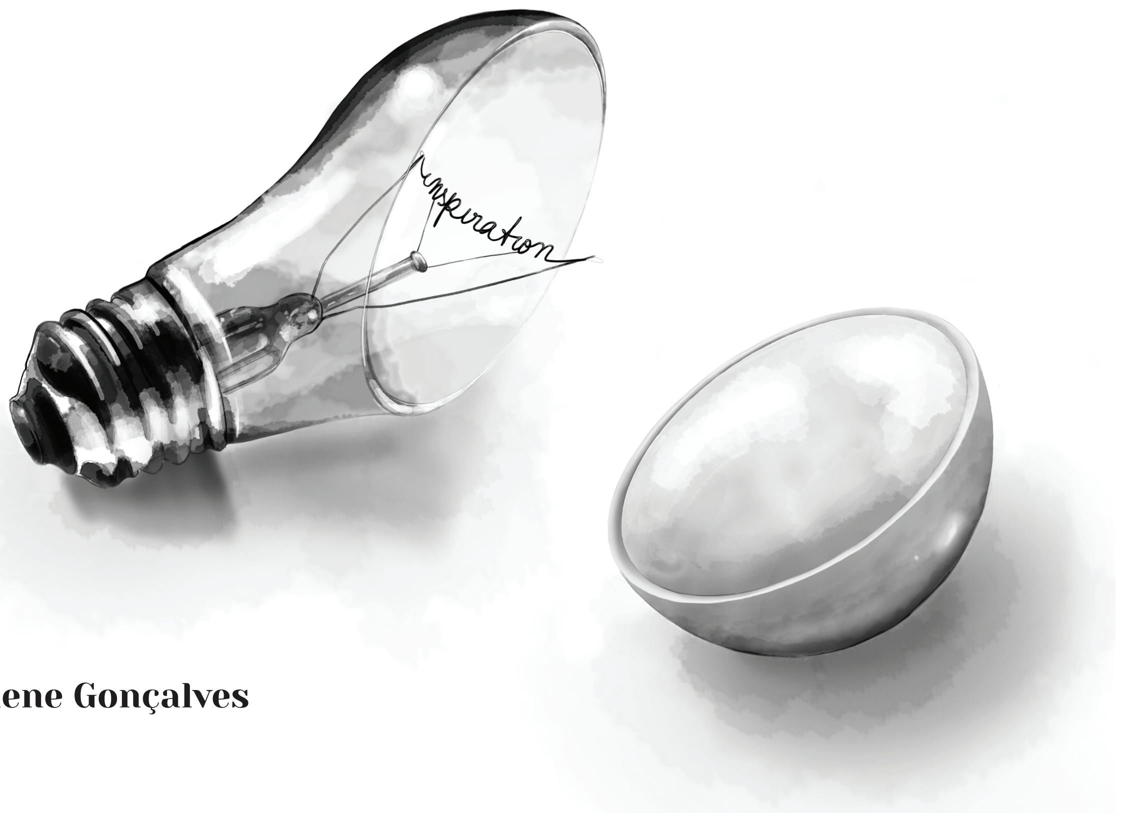
# Decoding designers' inspiration process




Milene Gonçalves

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Milene Guerreiro GONÇALVES

Mestre em Design de Produto
Faculdade de Arquitectura,
Universidade Técnica de Lisboa
geboren te Faro, Portugal

This dissertation has been approved by the
**Promotor:** Prof.dr. P. Badke-Schaub
**Copromotor:** Dr. C. Cardoso

**Composition of the doctoral committee:**

| | |
|---|---|
| Rector Magnificus | Chairman |
| Prof.dr. P. Badke-Schaub | Delft University of Technology |
| Dr. C. Cardoso | Delft University of Technology |

**Independent members:**

| | |
|---|---|
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Milene Gonçalves - milene.gg@gmail.com

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Table of contents 6
Acknowledgements 13

1

**Introduction** *(or Making the most of inspiration)* 17
1.1 Research methodology 21
1.2 Relevance of this research for design practice and education 24
1.3 Thesis outline 26
1.4 Main themes: following the red thread 29

2

**Chapter 2: On inspiration and creativity: a theoretical investigation** 33
*(or What you need to know before learning about inspiration)*
2.1. Designing in context 34
2.2. The role of inspiration in design 36
2.2.1. Differences in the use of stimuli: the role of expertise 41
2.2.2. Stimuli classification 44
2.2.3 Types of representation modalities: Visual stimuli 45
2.2.4. Types of representation modalities: Textual stimuli 46
2.2.5. Types of content: Semantically distant stimuli 48
2.2.6. Inspiration as a process 52
2.2.7. The process of stimuli selection 55
2.3. Creativity in context 57
2.3.1. Defining creativity 58
2.3.2. The role of knowledge in creativity 60
2.3.3. On the emergence of creative ideas 62
2.3.4. Cognitive processes responsible for creativity 65
2.3.5. Measuring design creativity 71
2.4. Stimuli preventing creativity 79
2.4.1. Functional fixedness 80
2.4.2. Mental set 80
2.4.3. Attachment to initial ideas or premature conceptualisation 81
2.4.4. Stuckness 82
2.4.5. Design fixation 83
2.4.6. Redefinition of design fixation 86

3


**Chapter 3: Study I** (or *An investigation into the inspiration preferences of student and professional designers*) 91

3.1. Rationale 92

3.2. Research question 93

3.3. Research study 94

3.4. Data collection 95

3.5. Data analysis 99

3.6. Results 99

3.6.1. The importance of inspiration 99

3.6.2. The importance of representation stimuli 101

3.6.3. Preferences for information sources 102

3.6.4. Frequencies of use of ideation methods 104

3.6.5. Reflection on the design process 105

3.7. Discussion 107

3.7.1. Representation stimuli 108

3.7.2. Sources of information 109

3.7.3. Ideation methods 111

3.7.4. Reflection on the design process 113

3.8 Conclusions 114


4


**Chapter 4: Study II** (or *How far is too far? The semantic distance between design problem and visual and textual inspiration stimuli*) 119

4.1. Rationale 120

4.2. Research question 121

4.3. Research study 122

4.4. Data collection 124

4.5. Data analysis 128

4.6. Results 132

4.6.1. Fluency of ideas 132

4.6.2. Flexibility of ideas 133

4.6.3. Originality of ideas 135

4.7. Discussion 136

4.7.1. ‘Control’ condition 136

4.7.2. 'Textual related' and 'Visual related' conditions 137
4.7.3. 'Textual distant' and 'Visual distant' conditions 138
4.7.4. 'Textual unrelated' and 'Visual unrelated' conditions 140
4.8. Conclusions 140

5

**5. Chapter 5: Study III** (or *Uncovering the inspiration process: a case study of novice designers*) 147
5.1. Rationale 148
5.2. Research question 148
5.3. Research study 149
5.4. Data collection 150
5.4.1. Daily work notebooks 151
5.4.2. Reports 154
5.4.3. Interviews 155
5.5. Data analysis 156
5.6. Results 157
5.6.1. Varity of inspiration sources 157
5.6.2. Seeking or waiting for inspiration 158
5.6.3. Searching for close and easily accessible inspiration sources 160
5.6.4. Searching for inspiration in people 161
5.6.5. Advantages and disadvantages of reflecting on inspiration sources 162
5.6.6. Search and use of inspiration sources within several phases of the design process 164
5.7. Discussion 167
5.8. Conclusions 170

6

**6. Chapter 6: Study IV** (or *Inspiration choices that matter: the selection of external stimuli and their influence on creative ideation*) 173
6.1. Rationale 174
6.2. Research question 176
6.3. Research study 176

6.3.1. Set up of the study 177
6.3.2. Search tool and stimuli 179
6.3.3. Design protocol analysis 180
6.3.4. Interview analysis 180
6.3.5. Analysis of the outcome in terms of creativity 181
6.4. Quantitative results: creativity score of the outcome 185
6.4.1. Inter-rater agreement between judges 185
6.4.2. Fluency 186
6.4.3. Flexibility 186
6.4.4. Novelty: Originality and Rarity 187
6.4.5. Usefulness: Feasibility, Relevance and Completeness 187
6.4.6. Overall score of creativity 188
6.5. Qualitative results: design process and interviews 188
6.5.1. Use of (and refusal to use) the search tool 188
6.5.2. Formulating keywords in the search tool 190
6.5.3. Forcing a strike of inspiration 192
6.5.4. Most selected stimuli from the search tool 193
6.5.5. Most used stimuli for ideas generated 194
6.5.6. Reasons for stimuli selection 196
6.6. Discussion 198
6.6.1. Inspiration avoiders and inspiration seekers 199
6.6.2. Drivers for inspiration search 199
6.6.3. Random active search of stimuli 200
6.6.4. Influence of the chosen stimuli in idea generation 202
6.6.5. Elaboration of designers' inspiration process 203
6.7. Conclusions 204

7

7. **Chapter 7: Conclusions** (or *Decoding designers' inspiration process*) 209
7.1. Summary of findings 210
7.1.1. What are the external stimuli designers search for during idea generation? 210
7.1.2. How do external stimuli, such as visual and textual stimuli, influence designers during idea generation? 212

7.1.3. Which processes do designers employ while searching and using inspiration sources for a design problem? 214
7.1.4. How do designers select external stimuli during idea generation and how does it influence creativity in the design process? 214
7.2. The inspiration process decoded 215
7.3. Contribution and implications for design practice and education 223
7.4. Recommendations for design practice and education 224
7.5. Limitations of this research 229
7.6. Recommendations for future research 230
7.7. Breaking through the mysticism of inspiration 234

Bibliography 237
Summary 259
Samenvatting 264
Appendices 269
About the author 284

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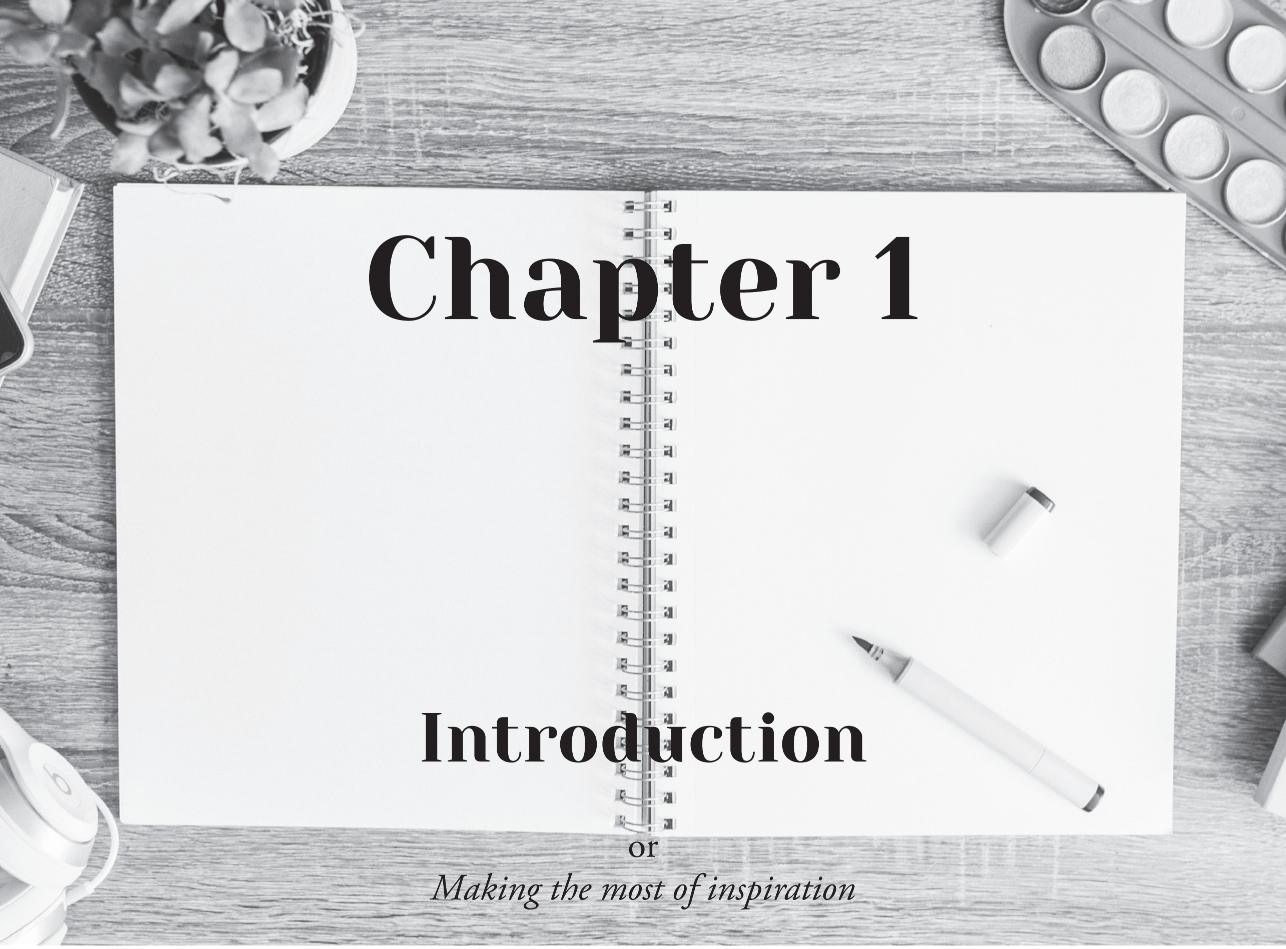

# Chapter 1

## Introduction

or

*Making the most of inspiration*

Many artists, problem-solvers and designers retrieve inspiration from all kinds of sources to stimulate their creativity. For instance, the work of Santiago Calatrava, a Spanish architect and engineer, is considered to be profoundly inspired by natural organisms (Kuhlmann, 2011; Pohl and Nachtigall, 2015). Calatrava, who has reached considerable prestige worldwide, follows an architectural language characterized by movement, dynamic structures and biomorphism. One of his most recognisable buildings, a skyscraper in Malmö, Sweden, was noticeably inspired by the twisting form of a human body. Appropriately called 'Turning Torso', the building resembles an earlier sketch and sculpture by Calatrava, which portray an abstract twisting human form (Figure 1.1).

The same applies to designers, as several scholars have remarked that, regardless of the problem at hand or their level of expertise, designers seek different kinds of support during their process (e.g., Eckert & Stacey, 2000; Casakin, 2004; Goldschmidt & Smolkov, 2006; Perttula & Sipilä, 2007; Liikkanen &

Perttula, 2008; Mougenot, Bouchard & Aoussat, 2008; López-Mesa et al., 2011). Designers extensively use information to support the development of design solutions for the existing gap between their own and required knowledge. However, complex problems like designing seldom require fit-in solutions. Instead, information might initiate the first step into a desired direction, an inspiration.

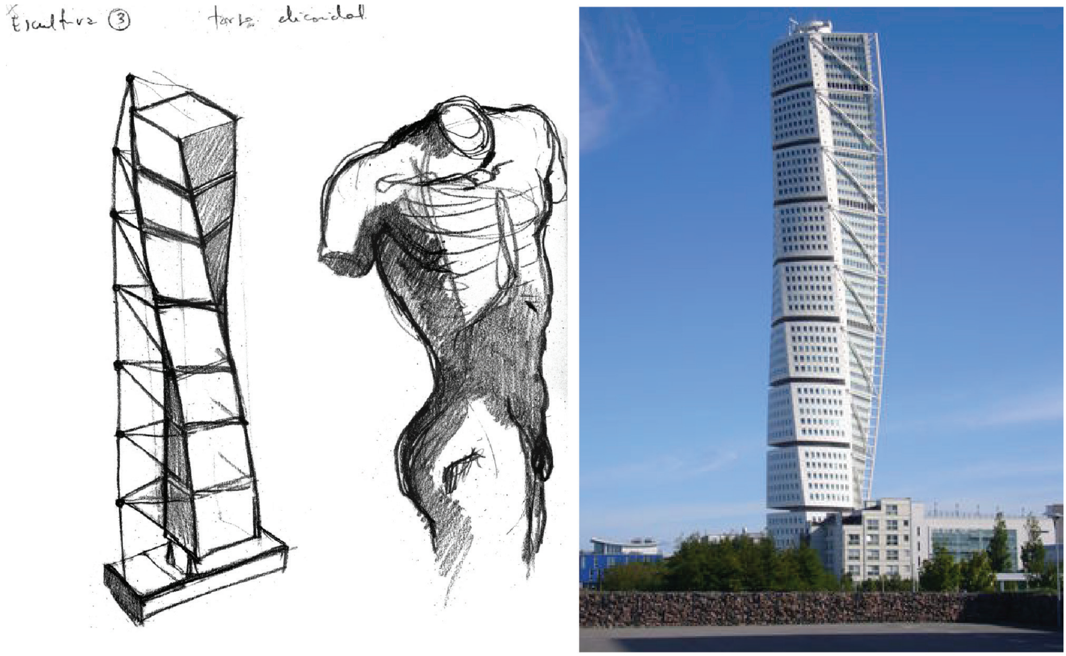

Figure 1.1: Santiago Calatrava's 'Turning Torso' and his inspiration in sketch form.

The process of searching for inspiration and acquiring knowledge comprises a broad variety of *internal*[1] and *external* stimuli. External stimuli, the cornerstone of this research project, are entities in the person's surroundings and can include, for instance, pictorial, textual, audible or tactile information (Eastman, 2001; Mougenot, Bouchard & Aoussat, 2008; Cai, Do & Zimring, 2010). External stimuli can also originate from conversations with others or from a range of everyday activities (Gonçalves, Cardoso & Badke-Schaub, 2014). The way these stimuli are perceived, retrieved, interpreted and (mentally) transformed

*1 Internal stimuli reside in the person's working and long term memory, and can take the form of mental imagery and verbal information (Eastman, 2001). Internal stimuli are outside of the scope of this research project.*

as inspirational material affect how problems are framed and how solutions are developed throughout the design process (e.g., Malaga, 2000; Goldschmidt & Smolkov, 2006; Perttula & Sipilä, 2007; Goldschmidt & Sever, 2010; Howard, Culley and Dekoninck, 2010).

Inspiration has been defined as “the process of being mentally stimulated to do or feel something, especially to do something creative” (Oxford University Press, 2015). This process is considered to roughly entail the intermediate steps of searching stimuli, selecting, retrieving and, finally, implementing stimuli in a context (Eckert and Stacey, 2003; Gonçalves, Cardoso and Badke-Schaub, 2013). In this case, inspiration during a creative problem-solving activity might trigger new directions, ultimately eliciting generation of new and creative solutions. In this thesis, a creative design solution is defined as any novel and useful outcome to a design problem (a complete definition of a creative design solution can be found in section 2.3.1). However, the use of inspiration in design is not necessarily a step-wise process provided by a method or a clearly defined procedure, as there is no certainty that a particular stimulus will trigger the generation of a more creative outcome than another (e.g., Cai, Do and Zimring, 2010). Likewise, use of inspiration depends on the designer’s experience and preferences, as well as on the type of problem being solved.

To understand the nature of a problem, designers often search for visual examples of similar solutions, to establish a benchmark comparison to what has been done before and what could be improved (Pasman, 2003; Eckert and Stacey, 2003). This type of example can be considered as within-domain or closely related to the problem at hand, as opposed to between-domain or distantly related stimuli (which are stimuli outside of the main scope of the problem). However, instead of being inspirational, these examples can result in restrictive frames of reference, thus anchoring reasoning processes to existing examples, which reduces the likelihood of generating new solutions (Gentner and Markman, 1997; Christensen and Schunn, 2007; Bonnardel and Marmèche, 2005). In fact, previous empirical investigations have demonstrated that some types of stimuli, especially visual ones, can prompt a *dual-effect* on designers’ performance (Cai, Do, & Zimring, 2010; Perttula & Liikkanen, 2006), resulting in both creative and uncreative outcomes. One of these detrimental consequences for creativity is *design fixation* – an unconscious tendency to reuse parts and principles from examples without considering their appropriateness (e.g., Jansson & Smith, 1991; Purcell & Gero, 1996; Cardoso, Badke-Schaub, & Luz, 2009).

When searching for inspiration, designers generally prefer using external pictorial stimuli during idea generation (Hanington, 2003; Henderson, 1999; Muller, 1989). This preference for visual stimuli is also the reason why designers are considered being primarily visualizers and thus, also highly competent in the use of images (Mednick, 1962; Malaga, 2000). However, although designers also encounter other types of sources in their search for inspiration, they seem to disregard other types of external stimuli, such as textual representations (Gonçalves, Cardoso & Badke-Schaub, 2014). In fact, there is a lack of information on the specific types of external stimuli designers might use for inspiration. This becomes even more relevant when taking into account the considerable number of studies that show the potential detrimental effect of visual stimuli in design (e.g., Jansson & Smith, 1991; Christiaans & Andel, 1993; Purcell & Gero, 1996; Cardoso, Badke-Schaub and Luz, 2009; Viswanathan & Linsey, 2013). Knowing more about the inspiration sources designers use in their work is thus a critical step towards supporting designers in the successful generation of creative solutions. Furthermore, despite designers' apparent preference for certain stimuli, such as visual examples, it is relevant to explore whether other sources might also have the potential to be used as inspirational material when generating ideas. In this way, designers can become better informed on how they can take advantage of available stimuli.

Previous research has taught us much about how expert designers think and act while they design, and how their approach differs from novices. (e.g., Casakin & Goldschmidt, 1999; Frankenberger & Badke-Schaub, 1999; Cross, 2004; Lawson, 2004; Atman et al., 2005). However, past studies have as of yet ignored designers' approaches to inspiration. Consequently, understanding the different approaches of novice and expert designers on this matter can potentially help support them in a more efficient search, retrieval and usage of available inspiration sources.

Another important aspect on designers' use of external stimuli, which has not been previously investigated, is the *selection* of inspiration sources. An unlimited

number of stimuli is available for designers and selecting and using an adequate source of inspiration is often an implicit decision. Understanding the criteria that guide designers' selection of stimuli during their design process is essential to fully support the creative outcome of designers' inspiration process.
Any potential stimulus consists of two elements crucial to the creation of an appropriate stimulation: *content* – what a person might perceive from the stimulus; and *representation or form* – how the stimulus is physically presented, for instance, if the stimulus is portrayed in visual, textual or other media form (Sarkar & Chakrabarti, 2008). Therefore, this thesis explores the usefulness of different *representation modalities* and *content* of stimuli during the design process. Usefulness, in this context, refers to the extent to which particular types of stimuli might support the designer in achieving more novel solutions, especially when compared to situations where no such stimuli are present.

## 1.1. Research methodology

This research project follows a designer-centred methodology (Badke-Schaub, Daalhuizen and Roozenburg, 2011). Hence, the focus is on designers, their thinking processes, and their behaviour, especially in developing creative solutions. In the context of a designer-centred methodology, designers are simultaneously the source that informs this investigation (as the subjects of the four studies that compose this research project) and the audience that it aims to support. It is then natural that designers feature so prominently in the research aim that guides this investigation.
The aim of this research project is to investigate and support designers' search and selection process of external stimuli. Thus, the research question that guides this investigation is the following:

*How can we support designers in searching, selecting, retrieving and implementing external stimuli to improve creativity in the design process?*

To answer the main question of the thesis, a number of sub-research questions were formulated[2].

**1.** What are the external stimuli designers ***search*** for during idea generation?
**2.** How do external stimuli, such as visual and textual stimuli ***influence*** designers during idea generation?
**3.** Which ***processes*** do designers employ while searching and using external stimuli for a design problem?
**4.** How do designers ***select*** external stimuli and how does it influence creativity in the design process?

Each study presented in this thesis aims to answer one sub-question, which reflect different dimensions of inspiration in design, visualised in table 1.1. This table establishes a link between how each of the sub-questions was answered by a particular study and which methods were used. A brief description of their set-up is also included.
This research project combines quantitative and qualitative empirical methods. The reason for this is twofold:
Firstly, a combination of methods enabled triangulation of results between different viewpoints. In this case, triangulation was achieved by combining quantitative methods (questionnaire and experimental studies) and qualitative methods (case study and interviews), which, according to Flick (2011, p.186), makes it possible to observe convergence between results across the different methods.
Secondly, different methods give the opportunity to approach the same issue in contrasting perspectives, adapting the focus of the research either in a more detailed and sharp manner or to enable a broader analysis of the topic.

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*2 Please note that the focus of the sub-research questions have gradually changed during the development of this doctoral research. Thus, the first three questions (which refer to Studies I and II) mainly address the influence of external stimuli during idea generation, whilst the last two questions (Studies III and IV) adopt a more general perspective. The decision to approach the overall design process instead of a specific phase was taken when the first two empirical studies revealed that the use of inspiration sources does not solely occur during ideation.*

| **Data** Collection | **Sub-**Questions | **Set** Up |
|---|---|---|
| **Focus** - INPUT | | |
| **Study I**<br>**Questionnaire** | **Sub-question 1**<br>What are the external stimuli designers **search** for during idea generation? | Online questionnaire (NetQ Software)<br>Answered by: 103 student designers (Industrial Design Engineering Faculty-TU Delft bachelor & master students) + 52 professional designers (european studios, mainly from Portugal & The Netherlands) |
| **Focus** - OUTPUT | | |
| **Study II**<br>**Experimental study** | **Sub-question 2**<br>How do external stimuli, such as visual and textual stimuli, **influence** designers during idea generation? | Experimental study with 137 novice designers (Industrial Design Engineering Faculty-TU Delft) answering a design brief for a period of 45 min.<br>7 conditions: Control<br>Visual related stimuli<br>Visual distant stimuli<br>Visual unrelated stimuli<br>Textual related stimuli<br>Textual distant stimuli<br>Textual unrelated stimuli |
| **Focus** - PROCESS | | |
| **Study III**<br>**Case study** | **Sub-question 3**<br>Which **processes** do designers employ while searching and using external stimuli for a design problem? | Case study within the Bachelor Final Project (with 8 novice designers of Industrial Design Engineering Faculty-TU Delft) |
| **Study IV**<br>**Experimental study with Verbal Protocol Analysis (VPA) and interviews** | **Sub-question 4**<br>How do designers **select** external stimuli and how does it influence creativity in the design process? | Experimental study with 31 novice designers (Industrial Design Engineering Faculty-TU Delft) answering a design brief for a period of 40 minutes (30' - diverging phase + 10' - converging phase).<br>All participants' process was videotaped, enabling verbal protocol analysis.<br>All participants were subsequently interviewed.<br>3 conditions: Control<br>Unlimited selection of stimuli<br>Limited selection of stimulus |

**Research** Question

How can we support designers in searching, selecting, retrieving and implementing external stimuli to improve creativity in the design process?

Table 1.1. Overview of the methods used in this thesis and their corresponding sub-research questions.

Figure 1.2 illustrates the research model employed in this thesis, adapted from Punch (2005, p. 32 – 43). This model identifies the most important components of this research project in two phases: the research theory-analytical phase and the research design-executive phase. The model shows how, initially, the research problem is formulated around a context (design idea generation), a research area (creative problem solving) and main literature topics, which naturally evolve into the main research question (and sub-questions). In the research design-executive phase, the model clearly identifies the steps taken to acquire and analyse the data to answer the main and sub-research questions.
Finally, as indicated in the research model of Figure 1.2, the ultimate goal of this research project is to develop an inspiration process model, in order to create an approach for tackling the challenges associated with positive and negative influence of external stimuli in creative design problems.

## 1.2. Relevance of this research for design practice and education

A successful design outcome is the result of a variety of circumstances and influencing factors that come together at different stages of the design process. The creativity of an idea constitutes one of the most important elements that determine how effective a design solution might be. Generating new and creative solutions is therefore an essential phase preceding the implementation of innovative design outcomes. However, generating successful design solutions is not a straightforward process. Each day, designers come across different kinds of stimuli, which play a crucial part in how they understand a problem, in their exploration of ideas and the further development of those ideas. Since such important parts of the creative design process lie in the influence of stimuli, it is essential to understand how designers might be supported in their inspiration strategies.
Learning about the usefulness of inspiration sources during the design process can provide new directions for design research, practice and education. For design research, knowing how and why particular stimuli support or hamper the development of creative solutions can be a starting point to help designers

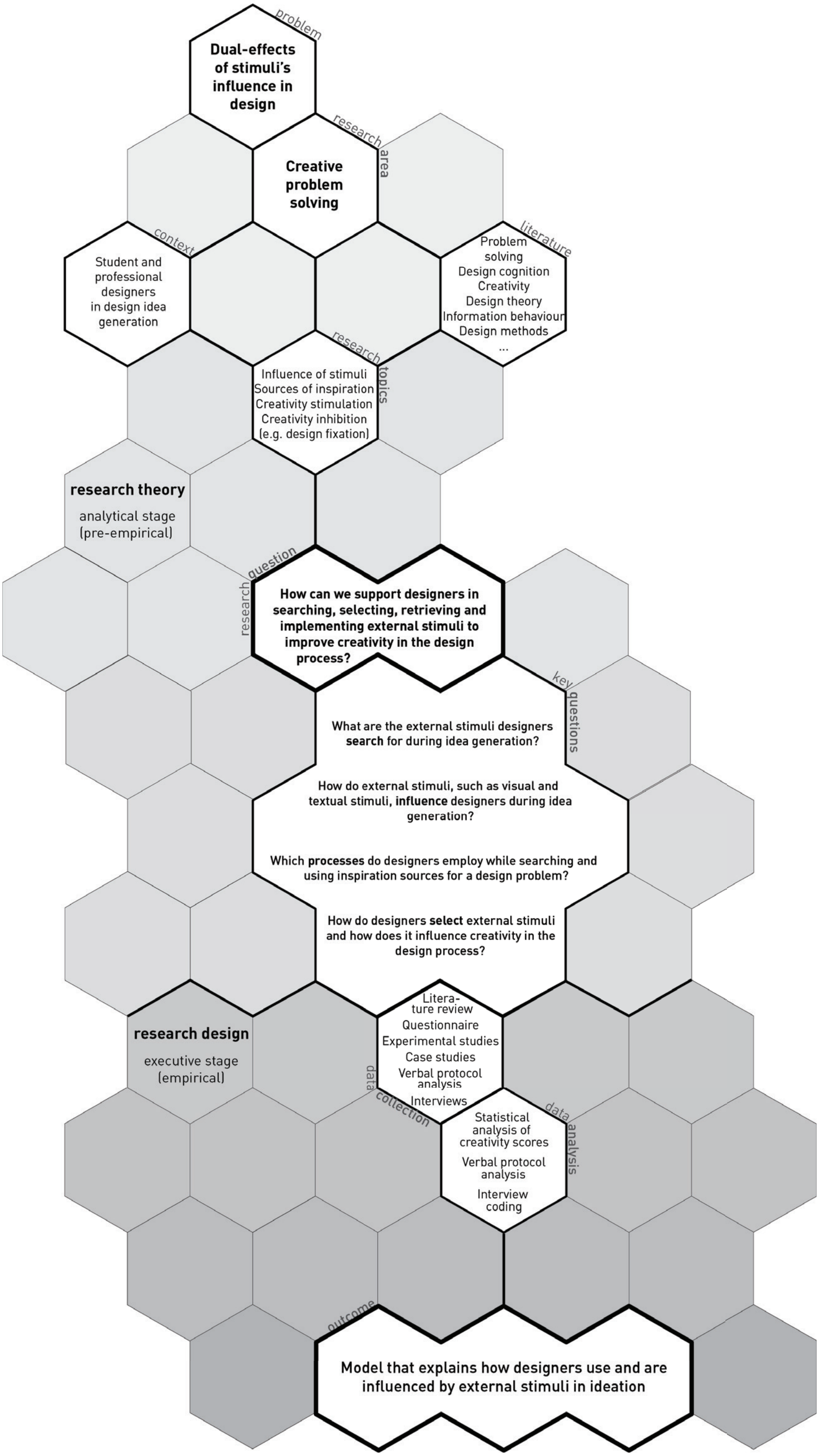


Figure 1.2. Model of this research project, adapted from Punch (2005).

to better select and make use of the rich variety of sources of inspiration around them. Furthermore, understanding how designers select and work with different stimuli can support the development of different ways of coping with behaviours possibly detrimental to creativity and innovation, such as design fixation.
Regarding professional practice, this research project means to support designers in their selection approaches, in face of the immense diversity of available inspiration sources. By investigating designers' inspiration processes, this research project promotes the awareness that the most easily accessible and most salient stimuli may not be the most effective for the generation of successful, creative solutions.
Concerning the impact of this research on design education, the in-depth knowledge that is presented in this thesis ought to make it possible to think (or rethink) how an unreflective use of inspiration could be improved and adjusted to the needs of novice designers but also those of expert designers.
This thesis contributes to knowledge in the area of creativity in design, as it carries out empirical work on the influence of a number of external stimuli that have not been previously investigated by other researchers. Therefore, it extends the existing knowledge on the influence of stimuli in design.

## 1.3. Thesis outline

This thesis is organised in seven chapters, as illustrated in Figure 1.3. Using the 'input-output' information processing system as a metaphor, the starting point of this research project is to investigate which 'input' (i.e., external stimuli) designers search for and use while designing and how this input influences the 'output'. To fully support designers in their selection and use of stimuli, it is vital to understand what happens in the process between 'input' and 'output' (figure 1.3). Note that this is not a chronological timeline, but a representation of the use of stimuli as 'input' (what inspires designers), 'process' (characterisation of the inspiration process) and 'output' (how do inspiration sources influence designers' outcome)[3]:

*3 On the other hand, the studies are numbered in a chronological way, as they were conducted. Thus, study I was the first one to be conducted, whilst study IV was the last.*

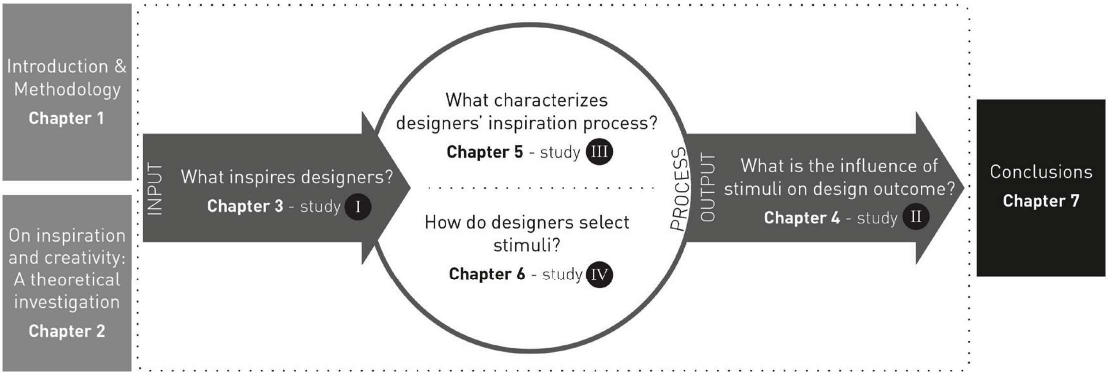


Figure 1.3. Overview and structure of this thesis, organized from the perspective of the inspiration process as an 'input-output' information processing system.

**Chapter 1** provided an overview of the context that encompasses the main research problem and a description of the research methodology used in this doctoral investigation. The main research question was broken down into four sub-questions and different research designs were used to answer each. This chapter introduces the several studies that were carried out and explains the reasoning behind each study.

**Chapter 2** – On inspiration and creativity: a theoretical investigation, or *What you need to know before learning about inspiration* – discusses the essential themes that underlie this research project, which define its context. This chapter offers an overview of the essential literature that support the studies carried out in this research project. It begins with an introduction to the topic of creativity in design, followed by the role of inspiration sources in creative idea generation. Furthermore, an analysis of the possible hindrances to creativity is presented, which explains the many pitfalls for designers while involved in creative problem solving. Subsequently, a section on the stimulation of creative thinking is presented, including a detailed review of the research related to creativity techniques and inspiration sources.

**Chapter 3** – *An investigation into the inspiration preferences of student and professional designers* – presents the results from Study I, a **questionnaire** on student and professional designers' preferences on inspiration sources. This method brought to light topics complementary to inspiration (such as ideation methods and reflection on barriers to creativity). This study illustrates what external stimuli designers search for in a design problem, and what the differences and similarities are on the inspiration search processes of novice and expert designers. The results from the questionnaire from study I served as the foundation for the studies reported in chapters 4, 5 and 6.

**Chapter 4** – *How far is too far? The semantic distance between design problem and visual and textual inspiration stimuli* – describes study II, an **experimental study** with seven conditions. Whilst Study I identified what designers reportedly prefer to use as inspiration sources, study II experimentally investigates the influence of specific external stimuli during ideation. Study II explores the usefulness of exposing designers to stimuli that varied both on representation and content (in this case, semantic distance).

**Chapter 5** – *Uncovering the inspiration process: a case study of novice designers* – builds on the results from study II on the influence of external stimuli topic and increases the depth of the analysis. Study III is a **case study**, moving the focus from quantitative to a qualitative approach. It examines how eight bachelor design students, in their Bachelor Final Project course, use inspiration sources throughout their last project, in a 'natural' educational environment (as opposed to artificial experimental settings). For this purpose, a number of units of analysis were collected. This data included: designers' daily work notebooks; individual assessment of their design skills and creativity; intermediate and final reports; and, individual interviews. These interviews allowed for a retrospective analysis of their design process, whilst the daily notebooks and reports gave a more complete perspective. This study was a next step in investigating how novice designers use external stimuli, but, this time, the focus was on the inspiration process (rather than the outcome, which was the aim of Study II).

