methodological research

There are four very promising areas for further research in the area of new concept development. Firstly, defining different areas for the development of new concepts, equally promising for the different companies involved. Also, different combinations of companies should be comparatively analysed as well. Secondly, defining an approach that compares the individuality of the designer, and the productivity of those working in groups. Such study may reveal the tasks that are more effectively developed by an individual, and the ones that are better conceived by design teams. Thirdly, testing the insertion of an external and non-experienced element in each company involved in the conceptual project to analyse. These external elements might bring different perspectives, and not biased, that could enhance the levels of creativity to conceptualisation. Finally, defining a research that analyses the methodological and systematic application of the technology epiphanies trend. This research would gain in relevance if expert scholars and/or expert companies would accept to be involved.

Additionally, the recent revival of interest in Europe over the Iberian science and technology in the 15$^{th}$ and 16$^{th}$ centuries admits a wide space for research. Also, in 2014 the prestigious Portuguese award *Prémio Pessoa* was attributed to a scholar that pioneered this work in Portugal[4].

[4] http://www.publico.pt/ciencia/noticia/premio-pessoa-2014-atribuido-a--1679186

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# 10 APPENDIXES

## 10.1 APPENDIX A

Questionnaire distributed to the consortium

# Inquérito de João Filipe Figueiredo

análise à colaboração conceptual de uma equipa interdisciplinar

1. **Que razões o levaram a participar neste projecto?**

   *Tick all that apply.*

   - [ ] experiências anteriores com os restantes parceiros
   - [ ] interesse no tema a desenvolver
   - [ ] futuros projectos e parcerias
   - [ ] financiamento de ideias de projecto
   - [ ] partilha de conhecimento e novas ideias
   - [ ] Other:

2. **Este projecto faria sentido sem as competências de cada um dos parceiros?**

   *Mark only one oval.*

   - ◯ sim
   - ◯ apenas com as competências de alguns
   - ◯ não

3. **Percepcionou visões diferentes do projecto entre os diferentes parceiros?**

   *Mark only one oval.*

   - ◯ sim
   - ◯ não

4. **Quais foram essas diferenças?**

   caso tenha respondido "sim" na pergunta anterior

   _______________________

   _______________________

5. **Essas visões diferentes foram decisivas para o desenrolar do projecto?**

   caso tenha respondido "sim" na pergunta 3

   *Mark only one oval.*

   - ◯ sim
   - ◯ não

6. **Ao longo do projecto, identificou requisitos contraditórios?**

   *Mark only one oval.*

   - ◯ sim
   - ◯ não

7. **De entre os requisitos identificados, indique os principais.**

   caso tenha respondido "sim" na pergunta anterior

   _______________________

   _______________________

8. **Acha que este projecto acrescenta valor tecnológico e/ou social?**

   *Mark only one oval.*

   - ◯ não
   - ◯ apenas tecnológico
   - ◯ apenas social
   - ◯ ambos

9. **Algum destes prevaleceu sobre o outro?**

   *Mark only one oval.*

   - ◯ não
   - ◯ a componente tecnológica
   - ◯ a componente social

10. **Qual a sua opinião sobre a estrutura/metodologia inicialmente desenvolvidas?**

    abordagem combinada entre a tecnologia e a sociedade

    *Tick all that apply.*

    - [ ] pouco criativa
    - [ ] demasiado criativa
    - [ ] adequada
    - [ ] pouco estruturada
    - [ ] muito estruturada
    - [ ] Other: _______________________

11. **Esta metodologia inicial foi decisiva para a obtenção do financiamento externo?**

    abordagem combinada entre a tecnologia e a sociedade

    *Mark only one oval.*

    - ◯ sim
    - ◯ não

12. **Qual o impacto da metodologia no decurso do projecto?**

    *Mark only one oval.*

    - ◯ inadequado
    - ◯ irrelevante
    - ◯ positivo
    - ◯ decisivo
    - ◯ Other:

13. **Acha que o plano inicial foi cumprido?**

    *Mark only one oval.*

    - ◯ sim
    - ◯ não

14. **Qual a sua opinião sobre as reuniões mensais?**

    *Tick all that apply.*

    - [ ] demasiado formais
    - [ ] demasiado informais
    - [ ] inócuas
    - [ ] decisivas
    - [ ] em número insuficiente
    - [ ] em número excessivo
    - [ ] Other: _______________________

15. **Sentiu algum choque de interesses engenharia/design durante estas reuniões?**