**Chapter 6** – *Inspiration choices that matter: the selection of external stimuli and their influence on creative ideation* – describes the final study of this thesis, which tackles the issue of how designers select inspiration sources during the development of a design problem. Whereas Study I revolves around the topic of search of stimuli, Study II focuses on the influence of certain stimuli in ideation and Study III addresses the inspiration process, Study IV – presented in this chapter – investigates the selection of external stimuli in design. This is achieved by combining quantitative and qualitative data collection and analysis: an **experimental study** that included **verbal protocol analysis** of the design process (resulted from the video data collected during the experiment), followed by **interviews**. Thus, both quantitative (analysis of the design outcome) and qualitative results (analysis of the design process and interviews) were gained and combined.

**Chapter 7** concludes this thesis, presenting a review of the empirical findings revealed by the aforementioned studies, which culminates in a model of the inspiration process. This model explains how designers search, retrieve and use diverse stimuli and where designers can be supported better in their inspiration process to enhance their creativity. This chapter discusses the limitations of this research project and possible implications for design education and practice, as well as pointing out directions for further investigation.

## 1.4. Main themes: following the red thread

A doctoral thesis can feel labyrinthine: following its intricate structure and formal protocols can become a daunting task, which tends to drive readers away. To smooth the path of the reader, as Ariadne aided Theseus out of the labyrinth of Minotaur with a red thread, the reader of this thesis can choose which reading path to follow (see Figure 1.4).

This thesis presents an academic and scientific exploration of the ubiquitous topic of inspiration and creativity. Because inspiration is a very approachable subject, with such a widespread use in everyday language, it is a topic prone to elicit discussion across a number of perspectives. For the purpose of this thesis, a cluster of themes was selected. These themes, indicated in Figure 1.4, form the scope of this thesis and were considered essential to investigate the inspiration process within design and its influence on creativity.

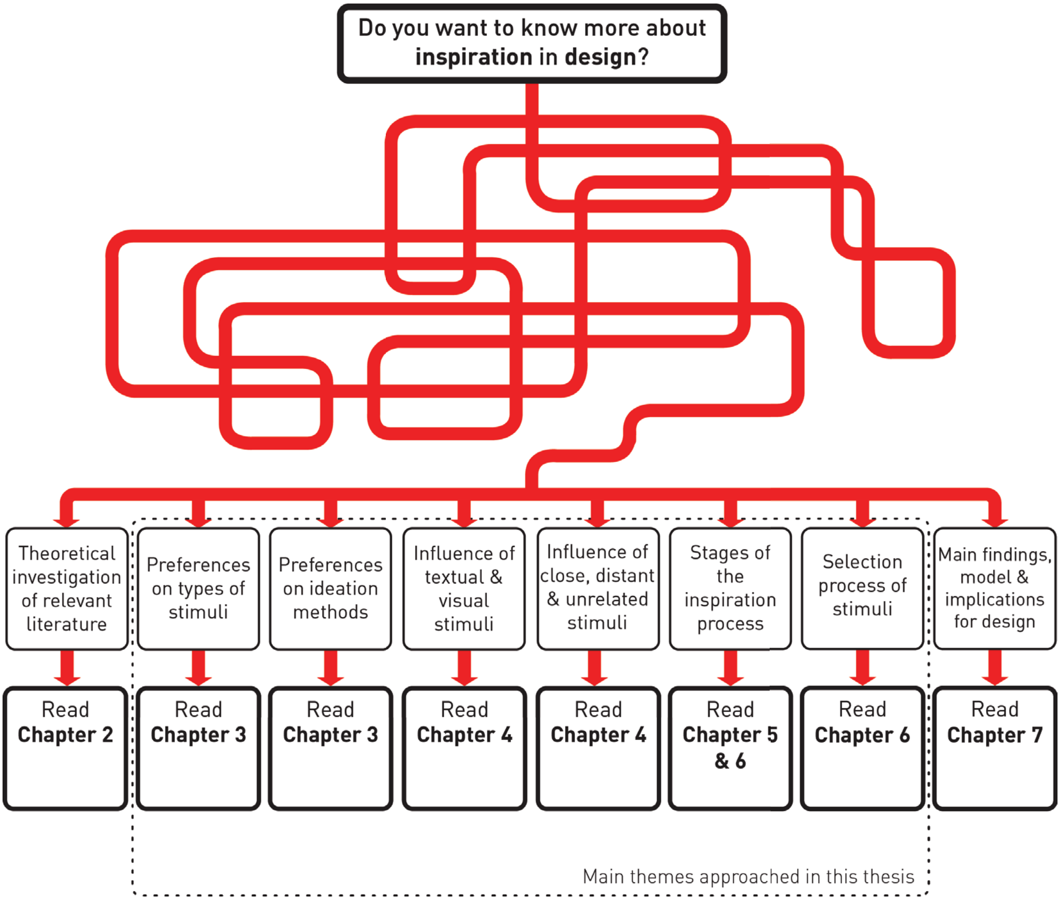


Figure 1.4. Flowchart on the most important themes discussed in this thesis, and where to find them.

Chapter 2 figure:
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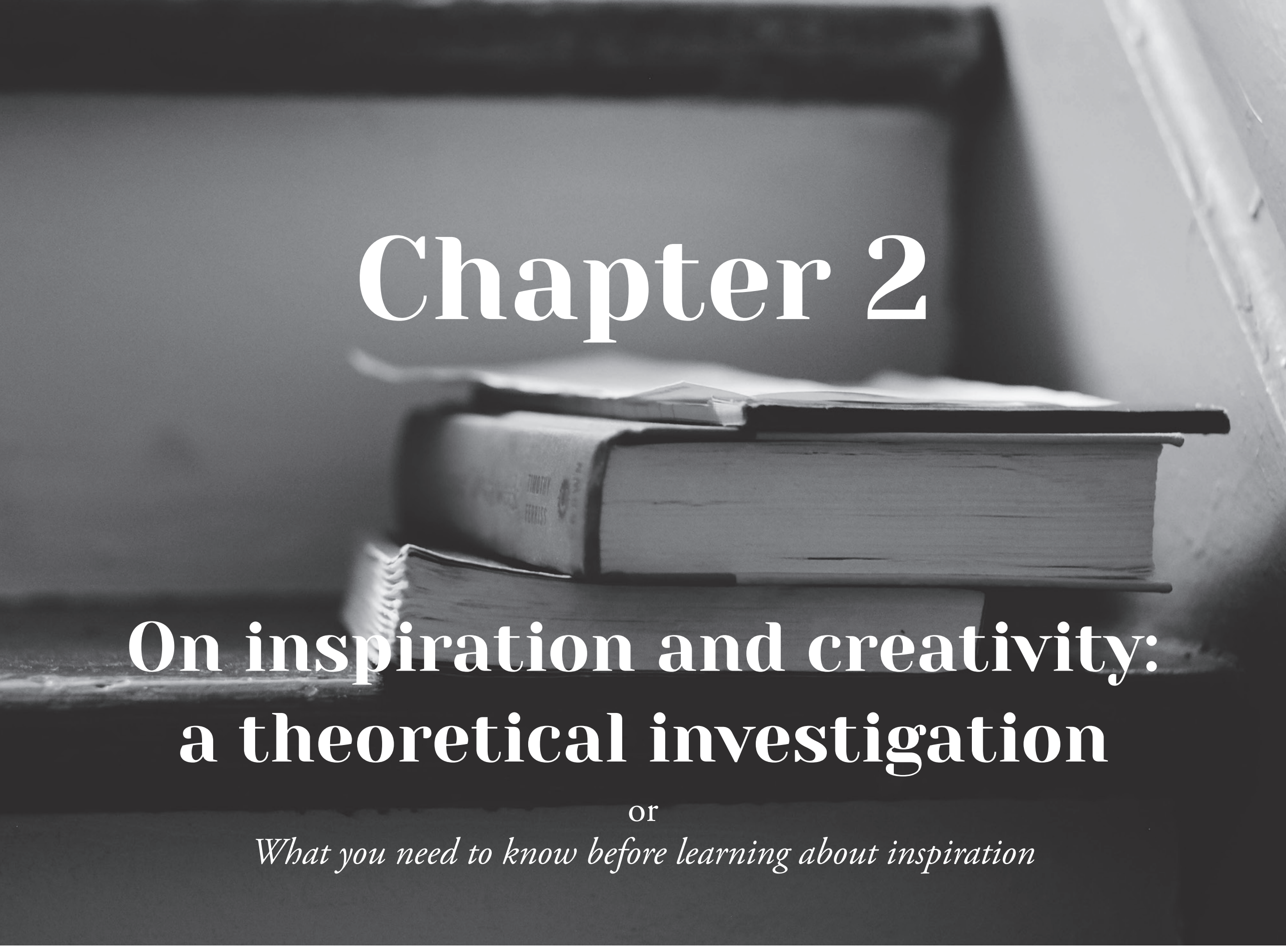


# Chapter 2

## On inspiration and creativity: a theoretical investigation

or

*What you need to know before learning about inspiration*

*This chapter presents an overview of literature relevant to the topic of inspiration in design. As many of the sub-research questions (introduced in Chapter 1) emerged from knowledge gaps, they were integrated in this overview. The positioning of sub-research questions in the review of specific streams of literature highlights the main issue(s) they aim to tackle and establishes the motivation of the following empirical chapters (Chapters 3 to 6).*

## 2.1. Designing in context

Design is at the core of innovation and at the start of many new technology advancements, and it is an irrevocable part of business success (Brown, 2008). Designers are often expected to foresee trends, fulfil unknown user needs and deal with uncertainty, and ultimately create novel solutions. For these reasons, design problems are considered to be nonroutine, as opposed to routine problem solving tasks, which are characterized as well-defined, within typical parameters and with clear goals and formulations (Gero, 2000). Design problems, instead, can be characterized as ill-defined. There are several characteristics that distinguish ill-defined problems: considering their unclear formulation, both the problem and solution spaces need to be explored and are dependent on each other; goals are often unknown or permutable; and there is never one correct solution but many possible ones (Simon, 1973; Goel, 1995; Goldschmidt, 1997; Paton and Dorst, 2011). Besides being ill-defined, some design problems can also be considered to be 'wicked', as opposed to 'tamed' or 'benign' (Rittel and Webber, 1973). This is the type of problems designers increasingly seek to tackle, as wicked problems are commonly associated with societal or cultural issues (Dorst, 2015). These dynamic and interconnected problems are usually considered to be too open to consider all possible solutions and, hence, it is difficult to perceive when the problem is solved. Furthermore, wicked problems are unique, as they are dependent on how stakeholders perceive their many ramifications and, in this way, many frames of interpretation of a problem result in different solutions (Rittel and Wibber, 1973). To design, then, is to explore what does not yet exist to solve current or even unforeseen problems.

From the start of a project, designers are asked to interpret a design problem and formulate its context: how they structure the design situation is shaped by their knowledge of the problem at hand and target group, by considerations that range from materials to cultural impact, by their knowledge of existing solutions and by their own expertise. Thus, designers dealing with the same brief tend to have different interpretations and create distinct problem definitions. As Gero (2000, p.185) suggests: "The situation [of the design activity] shifts as the designer's perception change". These differences are attributable to, for instance,

how designers search, encode and recall relevant information (Eastman, 2001). However, a designer's problem definition is rarely static. Design activities are considered to be highly iterative and co-evolving (e.g., Maher and Poon, 1996; Maher, 2000; Dorst and Cross, 2001; Wiltschnig, Christensen and Ball, 2013), as both the design problem definition and solutions are recurrently adjusted.
In this co-evolution perspective of design, there is a dialogue between the interpretation of the design problem context and its requirements (referred to as *problem space*) with the generation of ideas (described as the *solution space*), which results in the bi-directional interaction and co-evolution between the two design spaces (Dorst and Cross, 2001).
Christensen and Ball (2013) established a connection between co-evolution of the problem and solution spaces with epistemic uncertainty, which has been defined as the moments when designers lack certainty about how to continue in a design problem, normally caused by insufficient knowledge (e.g., Ball and Christensen, 2008). These authors identified epistemic uncertainty episodes especially when designers are exploring the solution space, as it requires that they go beyond their existing knowledge to be able to create novel ideas. Furthermore, the work of Dorst and Cross (2001) suggests that design information can be one possible instigator for the co-evolution of problem and solution space. In their study, which comprised a protocol analysis of the work of nine designers, information sheets were provided whenever the participants required it. Their analysis showed that participants used the information provided to explore and adapt both the problem and solution space, triggering them to iteratively re-formulate the problem definition and expand the solution space.
One of the possible strategies to cope with uncertainty, besides gathering experience or applying methods, is to use information (Tseng and Ball, 2010). This doctoral thesis is mainly concerned with how designers use information for inspirational purposes in the design problem. This theoretical overview continues by deriving knowledge from different fields, such as design, information sciences and cognitive psychology. It uses as a standpoint design cognition, defined by Eastman (2001, p. 147) as "the study of human information processing in design, using different theoretical and empirical paradigms", which provides a connection between the aforementioned fields. The purpose is to develop a model

that explains designers' inspiration process, which is presented in Chapter 7. Nevertheless, we begin by examining the general role of information in design.

## 2.2. The role of inspiration in design

The design process is supported by information (Baya, 1996; Howard, 2008). Throughout every project, designers encounter all kinds of external stimuli, which can eventually become inspirational and influence their solutions. In this thesis, information, stimuli and inspiration sources are considered distinct but connected concepts, as they represent different parts of the same process. A diagram of basic definitions of information, stimuli and inspiration sources can be found below (Figure 2.1).

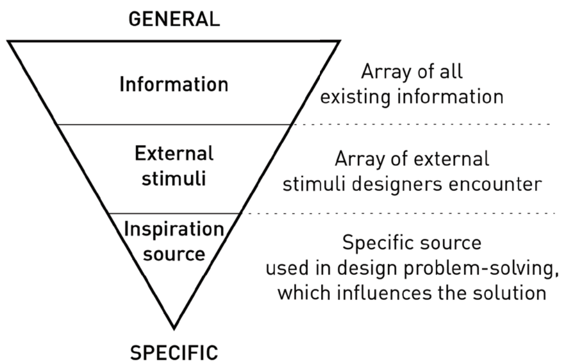



Figure 2.1. Differentiation between information, external stimuli and inspiration sources.

In the field of design engineering, *information* is defined as data with context, which in general terms refers to facts that carry meaning (Court, 1995; Ahmed, Blessing and Wallace, 1999; Hicks et al., 2002; Howard, 2008). Information can either be interpreted in subjective or objective terms according to each individual's context. Once information is understood, processed and incorporated, knowledge can be created (Ahmed, Blessing and Wallace, 1999). Within this thesis, information is referred as any type of data, which has not necessarily been interpreted. Once it is interpreted, information can become stimuli.

*Stimulus*, as used in every day language, is defined as "a thing that arouses activity or energy in someone, or something; a spur or incentive" (Oxford University

Press, 2015). Sarkar and Chakrabarti (2008) set off from the same starting point to define stimulus as a trigger, i.e., "an agent that activates exploration and search in design". Thus, an external stimulus could be any information that has been interpreted and prompts a reaction to explore the problem and solution space (Sarkar and Chakrabarti, 2008). External stimuli are not directly translated into inspiration sources. In this thesis, a stimulus becomes inspirational only after it is perceived, understood by a receiver (e.g., designer) and included in the mental model of generation of ideas and concepts.

Thus, an *inspiration source* is a stimulus that carries specific information that has an actual impact on the creation of ideas. This definition includes any entity that is consciously or unconsciously perceived, retrieved (from one's memory or from the outside world), interpreted and (mentally) transformed as inspirational material, which influences the generation and exploration of ideas. These entities are expected to have an impact on the ideas generated, ultimately influencing the design outcome, directly or indirectly. This definition of inspiration describes tangible entities but also digital artefacts such as web pages, or even intangible entities, for instance, talking to a friend (Eckert and Stacey, 2003a; Mete, 2006; Mougenot, Bouchard and Aoussat, 2008; Herring et al., 2009; Setchi and Bouchard, 2010). The differentiation between stimuli and inspiration sources is discussed in greater detail in section 2.2.6.

While preparing this overview, it was noticeable that knowledge on designers' information use is scattered, both in the design field itself but also in information science and cognitive psychology. A number of researchers have been engaged in understanding what type of information designers use (e.g., Court, Culley and McMahon, 1993; Mougenot, Bouchard and Aoussat, 2008; Howard, 2008), whilst others are engaged in mapping designers' information needs (e.g., Heisig, Caldwell, Grebici and Clarkson, 2010). Another stream of research focuses on the influence of different types of information on the design outcome (e.g., Perttula and Sipila, 2007; Malaga, 2000; Sarkar and Chakrabarti, 2008). Little is still known regarding how the types of information designers seek can influence the design process.

This act of gathering all kinds of information is generally seen as ubiquitous and indispensable (Eckert and Stacey, 2000), not only for solving immediate problems, but also for the development of design expertise (Popovic, 2004). The task of handling information is continuous and can take place in the designers' minds, but also while they interact with their surroundings. Designers tend to actively collect physical and/or mental visual samples for inspirational purposes, both while working in specific projects as in daily life (Keller et al., 2009). Physical collections of stimuli include notebooks, visual collages, magazines, but ever more frequently, designers tend to collect stimuli digitally (Keller, Pasman and Stappers, 2006; Mougenot, Bouchard and Aoussat, 2008).

According to Court et al. (1993), who developed a questionnaire on the information requirements of engineering designers in the United Kingdom, 18% of the designers' time is spent searching for information. This is a substantial amount of time, especially when considering its impact in productivity and quality of design outcome (Court, Culley and McMahon, 1997). The information needs of designers vary when taking their expertise into account, as novice designers tend to be unaware of what they should know (Ahmed et al., 2000; Ahmed and Wallace, 2004). Likewise, the type of information designers seek changes considerably across the different phases of the design process (Allen, 1966; Hicks et al., 2002), and many sequential searches can occur for the same problem (Spink, 1996). According to Heisig et al. (2010), one of the most important information needs engineering designers require is on the rationale of the problem, for clarifying and justifying decisions at the fuzzy front end of the design process. Especially in the initial phases, when designers need to define and explore the problem scope, information can help to reduce uncertainty (Eckert, Stacey and Earl, 2003; Guo, 2011).

The prominent role given to information in the design domain can be explained by a number of reasons (e.g., Eckert and Stacey, 2000):

- to reduce uncertainty in the design process;
- to stimulate creativity and arouse breakthroughs throughout the creative process;
- to support awareness for previous solutions;
- to create the appropriate frame of reference to new innovate designs;
- to share and receive knowledge with and from other stakeholders;
- to facilitate and accelerate the idea generation process.

When it comes to the types of information designers employ, research has continually demonstrated that designers' creative performance during idea generation is influenced by previously acquired knowledge (Weisberg, 1999; Pasman, 2003; Liikkanen & Perttula, 2006). Purcell and Gero (1992) described two main sources from where designers retrieve knowledge for understanding and coping with specific encountered design problems. The first source is knowledge gained from everyday encounters in a more serendipitous manner. The second is knowledge that arises from intentional learning, therefore structured and specific domain oriented. Both types of knowledge play an important role in the design process.

Besides previously acquired knowledge, designers also encounter different types of stimuli while searching for information. Internal stimuli can reside in the person's working and long-term memory, and can take the form of mental imagery and verbal information. Initially, what is encoded in long-term memory is mostly decided by selective attention (Craik and Lockhart, 1972 in Eastman, 2001) in combination with continuous background control. Subsequently, a stimulus may move from working to long-term memory and vice-versa. In a design problem, specific stimuli may be retrieved from long-term memory to working memory.

On the other hand, external stimuli are entities in the person's surroundings that can be revealed in many different representation modalities, for instance, pictorial, textual, audible, or tactile information (Eastman, 2001). External stimuli can carry different types of information and be encoded in various manners, such as pictorial stimuli into sketches and textual stimuli in books. Moreover, external stimuli can also originate from conversations with others or from a range of everyday activities, not specifically connected to a single representation modality. Perception of these stimuli are understood and encoded in the person's mind by sensory modalities, such as sight or touch (Eastman, 2001). While all external stimuli that ultimately influence designers' output is first perceived and later mentally processed, thereby becoming internal stimuli, this research project focuses mainly on external stimuli. Figure 2.2 explains how internal and external stimuli interact in a person's mind. Designers can create design concepts based on the combination of their previously acquired knowledge/experience and external sources of encoded information. Information is encoded in different representation modalities and they are experienced through multiple sensory modalities.

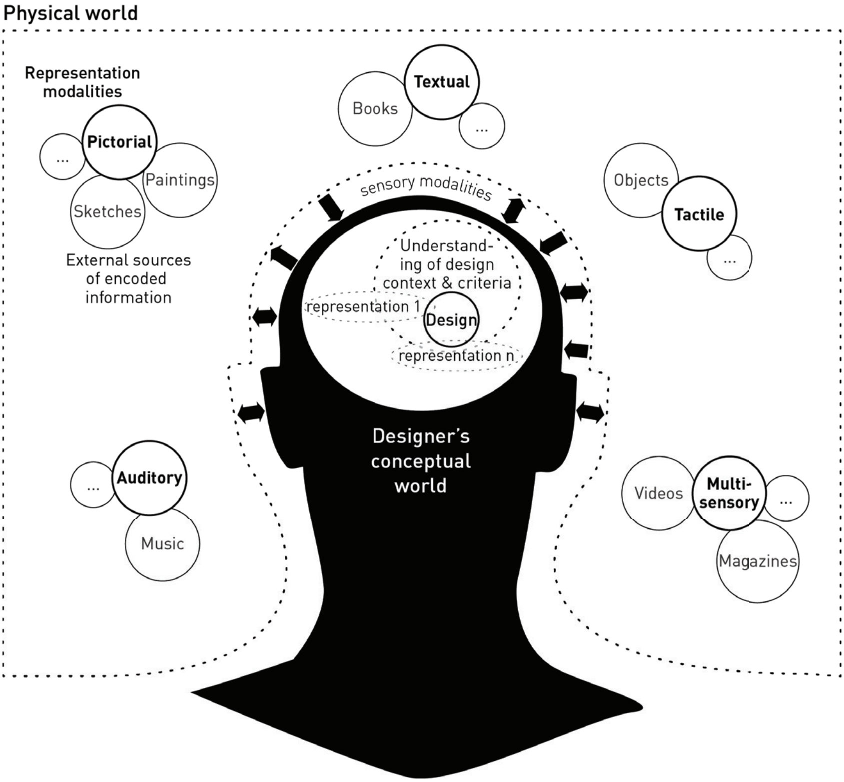



Figure 2.2. Visualisation on the interaction between individuals and internal and external stimuli (Adapted from Eastman, 2001).

Designers, especially novices, seem to struggle to identify what is the most adequate information for the problem at hand (Hicks et al., 2002; Ahmed et al., 2000; Ahmed and Wallace, 2004), as there is an overwhelming number of possible stimuli a designer can search for and use. Past studies have made efforts to investigate which information sources are mostly used in the engineering context (Court, 1995; Allen, Hicks and Culley, 2000). However, these studies focus solely on the engineering field and might be out-dated, considering the ubiquitous use of Internet nowadays. Therefore, and as far as the author of this thesis can ascertain, there is no recent comprehensive overview of the types of information designers reportedly use, in the field of design. Knowing more about the external stimuli designers apply in their work is an essential step towards investigating the influence of inspiration during idea generation. Moreover, understanding the different approaches of student and professional designers on this matter can potentially help to support them in a more efficient search, retrieval and usage of available stimuli. This motivated the development of Study I (Chapter 3), which was guided by the following sub-research question: **What are the external stimuli designers *search* for during idea generation?**

### 2.2.1. Differences in the use of stimuli: the role of expertise

Several studies acknowledge that the use of stimuli is relevant to a large number of creative disciplines, such as architecture (Casakin, and Goldschmidt, 1999; Cai, Do, Zimring, 2010; Ozkan and Dogan, 2013), engineering (López-Mesa et al., 2011) or fashion design (Mete, 2006; Eckert and Stacey, 2003a/2003b). Likewise, the use of stimuli is also relevant to designers from all levels of expertise (e.g., Mougenot, Bouchard and Aoussat, 2008; Cai, Do and Zimring, 2010).
A large and growing body of literature has investigated how experts differ from novices in creative problem solving, but so far, research has not addressed differences in the use of stimuli in design.
The accumulation and development of design expertise is a process designers go through from their early design education until they reach a particular degree of proficiency in their field. However, this is not a linear process. Each designer is likely to have a unique background in terms of knowledge and experience, as well as different motivational and personality traits, which influence how they progress. Also, going through different levels of expertise is not necessarily a sequential and gradual process - instead, it could entail stagnant, slow, or chaotic levels as well as leaps of development (Lawson & Dorst, 2009).
According to Lawson and Dorst (2009) and Dreyfus and Dreyfus (2005), there are seven discrete levels of design expertise: novice, beginner, advanced beginner, competent, expert, master and visionary. However, these distinct levels of expertise are unlikely to provide a complete categorisation of a particular designer. In fact, a designer's level of expertise could vary according to the problem at hand. Consequently, whilst different designers might be competent in a certain situation, they will be beginners in another (Lawson & Dorst, 2009).
Nevertheless, the expertise model levels previously mentioned are generally

recognisable to people involved in design (Lawson & Dorst, 2009).
Schön (1983) elaborated on the role of reflection in practice, which is connected with expertise. According to his work on reflective practice, expert designers can be considered reflective practitioners. In this way, knowledge is not only gathered in a declarative and rational manner, but also through action and reflection (Schön, 1983). As designers learn by doing and gain experience, some of the knowledge gathered is implicit – what Schön refers to *knowledge-in-action* – and thus, it is employed in action but it can hardly be expressed or explained to others. On the other hand, designers, as practitioners, can also consciously *reflect-in-action*: this is the ability to explicitly reflect while designing, where actions are evaluated and new perspectives can be gained. Episodes of reflection-in-action tend to occur when a surprising or unexpected event happens. Such events can result from uncertainty of a problem, an unpredicted negative consequence or also a serendipitous moment and, when they occur, they prompt 'back-talk'. According to Schön, 'back-talk' refers to the moment where a designer reflects or evaluates the present situation. This interactive conversation between the designer and the context normally results in iterations of the design process, i.e., a new frame of the problem or solution or in a new action into the design process. While investigating the design behaviour of freshmen and senior designers, Adams, Turns and Atman (2003) determined that iterative activities are related to reflection-in-action, which normally resulted from searching information, (re) framing problem requirements or evaluating solutions. Moreover, the authors identified that more experienced designers iterate more often than novices and that the former group were more likely to reflect on previous steps of the process. By building their repertoire of experiences, designers with many years of practice increase their knowing-in-action: intuitively know how to approach a problem, by relying on their past experience (Schön, 1983). During design practice, it is sometimes then unlikely to explicitly reflect-in-action, i.e., 'think on one's feet'. Instead, reflection can also occur after the conclusion of a project, which Schön refers as to *reflection-on-action.* In this type of reflection, the designer withdraws from practice and evaluates his or her actions at a distance (normally after the design process is complete). Whilst *reflection-on-action* could be characterized as 'routine monitoring' of the design process (Mumby, 1989), *reflection-in-action* is

prompted by surprises.

Previous research comparing levels of design expertise postulate that the main differences between novice and expert designers lie in two patterns of thinking: focus and search patterns of information. Regarding the focus, there seems to be evidence that experienced designers follow a solution-focussed approach to understand the problem, where precedent solutions are tentatively used to explore both the solution and problem space. Conversely, other kinds of problem solvers, with no experience in design, tend to tackle design problems in a problem-focussed manner (Lawson, 1979; 2004). Lloyd and Scott (1994) built on Lawson's work and established a link between the solution-focussed strategy of experienced designers with generative thinking processes. In contrast, less experienced designers tend to adopt more deductive than generative reasoning. Whilst generative reasoning is characterised by the introduction of new information (such as a solution or parts of it) in order to tackle the design problem, deductive reasoning entails understanding and representing the problem.

Concerning search patterns of information, Cross (2004) suggested that novice designers do not usually have a clear structure to guide them. On the other hand, experienced designers are prepared to extensively analyse the problem at hand and embark on a quest for all kinds of information that might help in following the process. Other studies have reported similar results, where more experienced designers tend to collect more information, which results in a better problem definition and a larger flexibility of the solution space (Atman et al., 1999). On the other hand, less experienced designers have difficulties in proceeding from information gathering to idea generation, as they might not know what to search for or how to proceed into the following phases of the design process (Atman et al., 1999; Christiaans and Dorst, 1992).

In a study investigating the role of expertise in analogy, Ozkan and Dogan (2013) explored how architects with different levels of experience selected and used visual stimuli displaying near- and distant-domain information. Novice architects selected distant domain analogs (claiming their selection would lead to unique and original results) more often than experts, who selected more near-domain analogs (as a strategy to provide cognitive or time economy). However, experts

were not impaired by their selection, as they were able to focus on structural similarities and avoid superficial ones. Conversely, novice architects recognised the potential use of distant-domain analogs but still gave more emphasis to superficial similarities. Chi, Glaser and Rees (1982) identified the same behaviour when researching general problem solving skills.
Generally speaking, once information is acquired, both experts and novices tend to categorise information in different ways: novices organise information according to more superficial characteristics, whereas experienced designers are able to analyse information on the basis of many cases of solution principles they have stored in the past (Lawson, 2004; Petre, 2004). Thus, experts can address a problem from several angles. Research conducted in different disciplines compared various aspects of behaviour between novice and experienced designers (Lloyd & Scott, 1994), but so far no study has explicitly addressed their choices and preferences regarding inspiration approaches. To bridge this gap, Study I (in Chapter 3) includes a comparison between student and professional designers regarding their *search* of external stimuli. Although this was not considered an essential component to ultimately include as a sub-research question in this thesis, the comparison across expertise levels ought to provide a more complete overview of the phenomenon of inspiration across the overall population of designers.

### 2.2.2. Stimuli classification

Stimuli can vary in form (or representation), content or medium (Sarkar and Chakrabarti, 2008). In the context of this research project, the form of a stimulus varies according to the representation modality used (i.e., how the stimulus is physically presented to the subject). The content of the stimuli (discussed in section 2.2.4.) was analysed – in this thesis – according to its semantic distance from the design problem statement. External stimuli can also vary in terms of the medium in which they are conveyed and accessed (e.g., Internet or books). In the following section, an overview of research on the stimuli form is introduced, focusing on two types of representation modalities: visual and textual stimuli.

### 2.2.3. Types of representation modalities: Visual stimuli

It is generally known that designers, in searching for information, prefer visual ways of information processing and communicating (Hanington, 2003; Henderson, 1999; Muller, 1989). Moreover, designers seem to prefer to search for inspiration in images (Eckert & Stacey, 2000), especially those that highlight form and function (Herring et al., 2009). Riding and Cheema (1991) developed a classification of cognitive styles to explain information processing strategies (i.e., individual tendencies that guide one's information search and use processes). In their classification, they distinguish between *imager* and *verbaliser* cognitive styles. Being a imager or a verbaliser refers to the tendency to either use images or words to search and represent information and can be compared to Mednick's distinction between *visualisers* and *verbalisers* (1962). Not surprisingly, designers are considered to be visualisers and see themselves as highly competent in the use of images.

The advantages of using visual material within the design process are many: it facilitates knowledge sharing (Neumann, Badke-Schaub, & Lauche, 2009) and promotes the translation of semantic meaning between different stimuli modalities by providing straightforward and intuitive cues (Malaga, 2000). Depending on the content, images are generally more efficient than text in terms of conveying information, as accessing, storing and transmitting information from images requires less cognitive efforts than from texts (Ware, 2008, p. 107; Sarkar and Chakrabarti, 2008). This efficiency of images is achieved due to close relationship between what is represented in the image and our perception of what is represented (Ware, 2008).

Malaga (2000) studied designers working on ill-defined problems and exposed them to either pictorial stimuli, textual stimuli, or textual-pictorial stimuli combinations. Those exposed to pictorial stimuli generated more creative ideas than those exposed to the other stimuli. This led Malaga to suggest that textual stimuli might contribute to a type of design fixation. Design fixation has been defined as an unconscious tendency to inappropriately reuse parts/principles of previously seen examples during idea generation (Jansson & Smith, 1991). In another study, Casakin (2005) demonstrated that a rich collection of pictorial representations could help student and expert architects when dealing with ill-defined problems. In Casakin's study, which focussed on the influence of analogies during idea generation, the quality of the solutions generated by the participants was enhanced when a number of diverse images were made available to them. Participants were stimulated by visual analogues even when they were not explicitly instructed to use analogical reasoning to solve the problem. Contrary to these findings on the positive effect of visual stimuli, other research studies have shown that the use of pictorial representations of existing examples would limit the generation of creative ideas (e.g., Purcell & Gero, 1996; Jansson & Smith, 1991). Particularly, designers tend to feel fixated when examples (images of solutions that already answer the same design problem participants are tackling) are presented as stimuli. Therefore, while visual stimuli can sometimes enhance creativity, images can also lead to a particular mind-set where previously seen ideas are incorporated into new design solutions with poor creative results (Perttula & Liikkanen, 2006).

#### 2.2.4. Types of representation modalities: Textual stimuli

Language plays an important role in our thinking process and, thus, influences design activity (e.g., Dong, 2006; Ware, 2008; Mougenot & Watanabe, 2010). As it is considered a "reproduction of designer's thoughts" (Dong, 2006), language can support design practice and also the development of concepts. For instance, language can be used to communicate information, to create and solve conflicts, and also to facilitate interaction between different stakeholders in a design process. Language can take different forms, such as verbal, written, or graphical. Despite being a highly structured system, language offers multiple paths of interpretation, which can stimulate creative design activities, especially at the word level (e.g., Chiu & Shu, 2007, 2012). Therefore, (written) language could potentially be a valuable stimulus for designing.

Regarding the role of writing and reading in creativity, Wang (2012) indicated that when individuals are regularly exposed to these activities, they perform better in creative tests than participants who do not spend regular time in reading and writing. Accordingly, Wang advocates that these learning activities stimulate creative thinking. One reported justification suggests that the increased opportunities to encounter different realities while reading in turn might enable creative ideas to thrive (Sturgell, 2008).

Nagai and Noguchi (2002) examined the role of keywords in the creative process, by giving abstract goal descriptions (which were not directly related to a specific form) to the designers in order to generate visual design solutions. According to their study, participants had to deconstruct abstract keywords (portraying feelings or intangible concepts) into more concrete keywords in order to arrive at a visual form. Therefore, in order to produce visual information from textual input, especially when presented with abstract concepts, a higher level of abstraction may be required. This extra cognitive effort may explain why so many designers prefer visual stimuli over textual ones when generating ideas.

In addition, strict project deadlines are likely to impose time limitations, in terms of exploring stimuli that might require higher levels of abstraction, which may lead designers to prefer searching for pictorial stimuli. Nevertheless, Nagai and Noguchi's (2002) experiment demonstrated that the use of abstract keywords could extend designers' thinking pathways and, consequently, lead to more creative results. Other studies, such as Goldschmidt and Sever (2010), have empirically shown that text stimuli can have a positive influence during idea generation. They developed an experiment where the design outcome of two different conditions (written excerpts) and the control group was assessed. They found that groups exposed to textual stimuli exhibited higher originality ratings than the control group who received no stimuli.

Although the previous research results summarised here suggest the beneficial value of textual stimuli in idea generation, this type of stimuli seems to be generally disregarded as a potential inspiration source. Verbal and written language is very different from visual representations and visual thinking in terms of logic (as visual thinking is defined as the process through which any form of visual information is perceived, encoded and manipulated [Arnheim, 1969]). Verbal and written language already contains a level of abstraction and text can include conditional, additional or even contradictory elements, which cannot be clearly expressed in visual representations (Ware, 2008, p. 132). On the other hand, perceiving images is much faster (compared to reading their written counterparts), as it is possible to retrieve information from images with just a glance, without following any specific sequence (Ware, 2008, Ch. 6).

According to the Dual Coding theory (Paivio, 1971; Clark and Paivio, 1991), there are associative links between imagens and logogens (visual imagery or language stored in the working memory, respectively). Abstract words lead to more interpretations and thus, are less semantically coherent "and do not refer to concrete, tangible objects or events, and are less likely to evoke an image of specific referents" (Clark and Paivio, 1991, p.155). Thus, both systems (verbal and nonverbal – or visual) are connected and complement each other.

In conclusion, the most adequate type of representation modality might be task-dependent. Depending on the occasion, either textual or visual representations might be most appropriate; or perhaps, the combination of both can lead to optimal results (Paivio, 1983). Visual chunks of information are sometimes grouped with verbal chunks, temporarily combining visual and verbal working memory. In fact, visual thinking and language-based thinking overlap and interconnect (Ware, 2008).

Thus, confronted with contradictory evidence, which either advocate the use of visual or textual stimuli, it is important to clarify the usefulness of different types of stimuli for inspirational purposes. This was the motivation for Study II (Chapter 4), which was guided by the following sub-research question: **How do external stimuli, such as visual and textual stimuli, *influence* designers during idea generation?**

### 2.2.5. Types of content: Semantically distant stimuli

As previously mentioned, stimuli also differ in content. The previous section emphasised the differences between visual and textual representation modalities (form). Now, the focus is on how stimuli differ in terms of semantic distance – the degree of relatedness between two concepts, in terms of the meaning they entail (Mohammad, 2008; Gick and Holyoak, 1980). Stimuli are context-dependent: designers encounter myriads of stimuli that can be differently related with the design problem at hand.

Research on analogical reasoning (e.g., Gick and Holyoak, 1980; Gentner, 1983; Christensen & Schunn, 2007) has explored and largely expanded our understanding on the influence of closely and distantly related stimuli. Clear parallels can be found between literature on analogies and the influence of external stimuli in design. However, contrary to research on analogical reasoning, the author of this thesis is not solely interested in one single cognitive mechanism responsible for idea generation. Instead, analogical reasoning is considered as one of many possible cognitive processes responsible for creativity (this topic will be further explored on section 2.3.4).

| | |
|---|---|
| According to **Depth** | **SURFACE** analogies versus **DEEP** analogies<br>Eastman, 2001 |
| According to **Distance** | **WITHIN-DOMAIN** analogies versus **BETWEEN-DOMAIN** analogies<br>Casakin & Goldschmidt, 1999; Christensen & Schunn, 2007; Ball & Christensen, 2009 |
| | **LOCAL** analogies versus **REGIONAL** analogies versus **LONG DISTANCE** analogies<br>Dunbar, 1995 |
| | **INTRA-DOMAIN** analogies versus **CLOSE INTER-DOMAIN** analogies versus **FAR INTER-DOMAIN** analogies<br>Bonnardel & Marmeche, 2005 |
| | **NEAR** analogies versus **FAR** analogies<br>Ward, 1998; Dahl & Moreau, 2002; Kohn, 2008 |
| According to **relation to target/context** | **CLOSE ASSOCIATE** analogies versus **REMOTE ASSOCIATE** analogies<br>Malaga, 2000 |
| | **DIRECT LINK** versus **INDIRECT LINK** versus **EXTRA-CONTEXTUAL LINK**<br>Leclercq & Heylighen, 2002 |
| According to **Similarity** | **SURFACE SIMILARITY** analogies versus **STRUCTURAL SIMILARITY** analogies<br>Tseng et al., 2008 |
| According to **Abstraction** | **LOW ABSTRACTION** (Materials, colors, textures) versus **MEDIUM ABSTRACTION** (Products or sector names) versus **HIGH ABSTRACTION** (Atmospheres, sensations)<br>Mougenot et al., 2009 |
| According to **Result** | **CASE-DRIVEN** analogies versus **SCHEMA-DRIVEN** analogies<br>Ball, Ormerod & Morley, 2004 |
| According to **Synectics** | **PERSONAL** analogies versus **DIRECT** analogies versus **SYMBOLIC** analogies versus **FANTASY** analogies<br>Gordon, 1961 |

Table 2.1. Overview of analogical distance classifications.

Analogy is defined as a "similarity between relationships" (Goldschmidt, 2001, p. 201), in which a parallel between two domains is formed based on a common similarity. In analogical reasoning, stimuli can vary in terms of distance: i.e., the distance between the source of the stimulus and the target, the context of the problem at hand (Christensen and Schunn, 2007), which can be a large or small distance[1]. Depending on the researchers, there have been many different nomenclatures and classifications of analogical distance, presented in Table

1 *Note that research on analogical thinking includes other types of relationships, such as those based on visual characteristics (for instance, shape). For the purpose of this thesis, only semantic distance was investigated, as this type of relationship was considered to be relevant within the topic of inspiration in design.*

2.1. Although analogical reasoning is not central to this research project, it is still insightful to verify how the spectrum between source and target has been dealt in the field of analogies. Thus, Table 2.1 aims to clarify the similarities and differences between the several levels of analogical distance and other nomenclatures used in this thesis.

In summary, prior research has classified analogies in two or more levels, on a continuum (Dahl and Moreau, 2002) that, depending on what is analysed, varies between two extremes (such as retrieving analogs from a near or far domain[2], in relation to the design problem). To simplify matters and to be able to comprise other cognitive mechanisms besides the analogical one, this thesis does not employ the term *analogical distance*. Other terms have been proposed, such as *conceptual distance* (Chan, Dow and Schunn, 2014), to refer to the distance between source stimulus and target. In this thesis, the term *semantic distance* (Mohammad, 2008) is employed to define the continuum of relatedness between closely related stimuli, distantly related and unrelated stimuli (depending on how semantically related the stimulus is with the problem at hand).

Designers often search for existing and similar examples when tackling a problem, as these stimuli suggest a reference point to frame the context of the problem (Pasman, 2003; Eckert and Stacey, 2003a). These design precedents are considered to be closely related stimuli: they are found within the domain of the problem at hand, sharing primarily surface similarities with the problem. However, some research has demonstrated that while within-domain or closely related examples are easier to use during idea generation, they are also not as beneficial for creativity as more distantly related stimuli (Gentner and Markman, 1997; Christensen and Schunn, 2007; Bonnardel and Marmèche, 2005).

Distantly related stimuli are pieces of information that do not directly concern the problem at hand, but in which similarities can still be found, normally at the structural level. More specifically, surface similarity refers to appearance or visual characteristics, while structural similarity implies relationships at a higher level of knowledge, where only properties or principles are shared (Gentner, 1983;

2 *Domain refers to a particular area of knowledge. Considering the context of the design problem as starting point (for instance,* automotive design*), a near or closely-related domain could be* public transportation*. A far or distantly-related domain could be* animal locomotion.

Casakin, 2004; Tseng et al., 2008). Mednick (1962), from an associative thinking perspective, argued for a relationship between higher creative responses and the distance of associations. According to him, distant or remote combinations between associative elements can lead to more creative results.

A considerable number of studies supports the perspective that seeking for inspiration in distantly related domains can be more advantageous for creativity. Conversely, showing examples of design solutions closely related to the current problem to designers, prior to an idea generation activity, might narrow their self-generated solution space. In such situations, those examples could, for instance, lead designers into a design fixation behaviour (Cardoso & Badke-Schaub, 2009; Jansson & Smith, 1991; Purcell & Gero, 1992).

However, it is considered to be more difficult for designers to recognise and use distantly related stimuli, as they might share only functional or structural similarities (between source and target context of the problem). Consequently, the potential relations hip between stimulus and problem context is not obvious, which hampers designers ability to perceive potential stimuli for inspiration. After perceiving an adequate relationship, it is also challenging to transfer it to the problem context, to abstract it and finally transform it (Goldschmidt, 2001).

Recent findings by Chan, Dow and Schunn (2014) challenge the notion that distantly related stimuli are more advantageous for creativity than closely related stimuli. Their findings suggest that more concepts were considered to be creative when using near inspirations (closely related stimuli) than when using far inspirations (distantly related), which disputes previous research. Nevertheless, these authors did not clearly measure creativity; instead, they used a panel of expert judges, who simply chose which ideas were shortlisted (a list of selected candidates, but without having a final choice for the winner). Although expert assessments are considered to be an adequate measure of creativity (Amabile, 1982), their judging made it impossible to distinguish between different creativity metrics, such as *novelty, flexibility* or *usefulness*.

In a more neutral position, Plucker and Beghetto (2004) argued that, for creativity to flourish, there must be a balance between domain-general and domain-specific knowledge. These authors suggest that people who tackle problems using domain-general approaches may be constraining themselves to superficiality, without even coming near the gist of the problem. On the other hand, those who adopt a domain-specific approach could be shutting down access to other more elaborated perspectives. Consequently, although specific design knowledge is a valuable and an indispensable asset in design problem solving, other domains can complement the development of creative ideas.

Thus far, empirical evidence can be considered controversial and there is no general agreement about the influence of different semantically related stimuli in creativity. Thus, study II (Chapter 4) also seeks to address this knowledge gap, by comparing the usefulness of stimuli carrying different levels of semantic distance (closely related, distantly related and unrelated stimuli) in creative idea generation sessions.

However, not all information designers encounter becomes an inspiration source. Thus, the author will now explain when external stimuli indeed become inspirational.

### 2.2.6. Inspiration as a process

Inspiration is a term commonly defined as "the process of being mentally stimulated to do or feel something, especially to do something creative" (Oxford University Press, 2015). However, the concept of inspiration has changed considerably over time, reflected in the original Latin meaning of the word 'inspire'. It means 'to breathe into', and it reveals the past belief that one could only be creative if and when a divine presence descended or 'breathed into' the person.

Despite the word's origin, the creative mind is not a passive one, and inspiration does not come simply from muses. In the design domain, researchers have defined inspiration as the process that can integrate the use of any entity in any form that elicits the formation of creative solutions for existing problems (e.g., Eckert et al., 2000). For instance, inspiration may be elicited by design examples of products or buildings, art pieces, pictures, written documents, but also from diverse forms of life from nature or other phenomena. In design, inspiration during a creative problem-solving activity might prompt the generation of new ideas, ultimately eliciting a motivation to strive for new possibilities. However, the use of inspiration in design is not necessarily a straightforward, clearly defined procedure, as there is no certainty that a particular stimulus source will lead to a highly creative and successful outcome. Getting inspired by different types of stimuli can encompass an intuitive, systematic, or even accidental selection of information (Goldschmidt & Sever, 2010). According to Ware (2008), our search mechanisms are systematic, but the goal of the search is not always clearly defined. Therefore, inspiration as a process can entail several types of search procedures:

**Active search with purpose** refers to deliberately searching for particular information with a specific goal in mind. Examples of these practices are searching the Internet or in books for specific information, but can also include an intentional walk in a museum to observe a piece of art (e.g., Eckert and Stacey, 2003a).

**Active search without purpose** (or Ongoing search) refers to active search but without a specific intention to solve a problem at hand. The goal of this type of search is to update or expand one's knowledge on a topic (Wilson, 1997). Active search without purpose refers to designers' widespread routine of keeping informed about pertinent topics in their domain (Eckert and Stacey, 2003a).

**Passive search** for inspiration refers to random encounters with relevant information, which is consciously integrated in the design process, also known as serendipity (e.g., Keller, Pasman and Stappers, 2006). An example of passive search could be Alfred Nobel's accidental discovery of dynamite. While searching for a solution for a safer handling of nitroglycerine, Nobel accidentally dropped a vial of nitroglycerine on kieselguhr (a porous material), thus discovering a safer mixture, which he named dynamite (Encyclopaedia Britannica, 2015). Although there is a conscious goal to solve a problem in this type of situations, the search process is not deliberate and occurs unintentionally. Even when the search query (or keyword) is not fully defined, our mind is open to recognise information which could be somehow related to the current problem, and might fit a set of vague criteria (Ware, 2008; Wilson, 1997).

**Passive attention** refers to the moments when information is encountered but not consciously integrated in the context of an existing problem. This can occur while watching TV or while talking with someone, for instance. In this situation, there is no urgent intention to solve a problem nor a conscious perception of the

possible influence of a stimulus (Wilson, 1997).
Our constant state is one of passive attention, which can quickly change into a more alert or deliberate type of search of information. Therefore, all these search types can develop into another, depending on the situation.
The value of inspiration sources and their ubiquitous presence in design is often acknowledged by designers and in research (e.g., Yang, Wood, and Cutkosky, 2005; Eckert and Stacey, 2003a). However, the inspiration process requires more than knowing where to find it. Only a small number of researchers have been immersed in the topic of inspiration sources in design and an even smaller number has attempted to decode the inspiration process (Eckert and Stacey, 2003a; Mougenot, Bouchard and Aoussat, 2008). For instance, the inspiration process is considered to be continuous (Mougenot, Bouchard and Aoussat, 2008), as the collection of external stimuli for inspirational purposes occurs even beyond the period where designers are actively working on a design brief. According to these authors, the type of information designers search for is dependent on the context of the problem at hand and their preferences for representation modalities, semantic distance or even quantity might change drastically. Furthermore, search mechanisms also differ depending on whether designers are browsing the Internet or skimming through a magazine. Mougenot, Bouchard and Aoussat, (2008) claimed that any inspiration process is initiated by an intention (a keyword or reference), which guides the following steps of the process of integrating a possible inspiration source in a new idea. Eckert and Stacey (2003a) developed a flowchart, integrating some of the steps of the inspiration process within the basic design cycle, based on the analysis of knitwear designers. According to these authors, the inspiration process is cyclic and iterative and, when confronted with a design problem, designers use stimuli as a starting point – a possible inspiration source that needs to be *selected*, *analysed* and, depending on its suitability, *discarded* or *adapted* into a solution. To adapt a stimulus into a new design, it needs to go through a process of modification, addition or subtraction. At each phase, depending on the success of the selection or adaptation of the stimulus, the process is repeated until the problem is reformulated or solved. Eckert and Stacey's flowchart (2003a) and Mougenot, Bouchard and Aoussat's findings (2008) represent two attempts to

describe and understand the use of inspiration sources in design, but they only shed light on incomplete parts of the inspiration process. This thesis argues that a comprehensive understanding of this process could be used to support designers in their inspiration use. By reflecting on the inspiration process, designers can potentially engage in a deliberate process of finding and using the most advantageous stimuli, instead of blindly chancing upon an unlimited number of potential inspiration sources[3].

In order to achieve this goal, the following sub-research question was created, which is answered in Study III (Chapter 5): **Which *processes* do designers employ while searching and using external stimuli for a design problem?**

When designers choose to apply a specific piece of information in their design project, they undergo a complex process, in which information is perceived, evaluated, selected, transformed and rearranged, to finally generate (possibly new) knowledge (Yang, Wood, and Cutkosky, 2005). However, before examining how designers create new ideas, influenced by possible inspiration sources, it is important to understand how designers come across and select external stimuli.

### 2.2.7. The process of stimuli selection

A great number of studies (reviewed in this chapter) has examined what influences creative ideas. For instance, prior research has investigated which types of stimuli designers encounter (e.g., Eckert and Stacey, 2000; Keller, Pasman and Stappers, 2006; Mougenot, Bouchard and Aoussat, 2008) or explored the influence different types of stimuli have on designers' creative output (e.g., Malaga, 2000; Jansson and Smith, 1991; Perttula & Liikkanen, 2006). However, there has been little discussion about designers' selection process of stimuli. In analogical reasoning studies, the phase of stimuli selection has been characterized as the "least understood" moment of analogical problem solving (Holyoak and Koh, 1987). To be able to use stimuli for inspirational purposes in their

*3 Although this thesis argues for a more deliberate and reflective inspiration process, it does not attempt to deny the usefulness of chance or serendipity in creativity. Random encounters with stimuli that can inspire creative solutions can always occur, but they are unpredictable. In order to maximise the beneficial influence of stimuli, it is argued that designers can reflect on their inspiration process.*

projects, designers first need to search for and identify relevant information and subsequently, capture it and store it. However, little is known about the reasons behind designers' selection process of stimuli.

According to Wilson (1997), individuals are generally considered to have a *selective exposure* behaviour, regarding the use of information. People are drawn to information that is in agreement with their own concerns and requirements and, accordingly, tend to expose themselves – consciously or unconsciously – to information matching their own preferences and avoid conflicting ones.

It has been observed that accessibility (i.e., able to be reached but not yet available) is a decisive criterion of engineers' selection process of information (Gerstberger and Allen, 1968). Besides accessibility, other authors included availability (i.e., at one's disposal), relevance (i.e., related and appropriate to the present problem), currency (i.e., up-to-date with the state of the art) and reliability as the most important determinants to source selection for engineers (Kwasitsu, 2003). According to Turner (1978) and Hicks et al. (2002), in agreement with the aforementioned authors, the following four elements are the most decisive for information selection in the field of engineering: availability, authenticity, applicability and accessibility.

In literature on metaphors generation, two factors are considered crucial for stimuli selection (to create product metaphors) (Cila, 2013): salience (e.g., Ortony et al., 1985) and relatedness (e.g., Forceville, 2012). Salience refers to the extent to which a concept is defined by its most important characteristic. For instance, the most salient attribute when one thinks of a dog could be 'loyal', and in metaphor studies, a dog could be a useful source to create a metaphor to represent the meaning 'loyalty'. Relatedness is another important factor for source selection in metaphors and it describes the relationship between source and target based on similarity, i.e., the strength of the association between the stimuli and the domain of the problem at hand. An example of relatedness could be the visual similarity between Calatrava's HSB Turning Torso building in Malmo, Sweden and his own sculpture of a twisting male torso, which clearly inspired his work (chapter 1). According to Cila (2013), who explored the roles of salience and relatedness in source selection for metaphors creation, source selection occurs when it is both highly related to the target solution and its meaning is a highly salient characteristic of the source. Furthermore, two other criteria were observed to have an impact on source selection: novelty (but familiar) and applicability.

Most of the studies mentioned in this section do not refer specifically to designers' stimuli selection process and there might be idiosyncrasies particular to designers regarding on the reasons behind their inspiration choices. With the purpose to map designers' inspiration process, particularly focusing on their selection of stimuli, the following sub-research question was posed and addressed in Study IV (chapter 6):

**How do designers *select* external stimuli and how does it influence creativity in the design process?**

Considering that the stimuli designers use can have a positive or a negative influence in the creativity level of design outcome, it is essential to better understand their stimuli selection. However, what is creativity after all?

## 2.3. Creativity in context

This overview has, as starting point, a cognitive psychology approach of creativity. Creativity facilitated by personality traits (as treated in personality psychology, e.g. Runco and Albert, 2010) is outside of the scope of interest of this thesis. In fact, Sawyer (2006) argues that creativity is not a personality trait or an innate characteristic, as it depends on the domain. Instead, it can be improved, as it influenced by the society and culture a creative person is integrated in, within his/her collaborative group. Following those approaches, this thesis supports the argument of domain-specificity theory. Since creativity is not an individual trait, a person in one domain could probably not be as creative in a new domain without being knowledgeable about it. Before reflecting on creativity as a mental process, it is important to define creative thinking. According to Mednick (1962), creative thinking is the process of combining associative elements in novel ways with a useful purpose. In this definition, creative thinking can also include different types of reasoning, such as associative (Mednick, 1962; Malaga, 2000), analogical (Gick and Holyoak, 1980; Visser, 1996; Christensen and Schunn, 2007) or metaphorical reasoning (Casakin, 2007; Casakin, 2011).

### 2.3.1. Defining creativity

Answering the question "What is creativity?" has been, surprisingly, one of the most difficult tasks that researchers on the topic have faced. One of the reasons for this uncertainty is because creativity can be interpreted in many ways, such as a process or as an outcome (Rhodes, 1961). On the other hand, there are many subspecialties of the scientific study of creativity and very little overlap between them (Sternberg and Lubart, 1999). According to Hennessey and Amabile (1996), who conducted an overview of the main directions of literature on this topic, the study of creativity is increasingly fragmented.

Despite this lack of overlap on the ways creativity has been studied, there is a general agreement on a definition, normally described as the 'standard definition of creativity' (Runco and Jaeger, 2012). Creativity refers to the generation of *novel* (in terms of being original, unique, surprising) and *appropriate* work (with regard to being useful, effective and answering the problem constraints) (e.g., Stein, 1953; Lubart, 1994; Sternberg, 1988; Sawyer, 2006; Boden, 1994; Amabile, 1996; Hennessey and Amabile, 2010; Weisberg, 1993; Sarkar and Chakrabarti, 2007). *Novelty* and *appropriateness* (or *usefulness*) are the two terms present in most definitions, but depending on the research approach, the meaning of creativity is slightly reshaped.

A third factor is sometimes included in the definition of creativity too. Howard, Culley and Dekoninck (2006) and Lopez-Mesa and Vidal (2006), for instance, proposed that an idea, besides being *original* (*novel*) and *appropriate*, should also be unobvious, in order to be considered creative. Gero (1996) added *unexpectedness* as the third element and Simonton (2012), as the U.S. Patent Office, defends surprise as the additional third criterion. Amabile (1982) supported a completely different line of reasoning to define creativity, based on a sociocultural approach. This thesis advocates the use of the *consensual definition of creativity*, based on the assumption that the measurement of creativity is always subjective and depends entirely on the beholder. In that sense, an idea is considered creative when experts on the domain of the problem judge it novel and appropriate and reach a consensus.

Another way to define creativity is to distinguish between 'big C' or 'little c' creativity. The term 'big C' creativity requires *novelty* and *appropriateness* in order to be considered creative, which is the type of creativity discussed in this thesis. Hennessey and Amabile (2010) proposed that, to be considered 'big C' creativity, the event or artefact needs to be impactful to others. 'Little c' creativity refers to day to day creative acts, where no social value or appropriateness is required, such as finding an alternative way to take notes, if you are missing paper (Sawyer, 2006, p. 27).

Besides the differentiation between 'big C' and 'little c' creativity, Boden (1990) distinguished between psychological and historical creativity. Individuals who create ideas that are novel to them are considered psychologically creative (or p-creative). On the other hand, individuals are considered to be historically creative (or h-creative) when they produce completely novel ideas to themselves and to the world.

One of the most well known descriptions of the creative process is the one produced by Wallas (1926), who argued that the creative problem solving process is normally characterized as having four stages:

- Preparation (analysis of the problem and its context)
- Incubation (period where the problem solver is not consciously thinking or working on it)
- Insight (a solution arises, normally resulting from unexpected associations. This stage is also defined as 'Illumination')
- Verification (the solution is critically evaluated and elaborated)

However, the rather linear four-stage process has been considered obsolete, as it is better represented by a more cyclical and iterative process (Tardif and Sternberg, 1988). For instance, instead of a phase where the full idea bursts from a sudden insight, it is normally accepted that there are many incremental moments that lead to the Aha-moment. Likewise, the Aha-moment is rarely a single burst of creativity, but rather an on-going process of problem solving (Tardif and Sternberg, 1988).

Up until the 1950s, studies on creativity assumed that creativity and intelligence were highly correlated and were thus often studied together (e.g., Sawyer, 2006, p.44). The two research fields were set apart with the expansion of the study of divergent and convergent thinking (Guilford, 1950). While divergent thinking implies that one can generate many alternative solutions for a problem (a quality required in creativity), convergent thinking entails delivering one right solution (required in intelligence). Guilford (1950) was one of the most important contributors to the study of divergent thinking, as a mode of thought to enhance creativity. With the developments of research on creativity, the role of divergent thinking in creativity changed and it is now accepted that divergent thinking is just one element of creativity. Studies have shown that performing well in a divergent thinking test does not correlate with creativity (Sawyer, 2006, p.45; Zeng, Proctor and Salvendy, 2011).

For the purpose of this research project, creativity is defined as a function of novelty and usefulness (as supported by Runco and Jaeger [2012], Stein [1953], Lubart [1994], Sternberg [1988], Sawyer [2006], Boden [1994], Amabile [1996], Hennessey and Amabile [2010], Weisberg [1993] and Sarkar and Chakrabarti [2007]). Novelty and usefulness do entail further definitions and can be deconstructed into further criteria, as discussed in section 2.3.5. When considering creativity as a process, it is also important to take two other criteria into account (besides novelty and usefulness). These are fluency and flexibility, two components of divergent thinking (Guilford, 1967), which are examined in section 2.3.5.

### 2.3.2. The role of knowledge in creativity

Weisberg (1999) approached the topic of creativity by studying its strained relationship with knowledge. According to Weisberg, there are two opposite perspectives on the relationship between knowledge and creativity in literature. One of the perspectives assumes that there is a tension between creativity and knowledge: when one attempts to be creative within a field, background knowledge and too much expertise may create anchors, which impede the access to more creative ideas. The opposite direction – the Foundation theory – proposes that creativity is built on domain-specific knowledge, which leads to a positive relationship (Weisberg, 1999).

A large number of researchers support the position that prior knowledge is detrimental to creativity (e.g., Guilford, 1950; Luchins and Luchins, 1959; DeBono, 1968; Kuhn, 1970; Marsh, Ward and Landau, 1999). They suggested that, since creativity is so intrinsically related to novelty, past knowledge would not be reliable or beneficial in order to create original work. Instead, creative work could only be achieved by diverging or breaking away from previous patterns of thinking. Cognitively, the way that knowledge is processed and structured in the mind of a knowledgeable person might be too inflexible to generate creative ideas (Frensch and Sternberg, 1989). Simonton's work (1984), despite focussing on the education level and genius eminence (and not necessarily on creativity), provided further evidence to support the negative view of too much knowledge. According to his work, there is a curvilinear negative relationship between the number of years one studies and the genius eminence, where the peak of genius lies in the middle of this inverted-u.

Weisberg (1999), on the other hand, analysed a number of investigations made in the area of development of expert performance and encountered evidence to support the Foundation theory. Largely regarding creative fields such as music or painting, immersion in the field and domain-specific knowledge are essential as a basis for the enhancement of the creativity process. The 10-year rule seems to have been widely accepted as the number of years one needs to be immersed in the discipline, before being able to perform at an excellent level (Erickson, Krampe and Clemens, 1993). However, practicing is not necessarily decisive. One may spend years dedicated in learning a specific subject and not being able to reach creative outcomes – on the other hand, creative outcome cannot be achieved without having a large amount of knowledge and practice (which is not necessarily the same as formal education). Hence, Weisberg defends that all creative outcome have their source in the past, although some negative transfer can occur, as well as positive. No creative solution is originated without having a strong attachment to a frame of reference (such as an earlier product) that helps people to relate with it. For this reason, revolutionary creative examples might be difficulty to be understood when they are launched in the market, as no frame of reference can be used as an example (Hekkert, Snelders and van Wieringen, 2003). Knowledge is a prerequisite to creativity but it is not enough to be creative. In fact, according to Weisberg (1999), creative thinking involves the use of everyday cognitive processes, which applies knowledge and past experiences into new situations. Positive and negative transfer may occur, but this transfer (and further transformation) is essential for creative achievement.

### 2.3.3. On the emergence of creative ideas

Research on creativity, when considering it as a historical or cultural phenomenon, has presented two opposing perspectives on the emergence of creative ideas. Whilst one perspective posits that a new idea appears suddenly, as a disruption from the previous ones (e.g., Wallas, 1926; Akin and Akin, 1996), the other perspective suggests that a creative idea is produced by an accumulation of precedents (e.g., Amabile, 1983; Cross, 1997; Crilly, 2009). These two basic perspectives on the creative design process could be compared with Thomas Kuhn's work on scientific progress (1970). According to Kuhn, history is full of examples that show cycles of 'normal' and 'revolutionary' science, where intervals of cumulative progress are followed by paradigm shifts, caused by disruptive knowledge. Once the new paradigm is accepted, it leads to another phase of 'normal science', where knowledge is built upon precedents (Kuhn, 1970). A visualization of this process is presented in Figure 2.3.

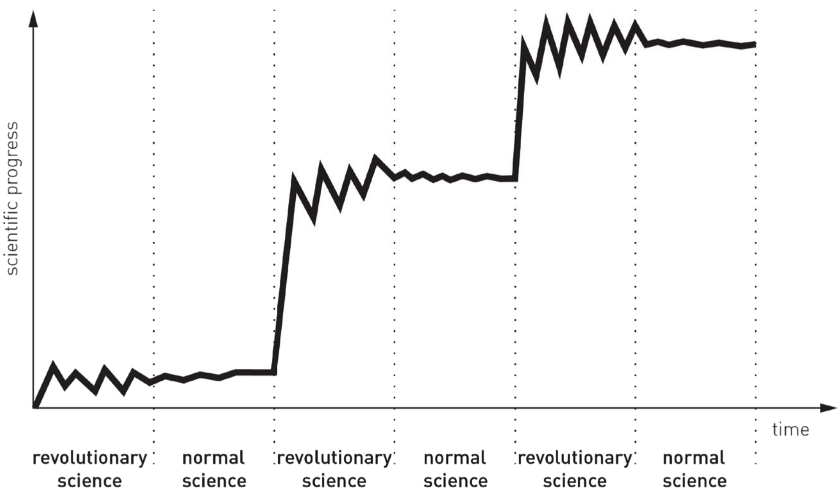



Figure 2.3. Visualisation of 'normal' and 'revolutionary' cycle phases, based on Kuhn's paradigm shifts theory (1970).

Kuhn's work has been applied in many other fields, including design, and his terminology has been partially adopted to distinguish between radical and incremental innovation (e.g., Ahmed and Christensen, 2009; Norman and Verganti, 2014) or between routine and inventive design (Howard, Culley and Dekoninck, 2009; Crilly, 2009).

Pahl and Beitz (1984) offer yet another distinction, by classifying design outcomes into three categories: Original, adaptive or variant design. Original design outcome refers to completely new solutions to a problem; adaptive designs involve the adaptation of an existing solution (or part of it) to solve the problem; and, finally, variant design outcome are existing solutions, with both function and principle unchanged, where only specific aspects are altered.

The first perspective – the sudden understanding of how to solve a problem (in its entirety or partially), which is not achieved in a structured or stepwise manner – has been investigated and defined as Insight, 'Aha! moments' (Akin and Akin, 1996) or 'creative leaps' (Archer, 1965; Cross, 1997; Cross, 2006;). Perhaps the most well-known episode of such insight, although anecdotal, was Archimedes', who, supposedly, shouted 'Eureka!' when he found the solution that led him to his theory of mass dissipation, when he was taking a bath (Perkins, 2000).

Some of these sudden leaps, as unexpected as they are or instantaneous as they look, hardly appear from thin air. Akin and Akin (1996) identified that sudden moments of insight (or Aha! responses) are dependent on two conditions. An existing frame of reference (i.e., requirements or problem formulations) needs to be lifted, but it also needs to be replaced by a new frame of reference (Akin and Akin, 1996). Initially, designers build a first mental sketch based on the assignment and what can be retrieved from memory and past experiences. The design brief usually entails requirements or goals, which helps forming an initial frame (Schön, 1983) – or primary generator (Darke, 1979). Nevertheless, neither the problem nor the initial frames are set in stone. Instead, they simply support designers to move from the problem space to explore the solution space (Cross, 1994; 1997; Dorst and Cross, 2001). According to Cross' model of the design process (1994; 1997), designers tackle the main problem by deconstructing it into sub-problems. Once is broken down, designers can then alternate between sub-problems and sub-solutions, by redefining the problem space and exploring the solution space: a process of co-evolution (Maher and Poon, 1996; Maher, 2000; Dorst and Cross, 2001; Wiltschnig, Christensen and Ball, 2013). In analysing the occurrence of an apparent creative leap in a design team, Cross (1997) identified that the sudden insight into the satisfying solution could be the result of a combination of earlier steps. Although Cross could not discern which cognitive process could have been involved in the sudden realization of

the solution, a number of procedures were put forward as possible examples. They were: combination, mutation (or transformation), analogy, first principles and emergence (Rosenman and Gero, 1993; Gero, 1994; Gero, 2000). In this way, Cross proposed that what seems like a creative leap, a sudden insight into the solution, resembles instead a bridge between problem-space and solution-space. The recognition might be sudden but the structure of the bridge was explored before (Cross, 1997). Dorst and Cross (2001) later elaborated the idea of a 'creative bridge' in relation to co-evolution of the problem and solution. Designers alternate between sub-problems to sub-solutions and vice-versa, which indicates that they progressively change together. This co-evolution eventually stops when a bridge is recognised, which indicates that a satisfying solution has been found: the problem-solution pairing (Dorst and Cross, 2001).
To bring the concept of co-evolution into the context of this thesis, external stimuli can support the exploration of the problem and solution space. Designers often retrieve external stimuli, either to analyse the problem context, to investigate what has been done before to solve similar problems, or to find inspiration in more distant areas (e.g., Eckert and Stacey, 1998; Howard, Culley and Dekoninck, 2011). Stimuli can then become relevant to establish links between the problem and solution space, which can lead to creative hops (instead of leaps) (Ozkan and Dogan, 2013). That is why the sudden *recognition* of a novel idea is normally considered creative, and not its *formation* (which might have been formed before but its origin was disregarded or forgotten) (Cross, 1997; Crilly, 2009).
In the beginning of this section, two apparently opposing perspectives were presented. One supported the sudden emergence of creative ideas, as pure strikes of illumination into a problem (e.g., Wallas, 1926; Akin and Akin, 1996). The other perspective advocated that creativity is reached by accumulation of precedents (e.g., Amabile, 1983; Cross, 1997; Crilly, 2009). Instead, both perspectives complement each other (Crilly, 2009), as creative leaps often originate from smaller, incremental steps.

#### 2.3.4. Cognitive processes responsible for creativity

Creative thinking involves the collaboration of a number of cognitive processes, rather than being a single process. However, the cognitive processes responsible for creativity are not solely reserved for it and they can also be involved in other areas of reasoning (Smith and Ward, 2012).

Generally speaking, the way we approach a new situation is directed by prevailing knowledge that helps us perceive and understand what exists around us. We rely on concepts – or mental representations of information and knowledge – to interact and discover unknown situations (Murphy, 2002). Likewise, new knowledge is based on familiar concepts, as new information is always related to the categories that already exist. For instance, we do not have to analyse each single example of a door to know how is it supposed to work; one just needs to relate the newly encountered door and compare it with similar objects in the related categories (Murphy, 2002). Thus, new ideas are also based on existing knowledge, which lead us to generally agree that any creative idea is never entirely original.

Smith and Ward (2012) have indicated that the main cognitive operations involved in creativity are the following: Combination; Remote Association; Visualization; Retrieval; Analogy mapping and Abstraction. The cognitive processes underlying design can be considered a precedent-based type of reasoning (Oxman and Oxman, 1992), in which past experiences and existing knowledge are retrieved when new situations are encountered. In this sense, knowledge is understood as being continuously transformed, in order to generate new knowledge. Oxman and Oxman (1992) have identified other two cognitive strategies employed by designers, which are refinement and adaptation. Refinement is based on the elaboration of knowledge from abstract terms to particularization, which is achieved through a process of substituting previous representations with more specific ones. Adaptation consists of modifying previously acquired knowledge as a means to create new design solutions, in which interpretation has a major impact in how creative these new solutions are. Similarly, Sawyer (2006, p. 65) recognised other cognitive operations underlying creativity. Some of these operations are involved in everyday activities, such as generative, filtering and exploratory processes (Sawyer, 2006, p.65). Generative processes consist of the creation of ideas via, for instance, combination, association, analogies and metaphors. Filtering processes enable the evaluation of ideas to select which ones should be further explored or abandoned. Explorative processes involve the elaboration of the selected idea, by modification, adaption or refinement, for instance. Nevertheless, the production of creative ideas cannot be explained with the investigation of only one of these processes, as it involves the combination of many different ones (Dunbar, 1997 in Sawyer, 2006, p.66). In the book 'Displacement of concepts' (1963), Schön explores the topic of concept formation, where he explains the theory of 'generative metaphors'. According to Schön (1963), generative metaphors provide a frame of reflection, which enables us to build intuitively and implicitly new knowledge based on existing one. However, existing information is not merely reused when new circumstances are presented. Instead, a transformation is required and new meaning is created from the relation between the known and unknown, according to the new settings. In other words, novel ideas can be generated when, within new situations, existing concepts are seen under different perspectives, triggering new interpretations. The process of displacement has four non-sequential but dependent phases: transposition (where an existing concept is transferred to a new setting only as a symbol), interpretation (when partial transferred symbols need adaptation to fit within new settings), correction (to detach existing concept symbols from previous framework) and spelling out (an evaluation moment between the existing and new concepts).

The way we process concepts and categories is by creating mental representations. Mental representations and, specifically, mental imagery is one of the most valuable capabilities for designers, to interpret information and to manipulate design representations (Athavankar, 1997). While the topic of mental representations has mainly been analysed by the field of cognitive psychology, mental imagery has become a popular theme in design literature, mainly regarding the context of sketching (e.g., Goldschmidt, 1991; Finke, 1996; Casakin, 2005). Mental imagery has been defined as the cognitive ability to mentally visualize, interpret and represent information, when this is physically absent (Eastman, 2001; Paivio, 1971). Finke (1990) investigated the cognitive mechanisms that play an important role in creativity and suggested that the manipulation of mental imagery can help to retrieve visual information but also to assist the generation of creative concepts. Similarly, Athavankar (1997) supports this position and adds that mental imagery can be considered as an enabler for the design thinking process. Hence, mental images can be manipulated and modified, in order to reach to a final concept, as detailed as using sketching. Goldschmidt (1995) additionally stated that creative design ideas are generated through the interaction between internal imagery and external images (e.g., pictures, drawings), going back and forth between inner and outer visual representations.