    *Mark only one oval.*

    - ◯ não
    - ◯ em parte
    - ◯ sim

16. **Alguma das disciplinas prevaleceu?**

    *Mark only one oval.*

    - ◯ a engenharia
    - ◯ o design
    - ◯ houve um equilíbrio

17. **Qual a sua opinião genérica sobre os worskhops?**

    personas; conceitos; avaliação dos conceitos

    *Tick all that apply.*

    - [ ] demasiado formais
    - [ ] demasiado informais
    - [ ] decisivos
    - [ ] criativos e produtivos
    - [ ] infrutíferos
    - [ ] Other:

18. **Algum dos conceitos poderá resultar num novo projecto e/ou produto?**

    *Mark only one oval.*

    - ◯ um
    - ◯ dois
    - ◯ três
    - ◯ nenhum

19. **Tem expectativas para outros projectos com os restantes parceiros?**

    *Mark only one oval.*

    - ◯ com nenhum parceiro
    - ◯ com um parceiro
    - ◯ com dois parceiros
    - ◯ com três parceiros
    - ◯ com quatro parceiros
    - ◯ com todos os parceiros

20. **Para si, quais foram as maiores inovações deste projecto?**

    indique pelo menos uma

    _______________________

    _______________________

    _______________________

21. **Acha que estas inovações seriam possíveis sem os restantes parceiros?**

    *Mark only one oval.*

    - ◯ sim
    - ◯ não

22. **Porquê?**

23. **Sugestões para futuros projectos.**

    _______________________

    _______________________

    _______________________

# 10.2 APPENDIX B

Briefing distributed to the teams conducting the experiment

## DESIGN CONCEPTUAL

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## DESIGN EXPERIMENT

- esta experiência versa o design de conceitos exteriores de aeronaves (*duração ± 2 horas*)
- será uma experiência filmada, apenas para efeitos de posterior análise (*não haverá outro uso para as imagens*)
- consiste em 2 actividades primordiais:

***I. geração do maior número possível de conceitos***

***II. selecção dos 3 conceitos mais promissores***

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## DESIGN EXPERIMENT

- não será necessário trazer qualquer material de desenho
- será também disponibilizado um computador
- antes do início haverá espaço/tempo (±5 min) para a explicação dos objectivos e funcionamento da experiência
- são disponibilizados alguns dados do mercado aeronáutico
- estes dados servem apenas de referência de mercado, de contexto e de configurações possíveis

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## PERSONAS

| Persona **Utilitário** |
|---|
| *Sr. Fagundes* |
| *45 anos* |
| *dono de uma quinta agrícola* |
| *1x por semana São Paulo - Belo Horizonte (600km)* |
| *maior velocidade de operação* |
| *maior alcance que um helicóptero comum* |
| *curta descolagem e curta aterragem* |
| *distâncias superiores ao helicóptero comum* |
| *8-12 pax* |

| Persona **Celebridade** |
|---|
| *Lady Fanny* |
| *29 anos* |
| *pop-star americana* |
| *concerto em Singapura* |
| *New York - Singapura (±15.000 km)* |
| *voo executivo* |
| *longo alcance* |
| *15-20 pax* |

| Persona **Família Feliz** |
|---|
| *Família Tung* |
| *42 anos<br>33 anos<br>2 anos* |
| *originários de Pequim* |
| *férias de Verão em Lisboa* |
| *Pequim - Lisboa (±10.000 km)* |
| *ligação em Abu-Dhabi (E.A.U.)* |
| *visão inovadora para a aviação comercial* |
| *150-200 pax* |

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## FACTORES DE CONTEXTO

| sustentabilidade | conectividade | personalização | experiência | conforto | mobilidade |
|---|---|---|---|---|---|
| *escolha sustentável* | *acesso permanente a informação* | *passageiro diferenciado* | *criação de memória* | *prevenção de ruído* | *maior conectividade* |
| *emissões reduzidas* | *convergência dos dispositivos* | *tratamento personalizado* | *tratamento da bagagem* | *maior conforto nos bancos* | *maior volume de passageiros* |
| *combustíveis alternativos* | *armazenamento de dados* | *diferentes operações* | *materiais naturais* | *área de trabalho* | *maiores distâncias* |
| *atitude sustentável* | | | *voo inesquecível* | *área de descanso* | *ligação a comboio alta velocidade* |

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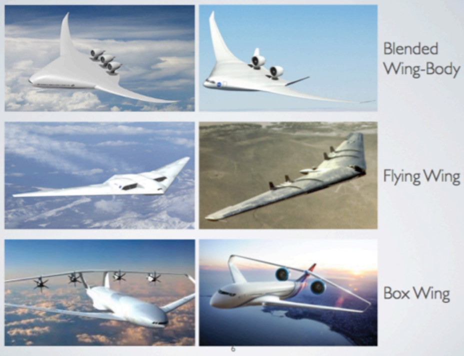