One of the most researched cognitive processes responsible for creativity is analogical reasoning. Goldschmidt (2001) defined analogy as "similarity between relationships", differing in this way from metaphors and similes[4]. Analogies are established when there is a relational similarity more than an attribute similarity (Gentner and Markman, 1997), in a similarity relationship, such as A:B as C:D (Eastman, 2001).
Analogical reasoning first requires the identification of a source analog. The source analog normally belongs to another domain, and it is then transferred to a target situation (the problem at hand), which enables the problem to be understood and tackled differently (e.g., Gentner, 1983). In section 2.2.5, a discussion on how stimuli can differ in terms of analogical distance was initiated. This section continues with an explanation of how analogical reasoning is an influential cognitive process in creativity. Analogical reasoning involves a number of cognitive processes, which are normally agreed upon, although divided differently according to the researchers. Novick (1988) has identified five primary cognitive processes (Problem representation – Search – Retrieval – Mapping – Procedure adaptation), but other authors have considered analogical reasoning a four-steps process (Eastman, 2001; Goldschmidt, 2001; Casakin, 2004[5]):

*4 Eastman (2001) defined simile and metaphor in the following manner: "similes are of the form 'A is like B', where A and B have some properties in common; metaphors are an unconventional way of describing one thing in reference to another, based on some common semantics."*

*5 Goldschmidt (2001) and Casakin (2004) discussed only two processes of analogical reasoning, but they grouped identification and retrieval together, as well as mapping and transference.*

• *Identifying abstract relationships of the target problem:* Possible relationships are identified between the target context and existing knowledge in memory;
• *Recalling and retrieving information from a source context:* Information can be retrieved from working and/or long-term memory;
• *Mapping the relations between source and target:* This occurs by projecting retrieved relationships from the source analog into the target problem, which have the potential to solve it. Mental imagery supports this step, i.e., inner representations of source and target are created in order to verify whether the mapping was successful;
• *Transferring and transforming relationships of the source analog into the target problem:* The last step involves de-abstraction, so that the mapped relationships are not only transferred but also transformed, to fit the target problem.
This four-step process, from source to abstraction and then from abstraction to target, is illustrated in Figure 2.4. Identification, retrieval, mapping and transformation are performed by manipulating inner representations of target and source.

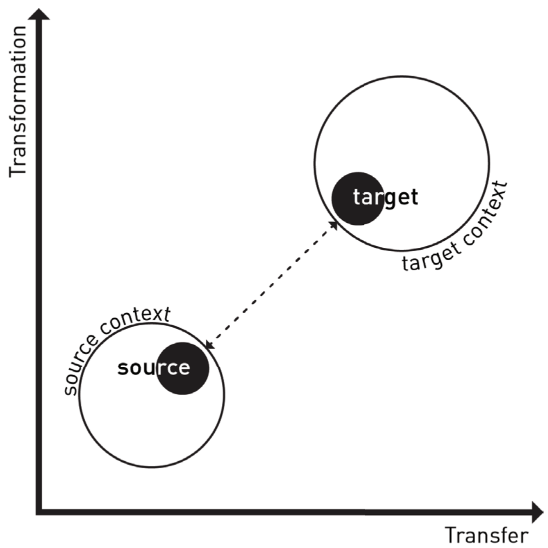



Figure 2.4. Adapted from Goldschmidt (2001), which clarifies the importance of mental imagery in the analogical thinking process.

According to Gick and Holyoak (1980), mapping is a determinant step to be able to successfully solve a design problem with an analogy. On the other hand, the mapping process is determined by the interpretation process of the first

step: the identification of relationships between source and target. The process of spontaneously using analogies is not easily captured in empirical studies, as it is usual difficult for people in general to recognise the relevance of analogs without direct prompting (Gick and Holyoak, 1980; Novick, 1988; Casakin and Goldschmidt, 1999). In this matter, Ball, Ormerod and Morley (2004) demonstrated that surface similarity between source and target seems to be a key element to promote spontaneous analogical reasoning. However, as was delineated in section 2.2.5, although it is easier to recognise and map possible relationships between source stimulus and target problem, surface analogies might not be beneficial for creativity (Gentner and Markman, 1997; Christensen and Schunn, 2007; Bonnardel and Marmèche, 2005).
Notwithstanding, analogical reasoning is considered to be influential in creativity and a large number of studies have come forth to promote the use of analogies in design (e.g., Helms, Vattam and Goel, 2009; Oriakhi, Linsey and Peng, 2011; Chan et al., 2011).

Another important cognitive process involved in creativity is associative thinking, where links between disparate domains are correlated, but not necessarily related in causal manner (Gabora, 2002). Associative thinking can be helpful for designers, as it enables them to reflect on the problem using different perspectives (Casakin, 2011), by using mental imagery to map possible links. One of the dominant theories to explain creativity is the associative theory of creative thinking (Mednick, 1962). One important feature of Mednick's theory is the concept of associative hierarchy – the organization of one person's associations by how strong associations are connected. Accordingly, the way individuals categorize information determines which associations will be stronger and will be activated first. Associative activation is the process where one cue (image, word, event…) triggers and evokes associations, connected by how coherent these elements are. These elements or nodes are organized and connected to many others in networks, which form the associative memory. When nodes are associatively coherent, other nodes are triggered as well, but not all of these associations happen in a conscious way (Morewedge and Kahneman, 2010). Morewedge and Kahneman (2010, p. 435) defined associative memory as: "a network of long-term memory for semantic information, emotions and goals that is governed by the spread of activation, as determined by the strengths of interconnecting weights (associations)". When an individual encounters a new piece of information, it is interpreted and stored in memory, following normally a comprehensive and consistent representation of the current context. When similar situations are encountered in the future, the previously encountered stimulus can be accessed and retrieved if it is associatively coherent with the current situation (Morewedge and Kahneman, 2010). A similar term to associative coherence is semantic coherence. According to Clark and Paivio (1991), on the context of interpretation of visual and textual stimuli, semantic coherence is related to the concreteness of stimuli, especially verbal (textual) stimuli. Abstract words, which enable many interpretations, are less semantically consistent than concrete words.

Mednick (1962), in his theory of associative theory of creative thinking, assumes that creative people have a flat associative hierarchy while non-creative people are characterized by steep associative hierarchy organization. With a flat hierarchy, different ideas are leveled and it is easier to make associations between disparate concepts, as the typical associations are not the most dominant. On the other hand, a steep hierarchy is characterized by ranking typical associations higher and more dominant, which hinders a connection between remote associations and, consequently, lead to the generation of less creative ideas. In summary, the way one individual is able to create associations largely depends on how new information and experiences were registered in his/her memory. When we encounter new information, this is registered in our memory to fit existing categories, following a number of defining attributes (Murphy, 2002), which are more or less dominant. Considering that memory is content addressable (Gabora, 2002), and if a concept was categorized with less dominant features, a person with flat hierarchy will be able to retrieve information from distant domains. For instance, one of the most relevant (or salient) features of an elephant is its trunk, normally defining its category. One less relevant but still accurate characteristic is that elephants live in matriarch societies. Supposing that an individual is trying to come up with examples of matriarch figures, it might be easier for a flat hierarchical person to create associations between elephants and matriarch

societies.
In conclusion, this overview provided important indicators that design creativity is strongly influenced by some cognitive processes, being visual imagery, analogical thinking and associative thinking amongst the most relevant ones. Furthermore, it is understood that, when designers encounter external stimuli and use them for inspirational purposes, designers are using one of these cognitive processes to employ inspiration sources in their ideas.

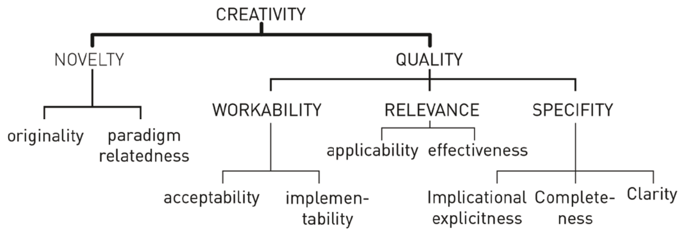
### 2.3.5. Measuring design creativity

As this thesis's ultimate goal is supporting design creativity, it is important to consider designers' creative process within their design process. As Howard (2008) observed, the creative and design process are interlocked, and creativity does not occur only during idea generation. Instead, different moments of the creative process take place at every phase of the design process.
As mentioned in section 2.3, we are following a cognitive psychology approach of creativity, connected with a sociocultural perspective, which means that this thesis is concerned with design creative *process* and *outcome*. Design creativity refers directly to the field of design, either product, interface, service or strategic (thus, it excludes the fields of art, music, writing and other sorts of performance). Considering that a creative product constitutes an end by itself, creativity can be measured by evaluating the outcome from a design project. This argument was posited by Amabile (1996) and Ghiselin (1963), who investigated a more objective analysis of the 'intrinsic quality' of creative products. Therefore, in this thesis, design creativity is measured by analysing product creativity (rather than the process or individual).
A large set of metrics have been put forward by researchers in the field of design and engineering to assess how creative an idea is. Nevertheless, there is usually no consensus regarding which metrics are the most appropriate to measure design creativity, as can be seen in many research overviews (Dean et al., 2006; Kudrowitz and Wallace, 2013; Sarkar and Chakrabarti, 2011; Shah, Vargas-Hernandez and Smith, 2002). Table 2.2 presents an updated overview, by showing the metrics used and whether these studies used an overall score of creativity. This lack of agreement on the measurement of creativity has its origin

| STUDY | SUMMARY | CREATIVITY AND OTHER METRICS |
|---|---|---|
| Guilford, 1950 | **An overal score of creativity was not computed.** Suitable to assess divergent thinking. | DIVERGENT THINKING = FLUENCY and FLEXIBILITY and ORIGINALITY and ELABORATION |
| Moss, 1966 | **An overal score of creativity can be computed.** Score results on a 9-point scale. | CREATIVITY = UNUSUALNESS x USEFULNESS<br>Unusualness (reverse probability or statistical infrequency of ideas, in a scale from 0 to 3)<br>Usefulness (comparing the product requirements of ideas with a "perfect idea", in a scale from 0 to 3) |
| Amabile, 1982 | **An overal score of creativity can be computed based on subjective evaluation of experts.** | CONSENSUAL DEFINITION OF CREATIVITY<br>(No discrete objective metrics) |
| Jansson & Smith, 1991 | **An overal score of creativity was not computed.** The metrics were used to assess design fixation. | CREATIVITY = FLEXIBILITY and ORIGINALITY<br>Flexibility (number of approaches to solve a design problem divided by total number of solutions)<br>Originality (based on statistical infrequency: Sum of 'o' scores for an individual's ideas divided by the number of ideas for that category) |
| Christiaans & Andel, 1993 | **An overal score of creativity was not computed.** Metrics adjusted to fit design brief used, assessed on a 10-point scale. | DESIGN QUALITY = Combination of 9 aspects metric<br>- Suitability for the target group; - Challenging fantasy; - child friendliness; - multifunctionality; - suitable to carry more than one child; - suitable for boys; - suitable for girls; - suitable for older children; - suitable for younger children. |
| MacCrimmon & Wagner, 1994 | **An overal score of creativity was not computed.** Not suitable to assess creativity of products. | CREATIVITY = ORIGINALITY and USEFULNESS<br>Originality (Novelty and Non-obviousness)<br>Usefulness (Relevance and Workability and Thoroughness) |
| Shah, Vargas-Hernandez and Smith, 2003 | **An overal score of ideation effectiveness can be computed.** Authors do not claim measuring creativity. | IDEATION EFFECTIVENESS = NOVELTY + VARIETY + QUALITY + QUANTITY<br>Quantity and Variety (regarding the entire idea generation session)<br>Novelty and Quality (scores computed for each idea) |
| Chakrabarti and Khadilkar, 2003 | **Only product novelty was computed.** Only suitable for final product designs. | PRODUCT NOVELTY = 'Similarity with existing products' and 'Different weight novelty levels' |

(Continues in the next page)

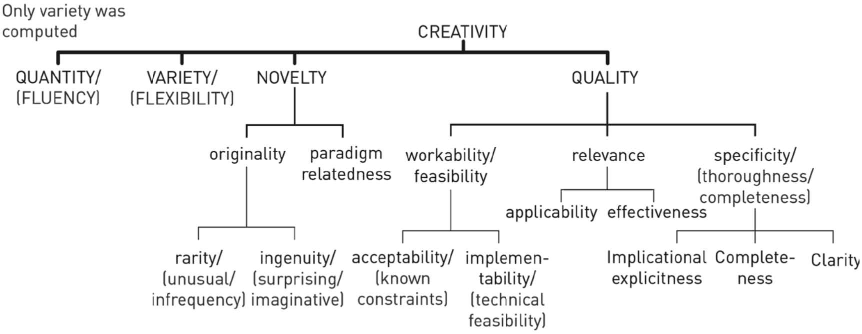
Table 2.2-a. Overview of creativity metrics used in previous studies over the last 65 years – continued on the next page.

| STUDY | SUMMARY | CREATIVITY METRICS |
|---|---|---|
| Dean, Hender, Rodgers and Santanen, 2003 | **An overal score of creativity was not computed.**<br>Discrete metrics were scored on either 3 or 4 point scales. | **CREATIVITY = NOVELTY + QUALITY**<br>**(workability + relevance + specificity)**<br> |
| Chakrabarti, 2006 | **An overal score of creativity was not computed.** | **CREATIVITY = NOVELTY and PURPOSEFULNESS and RESOURCE-EFFECTIVENESS** |
| Lopez & Vidal, 2006 | **An overal score of creativity was not computed.** | **CREATIVITY = NOVELTY (NON-OBVIOUSNESS and NEWNESS) and QUANTITY and QUALITY (FEASIBILITY)**<br>**Based on FBS model.** |
| Goldschmidt & Smolkov, 2006<br><br>Goldschmidt & Sever, 2010 | **Metrics were measured separately and an overal score of creativity was not computed.** | **DESIGN PROBLEM SOLVING = ORIGINALITY and PRACTICALITY and GENERAL QUALITY** |
| Sarkar & Chakrabarti, 2011 | **An overal score of creativity was not computed.**<br>Only suitable for final product designs. | **CREATIVITY = NOVELTY x USEFULNESS**<br>**(FBS + SAPPhIRE) x (importance x rate of popularity of use x frequency of use x duration of use)** |
| Howard, Culley & Dekoninck, 2011 | **An overal score of creativity was not computed.** | **CREATIVE PERFORMANCE = IDEA QUALITY and IDEA FREQUENCY**<br>**(ORIGINALITY and APPROPRIATENESS and UNOBVIOUSNESS)**<br>**Frequency (how many ideas are produced in a given time period)**<br>**Originality (whether it is a completely new/original concept or a routine one)**<br>**Appropriateness (whether it is rejected at the stage gate or selected for further exploration)**<br>**Unobviousness (whether the idea was generated quickly - obvious- or after a longer period)** |

(Continues in the next page)

Table 2.2-b. Overview of creativity metrics used in previous studies over the last 65 years – continued on the next page.

| STUDY | SUMMARY | CREATIVITY METRICS |
|---|---|---|
| Verhaegen, Vandevenne, Peeters & Duflou, 2012 | **An overal score of creativity was not computed.** Only variety was computed | **CREATIVITY = QUANTITY x VARIETY x NOVELTY x QUALITY** |




| STUDY | SUMMARY | CREATIVITY METRICS |
|---|---|---|
| Agogué, Kazakçi, Hatchuel, Masson, Weil, Poirel & Cassotti, 2014 | **An overal score of creativity was not computed.** | **CREATIVITY = FLUIDITY and ORIGINALITY**<br>**Originality based on statistical infrequency (0 = low originality; 1 = high originality).**<br>**Fluidity based on the number of solutions (fluency/quantity)** |
| Chiu and Shu, 2012 | **An overal score of creativity was not computed** Each metric was scored on an 11-point scale between 0 and 10. | **CREATIVITY = NOVELTY and USEFULNESS and COHESIVENESS**<br>**Novelty (newness, originality and surprise)**<br>**Usefulness (appropriateness and value)**<br>**Cohesiveness (wholeness, elaboration, detail, style and clarity)** |
| Kudrowitz & Wallace, 2013 | **An overal score of creativity can be computed (based on NUF).** Each metric was rated on a 3-point scale. | **INNOVATIVE IDEA = QUANTITY + CREATIVITY + NOVELTY USEFULNESS + CLARITY** |
| NUF (in Kudrowitz & Wallace, 2013) | **An overal score of creativity can be computed.** Each metric was rated on a 10-point scale. | **INNOVATIVE IDEA = NOVELTY + USEFULNESS + FEASIBILITY** |

Table 2.2-b. Overview of creativity metrics used in previous studies over the last 65 years – continued on the next page.

in the inconsistency of finding a generally accepted definition, as mentioned in section 2.3.1 (Defining creativity). Since the 1950's boom of research on creativity, initiated by Guilford during his time as president of the American Psychological Association (Guilford, 1950), a large number of creativity tests have been developed. All these tests focussed on different aspects of creativity, such as the process, the person, the product or the environment. One of the most well-known assessments of creativity is the Torrance Tests of Creative Thinking, also known as TTCT (Torrance, 1962), in which participants were asked to answer, in written, oral or drawing form, different categories of questions and tasks. Each category was then scored according to four criterion components of divergent thinking (Guilford, 1967), in terms of outcome:

*Fluency* is defined as the quantity of ideas produced. Given a similar period of time, those who create a larger number of ideas have a higher probability of generating more creative ideas. This was also supported by Osborn (1953), who created one of the famous mottos of Brainstorming: "quantity breeds quality in ideation".

*Flexibility* is the capacity to switch between different domains and, thus, altering how to approach a problem. During idea generation, flexibility becomes most relevant, because it reflects the importance of diverging into different directions to tackle the problem. Higher flexibility is usually related to the increased likelihood of devising more creative ideas.

*Originality*: refers to the capacity to develop unique and uncommon ideas, which is a definition closely related to divergent thinking. In this sense, Guilford's *originality* could also be identified as *rarity*, or the infrequency of responses.

*Elaboration* is defined as to what extent the idea was detailed and finalized. This component could only be evaluated when the solution was completed.

Although divergent thinking is considered to be one of the elements responsible for creativity, Guilford (1967)'s criteria do not include any metric on *appropriateness* or *usefulness* – a characteristic that most researchers agree on when defining creativity. Moreover, this type of creativity tests similar to TTCT (Torrance, 1962) are not necessarily concerned with the type of problems designers usually tackle.

In fact, when deciding on the creativity metric to judge solutions, the type of problem the ideas are trying to solve matters. In Dean's et al. (2006) overview on creativity metrics, based on the work of MacCrimmon and Wagner (1994), most of the studies presented dealt with situational problems, which involved a specific context (for instance, increasing the number of costumers of restaurant 'A'). This type of problems tends to give a stronger emphasis to *usefulness* and less to *novelty*. Furthermore, solving situational problems do not necessarily require sketching nor the development of prototypes, as design problems normally do. Thus, the creativity dimensions presented by Dean et al. (2006) and studies from their overview could not be directly translated to evaluate product design solutions.

On the other hand, several studies – normally those with a strong engineering component – have proposed creativity metrics for already finalized products and artefacts (Amabile, 1982; Chakrabarti and Khadilkar, 2003; Shah, Vargas-Hernandez and Smith, 2003; Sarkar and Chakrabarti, 2011). Although it is also interesting to measure the creativity level of final products, it is during idea generation that idea selection has a greater impact. After creating a large pool of ideas, designers normally have to converge and select which ideas have the most innovative potential to move forward. Thus, it is during this phase – when ideas are roughly sketched and open for discussion – that it would be more meaningful to evaluate the level of creativity.

As Table 2.2 illustrates, a number of researchers have dissected creativity in different metrics, by adding or removing some of Guilford's criteria for divergent thinking (Jansson and Smith, 1991; Shah, Vargas-Hernandez and Smith, 2003; Lopez and Vidal, 2006; Verhaegen et al., 2012; Agogué et al., 2014) or by including usefulness, besides novelty (Moss, 1966; MacCrimmon and Wagner, 1994; Dean et al., 2003; Chakrabarti, 2006; Sarkar and Chakrabarti, 2011; Howard, Culley and Dekoninck, 2011; Chiu and Shu, 2012; Kudrowitz and Wallace, 2013).

This subdivision of creativity in different metrics makes it easier to better understand of what makes an idea creative and allows for a more objective analysis. When using expert judges to evaluate creative ideas, it is easy to misinterpret one metric for another, and even consider one idea more creative when the quality of the sketch is higher than others (Kudrowitz, Te and Wallace, 2012). One of the most complete metric overviews is the one presented by Verhaegen et al. (2012). These authors combined the work of Dean et al. (2006), Shah et al. (2003) and still add two elements of Guilford's components of divergent thinking (1967): *fluency* and *flexibility*. Therefore, creativity defined by Verhagen et al. (2012) was branched off into *fluency, flexibility, novelty* and *quality.*

*Fluency* and *flexibility* were still defined similarly as explained by Guilford (1967) (see beginning of section 2.3.5), with some differences. Verhaegen et al. (2012) rechristened *flexibility* into *variety* and proposed a refined metric, based on Shah et al. (2003)'s idea genealogy tree.

According to Verhaegen et al. (2012) and Dean et al. (2006), *novelty*, one of the four elements to judge creativity, is found in new ideas, which have never been expressed before. However, novelty is further divided into *originality* and *paradigm relatedness*. The former refers to ideas that are both unique and ingenious/surprising (in the pool of ideas produced for that problem). The second part of *novelty, paradigm relatedness*, refers to radical ideas that require a transformation of the context of the problem.

The last essential element to measure creativity is *quality* (Verhaegen et al., 2012; Dean et al., 2006). Although a quite general term, *quality* is defined as the degree to which an idea appropriately meets the specifications of the problem (Shah, Kulkarni and Vargas-Hernandez, 2000) and, in that case, can be compared to *usefulness* or *appropriateness*. *Quality* can then be subdivided into *workability, relevance* and *specificity*. *Workability* – the degree to which an idea complies with existing limitations and can easily be implemented (MacCrimmon and Wagner, 1994) – is further separated in two subcomponents: *acceptability* and *implementability*. Whilst the former refers to ideas that are recognised valid according to social, legal or political constraints, the latter refers to ideas that can be implemented in technical terms. In this case, *implementability* can also be referred as *(technical) feasibility.*

*Relevance* – the degree to which an idea is the solution for the problem at hand (Dean et al., 2006) – can be further defined as being composed by *applicability* (how applicable or appropriate is the idea to the context of the problem) and *effectiveness* (how well does the idea solve the problem).

Finally, *specificity* (also named *thoroughness* or *completeness*) is not a common metric used to assess creativity, as it can only be used to assess final products and not ideas. In this way, specificity can be considered similar to the component *elaboration* (Guilford, 1967). It is defined as the degree to which an idea is clearly finalized and fully described (MacCrimmon and Wagner, 1994; Dean et al., 2006). Thus, *specificity* can be further divided into *clarity, completeness* and *implicational explicitness.* Whilst the first two are self explanatory, the latter refers to ideas that have a clear connection between the function presented and resulting outcome. Although *specificity* is normally not used to assess creativity, Kudrowitz and Wallace (2013) found that at least *clarity* has an impact on how creative ideas are perceived. According to these authors, ideas were perceived to be more creative when they were clearer (the sketch was well communicated and with enough details so the idea could be clearly understood), compared to ideas that had little to no details ('quick and dirty' sketch).

The majority of these studies have presented well-defined and fixed metrics to judge creativity, but it is important to consider that some of the metrics to be evaluated need to be adapted to the problem at hand. That is the example of Christiaans and van Andel (1993), who created a set of metrics adequate to judge creative solutions developed for a specific design problem. Because their design problem was to create a children's toy, the metrics focussed on suitability for the target group, which could be translated into the metric *applicability* or *relevance* (Dean et al., 2003; Verhaegen, 2012).

Finally, as a common result across the reported studies, only a few studies tried to reach an overall score of creativity (Moss, 1966; Amabile, 1982; Shah, Vargas-Hernandez and Smith, 2003; Kudrowitz and Wallace, 2013). The remaining studies could compute individual scores but they were unable to address creativity as a whole.

Four criteria to design a metric have emerged from this literature overview. A measure to assess design creativity needs to:

• Be suitable for design problems;

• Be appropriate to assess ideas (not finalized products);

• Include both dimensions of *novelty* and *usefulness* (although these should be divided into more manageable metrics, as both entail variations that can be interpreted differently. E.g., when judging *usefulness*, one could consider if the idea is implementable – *workability*, if the idea answers the problem – *relevance*, but also if the idea is clear – *specificity*);

• Be able to measure creativity as one entity (this facilitates the discussion of design creativity in empirical studies. Thus, after deconstructing creativity to enable a more objective assessment, it is necessary to recombine the individual metrics again so conclusions on creativity can be made).

## 2.4. Stimuli preventing creativity

As mentioned before (Chapter 1 and section 2.2), designers are generally receptive to external stimuli, especially during the conceptual design phases. These stimuli can come in a multitude of representation types and display content that can be interpreted differently. Despite the obvious potential positive influence that some stimuli can provide (in these situations, denominated as an inspiration source), stimuli can also have a negative impact (Perttula & Liikkanen, 2006; Cai et al., 2010). Such an effect can be both positive – where inspiration sources can expand the solution space and increase the potential pool of creative solutions (e.g., Goldschmidt & Sever, 2010); and negative – when the designer becomes 'blinded' or 'stuck', which results in the reduction of creative ideas (e.g., Jansson & Smith, 1991; Purcell & Gero, 1996).

As the previous sections of this chapter (2.2 and 2.3) mainly addressed the beneficial impact of stimuli, the following sections examine the detrimental effects that exposure to external stimuli may cause.

Fixation and its variants have been investigated in different fields, by designers, psychologists, architects and engineers (among others). The study of the phenomenon of fixation includes, for instance, the tip-of the-tongue experience (e.g., Brown and McNeill, 1966), the Einstellung effect (Luchins and Luchins, 1959), functional fixedness (Maier, 1931; Duncker, 1945; Luchins and Luchins, 1959), mental rut (Smith, 1995) or unconscious plagiarism (e.g., Tenpenny et al., 1998). What connects all these phenomena is the existence of "something that blocks or impedes the successful completion of types of cognitive operations, such as those involved in remembering, solving problems and generating creative ideas" (Smith, 2003, p. 16). Thus, fixation does not only occur in creative idea generation, but it can also manifest itself in well-defined problem solving tasks. Despite having potential harmful consequences, these cognitive blocks usually result from very convenient processes, which makes it possible react quickly to usual situations (Smith and Linsey, 2011). According to Smith and Linsey (2011), these are the same cognitive processes responsible for adaptive and

implicit reactions to every day and repetitive activities, such as identifying which tool we need at a certain moment. However, when existing knowledge is used in an undesirable manner, which interferes with the resolution of a problem, fixation is considered to have occurred.
The following sections introduce some of the most well researched fixation variants, which have been identified as cognitive hindrances to creativity.

#### 2.4.1. Functional fixedness

Gestalt psychologists were the first to study fixation, in particular the issue of functional fixedness (Maier, 1931; Duncker, 1945; Luchins and Luchins, 1959). This cognitive bias takes place when, in a situation where it is advantageous to use familiar objects in unusual ways, people cannot think of other possible functions for them.
A well-known experiment that exemplifies this cognitive bias is the one studied by Maier (1931). In a room where two ropes were dangling from the ceiling, participants were asked to tie them together. However, the ropes could not simply be tied together as they were not long enough to grab both of them at the same time. In the same room there was a range of everyday objects at the disposal of the participants. One such object was a set of pliers, which could be used as a weight and create a pendulum. In this way, the problem could be solved by tying the pliers to one of the ropes and by projecting it in the other direction, allowing the two to be tied together. However, this example solution was rarely formulated by the participants. Maier proposed that the participants were unable to recognise different functions or purposes for well-known objects, impeded by prior knowledge. Therefore, although one needs experience and knowledge of a certain topic to be creative, it can also lead to mental shortcuts that can hinder the resolution of a problem.

#### 2.4.2. Mental set

Another type of fixation is mental set (Einstellung effect or mechanized thought), which refers to a tendency to follow the same approach irrespectively of the problem at hand (Luchins and Luchins, 1959). Mainly studied by using mathematics and word related problems, this behaviour is considered to be situationally-induced (Jansson and Smith, 1991), as it is provoked by the inclusion of a known strategy, previously successful, when facing a new problem. Luchins and Luchins (1959) studied this type of fixation, denominated as Einstellung effect, which can be translated to 'setting'. These authors found that a previous solution to a problem can become an interference, which blocks its successful conclusion. Luchins and Luchins gave a series of problems to participants, which could be solved by using the same complex algorithm. However, when the last problem differed, participants were unable to use the complex algorithm and did not realize that it could be easily solved with a simpler operation. The authors concluded that previous knowledge, which earlier enabled participants to quickly answer a series of difficult tasks, also constrained the way they tackled a newly encountered problem. Mental set, as a cognitive bias, relates then to a vector of psychological inertia, a phenomenon demonstrated in the engineering field, where an approach is applied routinely, without considering other (possibly better) solutions (Arciszewski, 1998; Youmans and Arciszewski, 2012)

### 2.4.3. Attachment to initial ideas or Premature conceptualisation

When first presented with a design problem, designers tend to approach it by initially thinking of a possible solution, which helps frame how the design brief is understood (Darke, 1979; Lloyd and Scott, 1994). This is an experience that many designers share: an initial idea is formed at the beginning of the project, which makes the typical uncertainty of the fuzzy front-end phase more manageable. After observing examples of this behaviour, Darke (1979) developed the generator-conjecture-analysis model, where the initial concept is considered a primary generator: a starting point, formed as a single or many related ideas, which portray an appropriate set of goals to steer the design process. These goals can be previously established by the brief or can be self-imposed, and they are normally the result of intuitive decisions rather than rational deliberations. Despite the beneficial reduction of the cognitive effort when following only one direction or deciding on an idea, this early attachment to initial ideas might also lead to inhibitions in creative thinking. This phenomenon is designated premature conceptualisation (e.g., Smith & Ward, 2012). A premature and unreflective commitment to a first idea, when this is unsuitable to solve all constrains or goals of the problem, can lead to unsuccessful results. For this reason, the popular suggestion by William Faulkner, to "kill all your darlings", could be applied in the design process as in literature, when early attachments to initial ideas might lead to dead-end situations. This does not mean that all first ideas should be immediately discarded. Premature conceptualisation is connected with the 'path of least resistance' and the structured imagination theory (Ward, 1994). According to the latter, existing conceptual cognitive structures are the foundation for the creation of new ideas. The 'path of least resistance' can be considered a prevalent tendency to use specific examples or categories as a starting point, when creating ideas (Ward, Patterson and Sifonis, 2004). Thus, premature conceptualisation can occur when designers follow the path of the least resistance and place a considerable amount of effort and time on a specific solution. Because of this investment, designers consider the loss bigger if the idea is abandoned. However, this attachment can also be unconscious: once the primary generator is created to frame the design brief, it might be too difficult to release the 'anchor' and explore other directions.

#### 2.4.4. Stuckness

Stuckness is a term coined by Sachs, defined as "the culmination of an involuntary, unintentional process that begins with a breakdown in the student's capacity to respond to the studio requirements, and includes his/her recognition that he/she is stuck" (1999, p. 208). In this definition, stuckness does not represent a specific behaviour but comprises a number of hindrances to creativity, which share a common denominator: the feeling of being 'stuck'. These hindrances can range from:

- "Being at a standstill" (caused by uncertainty of not knowing how to proceed);
- "Taking too long" (caused by the inability of solving a part of the problem, and spending too much time on a phase of the design process);
- "Not moving past an initial diagram" (caused by the inability to create a primary generator: a frame of reference of the design problem);
- "Fixation" (self-imposed blocks on the development of a solution);
- "Repetition" (continuous cycle of procedural decisions that always lead to the

same result).
In general, stuckness is Sachs' attempt to characterize, under the same term, a number of situations recognised in design education and practice, which always have the same result: the inhibition of creative thinking. Stuckness is the only inhibitor of creative thinking from this overview that is characterized by the awareness and recognition that the designer is stuck. Recognition of being stuck can be attained when the designer encounters a 'breakdown' on the flow of the process, which results in the comparison between expectations and results. On the other hand, recognising stuckness does not necessarily lead to determining the sources or the solution to become un-stuck (Sachs, 1999).

### 2.4.5. Design fixation

Jansson and Smith (1991) and Purcell and Gero (1996) were some of the researchers that steered the development of the topic of fixation within the field of design science. Design fixation has been defined as an unconscious tendency to reuse parts and principles from those examples without considering their appropriateness (Jansson and Smith, 1991; Purcell and Gero, 1991; Cardoso and Badke-Schaub, 2011).
Using design problems and illustrations of existing solutions as priming examples, Jansson and Smith (1991) were the first to demonstrate that engineering students' work was influenced by illustrated examples, even when they were explicitly made aware that those contained negative characteristics. The given pictures provided solution ideas, which worked as precedent, thus restricting designers from thinking of alternative ideas. Design fixation occurred also when participants were instructed to avoid these features, or when the participants were professional engineers.
Moreover, Jansson and Smith (1991) proposed a theory to explain the basis of design fixation. According to these authors, a problem can be represented as two types of mental representation: the conceptual space, related to abstract knowledge, such as principles and procedures used to solve the problem; and the object space, in which objects gain physicality. They suggested that an iterative process between the two spaces is necessary, but generation of ideas would only occur in the conceptual space. Design fixation occurs when a priming example

obstructs the transition from object space to the conceptual space (Jansson and Smith, 1991). In this type of situations, it is possible to say that conceptual fluidity, a state characterized by quicker and stronger associations between stimuli (Gabora, 2002), has unexpectedly hindered the access to other stimuli.
Other studies tried to replicate Jansson and Smith's results (1991) with a different set up, but were unsuccessful (e.g., Purcell and Gero, 1992). This raised the hypothesis that familiarity with the design problem and the participants' lack of experience could be potential causes for fixation. Subsequently, Purcell and Gero (1996) managed to reproduce the same effect, when using the exact same experimental set up and design briefs. To investigate the relevance of specific domain knowledge, they compared the results of mechanical engineering students with advanced design students. Designers could develop more and different ideas than mechanical engineers, who showed evidences of fixation effects. However, designers did not necessarily produce more innovative results. Thus, the authors concluded that, due to their specific educational programmes, different reactions to examples could occur and, in this situation, designers were not fixated by the examples but in being different.
Chrysikou and Weisberg (2005), striving for a better understanding of how design fixation occurs, replicated Jansson and Smith's study. They used verbal protocols to analyse the influence of pictorial examples and, as a way to de-fixate participants, the authors included instructions to avoid potentially harmful features. The outcome of this study demonstrated that fixation effects can occur when pictorial examples are displayed, as the participants had a stronger tendency to focus on the images rather than the text. However, the fixation effect was neutralized when there were clear instructions prompting them to avoid the issues of the given example.
These results seemed to point out that fixation effects occur more frequently with pictorial stimuli, rather than when using texts, which are, to some extent, corroborated by Eastman (2001) and Chambers and Reisberg (1985). Mental imagery, a cognitive ability defined in section 2.3.4, uses frames of reference to enable interpretation of images (Eastman, 2001). Figure 2.5 is a classical example of an ambiguous image.
When observing Figure 2.5, one possible frame of reference enables people to see

a duck. To be able to reinterpret the image and see a rabbit, the frame of reference needs to be consciously altered, but mental imaging tends to fix interpretations (Chambers and Reisberg, 1985).

Thus, it is possible that a similar phenomenon is involved in design fixation: depending on how images are interpreted, frames of reference might negatively influence creativity and cause fixation effects.

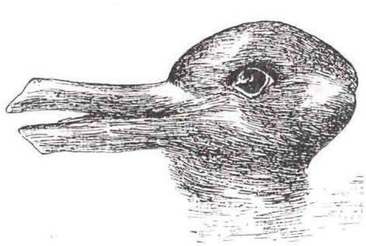


Figure 2.5. Example of an ambiguous image, which requires a change of frame of reference, to either see a rabbit or a duck (Source: Jastrow, 1899, p. 312).

Still focusing on pictorial stimuli, Cardoso, Badke-Schaub and Luz (2009) explored the influence of different levels of richness in design fixation. While previous experimental studies had only used line-drawing examples, these authors used a photographic representation of an existing product, and compared the influence of both pictorial materials. According to their results, there were no differences between both types of pictorial stimuli, but both led to fixation effects. Although there was a decrease in the quality and originality of ideas produced under the influence of both images, it seems that the reproduction of features of priming examples was not necessarily negative in all accounts. Ideas influenced by the pictorial stimuli were judged to be cheaper and easier to manufacture, since they followed the frame of reference of the priming examples.

The format and richness of the pictorial stimuli given was also investigated by Cheng, Mugge and Schoormans (2014). Although they did not directly analyse fixation effects, their results showed that the use of partial photographs (small details of a closely related example) led to more original ideas than full photographs of the same examples. This seems to indicate that changing the format of the pictorial format can be useful to overcome the 'path of least resistance' (Ward, 1994, see section 2.4.3). Moreover, partial photographs contain incomplete information, which might enable to build a looser frame of reference to interpret images (Eastman, 2001).

In general, these findings illustrate one of the problematic issues of studying design fixation: when is it appropriate to reproduce features of an example in a new design? As we have seen in section 2.3, new ideas are born from old concepts, and some sort of repetition is always present, even in the most revolutionary design solutions. Thus, it is reasonable to consider that not all acts of repetition are detrimental to creativity, but where is the dividing line?

#### 2.4.6. Redefining design fixation

Considering the overlap between the many inhibitive behaviours presented here, the study of fixation has become quite entangled. Since fixation can be encountered in so many forms in creative problem solving, there is no agreement between researchers on definitions nor certainty that researchers are all studying the same behaviour when they refer to design fixation. For instance, Hatchuel, Le Masson and Weil (2011) defined four different phenomena under the term 'fixation effects'. These included fixation caused by precedents, by knowledge acquisition processes, by collaborative work and by the organisation of the design process. Therefore, some researchers have attempted to explore the topic of design fixation under new perspectives (Youmans and Arciszewski, 2012; 2014; Crilly, 2014; Crilly, 2015; Vasconcelos and Crilly, 2015). Youmans and Arciszewski (2012, 2014) analysed previous research on design fixation and developed a classification based on three aspects: awareness, intentionality and type of knowledge (mental design space).

Regarding awareness, designers can either be conscious of the influence that external stimuli might have on their work or be completely oblivious to their own fixation. In the second case, an ***unconscious adherence*** to stimuli occurs. Examples of unconscious adherence have been studied by Jansson and Smith (1991), Youmans (2010), Linsey et al. (2010) and under the term of *unconscious plagiarism* (also referred as *inadvertent plagiarism* or *cryptomnesia*) (e.g., Marsh, Ward and Landau, 1999; Stark and Perfect, 2008; Tenpenny et al., 1998). To investigate whether fixation was occurring unconsciously, researchers in the design field used priming stimuli that contained disadvantageous characteristics (which were detrimental for the resolution of the design problem).  If the designers were aware of their repetition, they would at least avoid the negative features and copy only design elements that would facilitate the resolutions of the design problem. Surprisingly, both in the results of Jansson and Smith (1991) and Youmans (2010), participants were not aware that they were fixated, not that their solutions were influenced by the priming examples. Besides demonstrating that unconscious adherence can occur in design problems without even the designer's recognition, these investigations support a need for a differentiation between inhibitive creative behaviours that occur with and without the designer's awareness. In conclusion, the traditional definition of design fixation (discussed in section 2.4.5) can be considered an example of unconscious adherence if the designer is actually blind to the inappropriate adherence to stimuli.

In the situations where designers are aware they are fixated, a ***conscious blocking*** occurs (Youmans and Arciszewski, 2012; 2014). Designers from all levels of expertise will recognise the sporadic frustrating feeling of going around in circles, being unable to think of alternatives or to change their approach to a problem (Sachs, 1999). Alas, becoming aware does not necessarily help in unblocking one's mind. This conscious blocking could fall under the original definitions of design fixation (section 2.4.5), mental set (section 2.4.2) and attachment to initial ideas (2.4.3), but only when the designer becomes aware of the block. In the situation of a mental set, designers can be consciously blocked in the way the design problem was framed, by approaching it from their own particular field of knowledge. On the other hand, designers can feel that their initial ideas hinder the exploration of alternatives. In both cases, familiarity with a specific approach (Marsh, Ward and Landau, 1999), the path of least resistance (Ward, 1994) or too much knowledge about a topic (Luchins and Luchins, 1959) have been posited as different theories to explain what could be categorized as conscious blocking.

Youmans and Arciszewski (2012; 2014) introduced another type of fixation, where designers are both aware and determined to use the same approach or repeat the same (type of) solutions for a new problem. They described this as an ***intentional resistance.*** This case of fixation occurs, for instance, when designers are averse of risk or uncertainty, as in situations when an innovative solution represents a higher gamble of success than using an old solution that has proven to work many times before. The catchphrase 'Don't reinvent the wheel' is a clear representative of this resistance, as it can be considered to be fruitless or cost-prohibitive to change something that already works. This type of fixation has not been previously investigated in scientific research, since the decision to be traditional or conformist can be an intentional and legitimate option of the

designer.
Finally, Youmans and Arcizewski (2012; 2014) made a last classification, depending on the type of knowledge used by the designer, and considering the theoretical model of Jansson and Smith (1991). This theoretical model described two mental spaces, a configuration space and a concept space, as explained in section 2.4.5. With that in mind, Youmans and Arcizewski (2012; 2014) distinguished between conceptual-based fixation and knowledge-based fixation. The former occurs when the same kind of solutions is continually chosen, independently of the problem at hand. The latter refers to a failure to consider knowledge outside of the designer's domain of expertise and it can have several order of degrees: if the designer uses closely related information to the problem at hand, it is said that he might have a first order fixation.
Following a qualitative approach, Crilly (2015) investigated fixation from the perspective of design practice. By interviewing professional designers, Crilly identified how they relate to fixation in the 'real-world settings' and their approaches to overcome it. More importantly, Crilly recognised that, indeed, fixation is perceived in design practice, but more broadly than the usual definition of design fixation, which relates only to exposure to stimuli. Expert designers reported to recognise fixation in practice caused by precedents and by initial ideas, but also caused by organisational issues. Fixation prompted by organisational circumstances included project constraints (such as time or budget limitations), company culture (where risk tends to be avoided) and briefing (which refers to how the clients frame the design problem). According to Crilly's findings, expertise might have a twofold influence on fixation: On one hand, increased experience can lead to conservatism, where solutions that worked in the past are preferred; On the other hand, experience can also contribute to a stronger reflection on potentially fixation situations, which might result into countermeasure practices (Crilly, 2015).
In conclusion, external stimuli have the potential to influence positively (becoming a source of inspiration) but also to limit creativity, depending on several variables such as content and form, but also background or experience, for instance. This section presented an overview of the main findings on some known inhibitors to creative thinking. However, these phenomena are not fully

investigated in the following studies of this thesis, as they are one of the possible outcomes of using external stimuli in design.

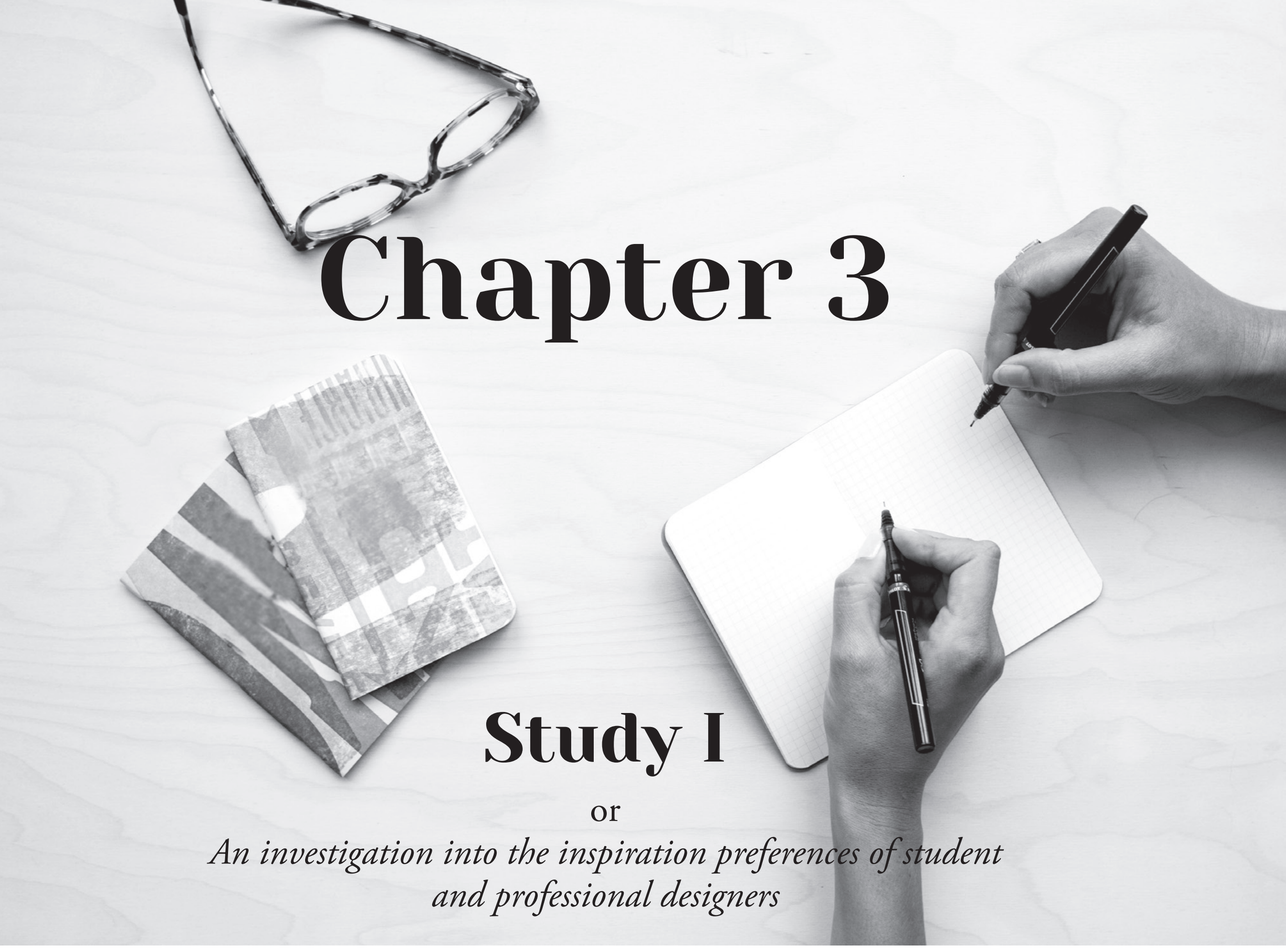
This chapter has presented the most relevant theoretical underpinnings on the influence of external stimuli in design. This thesis now proceeds with the four empirical studies, each exploring different facets of the influence of external stimuli in design. These are: Search and preferences on external stimuli and ideation methods, in regard to expertise (Chapter 3); Influence of external stimuli in design (Chapter 4); Inspiration processes (of search and use of external stimuli) (Chapter 5); and Selection of external stimuli (Chapter 6).

This chapter is an adaptation of Gonçalves, M., Cardoso C. and Badke-Schaub, P. (2014). What inspires designers? Preferences on inspirational approaches during idea generation. *Design Studies*, 35 (1), 29-53

Gonçalves, M., Cardoso, C., & Badke-schaub, P. (2011). Around you: How designers get inspired. In *International Conference on Engineering Design, ICED'11* (Vol. 7, pp. 1–10).

Gonçalves, M., Badke-schaub, P., & Cardoso, C. (2011). Searching for inspiration during idea generation. In *IASDR2011, the 4th World Conference on Design Research* (pp. 1–12)

Chapter 3 figure: Photo retrieved from deathtothestock photo.com



# Chapter 3

## Study I

or

*An investigation into the inspiration preferences of student and professional designers*

*In the previous chapter, the overarching themes employed in this thesis were discussed, and searching for external stimuli was considered to be an essential step in the initial stages of the design process. However, it was possible to recognise a lack of information on what designers search for during such a phase. There is no distinction between what student and professional designers use as inspirational sources or idea generation methods. This chapter presents the results of a questionnaire involving 103 student and 52 professional designers on their reported preferences for inspirational approaches. Students and, to some extent, professional designers seem to give an exaggerated importance to a restricted number of approaches, considering the wide range of available ones. Further results have uncovered possible research directions for the exploration of alternative stimuli for inspiration during ideation phases.*

## 3.1. Rationale

Chapter 2 (section 2.2) introduced the existing knowledge gap concerning the use of external stimuli in design. Designers are constantly surrounded by information and there is a myriad of available stimuli, which can potentially be inspirational or detrimental to creativity. However, despite many research studies have explored the influence of either visual or textual examples, it could not be ensured from any of these studies what designers actually use and prefer as stimuli in their work.

This indicates that important questions are still unanswered. For instance, how far do designers value inspiration sources? What kinds of potential inspiration sources do designers search for during idea generation? What might be the differences between student and professional designers on their preferences for stimuli, as well as most used idea generation methods?

This chapter presents Study I, which aims to answer these questions. This study provides the basis for the investigation into how designers can be better supported during the front-end of product/service design and development - where ideation is likely to greatly influence design outcomes. Gaining insights into designers' current inspirational strategies can help establish future research directions on how designers select and transform available stimuli to produce new solutions. Therefore, learning about what types of stimuli designers search for during the initial phases of the design process is a step towards finding out about the potential usefulness of particular types of inspiration sources.

However, as external stimuli are likely to be an integral element of different idea generation methods, this study also looks into some of these approaches. In fact, searching for, retrieving and using particular stimuli for inspirational purposes can be achieved via the implementation of more or less elaborated idea generation methods. Methods can range from informal activities, such as active/passive searching, collaborating, and socialising (Herring, Jones, & Bailey, 2009) to very formal procedures like brainstorming and morphological analysis (e.g., Allen, 1962; Shah, Kulkarni, & Vargas-Hernandez, 2000). Design methodology literature provides information on a vast number of methods aiming to support the different phases of the design process (e.g., Cross, 1994; French, 1985). A number of such methods places emphasis on the idea generation phase, typically originating from literature on creative thinking approaches (e.g., Michalko, 2006). Research on creativity has, for instance, identified as many as 172 creativity techniques for idea generation (Smith, 1998). Others have narrowed down this large number of techniques to 19 strategies used most often in design practice (Herring, Jones and Bailey, 2009). Nevertheless, previous studies have not been consistent in the type of methods they include in their overviews (for instance, Herring, Jones and Bailey included *reflection* and *socialising* as idea generation methods). Thus, it remains the need to investigate which ideation methods do student and professional designers mostly prefer for ideation purposes.

## 3.2. Research question

As introduced in chapter 2, section 2.2, this study aims to answer the following sub-research question: *What are the external stimuli designers* ***search*** *for during idea generation?*

Consequently, the expectations underlying this study were as follows:
- Regarding the comparison between professional and student designers, it was expected that both groups valued inspiration very highly (Eckert & Stacey, 2000). Although some studies have previously focussed on the topic of inspiration sources, they have provided only anecdotal evidence of their importance for designers. Additionally, from experience in teaching design students and working with design practitioners, it is observable that both give great importance to inspiration, even if they approach it in a variety of different ways. This comparison between professional and student designers on their stimuli preferences was deemed relevant to be able to understand the phenomenon of stimuli use, before delving into one specific group of interest. Thus, although the distinction across expertise levels enables a general standpoint to initiate this research project, it was not included a sub-research question;
- It was expected that pictorial examples could be the preferred type of stimuli for both student and professional designers. This is based on studies that suggest

that designers have a preference for using visual information (e.g., Muller, 1989; Henderson, 1999; Hanington, 2003). Additionally, images are considered to be the most effective representation modality for designers (Sarkar & Chakrabarti, 2008), which they opportunistically make use of during idea generation (Casakin & Goldschmidt, 2000; Goldschmidt & Smolkov, 2006);
- Although ideation methods were not the focus of this doctoral dissertation, this study provided the opportunity to explore designers' preferences, as hitherto there was no overview on which methods designers prefer during idea generation. Thus, (as with the distinction between professionals and students) no sub-research question was created about designers' usage of ideation methods. Nevertheless, it was expected that both student and professional designers could have a tendency to hold to a limited number of idea generation methods, brainstorming likely to be the most widely used technique (Daalhuizen & Badke-Schaub, 2011; Rietzschel, Nijstad & Stroebe, 2006). Brainstorming is considered to be the first idea generation technique ever invented, in 1953 (Osborn, 1953; Osborn et al., 1971) and it is generally considered to be the best-known creative technique. It is also the one technique that has been the target of more investigations (e.g. Diehl & Stroebe, 1987; Stroebe & Diehl, 1994; Paulus, Brown and Ortega, 1996; and Paulus, 2000). To the extent of the author's knowledge, however, no research has previously assessed how often brainstorming is used by designers in practice and education, a fact that also motivated the inclusion of ideation methods in this study.
In order to investigate these issues, a questionnaire study was conducted to learn about student and professional designers' preferences on 'sources of inspiration', including favoured stimuli and ideation methods. The type of survey described here ought to provide a first stage of important general information about inspirational approaches used by a considerable number of student and professional designers.

## 3.3. Research study

A questionnaire was developed using NetQ software (NetQuestionnaires Nederland BV) to find out about students' and professional designers' preferences regarding inspirational approaches. The questionnaire was devised around the following main topics: external sources of inspiration in design, preferences for particular approaches and most used ideation methods. The questions were iteratively formulated and refined on the basis of feedback from a pilot study, consisting of a small number of students, research colleagues and practising designers. The questionnaire used in this study can be seen in Appendix A.

## 3.4. Data collection

The survey involved 155 participants: 103 industrial design engineering Masters students and 52 professional designers (see Table 3.1). All the students participating in this study were from Delft University of Technology (i.e., Faculty of Industrial Design Engineering). The data from design professionals was collected mainly from the Netherlands (across the country) and Portugal (mainly Lisbon). The reason for this sampling was mainly practical, as it enabled the use of the author's existing network. There was no implicit or explicit goal to compare Portuguese with Dutch designers. In fact, within the sample of participants collected from the Netherlands, many were not Dutch, but international students and practitioners that were presently working in the Netherlands. The participants were either contacted in person or via e-mail. There were no specific criteria for participation.

| Years of experience | No. of participants |
|---|---|
| Less than 5 | 34 |
| Between 5 and 10 | 8 |
| Between 11 and 15 | 7 |
| Between 16 and 20 | 3 |
| Total = | 52 |

Table 3.1. Overview of the professional designers' years of experience.

In this study, the participants were divided into two main groups: students and professionals. As introduced in section 2.2, research has distinguished between seven discrete levels of design expertise (Lawson and Dorst, 2009; Dreyfus and Dreyfus, 2005). In this way, this group of student participants is potentially comprised by novices, beginners and advanced beginners. On the other hand, the group of professional participants is likely to be composed of competent¸ expert and master designers (Lawson & Dorst, 2009; Dreyfus & Dreyfus, 2005). Hence, it is noteworthy to mention that more experienced designers participating in this study have been purposefully labelled as professionals, rather than experts - as their professional experience as designers ranges from 2 to 18 years (Table 3.1).

The questionnaire could be filled in online or on paper. Pilot studies indicated that it took on average 15 minutes to be completed. Replies to the questions took various forms, namely 5-point Likert scales (e.g., 1 = never; 2 = rarely; 3 = sometimes; 4 = often; 5 = always), yes/no answers, and multiple choice. In order to further clarify some of the issues addressed and to obtain more information about particular topics, the survey included additional open-ended questions.

The questionnaire was divided into five sections with the following topics:

1. Background information about the participants;
2. Preferences for representation stimuli;
3. Preferences for type of information sources;
4. Frequencies of use of ideation methods.
5. Reflection on the design process

Topic 2 of the questionnaire (preferences on representation stimuli) addressed the frequency of use and the importance designers give to preferred representation stimuli, namely, visual, three-dimensional and textual. This same topic also included questions about the phase of the design process where such stimuli were perceived as being of major importance.

Topic 3 (preferences on the type of information sources) dealt with the specific kinds of sources designers prefer to use for inspirational purposes. A list of possible sources was obtained from informal talks with designers from different backgrounds, as well as from literature. This resulted into a total of 12 possible information sources (design magazines; design books; newspapers; magazines from other fields; Internet; art; competitor products; other designers; previous personal projects; memories/past experiences; nature; places).

In addition to these information sources, participants could add other options not included in the questionnaire.

Topic 4 (frequencies of use of ideation methods) focuses on designers' self-assessment regarding 14 idea generation methods, namely brainstorming, function analysis, scenarios, mind map, checklists, analogies, how to's, storyboard, metaphors, collage, context mapping, morphological chart, roleplaying and synectics. Ideation methods have been broadly categorised into two main groups: *intuitive* (e.g., brainstorming, roleplaying, metaphors, synectics); and *logical* (e.g., TRIZ and forward steps) (Shah, Vargas-Hernandez, and Smith, 2003).
Intuitive approaches, which despite their name include systematic procedures, are meant to help an individual to break routines and overcome mental blocks. Brainstorming is often reported as one of the most used approaches during idea generation by practicing designers (e.g. Herring, Jones and Bailey, 2009; Kelley and Littman, 2001), and often recommended as an idea generation method in different organisations (Kayser, 1994; Tobin, 1998). Other intuitive approaches, such as roleplaying, are implemented by well-known design consultancies like IDEO at the beginning of the design process when trying to guide both clients and potential end-users through an immersive experience about the situation/problem at hand (e.g., Simsarian, 2003). Metaphors, another intuitive method, has been used by designers as a way of framing and defining design problems, and helping communicating particular meanings about design situations (Hey et al., 2008). Examples include, for instance, Apple promoting their new computer (in 1981) as a bicycle for the mind (Hey et al., 2008); the extensive use of metaphors in the software industry, the desktop metaphor being the most common example (Madsen, 1994); or, Canon designers being inspired by the metaphorical idea of a beer can copier when developing a disposable copier drum (Nonaka, 1991).
Logical methods are largely based on existing available sources (e.g., TRIZ) and more scientific and engineering principles, and are aimed at thoroughly decomposing and analysing problems (Shah et al., 2003). Methods that at first sight could look entirely different might actually use the same underlying

cognitive processes. For instance, an intuitive technique such as synectics, or a logical one like TRIZ, are both based on the use of analogical reasoning during idea generation.

This study covers primarily a selection of intuitive idea generation methods (Shah et al., 2003), as they constitute the majority of methods that the participant audience (103 design students) are exposed to during their education at TU Delft (the Netherlands).

Appendix B (Glossary of ideation methods) includes a succinct description of each method referred in this section and the ones used in this study. The selection of these methods is not an exhaustive one, but rather a selective list primarily based on an educational resource used at the Faculty of Industrial Design Engineering, at TU Delft (Van Boeijen and Daalhuizen, 2010). This book comprises a range of design methods derived from a number of literary sources, including methods for idea generation. For a more detailed description of each method used in this survey, please see Appendix B.

Finally, topic 5 (Reflection on the design process) focussed on the participants' perception of barriers during the generation of ideas and their usual coping strategies to overcome such hindrances. We asked the participants to reflect on four possible detrimental situations to creativity and to report on the frequency of their occurrence:

*Attachment to initial ideas:* tendency where one is strongly committed to the first idea(s) and feels reluctant to abandon it/them (Darke, 1979). The question "How frequently do you keep your first idea during the whole design process?" was used to elicit information on participants' reflection on attachment to initial ideas.

*Stuckness:* in this context, stuckness refers to one's awareness of being caught in just one possible solution, without being able to think of other possibilities (Sachs, 1999). The question "How frequently are you aware of being caught in just one possible solution for the problem you are trying to solve?" was used to bring forth participants' reflection on stuckness.

*Mental set:* tendency to follow the same approach to solve problems, irrespectively of the situation (e.g., Luchins and Luchins, 1959). The question "How frequently are you aware you are following only one way of dealing with the problem you are trying to solve?" was used to elicit information on participants' reflection on mental sets.

*Design fixation:* unconscious propensity to repeat parts/principles of previously seen examples, without considering their appropriateness (e.g., Jansson and Smith, 1991; Purcell & Gero, 1996). The question "How frequently are you aware of repeating previously seen parts of examples/principles?" was used to prompt participants to reflect on design fixation.

## 3.5. Data analysis

The data collected were analysed in alignment with the aforementioned expectations (section 3.2) regarding how both student and professional designers favoured and claimed to use particular stimuli and methods for inspirational purposes. Therefore, student and professional designers' preferences on representation stimuli, information sources, frequencies of use of ideation methods and frequencies on reflection of the design process were analysed to search for possible variations within and between groups. Analysis of the former dealt with the individual responses within each group (students and professionals separately), computed using one-way repeated-measures ANOVA. The analysis of the latter compared the students' responses with those provided by the professionals, using Independent-Samples T-tests.

## 3.6. Results

In the following subsections, the results of the main topics of the questionnaire are presented.

### 3.6.1 The importance of inspiration

As expected (see section 3.2), the results reveal that the importance attributed to inspiration ranks between moderately and very important for both student and professional designers (on a scale from 1 to 5, in which 1 means 'not at all important' and 5 means 'very important' e students M = 4.39, SD = .660; professionals M = 4.44, SD = .639, Figure 3.1 left). Similar results can be found regarding student and professional designers' frequency of searching for inspiration on a scale from 1 e never e to 5 e always, with both groups reporting very frequent engagement in such activity (students M = 4.18, SD = .860 and professionals M = 4.33, SD = .857, Figure 3.1 right).

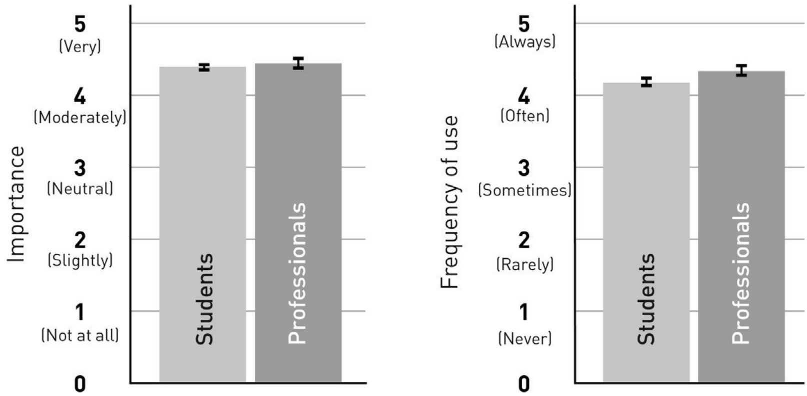



Figure 3.1: (Left) Importance attributed to inspiration – students and professionals; (Right) frequency of inspiration search – students and professionals, with standard error of means indicated.

A repeated-measures ANOVA was computed to assess the importance of inspiration sources at different stages of the students' design process. Mauchly's test indicated that the assumption of sphericity was violated [$\chi^2$=(27) = 137.063, $p$ < .05]. Thus, a Greenhouse-Geisser correction was used, which showed that the moments of the design process when inspiration is considered most important differed significantly for students [$F$(4.927, 502.598) = 23.596, $p$ < .001, $\eta p^2$ = .188].

Post hoc tests using the Bonferroni correction revealed that idea generation was considered to be the moment when inspiration was the most important for students ($p$ < .005, in relation to all other moments) (Figure 3.2, left).

Similar results were found with regard to the professional designers. There was a statistically significant effect on the moments of the design process when inspiration is considered most important [$F$(4.818, 245.700) = 8.193, $p$ < .001, $\eta p^2$ = .138, with Greenhouse-Geisser correction, as assumption of sphericity was

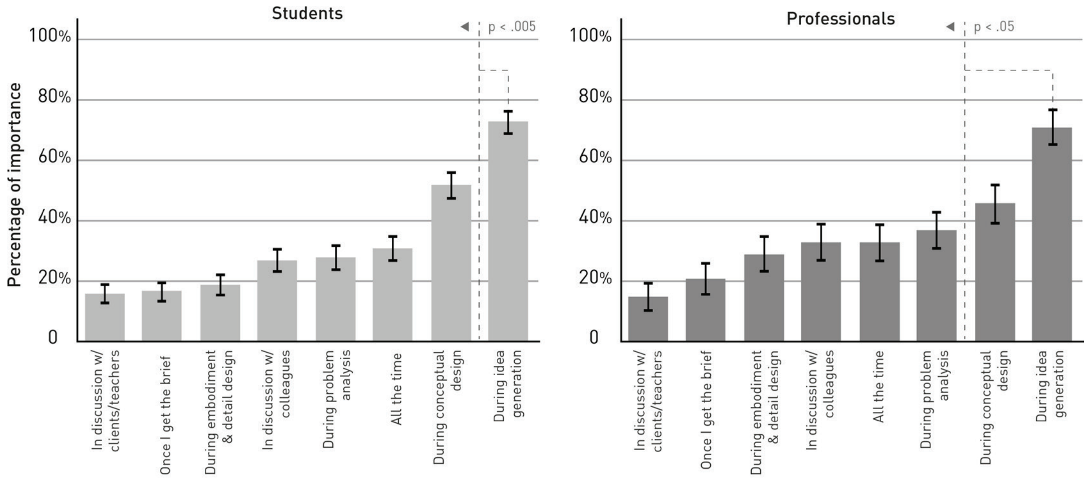



Figure 3.2: Moments when inspiration search is most important: (Left) students and (Right) professionals. Standard error of means are indicated.

violated: $\chi^2(27) = 85.662$, $p < .05$]. Post hoc tests with Bonferroni correction indicated that professional designers also consider idea generation to be the moment when inspiration sources are most important ($p < .005$, in relation to all other options but 'during conceptual design': $p = .151$) (Figure 3.2, right). These results suggest that the professionals have a more elaborated view on the phase of idea generation, and thus also see the importance for inspiration during conceptual design.

### 3.6.2 The importance of representation stimuli

On the matter of which types of stimuli are more important for the respondents, students rated images as between very and moderately important (M = 4.46, SD = .725), objects as moderately important (M = 4.05, SD = .922) and text as having between a moderate to neutral importance as a stimulus during the design process (M = 3.34, SD = 1.062) (Figure 3.3, left). Professionals, on the other hand, gave similarly high importance to images and objects (images: M = 4.37, SD = .668; objects: M = 4.35, SD = .903), while text was considered to be of only neutral importance (M = 2.98, SD = 1.090).

There was a statistically significant difference between the importance given to representation stimuli by the students [$F(2, 204) = 38.054$, $p = .001$, $\eta p^2 = .272$]. The assumption of sphericity was not violated: $\chi^2(2) = 2.812$, $p > .05$. To follow up these significant effects, a Bonferroni post-hoc tests was used, which showed that students gave higher importance to images compared to objects ($p < .005$). Both images and objects were significantly more important for students than text was ($p < .001$) (Figure 3.3, left).

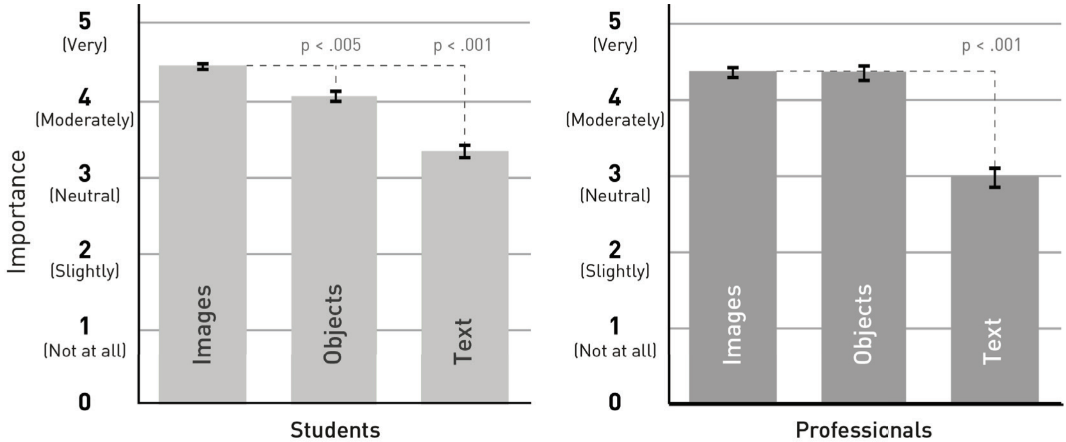



Figure 3.3: Importance of different representation stimuli: (Left) students and (Right) professionals, with standard error of means indicated.

For the professional designers, there was also a statistically significant difference in the importance given to representation stimuli [$F(1.488, 71.435) = 40.216$, $p = .001$, $\eta p^2 = .456$]. Post hoc tests using the Bonferroni correction showed that professional designers reported images and objects to be of similar importance, both of them being more important than text ($p < .001$) (Figure 3.3, right). When comparing students with professionals, both groups assign equivalent importance to the use of images, but not to the use of objects or text. As can be seen in Figure 3.3, professionals attach greater importance to objects as inspiration stimuli than students do [$t\ (153) = 2.046$; $p < .05$]. On the other hand, as compared to professional designers, students show a slightly stronger tendency to rely on text during idea generation [$t\ (151) = -1.841$; $p = .068$].

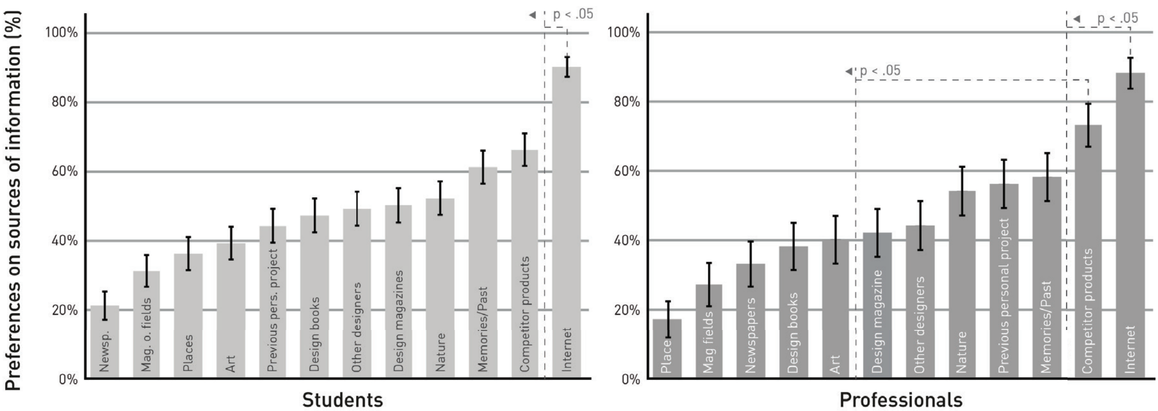
### 3.6.3 Preferences for information sources

Concerning student designers, there was a statistically significant differences between their preferences on information sources [$F(11,1224) = 14,936$, $p = .000$]. Bonferroni post-hoc tests confirmed that the students reported to significantly prefer to use the *Internet* (M = .90, SD = .298) over all other sources listed in the questionnaire (Figure 3.4, $p$ <.05 in relation to *competitor products* and $p$ <.001 in relation to remaining sources). *Competitor products* (M = .66, SD = .476) and retrieving inspiration from *personal memories* (M = .61, SD = .490) were the second and third most preferred sources of information (but still, significantly lower than *Internet*). Conversely, *newspapers* (M = .21, SD = .412), *magazines from other fields* (M = .31, SD = .465) and *places* (M = .36, SD = .482) were students' least preferred sources to obtain information.

There where also statistically significant differences across the preferences of professional designers [$F(11,612) = 9.255$, $p = .000$]. Bonferroni post-hoc tests revealed that professionals' preferences on information sources were similar to those of students, being *Internet* (M = .88, SD = .323), *competitor products* (M = .73, SD = .448) and *memories* (M = .58, SD = .499) also the most preferred sources. On the other hand, *places* (M = .17, SD = .382), *magazines from other fields* (M = .27, SD = .448) and *newspapers* (M = .33, SD = .474) were the least preferred ones by professionals. Whilst students chose searching for information on the *Internet* significantly more than any other source, this is not true for professionals. In fact, professionals reported to prefer to look into competitor products almost as much as browsing the *Internet*.

Finally, both groups portrayed a rather similar range of stimuli preferences but there were still statistical differences between student and professional designers on the preference of one type of sources of information. The results show that student designers gave higher preference to *places* for inspirational purposes than professionals did [$t\ (153) = -2.425$; $p < .05$].

Figure 3.4: Preferences on different types of information sources: (Left) students and (Right) professionals, with standard error of means indicated.



### 3.6.4 Frequencies of use of ideation methods

As can be seen in Figure 3.5, student designers indicated brainstorming as their most frequent used ideation method (M = 4.36, SD = .698). A repeated-measures ANOVA with a Greenhouse-Geisser correction showed that there was a significant effect on how frequently the students reported using the 14 different ideation methods [$F$(9.112, 929.428) = 31.255, $p$ = .001, $\eta p^2$ = .235, with Greenhouse-Geisser correction, as assumption of sphericity was violated: $\chi^2$ (90) = 272.301, $p < .05$]. Subsequently, post hoc tests were computed with the Bonferroni correction, which indicated that brainstorming was reported to be used significantly more than the other 13 methods listed in the questionnaire ($p < .001$, Figure 3.5). Roleplaying, morphological chart and synectics are the least used, compared to the remaining 11 methods ($p < .01$, Figure 3.5).

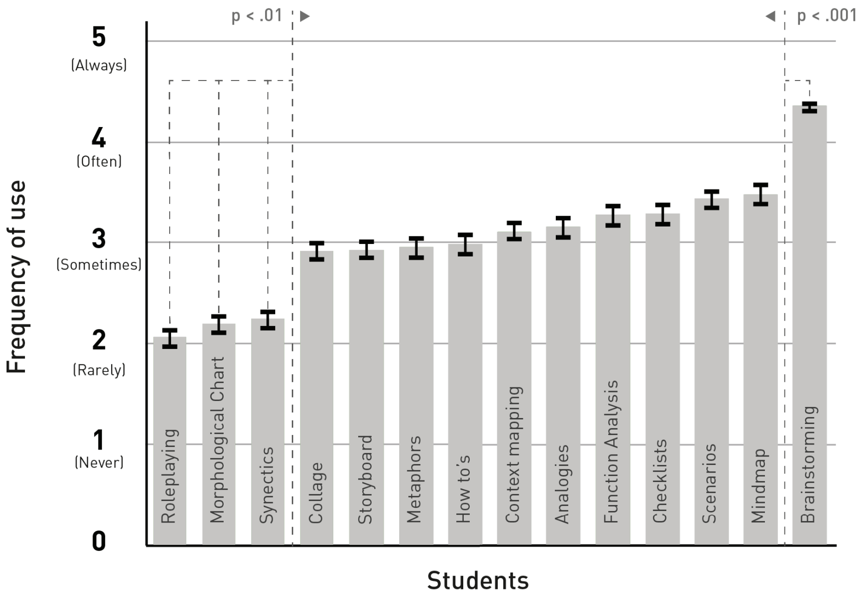



Figure 3.5. Student designers' reported frequency of use of ideation methods, with standard error of means indicated.