# 10.3 APPENDIX C

Questionnaire distributed to the structured teams

**Sessão de Ideação**

avaliação da sessão de ideação

*Required

1. **Qual a sua opinião geral sobre a experiência? ***
   avalie a globalidade da experiência, entre 1 (nada interessante) e 5 (muito interessante)
   *Mark only one oval.*

   1 2 3 4 5

2. **Como avalia a metodologia proposta e distribuição das diferentes fases (análise/síntese/avaliação/comunicação)? ***
   avalie entre 1 (inadequada) e 5 (totalmente adequada)
   *Mark only one oval.*

   1 2 3 4 5

3. **E qual a sua opinião geral sobre esta metodologia?**
   caso tenha algum comentário sobre a mesma

4. **Os dados fornecidos foram suficientes? ***
   factores de contexto, configurações, utilizadores
   *Mark only one oval.*
   - Sim
   - Não

5. **Se não, porque não consultou outros dados?**
   consulta online, por exemplo

6. **Como avalia a duração (2h) da experiência? ***
   *Mark only one oval.*
   - muito curta
   - curta
   - adequada
   - extensa
   - muito extensa
   - Other:

7. **Qual o impacto desta metodologia de ideação na integração do conhecimento individual? ***
   de que forma a perspectiva de cada elemento do grupo sai beneficiada com uma estrutura prévia
   *Tick all that apply.*
   - limita a criatividade
   - limita o diálogo interdisciplinar
   - integra positivamente diferentes perspectivas
   - beneficia o diálogo interdisciplinar
   - beneficia a criatividade focada em objectivos
   - Other:

8. **Com maior liberdade na sessão, que tipo de resultados poderiam ter sido obtidos? ***
   uma sessão não organizada, sem dados de suporte, e sem o limite de escolha de 3 conceit
   *Tick all that apply.*
   - piores resultados
   - resultados semelhantes
   - melhores resultados
   - resultados distintos
   - nenhuns resultados dado o excesso de liberdade
   - Other:

9. **Indique, por favor, limitações que tenha encontrado ao longo da experiência.**
   caso as tenha encontrado

10. **Avance, por favor, com algumas sugestões para futuras sessões.**
    não é obrigatório

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# 10.4 APPENDIX D

Questionnaire distributed to the non-structured teams

## Sessão de Ideação 4

avaliação da sessão de ideação

*Required

1. **Qual a sua opinião geral sobre a experiência? ***
avalie a globalidade da experiência, entre 1 (nada interessante) e 5 (muito interessante)
*Mark only one oval.*

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| ◯ | ◯ | ◯ | ◯ | ◯ |

2. **Como avalia esta sessão de ideação não estruturada? (sem duração da análise, da geração de ideias, da selecção das mais promissoras, e do processo refinamento) ***
avalie entre 1 (inadequada) e 5 (totalmente adequada)
*Mark only one oval.*

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| ◯ | ◯ | ◯ | ◯ | ◯ |

3. **Os dados fornecidos foram suficientes? ***
factores de contexto, configurações, utilizadores
*Mark only one oval.*

◯ Sim
◯ Não

4. **Se não, porque não consultou outros dados?**
consulta online, por exemplo

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5. **Como avalia a duração (2h) da experiência? ***
*Mark only one oval.*

◯ muito curta
◯ curta
◯ adequada
◯ extensa
◯ muito extensa
◯ Other: _______________

6. **Qual o impacto da ausência de estrutura na integração do conhecimento individual? ***
de que forma a perspectiva de cada elemento do grupo sai beneficiada com uma sessão aberta
*Tick all that apply.*

☐ limita a criatividade
☐ limita o diálogo interdisciplinar
☐ integra positivamente diferentes perspectivas
☐ beneficia o diálogo interdisciplinar
☐ beneficia a criatividade focada em objectivos
☐ Other: _______________

7. **Com uma sessão estruturada, que tipo de resultados poderiam ter sido obtidos? ***
uma sessão organizada, com tarefas e duração das mesmas, previamente definida
*Tick all that apply.*

☐ piores resultados
☐ resultados semelhantes
☐ melhores resultados
☐ resultados distintos
☐ nenhuns resultados dadas as limitações temporais
☐ Other: _______________

8. **Indique, por favor, limitações que tenha encontrado ao longo da experiência.**
caso as tenha encontrado

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9. **Avance, por favor, com algumas sugestões para futuras sessões.**
não é obrigatório

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