Likewise, brainstorming is the method professionals say they use the most during idea generation (M = 4.02, SD = .941). The reported frequency of use regarding the different ideation methods also differed significantly between methods [$F$(8.341, 366.998) = 14.736, $p$ = .001, $\eta p^2$ = .251, with Greenhouse-Geisser correction, as assumption of sphericity was violated: $\chi^2$ (90) = 154.783, $p < .05$]. Bonferroni corrections were applied to all post hoc tests and results from the professionals' responses show higher frequency of use for two methods: brainstorming (used more often than 11 other methods, $p < .05$, Figure 3.6) and function analysis (used more often than 7 other methods, $p < .05$, Figure 3.6). The methods least used by the professional designers are synectics, roleplaying and morphological chart (in which synectics is used less often than 10 other methods, $p < .05$, Figure 3.6).

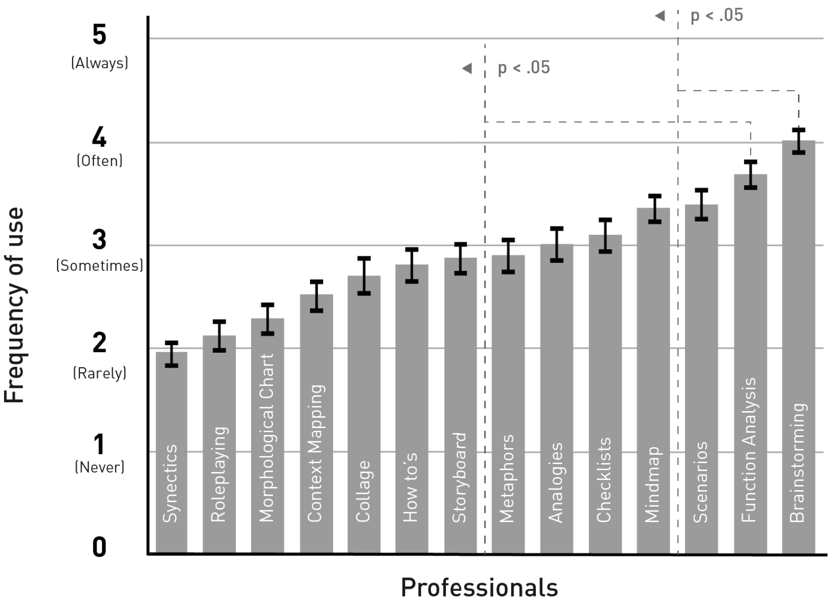



Figure 3.6. Professional designers' reported frequency of use of ideation methods, with standard error of means indicated.

When comparing the responses given by the students to those of the professionals, significant differences were found between frequencies of use of three methods only (out of the 14 selected): brainstorming, context mapping and function analysis. Students claim to apply brainstorming and context mapping more often than professionals do [$t$ (152) = -2.115, $p < .05$; and $t$ (151) = -3.133, $p = .005$, respectively]. Conversely, professional designers use function analysis more frequently than the students do [$t$ (151) = 2.216; $p = .05$].

### 3.6.5 Reflection on the design process

The participants were asked to reflect on their design process and report on possible detrimental situations to creativity. As mentioned in section 3.4, these were:

1. *Attachment to initial ideas*
2. *Stuckness*
3. *Mental set*
4. *Design fixation*

Analysis on the frequency of responses showed that there was no significant difference between the different detrimental situations, as acknowledged by the students [$F(3,408) = 2.086$, $p = .101$; *design fixation* (M = 3.13, SD = .882); *Attachment to initial ideas* (M = 2.91, SD = .853); *Stuckness* (M = 2.9, SD = .955); *Mental set* (M = 2.83, SD = 0.933)] (Figure 3.7, left).

In fact, repetition of (parts or principles of) precedents was the most recognised situation by both professional and student designers alike (Figure 3.7).

Regarding the professionals, there was a statistically significant difference between the four detrimental situations [$F(3,203) = 4.678$, $p = .003$]. Post hoc tests with the Bonferroni correction revealed that professional designers were significantly more aware of *design fixation* situations (M = 3.46, SD = .803), than they were of being caught in just one possible solution (*stuckness*: M = 2.94, SD = .873, $p < .05$) and awareness of exhibiting a tendency to use only one way to deal with a problem (*mental set*: M = 2.9, SD = .913, $p < .05$). There was a marginal significant difference between *design fixation* awareness and propensity for keeping the first idea (*attachment to initial ideas*: M = 3.04, SD = .824, $p = .078$). There was no significant difference between student and professional concerning their level of awareness of *attachment to initial ideas* [$t\ (152) = -.877$, $p > .05$], *stuckness* [$t\ (153) = -.249$, $p > .05$] and *mental set* situations [$t\ (153) = -.499$, $p > .05$] (Figure 3.7). However, there was a significant difference between student and professionals awareness of repeating previously seen parts of examples (*design fixation*) ($t\ (153) = -2.301$, $p < .05$). In fact, professional designers reported to be aware of the occurrence of such behaviour in their design process much more often than students (Professionals: M = 3.46, SD = .803; Students: M = 3.13, SD = .882).

For further clarification, we asked the participants to fill in additional open questions, to explain how they usually cope with such situations. It was possible to ascertain that professional designers considered *repetition* an advantageous and appropriate practice in order to achieve more effective solutions. Some of the answers given by the professional designers reflect an intentional commercial strategy, driven by a market that demands easy to implement, cheap and recognisable solutions. As stated by a professional participant:

> *"Often, the objective is to make something that you know works well and not trying to be innovative, as that can add costs and time to a project".*

Additional responses indicated also that the use of repetition as a strategy resulted from a learning process, where designers rely on previously proven solutions in order to tackle unfamiliar problems. This was illustrated by another respondent:

> *"If it is a good example, learn what's good about it and use it as inspiration. Don't reinvent the wheel".*

Ultimately, repeating parts or principles of previously seen examples was considered by the professional designers as an effective way to design, as stated by another participant:

> "I think it saves me a lot of work".

Therefore, the results suggest that the tendency to repeat parts or principles of successful existing solutions is not only considered a common practice, it is perceived as a well-established strategy in design practice.

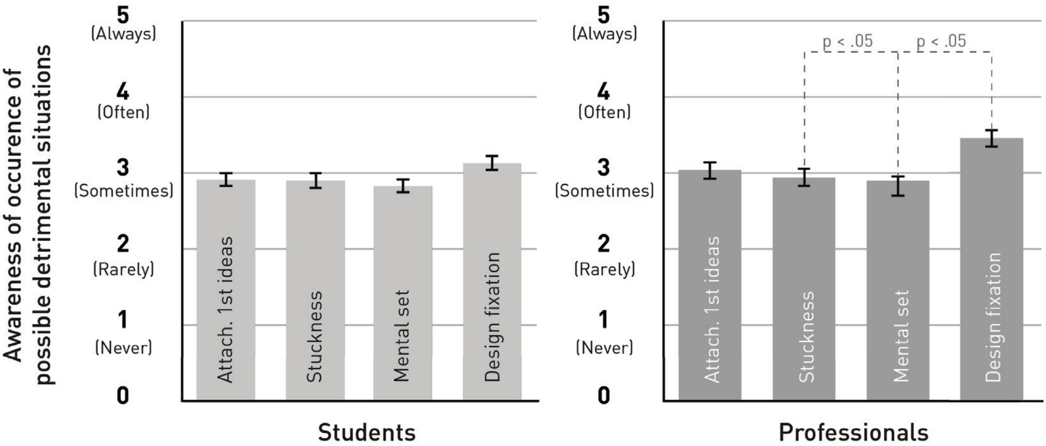



Figure 3.7. Reported frequency of detrimental situations to creativity: (Left) students and (Right) professionals, with standard error of means indicated.

## 3.7 Discussion

According to the results obtained, student and professional designers show clear differences between the inspirational choices (stimuli and ideation methods) they report using during idea generation. It is important to take into account that these results are self-reported, and that answers could therefore be biased by different memory retrieval failures, such as *motivated forgetting* (e.g., Mather, Shafir and Johnson, 2003). Also, while it was expected that some of the practices reported by the participants would also be shared by other designers with similar backgrounds, it is important to be cautious in any such estimation because of how the participants were sampled (Section 3.4). Indeed, different academic institutions where industrial design is taught may use distinct teaching material in their curriculum. Therefore, the sort of idea generation techniques the participants report using could be different to those used across various academic and professional settings and cultures.

### 3.7.1 Representation stimuli

Whilst stimuli can take different forms and comprise different levels of content, both student and professional designers in this study seem to prefer visual representations as stimuli for their work. This matches with the general assumption that designers have a preference for visual stimuli during the design process (Mougenot, Bouchard and Aoussat, 2008; Hannington, 2003; Henderson, 1999; Tovey, 1992; Muller, 1989). However, as mentioned above, research has demonstrated that exposure to visual stimuli can have both positive and negative effects on the generation of new ideas. It is therefore legitimate to question whether too much importance is given to images instead of a more balanced selection of diverse representation stimuli. Texts, for instance, seem to be as easily accessible and widespread as images, yet despite being potentially inspirational for designers they are far less utilised (Goldschmidt and Sever, 2010). These results indicate that students report using text more often than do professionals (although only marginally) when looking for inspiration. One possible explanation is that students are exposed to particular educational programmes where there are more opportunities to undertake diverse and exploratory design exercises. On the other hand, perceiving and interpreting a pictorial representation of an entity is obviously faster than reading through its written counterpart. Hence, typical time constraints observed in industry might explain why professionals spend less time browsing for inspiration in different types of text. However, designers' perceptions of how often they might use text as inspiration stimuli could actually be underestimated. For instance, the implementation of mind maps often relies on the use of words/text to generate and visualise ideas and information in a diagrammatic manner, to solve problems and hence search for inspiration. Likewise, brainstorming might be based on writing keywords on paper, rather than necessarily generating a large number of sketches.

The use of three-dimensional representations (such as mock-ups, prototypes and commercial products) as inspiration stimuli is highly rated by the professionals in this study. Professional designers report using objects more often than do students, which could be related to three main aspects. Firstly, financial resources would, in principle, allow professional designers easier access to rapid prototyping/additive manufacturing techniques, as well as the acquisition of available examples/products. Secondly, easy access to object representations, and the accumulation of years of experience might help professionals become more proficient at visualising things three-dimensionally, in comparison with student designers.

Thirdly, the apparent preference that professional designers seem to have for this type of stimulus could be related to the amount and importance of the information it provides to designers. That is, whilst the outcome from the students' work is often a conceptual representation of a possible solution (i.e., a design exercise), professional designers will be working on real design solutions (to be manufactured and distributed), where failures could result in serious financial and/or legal repercussions. Therefore, professionals, especially those working with three-dimensional entities, depend more on knowing in detail the physical attributes, mechanisms and principles of their creations, which could be enhanced by having access to different types of physical examples.

### 3.7.2 Sources of information

Two of the most preferred sources of information by students and professionals can be considered design-related, i.e., examples of competitor products or similar solutions on Internet. Nevertheless, it is important to consider that the selected stimuli used in this survey vary in terms of specificity. For instance, whilst competitor products (as source of information) refer to a well-defined category of design examples, Internet is a medium, thus, more general. In fact, we have no clear indication of what designers search for when they are browsing the Internet. From the survey's open questions, it is possible to assume that, especially in an initial phase, designers search for existing design solutions or problem-related information, which then places Internet as a design-related content stimulus. As it was described in chapter 2, section 2.4.5, research on design fixation has demonstrated that the use of priming examples as stimuli can result in counterproductive behaviours. One of such behaviours is the inadvertent repetition of parts/principles of examples, which can be a hindrance in creativity (e.g., Jansson and Smith, 1991; Purcell & Gero, 1996). Furthermore, as it was elaborated on chapter 2, section 2.2.5, previous studies have repeatedly demonstrated that it is more beneficial to seek for inspiration in distantly related sources, rather than close ones (e.g., Gentner and Markman, 1997; Christensen and Schunn, 2007; Bonnardel and Marmèche, 2005). For these reasons, it is possible to speculate that designers' tendency of relying too much on design-related stimuli (considered to be closely related) might increase the probability of design fixation behaviours.

Whilst students and practitioners seem to be hijacking their own creativity, there are reasons that justify this behaviour. Design-related stimuli, such as competitor products and iconic design objects, are easily accessible, both physically (through pictorial examples on the Internet, for example) and cognitively (part of the designers' mental collection of cases). Moreover, local or within-domain analogies (section 2.2.5) are easier to evoke, as they share a higher level of similarity between source and target problem (Christensen and Schunn, 2007). Consequently, distant or between-domain analogies, which are aroused by distantly related stimuli, can be rather difficult to evoke. However, designers are known to be skilled in establishing distant analogies (Casakin, 2003). Under typical time and budget limitations, the designers taking part in this survey showed a tendency to employ strategies of cognitive economy (e.g., Visser, 1996; Pasman, 2003; Goldschmidt, 2003) and constricted themselves by searching for the most immediate sources of inspiration. This is what seemed to occur when student and professional designers reported that they search for inspiration on the Internet and when looking at competitor products. Furthermore, the third most used stimulus for both levels of expertise was their own memory. This fact is congruent with the findings that designers rely on their own past experiences and knowledge of previous cases to find inspiration and to develop new ideas and concepts (Oxman, 1990). Also, professional designers in this study reported to frequently search for memory-related stimuli: they indicate looking for inspiration within their own memory ($M = .58$, $SD = .499$) and previous personal projects ($M = .56$, $SD = .502$). On the other hand, students also reported that they refer to memory when designing ($M = .61$, $SD = .490$) but less often retrieve information from previous personal projects ($M = .44$, $SD = .498$). It is easily understandable why students seem to not use previous personal projects, as their design knowledge is still limited. Memories and previous personal projects are still important for students; however, the amount of information in the required field of knowledge is probably smaller. In summary, these results support that designers, especially professionals, are able to apply a memory-based reasoning to stimulate creativity (Oxman, 1990). In line with that explanation can be seen also the prominence Internet seems to have for student designers' preferences for information sources. Whilst professionals choose three stimuli as the highest-ranking (Internet, competitor products and memories), students indicate Internet as significantly more important than all the other stimuli. This result may indicate that student designers tend to choose the most readily available stimuli compared to professionals, who rely on their bigger pool of internal stimuli available.

### 3.7.3 Ideation methods

Roleplaying, synectics and morphological chart were the methods least used by both students and the professionals, who reported utilising them rarely. The reasons why these three methods, which have very different goals, are rarely used might be explained by different aspects. Roleplaying focuses on user-product interaction, in which the designer re-enacts a possible situation of use. It is mainly used to understand the context of a possible concept/product in use, and thus it does not necessarily lead to the direct generation of ideas, which might be one of the reasons for its infrequent use. Applying synectics requires a comprehensive procedure that is supposed to help designers analyse a problem, and generate and select ideas based on the use of analogies. Analogical reasoning is an integral subsection of the mechanics of synectics. Synectics could be regarded as too complex to be easily implemented, and thus, discarded over Analogies, which are potentially simpler to implement. Finally, morphological chart is aimed at helping designers to identify functions and sub-functions of a problem. Similar to synectics, morphological chart is a complex method, which involves the prior employment of function analysis (to make an extensive listing of the parts and subsections of a problem) and the combination of the different components. Therefore, the reasons for the low rating on synectics and morphological chart in this study may reside in the complexity of using these procedures.

These findings suggest that, whilst students generally tend to use brainstorming more frequently than any other method, professional designers go a step further and rely not only on brainstorming, the most used technique, but also on function analysis and scenarios. Professional designers' most frequently used methods correspond to two very different, yet supplementary, approaches to design problems. Brainstorming enables the generation of large numbers of ideas, hence expanding the solution space. Scenarios facilitate an overall understanding of the users and the context of use. Function analysis represents a systematic analysis of the relationship between the functions and the different parts of the future product. The high frequency of use professionals reported for function analysis demonstrates their emphasis on the fulfilment of requirements that need to be met in practice, by highly competitive markets. On the other hand, students' most used three methods are, in general, related to the generation of ideas (brainstorming, mind map and scenarios). Thus, it could be argued that students seem to be mainly pursuing the generation of ideas, without much consideration for the next phases of the design process, where ideas will eventually be thoroughly 'tested' before implementation.

Efforts to make use of multiple approaches, as opposed to sticking to two or three methods, can potentially provide designers with a more comprehensive generation and exploration of the solution space. This suggests that student designers' tendency to favour brainstorming as a generative method so highly may be preventing them from benefiting from using other useful and complementary approaches more frequently. Nevertheless, it is unwise to state that a more frequent exploration and use of other idea generation methods will lead to more creative solutions, as it is not known how far the amount of methods a designer uses correlates to performance. On the other hand, there are an extensive number of ideation methods available to designers, with new methods and tools continuing to be developed. Therefore, it is valid to question whether designers, students in particular, are overlooking other potentially advantageous approaches.

### 3.7.4 Reflection on the design process

Regarding the awareness of potential pitfalls designers may fall into during idea generation, the results showed that professionals explicitly recognised the tendency to being fixated on available precedents and to repeat them during their design process. However, the respondents generally considered this as a natural and well-accepted procedure to adopt during idea generation. The participants reported on a number of reasons that can be linked to the following two main concepts:

1. Commercial strategy - one of the main goals in industry is to make products that satisfy a commercial and functional need, which does not necessarily depend on developing a completely novel idea.
2. Cognitive economy – in order to cope with time and budget constraints, professional designers seem to employ cognitive 'short-cuts', by reusing previously seen examples instead of creating everything from scratch (e.g., Visser, 1996; Pasman, 2003; Goldschmidt, 2003). Goldschmidt (2003), aiming to define what is good or effective design reasoning, proposed that the designer's mind tends to be 'economy minded'. This is, an effective design process tends to avoid 'waste': to seek out only design moves that contribute to the development of the design concept and avoid unnecessary steps. In the same way, designers from this survey seem to avoid extra cognitive effort during idea generation by reusing parts or principles of similar solutions. The professionals' responses on reusing precedents defy, to some extent, empirical studies on design fixation,

which found that repetition could at times lead to poorly design concept solutions. Obviously, little can be said regarding the quality or creativity of the work produced by these designers, as this survey could not assess their past work. Research on design fixation generally considers repetition/reuse of similar solutions as a hindrance to creativity, when transference between precedent and new solution was not thoroughly assessed and appropriately transformed (e.g., Goldschmidt, 2001). Therefore, as professional designers reported on repetition as a convenient approach in design practice (to simplify and accelerate the design problem solving process), it can be assumed that they might have been thorough about how they make use of available precedents. This can be an indication that professional designers engage in a deeper reflection compared to student designers.

## 3.8 Conclusions

This chapter provides insights into students' and professional designers' choices on sources of inspiration, frequency of use of particular ideation methods and reflection on hindrances to creativity. The knowledge gained from this chapter raises interesting issues regarding how designers might be using inspirational approaches, ultimately revealing several paths that are investigated in the following chapters.

In terms of possible implications for design education, these findings indicate that student designers are bounded to a limited range of representation stimuli and types of information. Furthermore, students also use a reduced number of ideation methods on a more regular basis. In light of the potential freedom that students should have to explore new and alternative inspirational and creativity approaches in their safe (academic) environments, it seems unnecessary and unproductive to limit oneself to such a narrow practice. Whilst to some extent there is an 'obvious' connection between the use of visual representations as inspiration for the generation of the typical design solution outcome (a visual three-dimensional embodiment per se), there is no immediate justification as to why other inspiration typologies (for instance non-pictorial ones) could not be equally explored while generating creative ideas. Research on the use of

text, as inspiration stimuli, is a promising example of such an alternative (e.g., Goldschmidt and Sever, 2010). The fact that both student and professional designers in this study clearly do not favour the use of text as an inspirational resource is, in itself, worthy of further investigation (which is explored in chapter 4). As previously mentioned, text is to some extent already used as a stimuli in a few idea generation methods (Section 3.7.1). However, the challenge is to identify and investigate when and in which format text could be presented to designers for them to explore the potential advantages of such stimuli.
Furthermore, the findings on designers' preferences on types of information support that both students and practitioners seem to restrict their inspiration process by focussing their search in the closest and most immediate source – the Internet. Contrary to past studies (Mougenot, Bouchard and Aoussat, 2008), designers' main sources of inspiration are not magazines or design books anymore, but the Internet. With its ubiquitous presence in every design office or school, the Internet has become the number one inspirational tool for designers. Considering that the second most preferred information source is competitor products, it is possible to assume that designers' inspiration focus is on design related stimuli, which can be considered closely related to the problem at hand. Thus, to fulfil the ever-constant flow of deadlines, designers may be creating barriers for their own creativity, due their own choice of material sources. One of the possible reasons for this is that designers are using an economical approach to inspiration search. By searching for the most accessible and related information, designers can save time and cognitive effort, which enables to move forward with ideation faster. However, this economical approach to inspiration can be detrimental to creativity. That will be the focus of the following chapter (Chapter 4), which presents Study II and investigates the influence of both semantic distance and types of representation stimuli in design ideation.
Moreover, there were not many striking differences between student and professional designers regarding their choices on the most influencing stimuli for idea generation. This similarity suggests that if the range of preferred stimuli is not different between students and professionals, their possible contrasting performances can be due to their distinct cognitive processing. Therefore, a successful creative outcome may not depend solely on the frequency and with

which variation certain sources of inspiration are used but rather on how stimuli are transformed to generate innovative solutions.

On the matter of most frequently used idea generation methods, the participants in this study favoured brainstorming over other methods. Brainstorming appears to generate a feeling of progress and creative freedom, due its potential to prompt the rapid generation and flowing of ideas and the conscious non-criticism of results. However, student designers at TU Delft are exposed to several other methods besides brainstorming during their education. The reasons for such an 'exaggerated' use of this method are still unclear and it becomes particularly pertinent considering that previous research showed the disadvantages of group brainstorming, for instance, in comparison to individual brainstorming (e.g., Taylor et al., 1958; Diehl and Stroebe, 1991). Nevertheless, more emphasis could be placed in explicitly devising design exercises where students have to implement particular ideation methods. Encouraging the exploration of diverse ideation methods might also be triggered by more active approaches to reflection during the design process.

On the topic of reflection, these findings indicate that professional designers consciously apply what could be considered a potential counterproductive behaviour, i.e., the repetition of parts or principles of previously seen examples (design fixation). This fact is consistent with an apparent practice of cognitive economy, especially to cope with limitations in regard to reasoning resources (e.g., Visser, 1996; Pasman, 2003; Goldschmidt, 2003). Whereas this would normally be considered a risky procedure when a high original product is the desired goal, it could also be seen as a suitable behaviour if a rich level of awareness is present. According to these results, and applying these insights into the design education realm, there are three major factors to consider: Firstly, it is necessary to broaden how student designers deal with external stimuli and how they apply ideation methods. Secondly, professional designers should be aware that even if the practice of a cognitive economy strategy can be advantageous in specific situations with financial and resources limitations, it can also become limitative to creativity. Lastly, these two factors can be improved by enhancing the importance of reflecting during the design process. Reflection is an essential activity humans can apply to flexibly adapt to different circumstances and changes in their environment. As no single strategy is universally suitable to all situations, the ability of a person to acknowledge and adapt their own behaviour is an essential success factor in complex contexts such as design projects (Dörner, 1978). Whilst reflection can occur naturally, people are frequently prompted to reflect when they come across mismatches between what they expected and the actual situation. There seems to be evidence that reflection should be taught and trained as a meta-cognitive skill (Badke-Schaub et al., 2010). As the differences across expertise levels were not striking, and considering the role of reflection, which emerged from these results, a change in lens is adopted in the following studies. Whilst the comparison between professional and student designers in study I enabled an initial general viewpoint of the use of stimuli in design, studies II, III and IV focus on student designers. This shift was deemed more beneficial, as it enables a closer interaction between research and education.

Finally, a number of caveats should be reported: as previously acknowledged, the sample of participants, which turned up to be mainly from two countries (Portugal and the Netherlands), could be improved. For instance, to avoid sampling bias, the nationalities of the designers should have been controlled in a more systematic manner. To maintain consistency, for instance, participants from only one country would have been advised. On the other hand, culture and/or nationality were not a focus on this study (or following studies) and they were not considered to be influential for the discussion of stimuli preferences. Furthermore, the participants from this questionnaire were not distinguished regarding their design specialisations. Although the goal of this study was to achieve an overall appreciation of designers' preferences, independently of their expertise level, nationality or general background, these possible limitations should be observed when considering the findings.

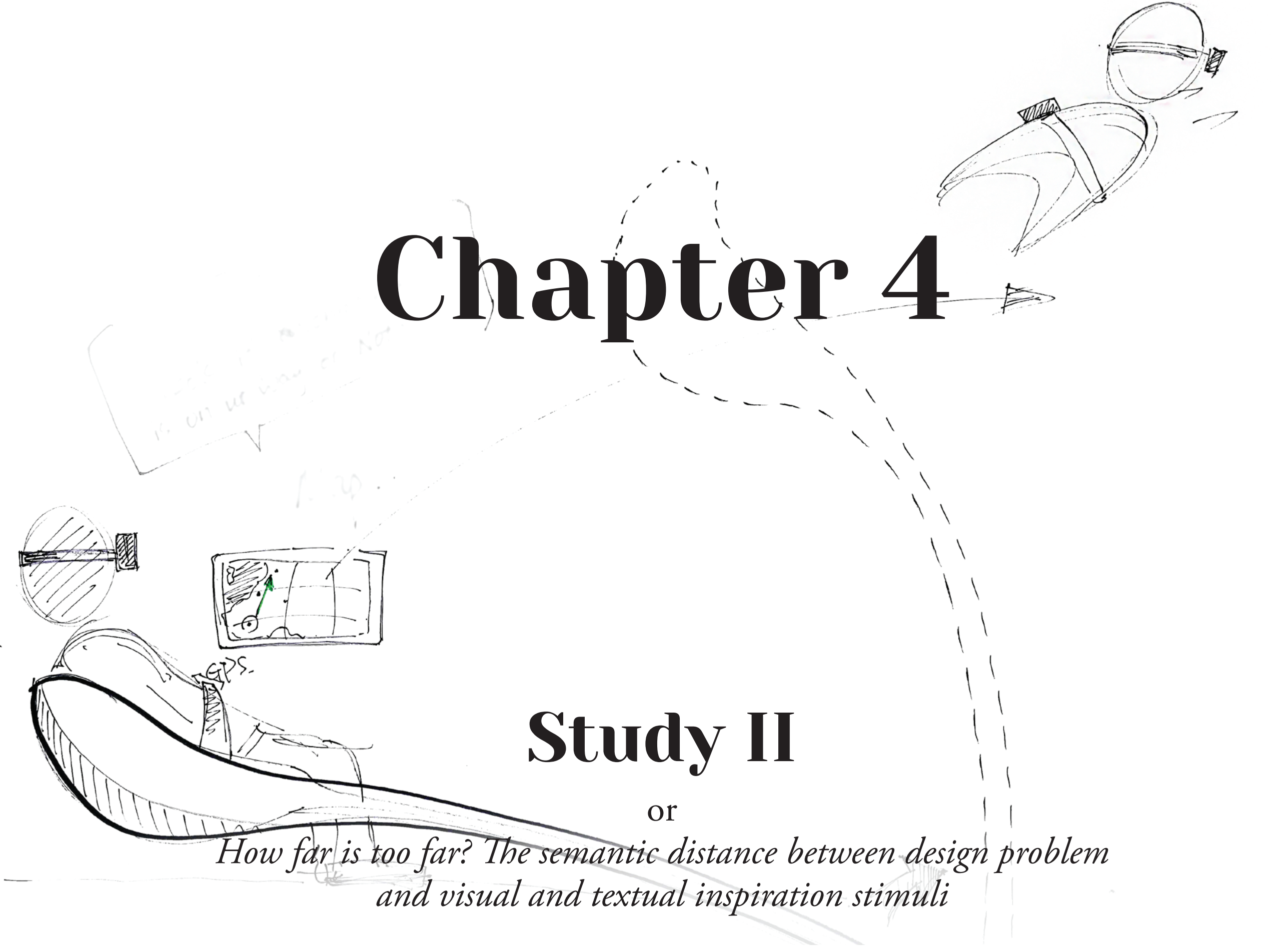
We are now in a better position to know more about when and what designers reportedly look for when they are searching for inspiration. It is important to consider the value of widening the search for different stimuli typologies and representation modalities as cues to creative problem solving. Ultimately, a major challenge for designers lies in acquiring the mechanisms to conduct a timely and appropriate selection of functionally useful stimuli amongst the overwhelming diversity of available sources.

This chapter is an adaptation of Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2013). Inspiration peak: exploring the semantic distance between design problem and textual inspirational stimuli. *International Journal of Design Creativity and Innovation*, 1(4), 1–18.

Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2012). How far is too far? Using different abstraction levels in textual and visual stimuli. In *International Design Conference - Design 2012* (pp. 1–10).

Chapter 4 figure: Idea generated by participant from Study II.

Gonçalves, M., Cardoso, C., & Badke-schaub, P. (2012). Find your inspiration: Exploring different levels of abstraction in textual stimuli. In *The 2nd International Conference on Design Creativity (ICDC2012)* (pp. 1–8).




# Chapter 4

## Study II

or

*How far is too far? The semantic distance between design problem and visual and textual inspiration stimuli*

*In the previous chapter, the results of study I revealed that designers seem to prefer using visual stimuli despite empirical investigations indicating possible disadvantages of such unimodal approaches. Therefore, it is valid to ask whether designers are disregarding other available stimuli, such as textual representations. In order to answer this question and to find out about the usefulness of different textual stimuli during ideation phases, novice designers were exposed to three types of written stimuli, with different semantic levels. The results indicate that between close and very distant related types of stimuli, there is an intermediate type that is likely to stimulate participants to generate a larger number of more flexible and original ideas. This intermediate type of stimulus seems to prompt designers to generate ideas that are more creative in terms of fluency, flexibility, and originality. Conversely, the too close and the too distant (unrelated) stimuli reveal being less useful for creative problem solving. Looking into alternative types of stimuli, as well as stimuli entailing varying levels of distance with the problem at hand, can possibly help designers in increasing their creative potential.*

## 4.1. Rationale

Chapter 2 (section 2.2.3 and section 2.2.4) introduced the existing conflicting view on the usefulness of different types of representation stimuli in design idea generation, namely visual and textual stimuli. Subsequently, in chapter 3, it was possible to demonstrate that both professional and student designers give a prominent preference to visual stimuli, whilst disregarding textual sources. Considering these findings, the author of this thesis argues that there is a lack of attention to the question whether equivalent textual counterparts could also prompt the generation of creative results. Despite designers' obvious preference for pictorial representations, it seems appropriate to assume that other sources might also have the potential to be used as inspirational material when generating ideas. The findings of study I (chapter 3) also revealed that designers might be applying an economical approach to inspiration. Designers rely mostly on the Internet to obtain the most immediate accessible sources, which are pictorial stimuli, normally carrying closely related information. For instance, images of competitor products are perfect examples of this type of stimuli. Numerous empirical studies have identified possible counterproductive effects of employing within-domain stimuli during design ideation (see chapter 2, section 2.2.5) and it is widely accepted that between-domain stimuli have the potential to be more beneficial to design, than within domain examples. Contrary to this perspective, Howard, Culley and Dekoninck (2011) proposed that the influence of stimuli from within the industrial domain of the task at hand would be beneficial for the generation of creative ideas. Their argument was that highly relevant stimuli would stimulate more ideas and, specifically, more appropriate ideas. Similar findings were also brought by Chan, Dow and Schunn (2014), who suggested that seeking exclusive support from distantly related stimuli might be detrimental to creativity, due to excessive cognitive costs.

Observing the divergence of opposing perspectives about this subject, it is still not clear which semantic distance level is the most desired for inspirational purposes in design (for a definition of semantic distance, please see Chapter 2, section 2.2.5). Despite the preference designers manifest regarding the use of competitor products and design related stimuli as inspiration sources, are

these the most appropriate stimuli for idea generation? In addition to the aforementioned questions concerning the use of pictorial and textual stimuli, it is important to assess the influence of different levels of semantic distance.
As between-domain stimuli can be advantageous to the exploration of creative solutions, when does the semantic distance to the problem at hand become too remote and, potentially, not beneficial? In order to verify the influence of close, distant and unrelated stimuli (text and image) in idea generation, an empirical study was developed and is described in the following sections.

## 4.2. Research question

As introduced in chapter 2, section 2.2.4, this study aims to answer the following sub-research question: *How do external stimuli, such as visual and textual stimuli, **influence** designers during idea generation?*

The aim of this study was to investigate the usefulness of different types of visual and textual stimuli as an inspiration source during idea generation. Usefulness in this context refers to the extent to which particular types of visual and textual stimuli might support the designer achieving more creative ideas, especially when compared to using no stimuli. At this stage, it is important to note that this paper discusses solely the usage of external stimuli in design in the form of printed image and text, as opposed to other types of external stimuli (e.g., auditory and olfactory).
This study also focuses on the usefulness of different levels of semantic distance between the written description of the design problem and the stimuli used, which can range from close through distantly related till far too distantly related.

The expectations from this study were the following:
- Despite designers substantial preference for images (see Chapter 3), it was expected that textual stimuli could be as beneficial to the development of creative ideas as visual stimuli. This expectation is based on the apparently contradictory results of previous studies on external stimuli. Many researchers have advocated images supremacy in design (Muller, 1989; Henderson, 1999; Malaga, 2000;

Hanington, 2003; Sarkar & Chakrabarti, 2008). However, a growing amount of studies have reported on the positive usefulness of using textual stimuli in design idea generation (Goldschmidt and Sever, 2010; Chiu & Shu, 2007, 2012). Taking these findings into consideration and keeping in mind that the majority of these studies did not directly compare the influence of pictorial to textual stimuli, it is expected that the usefulness of either using images or text as stimuli could carry similar results.
- It was expected that whilst closely related stimuli could influence designers to generate ideas that would fall within similar categories of the priming example, distantly related stimuli could lead to more creative ideas. This expectation stems from numerous studies, which claim the creative advantage of using distantly related stimuli compared to closely related stimuli (Gentner and Markman, 1997; Christensen and Schunn, 2007; Bonnardel and Marmèche, 2005).
- It was expected that unrelated stimuli could influence designers to generate more original and flexible ideas, although less feasible. This expectation derives from the assumption that remote stimuli can elicit unexpected associations and, thus, more unique solutions (Mednick, 1962). Despite being potentially able to influence the generation of more unique ideas, unrelated stimuli might also be detrimental to feasibility, as the stimuli's and the design problem's domains might be too far apart to be able to translate into realistic ideas.

Learning about the impact of alternative inspiration sources during design idea generation can provide new directions for design research, practice and education. Further research can provide a better understanding on how and which kind of information processes are chosen, how they are structured and which variables are determining the search, retrieval, transformation and use of visual and other types of stimuli. For professional practice, the findings from this study should support designers in questioning their selection approaches to inspiration sources, in face of the overwhelming diversity of available material.

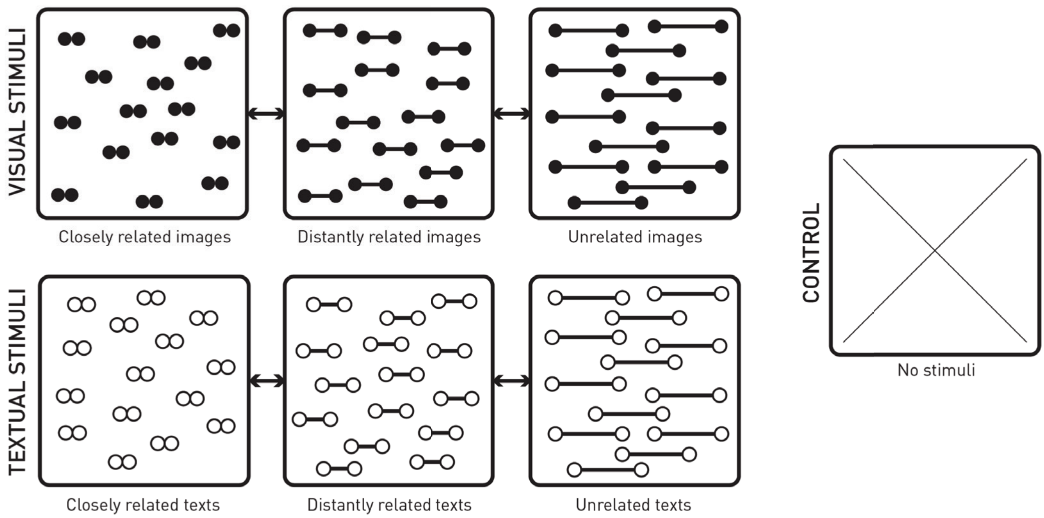
## 4.3. Research study

For this study, an empirical study approach was employed, with seven conditions

(Figure 4.1): three conditions who received visual stimuli, three other with textual stimuli and one control condition, without any given stimulus. Stimuli can vary both in the relatedness of semantic content as well as the level of abstraction. Here, the chosen stimuli varied in terms of their semantic content. That is, these stimuli describe objectively specific elements and/or situations. Therefore, the aim was to investigate the usefulness of exposing designers to different types of textual stimuli, varying in terms of semantic distance from the design problem statement. However, another level of textual and visual stimuli was added along this continuum, ranging from closely to distantly related semantic content. An additional textual stimulus was purposefully introduced that was meant to be too distantly related to the problem description, even potentially unrelated. The aim was to explore whether there would be areas along the continuum that could be of more or less benefit for designers whilst trying to generate novel ideas.

All experimental sessions were conducted in similar laboratories (specialized rooms, equipped to capture video and audio recordings of the participants' behaviours in a non-obtrusive manner). The rooms were windowed, containing only a large table and chairs, with no visual displays on the walls. Although the data collection took place in a number of rooms, all efforts were made to keep it as similar as possible.

Figure 4.1: Diagram explaining the seven conditions of this study and how they relate to each other



## 4.4. Data collection

This experimental study was conducted with the participation of 137 novice designers, bachelor (N = 35) and master students (N = 102) from an industrial design engineering course. The participants were considered to be novice designers but with sufficient experience with idea generation process to be able to complete a design problem.
From the 137 participants, 60 were female and 77 were male, with an average age of 23.9 years old (SD = 2.38). None of the participants reported having previous work experience. The participants were asked to carry out an idea generation exercise, with the following design brief: *"Your task is to think about how human transportation will be like in 2050. You are kindly asked to draw as many different ideas as you can in 45 minutes".*

Participants were also asked to take into account the following three requirements: enable the public transportation of at least 10 people; enable a short urban journey; and provide a safe journey. The design brief provided was intended to enable the generation of diverse ideas without being particularly attached to current examples of human transportation. Participants were asked to illustrate their solutions through sketches and text/keywords (for further clarification of their ideas) and to number each sketch in a chronological manner. To investigate the influence of textual stimuli, three written excerpts were devised, which presented three levels of semantic distance, between one another and in relation to the design brief. The 137 participants were randomly allocated into the following conditions:
**'Control group'** (N=18): This group was not provided with any given stimulus other than the design brief.

**'Textual related stimuli group'** (N=20): This group (henceforth referred as 'text-related') received a textual stimulus: a written description of the 'Straddling Bus', an example of a transportation concept for the near future (1-5 years), by Shenzhen Hashi Future Parking Equipment Co., Ltd. This example, which is an existing concept for a possible near future transportation concept, was selected because it embodies a realistic perspective for a futuristic public transportation vehicle. The textual related stimulus was as follows: *"Imagine a new concept for future public transportation where an electric-powered vehicle drives over traffic jams. Its design resembles a modern tram with a wide stretched cabin covering a two-lane motorway. This vehicle is a little wider than two contemporary motorcars place side by side, and its length is about six cars in a row. Supported by extended 'legs', which run on rail tracks on both sides of the road, the vehicle's cabin is elevated above the cars on the motorway. Cars can drive under the vehicle when it is stopped on designated (elevated) passenger stations".*

**'Visual related stimuli group'** (N=20): This group (i.e. 'visual-related') were provided with a visual counterpart of the aforementioned description. The coloured image displayed the 'Straddling Bus', as shown in Figure 4.2.

Figure 4.2: Visual stimulus presented to the 'Visual related stimuli group' – the 'Straddling Bus', a conceptual transportation system for the near future (1-5 years).

**'Textual distant stimuli group'** (N=20): The textual distant group (i.e. 'distant') was presented with a textual stimulus, which contained an excerpt from the book *The Wonderful Wizard of Oz* by L. Frank Baum. In it, Dorothy, the main character, is lifted by a cyclone while inside her house. The concept of a cyclone was used due its relation with movement, direction and 'transport' of objects and debris, yet distantly related to the domain of human transportation. Therefore, the excerpt from *The Wonderful Wizard of Oz* was chosen, because it describes a particular weather phenomena (cyclone) in a nonliteral manner, yet still keeping a possible distant relationship with the idea of movement. The text presented was as follows: *"Then a strange thing happened. Dorothy felt as if she were going up. The north and south winds met and made it the exact centre of the cyclone. In the middle of a cyclone the air is generally still, but the great pressure of the wind on every side raised it up higher and higher, until it was at the very top of the cyclone; and there it remained and was carried miles and miles away as easily as you could carry a feather."*

**'Visual distant stimuli group'** (N=20): This group (i.e., 'visual-distant') was presented with a pictorial stimulus representing a cyclone. The cyclone was chosen because it was considered to be distantly related to the topic of transportation: it conveys the notion of transport, in this case, of air and debris. The image shown to the participants from this condition is presented below (Figure 4.3).

Figure 4.3: Visual stimulus presented to the 'Visual distant stimuli group' – a picture of a tornado.

**'Textual unrelated stimuli group'** (N=20): This group (i.e. 'text-unrelated') was given a textual description of a mirage. Although this choice was arbitrary, it has nevertheless an intentional relation with the cyclone, as both of them are weather phenomena. To choose a possible unrelated stimulus, other possible weather phenomena were considered, which did not have apparent connections with the idea of movement. The mirage matched these requirements. The textual unrelated stimulus was as follows: *"A mirage or fata morgana occurs when two layers of air of different temperatures meet. The basic, or inferior mirage of the sort we see in summer on the roads, arises when the cold air above begins to warm as the heat rises from the hot road surface. This causes the boundary where the layers meet to appear to shimmer like water when viewed from a certain angle. This is due to light refraction, or bending really, and instead of seeing the road, we see the reflection of the blue sky which appears like water."*

**'Visual unrelated stimuli group'** (N=19): The participants from this group (i.e. 'visual-unrelated') received a visual stimulus, which was unrelated with the design brief. This stimulus – picture of a mirage, was chosen randomly (although it had an intentional connection with the representation of the cyclone, by being a weather phenomenon). Figure 4.4 displays the pictorial stimulus shown to the participants of this condition.

Figure 4.4: Visual stimulus presented to the 'Visual unrelated stimuli group' – a picture of a mirage.

To verify whether the text excerpts were semantically equivalent to their visual counterparts, the textual stimuli were evaluated by three individuals, who were not involved in the study. Thus, the three individuals were asked to sketch what the texts described. Their sketches were quite similar to the depicted visual stimuli and it was considered that the stimuli were semantically comparable.

Nevertheless, it is necessary to acknowledge that this is a rather qualitative approach and it is not possible to fully assure that all stimuli carried equal meaning, across the three levels of semantic distance.

The stimuli were included along with the design brief in a 'subtle' manner, as to not impose their use: *"You can choose whether you would consider (or not) this text when generating ideas"*. The aim was to suggest they could read the text and use as they saw fit.

Besides the design brief, the participants were asked to answer a pre- and post-questionnaire. The former collected information on the participants' age, gender, education and perception on their own design skills, which showed no effect in the results. The latter was intended to find out, if and how these variables might also have an influence on the result.

## 4.5. Data analysis

Two independent expert judges assessed the participants' drawings, regarding the fluency of ideas, their flexibility and originality. These are three of the four basic elements of divergent thinking, elaboration being the fourth (Guilford, 1950). These three measures were chosen to evaluate the creativity of the participants' ideas as they reflect important competences that need to be attained to perform a creative idea generation process.

Fluency is defined as the quantity of ideas produced and was measured by the number of comprehensive ideas, portraying the purpose and functionality of a solution in sufficient detail (Guilford, 1950). Therefore, given a similar period of time, those who create a higher number of ideas, have a higher probability to generate more creative ideas. Sketches that did not offer clear indication of their functions and purpose were disregarded, even if these were enumerated by the participants as ideas.

Flexibility is considered to be the capacity to switch between different domains and thus, being able to alter how a problem is approached (Guilford, 1950). During idea generation, flexibility becomes most relevant, because it reflects the importance of diverging onto different ways to tackle the problem. Higher flexibility is usually related to the increased likelihood of devising more creative ideas. Prior to the analysis of idea flexibility, the sketches were clustered into three main categorization systems, each one comprising further sub-categories. Each idea was placed into one of the three categorization systems and in turn mapped to one or more sub-categories of each system (for instance, one idea could belong to both aerial and terrestrial modes of transportation - see Table 4.1). As an example, an idea portraying a futuristic electric car would be categorized as *single-vehicle* (in terms of the category *type of entity*), *terrestrial-above* (regarding the category *transport mode*) and *powered electrically* (concerning the category *powered mode*). To have an overview of how these categories were represented by the participants, Figure 4.5 shows examples of solutions portraying the five sub-categories of the *transport mode* categorization system.

| 1) TYPE OF ENTITY | 2) TRANSPORT MODE | 3) POWERED |
|---|---|---|
| a) Single unit<br>b) Infra-structure<br>c) System | a) Terrestrial-above<br>b) Terrestrial-under<br>c) Aerial<br>d) Fluvial<br>e) Teletransport | a) Human<br>b) Solar<br>c) Wind<br>d) Electrical<br>e) Fuel/gas<br>f) Nuclear<br>g) Mechanical<br>h) Animal |

Table 4.1. Categorisation of ideas: type of entities, transport modes and powered mode.

This categorization system is used to assess flexibility in two different but complementary ways:
(1) Comparison of the frequencies of the use of the categories between conditions (i.e. control, textual related, distant and unrelated). This assessment enables us to understand which categories were used by some conditions in more or less frequency. For instance, it allows us to find out whether a specific stimulus might lead to the generation of ideas that fall under some categories more than others. However, this first level of analysis does not indicate which condition was more or less flexible and a second analysis of flexibility was needed.
(2) Comparison of idea flexibility, in order to discriminate which condition was the most flexible in terms of the types of idea categories generated. In any case, the first level of flexibility analysis (1) was needed in order to compute the second analysis. This assessment was adapted from an approach used by Jansson and

Smith (1991): flexibility was computed by counting the number of completely diverse solutions to answer the design brief. A high number of different approaches by the participant reflect higher flexibility exploring wide-ranging solutions for the same problem. Conversely, participants who produced ideas related to only a few different categories would receive a low flexibility grade.

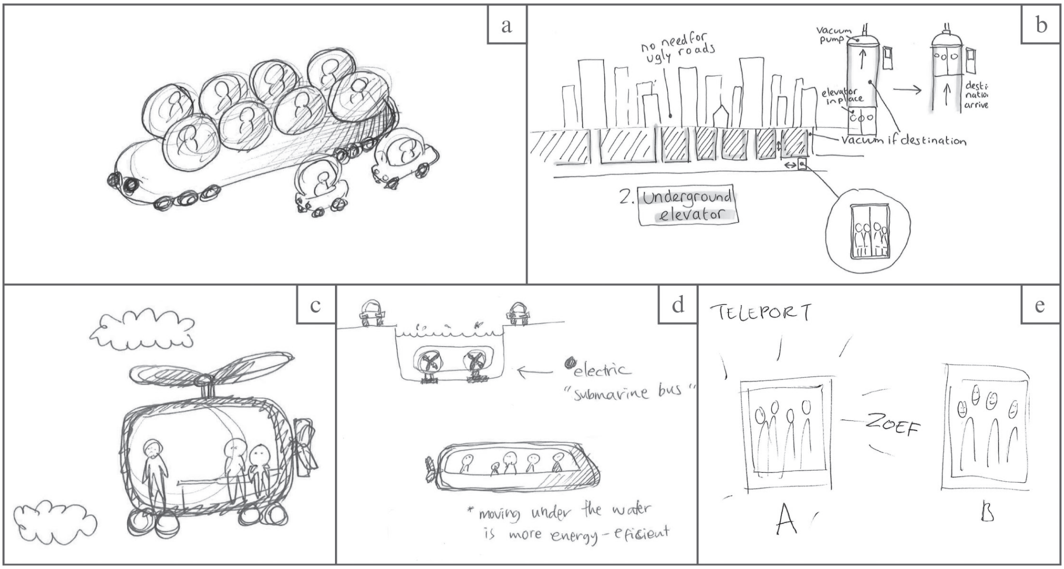
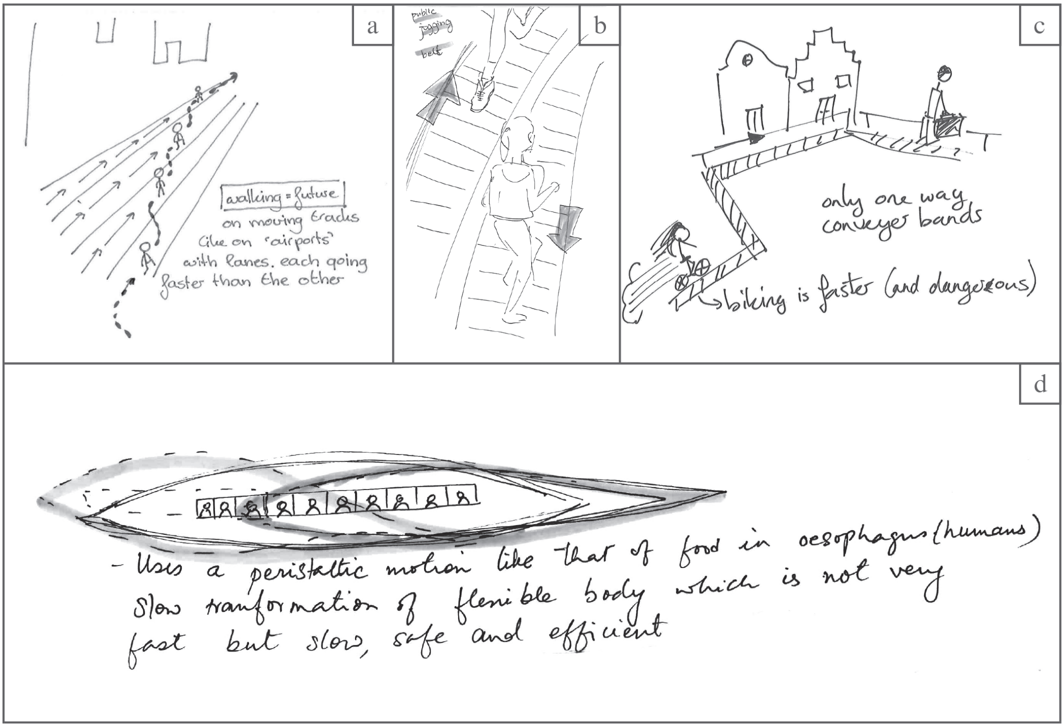



Figure 4.5. Examples of ideas portraying five sub-categories of the Transport Mode categorisation system. Figure 4.5 a). Terrestrial above; Figure 4.5 b). Terrestrial-under; Figure 4.5 c). Aerial; Figure 4.5 d). Fluvial; Figure 4.5 e). Tele-transport.

Originality, within Guilford's construct (1950), refers to the capacity to develop novel and uncommon ideas. Originality is considered an important factor to define creativity, along with the usefulness and appropriateness of the idea (Amabile, 1996). Following the approach applied by Wilson, Guilford and Christensen (1953) and Mednick (1962), an original idea was defined as an uncommon response to the design brief and was assessed by the statistical infrequency of each solution. Thus, originality is inversely correlated to the probability of being generated by the participants: the fewer times an idea is reproduced across participants, the more original it is. From the total number of ideas generated across the four conditions (796 ideas in total), 88 completely *different* ideas were found, whilst the remaining were reoccurrences of the other ideas. An idea would be considered a *reoccurrence* when the principle that defines the idea had been reproduced by other participants. As it is observable in Figure

4.6, the sketches a, b and c portray the same idea of a *travelator*, despite having small differences in usability or particular physical features. Figure 4.6 d shows a unique idea, created by only one participant (a peristaltic motion vehicle). The analysis showed that the maximum number of reoccurrence of an idea was 50 times, thus establishing the lowest level of originality. The originality score of each participant was achieved by calculating the average of the number of times each idea was reproduced divided by the total number of ideas each participant had. This resulted that a lower number (of reoccurrences) meant a high score in originality and vice versa, as it indicates that the participant created more unique ideas. To facilitate the findings interpretation, the originality metric was computed into a 1 to 10 scale, using the formula presented in appendix C.

Figure 4.6 a, b and c. Three examples of a non-original idea – a travelator – reproduced by 30 different participants in total. Figure 4.6 d. Example of an original idea – a vehicle using peristaltic motion – created by only one participant, thus unique.




Feasibility or practicality of ideas was not taken into account in the analysis of results. The reason for this is related to the fact that as the brief was set in the future (for 2050), it did not seem appropriate to assess solution ideas whose technologies are (yet) not available. This would most likely result in very original ideas being rather unpractical.

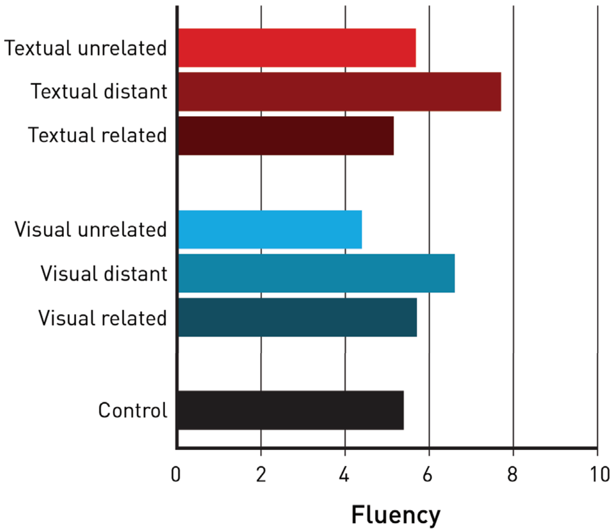
## 4.6. Results

The following sections presents the results obtained from the comparison of the constituents of creativity: fluency, flexibility and originality. Parametric tests were used for the comparison of the three conditions.

### 4.6.1 Fluency of ideas

Looking at the pure numbers, there is an obvious numerical difference between the groups, however an one-way between subjects ANOVA revealed that there was only a marginally significant difference ($F$ [6,130] = 1.938, $p$ = .079). The 'textual distant' group generated the highest number of ideas (i.e., 154 ideas, see Figure 4.7), followed by the 'visual distant' group (i.e., 132 ideas). However, the 'textual distant' condition showed also the highest standard deviation of the seven groups, with a mean of 7,7 ideas created and a standard deviation of 6 ideas. This might be also a reason for the lack of significant differences between the conditions. Nevertheless, the other conditions also had high standard deviations. Further analysis showed a medium-sized effect, $\eta p^2$ = .082, which indicates that the ANOVA test would be significant providing the sample was larger.

Figure 4.7. Fluency of ideas. On the left: bar chart with the mean number of ideas created from the seven conditions. On the right: sum (second column), mean (third column) and standard deviation (fourth column) of ideas produced by each group.




| Fluency | Sum ideas | Mean | SD |
|---|---|---|---|
| Textual unrelated | 113 | 5.65 | 4.37 |
| Textual distant | 154 | 7.70 | 5.99 |
| Textual related | 103 | 5.15 | 2.30 |
| Visual unrelated | 83 | 4.37 | 2.16 |
| Visual distant | 132 | 6.60 | 2.58 |
| Visual related | 114 | 5.70 | 1.66 |
| Control | 97 | 5.39 | 2.57 |

A two-way ANOVA was also computed to assess whether there was an interaction between two independent variables, in this case, representation mode (visual or textual) and semantic distance (related, distant or unrelated). There was no statistical significant interaction between the influence of semantic distance and representation mode in fluency [$F\,(2, 113) = .812$, $p = .446$]. Although there were no statistical significant differences in mean mode representation ($p = .348$), there were statistical significant differences in the influence of semantic distance in the number of ideas ($p = .019$).
Bonferroni post-hoc tests revealed that the mean in fluency is higher when the semantic distance is distant rather than unrelated ($p = .026$). There were no other significant differences between distant and close, and close and unrelated stimuli ($p > .05$).

### 4.6.2 Flexibility of ideas

As aforementioned, two measures of flexibility have been assessed. The first analysis focussed on how the different categories were explored by the groups, according to the categorization scheme in Table 1. An one-way ANOVA showed significant differences across the seven conditions in the use of six sub-categories (Table 4.2):

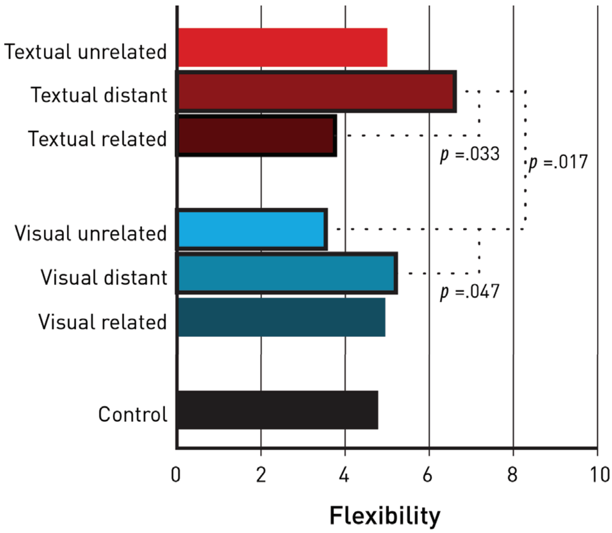
| | | |
|---|---|---|
| **Type of unit** | Single vehicle | $F\,(6,130) = 3.162$, $p = .006$ |
| **Transport mode** | Aerial | $F\,(6,130) = 5.070$, $p = .000$ |
| **Powered** | Wind power | $F\,(6,130) = 3.657$, $p = .002$ |
| | Electrical power | $F\,(6,130) = 2.478$, $p = .027$ |
| | Mechanical power | $F\,(6,130) = 6.963$, $p = .000$ |

Table 4.2. Significant differences on six sub-categories (single vehicle, terrestrial above, aerial, wind power, electrical power and mechanical power) between all conditions.

Post hoc tests with Bonferroni correction revealed that, in the case of *single vehicle* categories, the 'textual related' condition developed significantly more ideas portraying an apparatus (instead of developing an *infrastructure* or *system*) than the 'control' group ($p$ = .017).

Regarding the generation of *aerial transportation* vehicles, the 'textual distant' condition (who received the passage about the cyclone in *The Wonderful Wizard of Oz*) developed significantly more airborne vehicles than the 'control' group (p = .000), the 'textual related' (p = .000) and the 'textual unrelated' (p = .031). The 'textual distant' condition also created significantly more aerial transportation vehicles than the 'visual related' (p = .003) and the 'visual unrelated' conditions (p = .040). Moreover, the 'textual distant' condition generated significantly more *wind-powered* vehicles than the 'control' ($p$ = .021) and both 'related' conditions, textual ($p$ = .002) and visual ($p$ = .043). There were also significant differences in the development of *mechanical-powered* ideas, in which the 'textual distant' group devised much more ideas within this category than any of the other conditions ('control': $p$ = .000; 'textual related': $p$ = .000; 'textual unrelated': $p$ = .045; 'visual related': $p$ = .000; 'visual distant': $p$ = .000; and 'visual unrelated': $p$ = .000). On the other hand, the 'textual related' group produced significantly more ideas portraying *electrically powered* vehicles (similar to the bus in the 'related' stimulus) than the 'textual distant' group, but only marginally ($p$ = .062).

Figure 4.8. Overall assessment of flexibility of ideas. On the left: bar chart with the mean number of flexible ideas from the seven conditions. On the right: mean (second column), and standard deviation (third column) of the flexible ideas produced by each group.




| Flexibility | Mean | SD |
|---|---|---|
| Textual unrelated | 5.00 | 3.49 |
| Textual distant | 6.60 | 4.55 |
| Textual related | 3.75 | 2.27 |
| Visual unrelated | 3.53 | 1.07 |
| Visual distant | 5.20 | 2.16 |
| Visual related | 4.95 | 1.61 |
| Control | 4.78 | 2.34 |

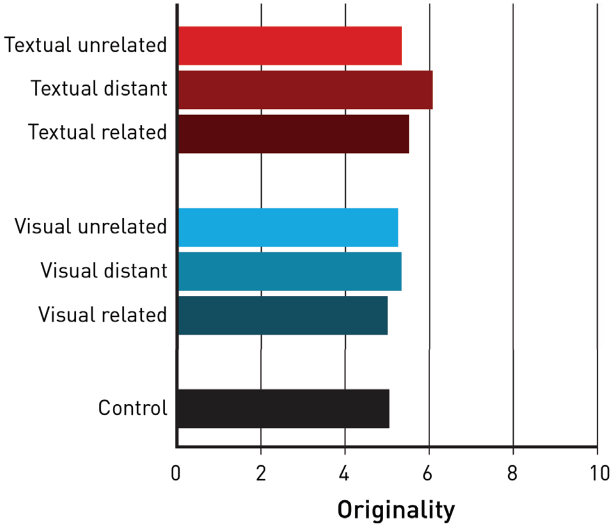
A second analysis was performed to assess an overall score of flexibility, which revealed a significant difference between conditions ($F$ (6,130) = 2.727, $p$ =

.016), with a very large effect size ($\eta p^2$ = .117). Post hoc tests with Bonferroni correction indicated that both 'distant' conditions created the most flexible ideas (see Figure 4.8). The 'textual distant' condition was significantly more flexible than the 'textual related' (p = .033) and the 'visual unrelated' ($p$ = .047). Similarly, the 'visual distant' condition generated significantly more flexible ideas than the 'visual unrelated' group ($p$ = .047).

To determine whether there was an interaction effect between representation mode (visual or textual) and semantic distance (related, distant or unrelated), a two-way ANOVA was used. In this case, there was a marginally statistical significant interaction between the influence of semantic distance and representation mode in flexibility [$F$ (2, 113) = 2.979, $p$ = .055]. This marginally significant interaction effect confirms the findings from the one-way ANOVA. The highest flexibility of ideas can potentially be achieved when stimuli is presented in a distant form (not too close, not too unrelated). This occurs both for visuals (visual related: M = 4.95; visual distant: M = 5.20; visual unrelated: M = 3.53) and textual representations (textual related: M = 3.75; textual distant: M = 6.60; textual unrelated: M = 5.00).

### 4.6.3 Originality of ideas

The analysis of the scores on 'originality' reveals that the 'textual distant' group (M = 6.07) had the best performance in the generation of unusual ideas (see Figure 4.9). However, the high standard deviations, observed in all conditions, and a thorough analysis of the sketches generated, suggest that even the participants with better original scores could not maintain a consistent level of originality across their entire process. In fact, similar to the other groups, participants in the 'textual distant' group produced recurrent ideas, yet they were also able to generate more unusual ideas. Regarding originality, the statistical analyses did not reveal significant results for the between-groups analysis ($F$ [6,130] = 1.102, $p$ = .365), with only a small to medium-sized effect ($\eta p^2$ = .048, which indicates that it might be worthwhile to increase the number of participants and thus enlarge the probability to arrive at significant results).




| Originality | Mean | SD |
|---|---|---|
| Textual unrelated | 5.34 | 1.52 |
| Textual distant | 6.07 | 1.25 |
| Textual related | 5.51 | 1.89 |
| Visual unrelated | 5.25 | 1.75 |
| Visual distant | 5.33 | 1.14 |
| Visual related | 5.00 | 1.17 |
| Control | 5.05 | 1.36 |

Figure 4.9. Originality of ideas. On the left: bar chart with the mean number of original ideas from the seven conditions. On the right: mean (second column) and standard deviation (third column) of original ideas produced by each group.

A two-way ANOVA revealed that there was no statistical significant interaction between representation mode (visual or textual) and semantic distance (related, distant or unrelated), in terms of originality [$F$ (2, 113) = .464, $p$ = .630]. Simple main effects analysis showed no statistical significant difference in terms of representation mode ($p$ = .117) and in semantic distance ($p$ = .363).

## 4.7 Discussion

This study aimed at finding out in how far different types of textual and visual stimuli, entailing varying levels of semantic content, would influence the generation of ideas in terms of fluency, flexibility and originality across seven different experimental conditions.

### 4.7.1. 'Control' condition

The 'control' group was the only one relying solely on the ability to retrieve inspiration sources from their memory. This could have been a challenge, considering that novice designers' stock of available sources (committed to their memories) might still be limited at this stage of their careers (Goldschmidt & Sever, 2010). However, in all the three creativity variables (fluency, flexibility and originality) the 'control' group performed as well as, or even slightly better than, the visual and textual ‘related’ and ‘unrelated’ conditions (but not significantly). This result seems to hint that the novice designers from this study were able to explore many and different ideas, even if they did not receive any incentive in the form of external stimulus. Although the results of the groups with related and unrelated stimuli were not significantly different from the ‘control’ group, these results might suggest that being exposed to stimuli during idea generation is not always a guarantee for producing more creative solutions.

### 4.7.2. ‘Textual Related’ and ‘Visual Related’ conditions

In regards to the fluency of ideas, the visual ‘related’ group created the lowest amount of ideas, when compared to the other conditions (but not significantly). The participants in the ‘visual related’ group might have been constrained by the influence of such a specific and closely-related stimulus, some of them soon running out of diverse (and, ultimately, producing fewer) ideas.

On the other hand, the textual counterpart of the ‘related’ group created one of the lowest overall scores of flexibility, being significantly lower than the ‘textual distant’ condition. Furthermore, the stimuli given to the different experimental groups seem to have promoted the exploration of specific sub-categories over others. Besides creating less flexible ideas than the ‘distant’ condition, the participants from the ‘related’ condition generated ideas that incorporated elements from the ‘related’ stimulus. The ‘textual related’ group reproduced significantly more ideas than the ‘textual distant’ condition portraying electrically powered vehicles that travelled on or above the road. Although design fixation was not assessed in this study, the participants in the ‘textual related’ condition seemed to have been constrained to mainly create ideas that shared similarities with the given stimulus. Conversely, the ‘textual related’ group created significantly fewer ideas than the ‘textual distant’ group that explored other modes of transportation or power sources, such as aerial and wind-powered vehicles. There were no statistical differences between the visual counterparts of the ‘related’ and ‘distant’ conditions, even though the ‘visual related’ stimulus depicted the same electrically powered ‘Straddling Bus’ as in the ‘textual related’ passage. Whilst in the ‘related’ text there was clearly an indication that the ‘Straddling Bus’ was powered by electricity, in its pictorial representation this was

only indicated by the presence of rail tracks (see Section 4.4).
Referring to originality, the 'related' conditions were very similar to the other groups and there were no statistical differences.
A pattern is observable from Figures 4.7, 4.8 and 4.9, in all the assessed measures of creativity (fluency, flexibility and originality). If textual and visual conditions are seen in isolation, and considering that the types of textual and visual stimuli used here as sitting somewhere along a spectrum, related and unrelated stimuli sit at opposite ends. Related stimuli belong to within-domain examples that seemed to have hindered the participants to expand their solutions space. Unrelated stimuli seemed to have left participants confounded about how to make use of this material. However, in-between, distant stimulus seemed to have encouraged the participants to keep enough semantic distance from the more obvious solutions, yet enabling sufficient cues to relate with the problem at hand.
In the analysis of the post-questionnaires, the participants from both 'related' conditions, who received a written description of the 'Straddling Bus' transportation concept, reported having no previous knowledge of it. This can suggest that whatever influence this stimulus might have had in the participants of the 'related' condition, it was not prompted by the retrieval of a previously seen picture of the 'Straddling Bus', but by the textual and visual stimuli.

#### 4.7.3. 'Textual Distant' and 'Visual Distant' conditions

Regarding fluency, whilst there was no statistical difference between the seven conditions, the 'textual distant' group was the one generating numerically more ideas. As this stimulus described a situation that was (distantly) different from the problem description (excerpt from *The Wonderful Wizard of Oz*), some of the participants in this condition might have been influenced to generate a multitude of different concepts (this is also supported by the results on flexibility, Figure 4.8). Between obvious types of solutions and more distant ones, there could have been a motivation to expand the solution space. This interpretation can be extended to include the 'visual distant' condition, which also outperformed (not significantly) the 'visual related' and 'unrelated' groups.
Concerning flexibility, it is plausible to state that the 'distant' text had a considerable influence on the participants under that condition. The 'textual

distant' group created a significant higher number of ideas in the categories of *aerial transportation* and the use of *wind-power*, when compared with the other conditions (excluding its pictorial counterpart, 'visual distant' condition). This can be explained by exposure to the textual description of a cyclone, entailed by the distant stimulus. The image of the cyclone (Figure 4.3) did not seem to convey so strongly the idea of aerial transportation as its textual counterpart. Another reason that may have augmented the prevalence of applying airborne or wind-related solutions is the occurrence of a behaviour called *recency-effect*, in which the last perceived elements/words of a text will be easier to recall or considered more important. This is illustrated by the verb *carry* at the end of the 'distant' excerpt - "(…) and there it remained and was *carried* miles away as easily as you could *carry* a feather (…)". Interestingly, the 'textual distant' group explored more *mechanical-powered* means of transportation than any other groups. This category is almost exclusively related to the use of catapults, where people are projected through the air into a different location. No other condition generated such ideas, which could indicate that this group did not feel constrained to solely stick to 'realistic' solution ideas. Therefore, the 'distant' stimuli (visual and textual) tended to prompt more flexible ideas than the other stimuli. The textual and visual 'distant' groups developed more ideas spread across different sets of categories and explored more ideas within particular categories, especially when compared to those in the 'textual related' and 'visual unrelated' conditions, who had the lowest levels of flexibility.

In regards to originality, there were no significant differences between the groups. Numerically, the 'textual distant' group devised a higher number of original ideas when compared to the other conditions, which may suggest that exposure to the semantic associations evoked by the 'distant' text excerpt could have supported the generation of more unusual ideas, with higher originality. These results seem to be in agreement with the findings of Goldschmidt and Sever (2010), who demonstrated the benefit of using text as a possible source of inspiration. It is important to note that, in this study, an original idea was considered to be a singular and atypical response, within the pool of all ideas generated. As mentioned before, feasibility, or practicality, of the ideas were not assessed.

Overall, the results seem to indicate that there is an 'optimal' range of semantic distance between very close and very distant stimuli that makes a stimulus an appropriate trigger for the generation of original ideas.

#### 4.7.4. 'Textual Unrelated' and 'Visual Unrelated' conditions

The 'unrelated' conditions (especially the 'visual unrelated') consistently obtained some of the lowest scores, regarding fluency, flexibility and originality of ideas, when compared to the other groups. The participants in the 'unrelated' conditions might have spent more time and effort trying to import cues from a stimulus that was too far to be relevant for the problem at hand. Thus, this could have slowed down their generation of ideas. Moreover, only 40% of the participants from the textual and visual 'unrelated' conditions reported, in the post-questionnaire, that their ideas were influenced by the 'mirage' description. Displaying no apparent relationships with the problem at hand, many of these participants might have decided to ignore the stimulus, instead of trying to find inspiration in the mirage description.

In regards to the pattern that seems to emerge from the results on fluency, flexibility and originality of ideas, the 'unrelated' conditions occupy the furthest extreme of this textual semantic continuum (though the continuum could actually extent beyond the limits suggested here). As mentioned before, when we move from the close related example to a more distant one, fluency, flexibility and originality of ideas increased. However, when the distance of the stimulus reaches a level that is beyond a between-domain example (in reference to the problem at hand), fluency, flexibility and originality of ideas seem to decrease. The 'unrelated' stimuli may have been too vague or irrelevant for the participants to make use of it, not yielding enough links to establish possible associations between stimulus and problem. These results seem to indicate that an appropriate inspiration stimulus should not be too semantically close to the area of the problem, nor too far, so that there are no evident links to build connections between target problem and inspiration source.

## 4.8. Conclusions

This study investigated the influence of textual stimuli, with different levels of semantic distance, as potential inspiration sources during idea generation in design. Although research has given some preliminary indications that textual stimuli seem to be potentially useful for creative idea generation (Goldschmidt & Sever, 2010), there was no previous research on how would stimuli with different levels of semantic distance influence idea generation. Therefore, our most relevant finding from this investigation, albeit at times not reaching statistical significance, is the curvilinear pattern observed in the fluency, flexibility and originality results, which shows that the usefulness of inspiration stimuli can vary in a *curvilinear fashion*, a tendency also observed by Fu, Chan, Cagan, Kotovsky, Schunn and Wood (2012) and proposed by Gick and Holyoak (1980). This pattern varies according to the use of 'related', through to 'distant' and finally 'unrelated' textual and visual stimuli, with 'related' and 'unrelated' being less useful for generating creative ideas (Figure 4.10). Figure 4.10 shows an idealised representation of assumptions from our results, which illustrates a general potential relationship between the semantic distance level of textual and visual stimuli and certain aspects of creative outcome. This idealised model was represented as a normal distribution but it could assume other shapes. Participants exposed to the 'related' stimuli conditions appeared to stick more frequently to the repetition of certain within-domain types of ideas, impeding further exploration of their solution space. Participants exposed to the 'unrelated' stimuli conditions, however, seemed to struggle to make sense of a too distant and thus seemingly irrelevant stimulus, that did not yield any opportunity to establish possible associations with the context of the design problem. Consequently, somewhere along that *continuum* lies a sensitive area comprising an inspiration peak. This peak, materialised in our study as 'distant' stimuli, seemed to enable participants to maintain enough semantic distance from the more obvious solutions, yet establish sufficient cues to relate with the problem at hand. However, such inspiration peak is more likely to be part of a larger area, where a number of suitable stimuli could be located, rather than being a discrete point along the continuum. If there is indeed such an ideal distant-related part of the continuum, the main challenge lies in being able to quantify the distance from other types of stimuli, and the problem statement. Efforts to quantify such distances would lead to an attempt to identify the *thresholds* that would enable a designer to recognise the level of suitability of a stimulus, between too close and too distant from the problem. Ultimately, it will probably be complex to realise that one has gone into an unrelated, and hence less useful, part of the continuum.

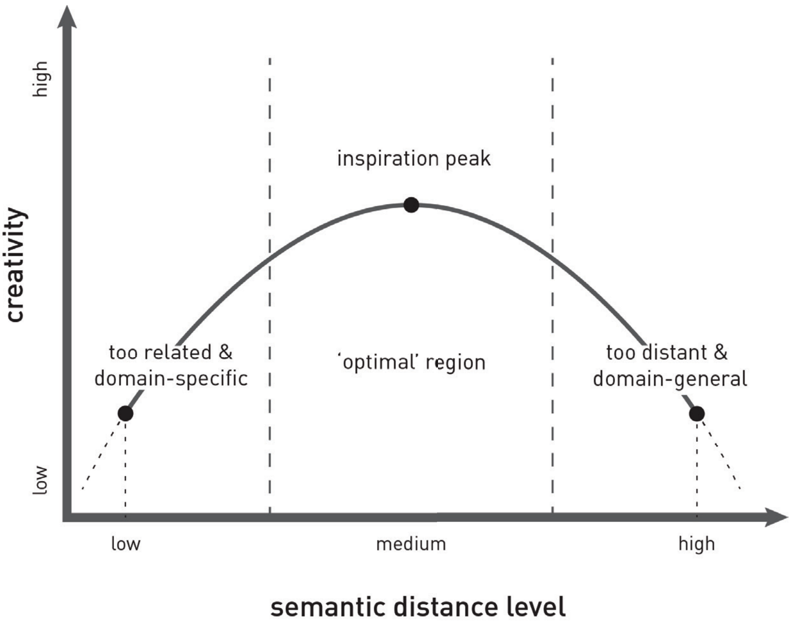



Figure 4.10. Diagram illustrating an idealised network of assumptions, indicating a potential inspiration peak between related and distant stimuli, where there is an 'optimal' area for inspiration.

In spite of these challenges, and congruent with theory and empirical findings on the use of between-domain analogies, distantly-related textual and visual stimuli could be beneficial to enhance creative idea generation in design. In fact, this study indicates that, unlike the challenges in sometimes making use of between-domain visual/pictorial analogues, retrieving useful and inspirational elements/aspects from textual stimulus might not be that difficult. Visual analogues that belong to distant (yet somehow still related) domains are reported to be more difficult to access than close analogues (Christensen & Schunn, 2007). However, our study indicates that textual distant-related stimuli has been used in a beneficial way, prompting the designers in our study to generate more ideas that presented higher levels of flexibility, across categories (and, to some extent, originality). Although there were not many direct differences between visual and textual stimuli across conditions, our results support that textual stimuli, especially distantly-related, can be as inspirational as their visual counterparts.

It seems, therefore, appropriate to encourage novice designers to explore several possible stimuli available, rather than constraining themselves to the sole use of pictorial sources.

In regards to the role of semantic distance in textual and visual stimuli, it is argued that inspiration can be provided both by domain-specific and domain-general stimuli. As Plucker and Beghetto (2004) pointed out, creativity is potentially both context-dependent and context-independent, with its combination being the most appropriate for the development of creative ideas. Searching for similar solutions to a design brief offers an overview of what has been done and what remains unexplored, and may be the first step to generate diverse ideas. However, a broader perspective of the problem and an appropriate choice of information brought from another domain can also support creativity. Naturally, a too strong focus on domain-specific knowledge could lead designers into design fixation behaviour. Conversely, a too distant and domain-general information can impede designers from fully answering the problem at hand (Plucker & Beghetto, 2004).

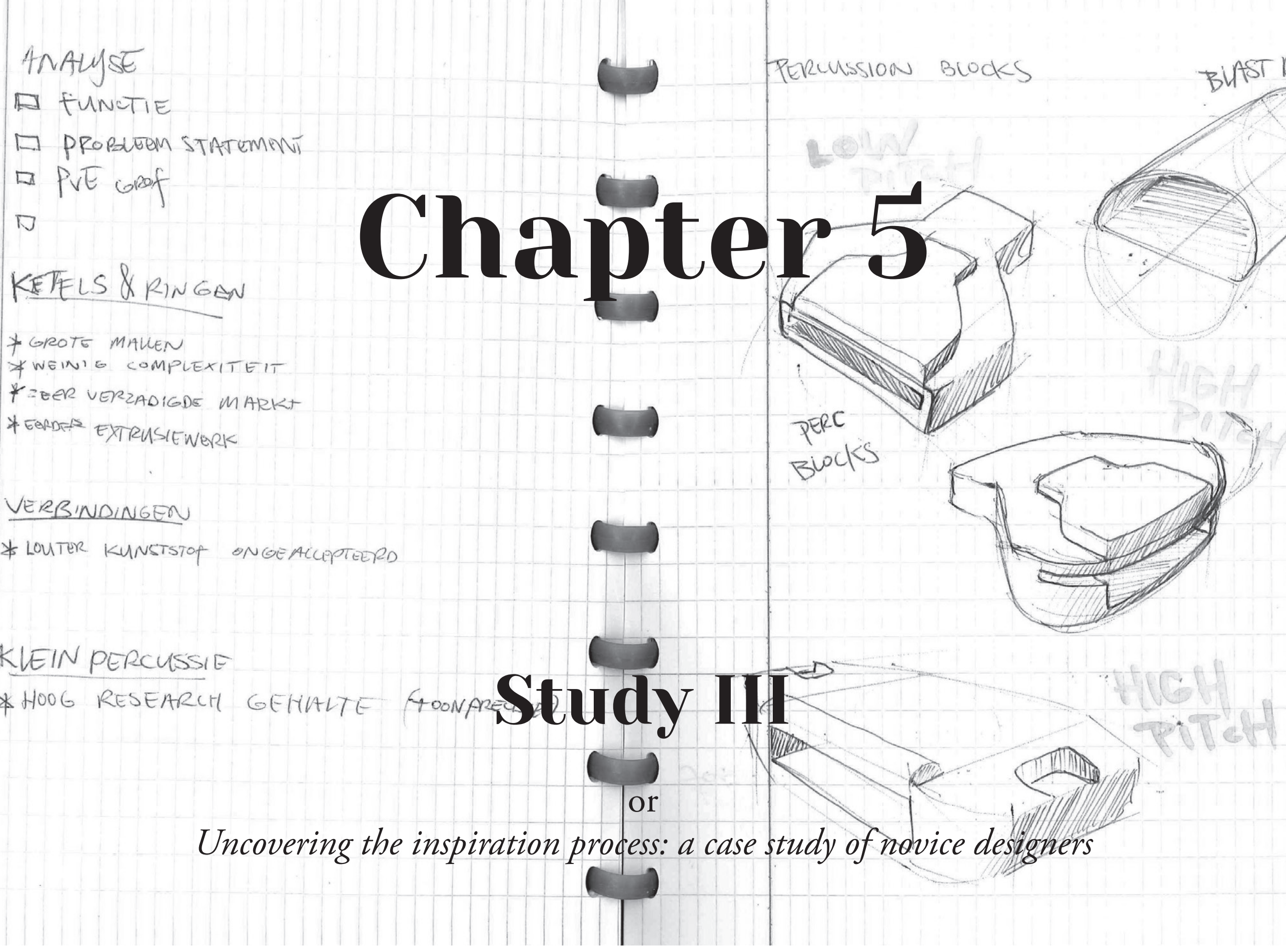
In summary, this study suggests that as the content of textual (and, to some extent, also visual) stimuli become more distant, more diverse and potentially more original ideas can be produced. However, as we increased the semantic distance level, such type of stimuli can also become too unrelated to enable the participants to establish any link between stimuli and problem presented. Consequently, an unrelated example, with no links to the problem at hand, might not be inspirational. The issue is whether designers could be guided while searching for inspiration sources that fall within the boundaries of the favourable peak of use of certain stimuli.

A number of limitations need to be considered. In this study, three kinds of textual stimuli and three of visual stimuli, with different semantic distances were compared. However, it is acknowledged that there are many other kinds of textual and visual stimuli or levels of semantic distance that could have been added to this study. For instance, the stimuli investigated here represented only three levels of semantic distance along a possible (part of a) *continuum*.

Further research will continue to investigate the role of inspiration sources in design ideation, with special interest on its process. This is explored in the following chapters 5 and 6, where the inspiration process is investigated, in order to understand what are the steps designers go through while using inspiration and what motivates their selection of stimuli. Together, these empirical chapters aim to support designers to appropriately select and use available inspiration stimuli at different moments of the design process.

Chapter 5 figure: Notebook page generated by participant from Study III.

This chapter is an adaptation of Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2013). Through the looking glass of inspiration: Case studies on inspirational search processes of novice designers. In *IASDR2013, the 5th World Conference on Design Research*, Tokyo, Japan.




# Chapter 5

## Study III

or

*Uncovering the inspiration process: a case study of novice designers*

*In the previous chapter, the influence of external stimuli during a design problem was investigated. Now, we turn our attention to how designers are influenced by stimuli, by focusing on the inspiration process. When engaging in new and ill-defined problems, designers are challenged with many ambiguous moments, such as finding how to start, for instance. However, much is not yet known regarding the individual steps designers experience when using stimuli during a design process. This chapter presents the results of the analysis of case studies on the design process of eight novice designers, by addressing their inspirational approaches in particular. Whilst all novice designers chose to tackle the design brief in different ways, similarities were found regarding the patterns of search of inspiration. These case studies reveal that while searching for inspiration is mostly an unconscious process, designers would benefit from making it a conscious and reflective approach. Thus, the chapter promotes a change in the perception of the inspiration processes, which can have important implications for design education.*

## 5.1. Rationale

Inspiration sources were defined in Chapter 2 (Section 2.2) as internal and/or external stimuli with a direct and/or indirect impact on idea generation. However, individuals tend to have a more intuitive and ambiguous definition of inspiration and, in general, asking people what inspires them will most likely lead to vague answers such as "anything can be inspiring" or "I get inspiration all the time, everywhere". Despite their ambiguous nature, the value and ubiquity of inspiration sources are often acknowledged in research and in design practice (e.g., Yang, Wood and Cutkosky, 2005; Eckert and Stacey, 2003; Goldschmidt and Sever, 2010). Seeking support in inspiration sources becomes particularly important when designers start a new design problem, where the problem and its requirements are still unclear and need further definition (e.g., Dorst and Cross, 2001; Goldschmidt, 1997; Heisig et al., 2010). Novice designers are especially affected by such ambiguity, as their attention focus tends to be unstructured, struggling to perceive what is relevant (Kavakli and Gero, 2002). Therefore the identification, selection and transformation of inspiration sources during a design problem can have a profound impact on the generation of innovative solutions. Nevertheless, finding and using inspiration sources can be a wandering and muddled process, where it is unpredictable whether the use of a stimulus source will benefit or hamper the generation of creative design. In chapter 3, the results of Study I investigated the type of inspiration sources designers report to use. In chapter 4, Study II explored how specific categories of stimuli influence designers' creative outcome. As some of the results from Studies I and II seem to point, and as indicated by other researchers (chapter 2), designers might be hindering their creative process due to their unreflective choices of what can be considered appropriate stimuli for each situation. However, little is still known about the inspiration processes of designers. This study aims at understanding the inspiration processes novice designers (i.e., student designers) undergo while involved in a design problem.

## 5.2. Research question

The research question that guides this study is the following: *Which **processes** do designers employ while searching and using external stimuli for a design problem?*

This chapter presents an analysis of the case studies on the inspiration processes of eight novice designers. There are two goals: firstly, to investigate how can these processes be described; and secondly, to understand if such processes can be supported. Inspiration is commonly considered a result of serendipity, which can hardly be controlled nor predicted. In this way, by finding how to support designers' inspiration process, it would be possible to improve the likelihood of designers successfully finding and using inspiration sources to generate creative solutions.
Considering the qualitative nature of this study, there were no specific expectations. Instead, the intention was to explore and capture the apparently serendipitous and spontaneous process of inspiration, by analysing which procedures designers employ, with which level of structure and organisation and how much reflection is involved in such process. Thus, this study is relevant for design practice and education as it explores the possibility of designers engaging in a deliberate and reflective process of finding and using the most advantageous stimuli. Previous studies on the influence of stimuli in design have mainly explored their influence on outcome. This study brings into focus the process. By identifying the procedures designers go through to find and use possible inspiration sources in their design solutions, it can be possible to recognise which elements of the inspiration process could be better supported to promote creativity.

## 5.3. Research study

This study uses a case study approach to capture the design process, focusing on inspiration processes. The design process of eight individual novice designers was analysed by collecting a number of units of analysis: designers' daily work notebooks; individual assessment of their design skills and creativity; intermediate and final reports; and, individual interviews. Thus, not only it was possible to cover a retrospective analysis of their design process via the interviews, but also to include a more complete perspective, with the daily notebooks and reports. Analysing the design process of these designers from different angles should enable a more accurate representation of the inspiration processes and development of creative ideas they go through. The case study took place in parallel with the course Bachelor Final Project (undergraduates from their 3rd final year). The design instructors engaged in the evaluation of these novice designers were not involved in the study. Likewise, the instructors were unaware of the specific goals of the study. Interference of the original course settings was kept to a minimum: notebooks were collected in three moments of the project (after presentations), scanned and quickly returned back to the students within a day; the intermediate and final reports were simply collected digitally; and the interviews took place outside of the design studio, in the participants' own time.

## 5.4. Data collection

During a period of ten weeks, the final project of eight 3rd year bachelor design students, from an Industrial Design Engineering course, was followed. Their information was anonymised using an appropriate coding scheme and henceforward, they are identified by the following letters: A, D, F, M, N, P, R and T. All of the participants were Dutch, with an average age of 22 years (M= 22.125; SD = 1.356), where seven of them were male and one was female.
The students worked on a project for the last design course of their bachelor degree ('BSc End Project' course), where they had to develop a full design project from task clarification until detail design (according to the design model of Pahl and Beitz, 1984). Consequently, they had to create a design challenge, explore business and design opportunities, generate ideas in order to arrive to a final concept. Finally, they had to conclude the project with a detailed design and a business proposal. The 'BSc End Project' course is carried out within the context of an existing company, and in the case of these eight students, the company was Promolding BV, located in The Netherlands. The company is specialized in the development and manufacturing of polymer solutions. The students received an open-ended design brief: "Create a product which can be produced by injection molding and can potentially open other markets for Promolding."

As represented in Figure 5.1, the students had three main moments of evaluation and deliverables: at the end of the strategy and analysis phase (3 weeks - task clarification, according to Pahl and Beitz, 1984); at the end of the concept design phase (7 weeks - conceptual design); and at the end of the embodiment design and implementation phase (10 weeks – detail design). At these three moments, the students presented their current project to coaches and company representatives.

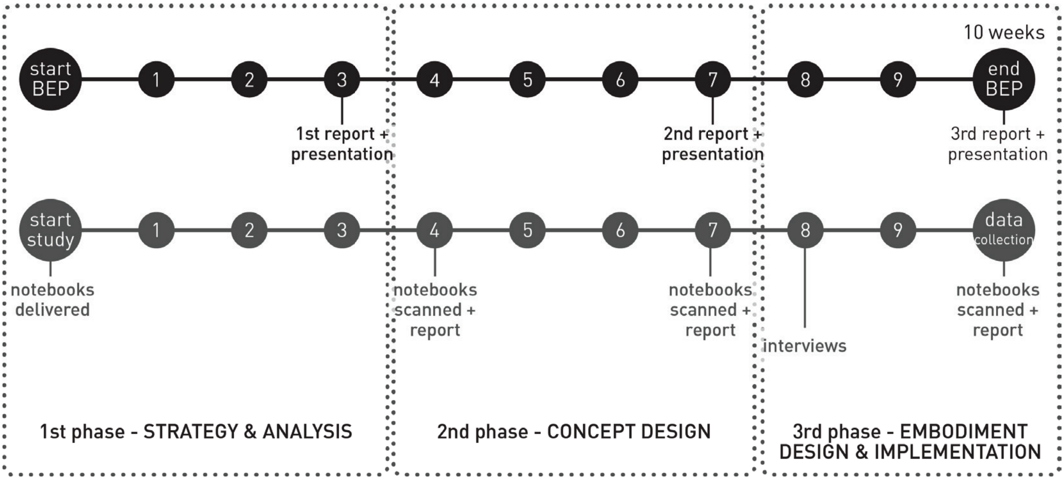



Figure 5.1. Overlap between BEP (BSc End Project) course (in black) and research study (in grey).

During the development of this project, students usually shared a studio, but worked individually in their own interpretation of the design problem. A design instructor and a research coach supported the students during this process, and multiple meetings with the company representatives, either in the studio or in the company facilities, took place throughout.

Several items were collected for the purpose of this study: daily work notebooks; reports; and interviews.

### 5.4.1 Daily work notebooks

At the beginning of the course and the research study, the students received A5 notebooks to use during the ten weeks of the project. Although it was recommended to use the notebooks supplied in the beginning of the project (for the purpose of the study), this was not imposed. A small number of students decided to use another type of notebook due to personal preferences and one

student only used loose A4 pages.
To keep a design notebook (also known as diary, design journal or even a 'dummy') is a usual part of designers' routines (Sobek, 2002; Oehlberg, Lau and Agogino, 2009). According to McAlpine et al. (2006), design notebooks (or 'logbooks') are defined as "typically paper-based notebooks used by individuals to record personal, informal notes and information relating to a particular task or activity" (p. 482). Thus, designers' notebooks can provide a source of informal information, which can be captured as it is created, with little editing and informal structure (Yang, Wood, and Cutkosky, 2005). Notebooks can contain every kind of information, partial or finalized, from doodles to finished ideas, and also 'to do' lists and early requirements (McAlpine et al., 2006). They also can operate as recipients of the designer's external memory: a working medium for the designer to keep track of the idea generation process (Van Der Lugt, 2005). Moreover, it has been suggested that design notebooks can provide a platform for reflection, as they might enable designers to visualize how their design process evolved and to develop their design discourse (Oehlberg, Lau and Agogino, 2009). The language used in notebooks displays a quest for the right terms, determining the directions the design adopts. Thus, the analysis of notebooks can provide an authentic and unprocessed perspective of the design process, which can be lost while formalizing the information into final presentation reports. Likewise, the type of sketches included in design notebooks could be defined as mainly *explorative*, and on occasions could also contain *explanative* and *persuasive* sketches (when considering Olofsson and Sjolen (2005)' taxonomy). Evans and Pei (2010) and Pei, Campbell and Evans (2011) further differentiated sketches into eight classifications:
• *Idea sketch* (quick and dirty externalization of thoughts);
• *Study sketch* (used to explore the look and feel of an idea);
• *Referential sketch* (to be used as a reminder of possible metaphors or analogies);
• *Memory sketch* (normally in the form of mindmaps), Coded sketch (abstract visualisation of principles);
• *Information sketch* (used to communicate concepts and referred also as explanatory [Olofsson and Sjolen, 2005]);
• *Sketch rendering* (refined and realistic visualizations of the final concept, also

known as persuasive sketches by Olofsson and Sjolen, 2005);

• *Prescriptive sketch* (visualisation of mechanisms and other technical considerations).

Notebooks rarely include *Information/Explanatory sketches* and *Rendering/Persuasive sketches*, as notebooks are normally personal and not meant to communicate concepts. These type of sketches require much more effort and detail than *exploratory sketches*, and are only produced for the purpose of presentations or reports. Therefore, daily work notebooks tend to present preliminary and incomplete results, which can only be entirely observed in final reports.

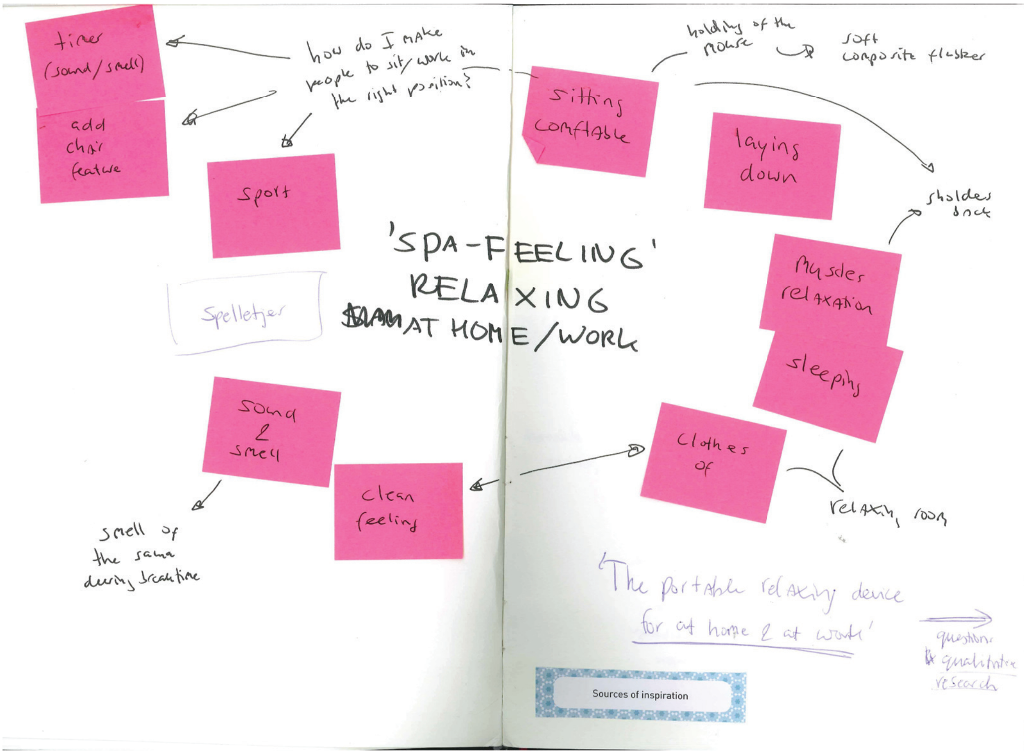



Figure 5.2. Example of the type of information present in a notebook, from participant M: mindmaps, post-its and incomplete information.

In the context of this study, the participants also received multiple stickers with two labels: 'Sources of Inspiration' and 'Ideas', along with instructions on how to use these stickers. The students were asked to:

• Differentiate the notebook pages with either one of the stickers, by signalling

each page meant for the generation of an idea;
• Using the immediate following page to describe the inspiration source, which might have been the starting point of the idea. They also received different coloured stickers to mark the progression of ideas (to distinguish between discarded concepts and concepts to follow up).
The students could either use the stickers while creating ideas or retrospectively, before the interview took place. Figure 5.2 shows an example of a report from participant M.

### 5.4.2 Reports

The intermediate and final reports are considered formal design information, characterized by being structured and presenting complete ideas, such as conclusions on a project, final concepts and computer drawings (Yang, Wood, and Cutkosky, 2005). Final reports tend to include *Information/Explanatory sketches* and *Rendering/Persuasive sketches*, as the goal is to clearly communicate the final concept at its best and to convince clients/coaches of the concept's quality (Olofsson and Sjolen, 2005; Pei, Campbell and Evans, 2011). Depending on the phase of the design process, reports can also include quick representations of explorative sketches, to illustrate the evolution of a concept (although that is not usually a requirement imposed by the coaches). Furthermore, reports usually include other forms of design information, which Pei, Campbell and Evans (2011) refer as *drawings*: unambiguous representations of the concept's intent. These can include *scenario, storyboards, technical drawings or presentation renderings,* for instance. In terms of language, a report usually presents the final form of the design discourse, which is much more structured than the language in design notebooks (Yang, Wood, and Cutkosky, 2005).
The participants did not receive instructions for the production of the reports (besides the ones specified by the coaches of the course). After each delivery and presentation of the project, copies of all three reports were collected to add to the analysis (Figure 5.1). Figure 5.3 contains one such example pages of a report, from participant A. The analysis of both informal (notebooks) and formal (intermediate and final reports) design information can offer a more complete perspective of the participants' processes.

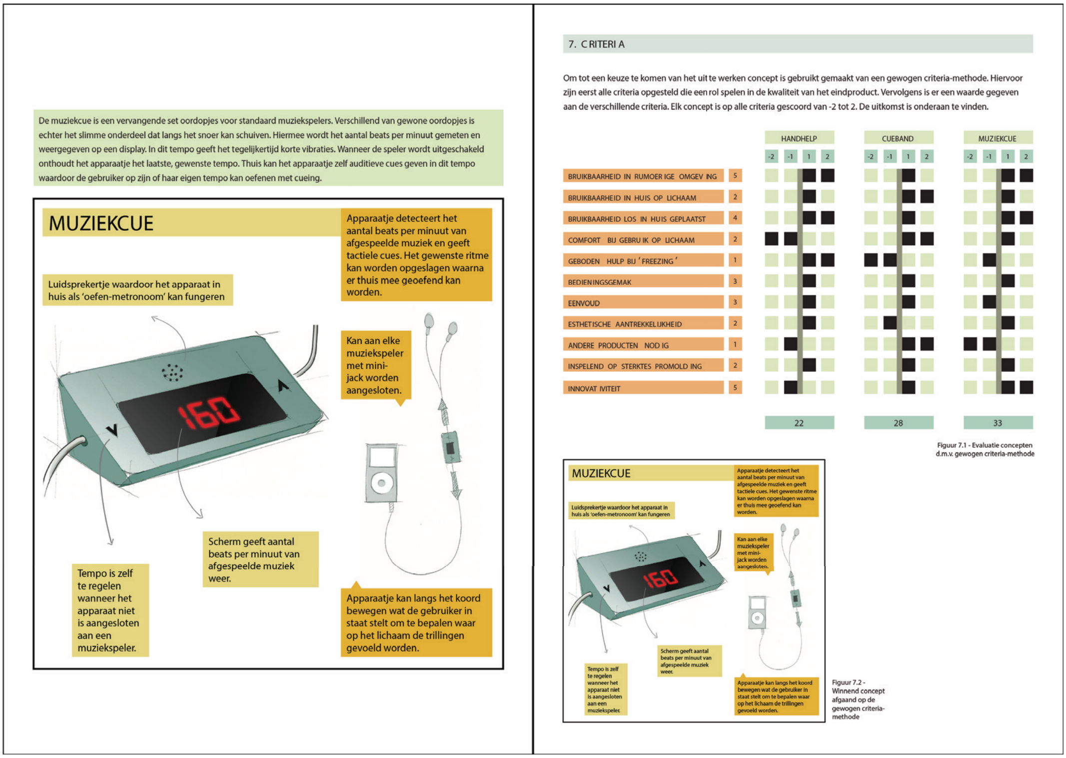



Figure 5.3. Example of the type of information present in a report, from participant A: final concept drawn in the style of Information/ Explanatory sketches and Rendering/ Persuasive sketches and structured information.

### 5.4.3 Interviews

The eight semi-structured interviews were carried out during the embodiment and detail design phase, as that was considered an important moment to encourage the novice designers to reflect on their process. At this stage of the course (7/8 weeks), the students had just finalised a period of extensive idea generation and selected a final concept to continue further elaboration. Idea generation (or the conceptual design phase, according the nomenclature of Pahl and Beitz, 1984) can be assumed as the stage of the design process where external stimuli can have a stronger impact (Perttula and Liikkanen, 2006). Therefore, it was considered to be an adequate moment to interview the participants about their use of inspiration sources. Each interview was audio recorded, individually, and took one hour on average. The interview script was organized into four sections: *background information*, where they were questioned about their educational experience and perception on their design skills; *overview of the project*, where they were inquired about their design process and about methods they might have used; *analysis on inspiration sources*, where they were asked on their use of inspiration sources throughout the project, by asking where, when, who and what do they search for when looking for inspiration; and *reflection on the experiment*, where the aim was to promote a reflective moment on the use of inspiration sources. The interview questions can be found in Appendix D. The students were also encouraged to share their experience in other projects to complement the analysis of their design process. In order to complement the interviews and to access specific information, the participants' notebooks and intermediate reports were used as visual elicitation material during the interviews (Crilly, Blackwell and Clarkson, 2006).

During the interviews, the students were also requested to evaluate their skills in several domains of design activity. Furthermore, they were asked to fill in an online creativity test, based on divergent thinking. These two additional evaluative elements, based on the students' perception, were aimed at complementing the analysis of their notebooks, reports and interview's answers, as they can be used as tools to evaluate creativity in the context of design education (Casakin and Kreitler, 2006).

## 5.5. Data analysis

The data retrieved from the participants was analysed and combined to extract meaningful themes for discussion. All eight interviews were audio recorded, fully transcribed and manually coded into emergent categories. This process resulted into 56 codes, grouped into 16 categories and three main themes: Inspiration process; Design process; and Reflection. The focus of this chapter is mainly on the first theme, but several of the other categories (from the other themes) are included in order to have a more detailed analysis of the participants' inspiration process. The coding scheme used to code the participants' interview replies can be found in Appendix E. The notebooks and reports were analysed together, to observe how ideas progressed from students' initial collection of information and research and how they evolved into final concepts. The creativity or quality of the ideas created during the project were not analysed for the purpose of this study, as the goal was to focus on the process. Nevertheless, the design coach evaluated the students' overall work and the grades are included in the analysis. By combining the three sources of information, it was possible to create visual models of their design process, as well as their inspiration process. The Systematic Design Model developed by Pahl and Beitz (1984) was used as the foundation for the development of the students' design and inspiration processes.

## 5.6. Results

The following sections present the results from the interviews and their results were complemented with the analysis of the daily notebooks and reports.

### 5.6.1 Variety of inspiration sources

The variety of inspiration sources that the participants indicated reveals their widespread use in these design projects (Figure 5.4).
As it was expected, when inquired about inspiration, some participants replied vaguely, such as *"everything"* and *"all day life"* as being inspirational and that they searched for it *"all the time"*. As participant N referred:

> *"I think always. I'm always up to [search for inspiration]. And… Maybe this is stupid but anywhere, you can use everything as inspiration".*

Once inquired in detail about their use of inspiration, all participants reported searching for it during several moments of the design process (Figure 5.4 c.) According to six of the eight participants, inspiration sources are mainly obtained in the early phases of the design process. Curiously, none of the eight participants indicated the idea generation phase as their usual moment to search for inspiration. In fact, one of the participants explicitly stated that he does not search for inspiration during idea generation, which is precisely the phase creativity research normally focus on, especially in the field of inspiration sources. In the course 'Bachelor Final Project', students are encouraged to employ research techniques in order to strengthen their design process. Thus, the participants used a certain number of data collection and analysis methods throughout their project, supported by a research coach. As a learning experience, they conducted interviews with a small number of stakeholders. They also conducted surveys and collected information from scientific articles and informal material sources. Some of the participants indicated they do not consider the search for similar solutions or information on the problem as inspiration. Instead, they refer to it as researching the problem in order to define it. However, many of the participants' ideas were created in the early phases of their process, while searching for information about their chosen topic. Therefore, the information the participants searched for in the task clarification phase ultimately had an impact on the generation of their ideas, thus, it became inspirational. The participants used the terms *searching for information* and *searching for inspiration* interchangeably and it was difficult to clearly distinguish between both activities.

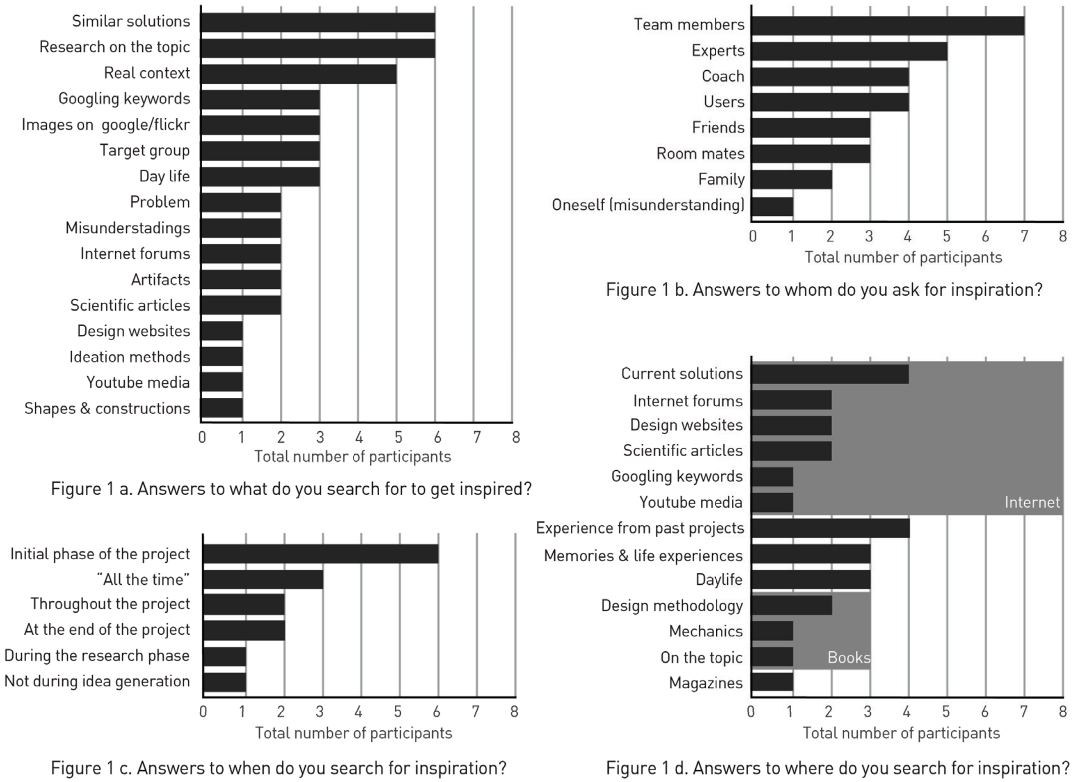



Figure 5.4. Answers to "What (5.4 a.) / Whom (5.4 b.) / When (5.4 c.) / Where (5.4 d.) do you search for inspiration?"

### 5.6.2 Seeking or waiting for inspiration

As previously indicated (Section 5.6.1), participants reported the initial stage of the design process – the task clarification phase – as the moment where they searched actively for inspiration sources. Nevertheless, the passive encounter with stimuli, which might have had an impact during the conceptual and embodiment design phases, still happened, as it was supported by the analysis of the participants' notebooks. Besides sketching their ideas, the participants were asked to write a short description of how the idea emerged, using keywords or by collecting visual exemplars of the inspiration used. Therefore, it was observable that inspiration sources were also searched for and used during the generation of ideas and development of concepts. Likewise, analysis of the interviews and notebooks also revealed that when the participants received the (open-ended and vague) design brief, they actively searched for information that could help them define the scope of the problem. To do this, the participants subdivided the problem into manageable parts. Hence, active search for inspiration answered specific sub-problems and not the main problem. However, passive encounters with meaningful information that contributed to the design process happened frequently and in a serendipitous way. As stated by the participants, inspiration sources found passively initiated an active search, normally in the Internet, in order to learn more about them. Figure 5.5 visualises this interdependency process between passive and active search.

Besides active and passive search of inspiration, participants frequently mentioned the on-going practice of collecting inspiration sources, which were not necessarily meant for the resolution of a current design project. The following quote from participant A exemplifies this practice of inspiration collection for a future occasion:

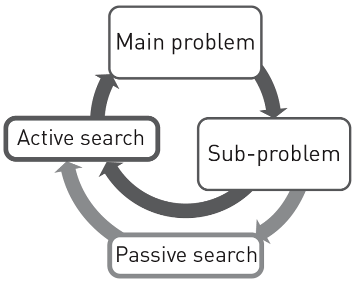



Figure 5.5. Diagram illustrating the interdependency between passive and active search of inspiration sources.

> "(…) just during the general day life, I'm always a bit aware of what could help me somewhere, sometime. Like I had this book at home, for myself… just things I see maybe in the newspaper or something, I think 'somewhere, sometime, I can use this'".

This practice of on-going collection of potentially inspiration sources can be considered active search, but without a goal to solve a problem at hand. It is meant to keep oneself informed and to have an easy accessible resource of previously encountered stimuli, which is a recognised practice in design (Eckert and Stacey, 2003).

### 5.6.3 Searching for close and easily accessible inspiration sources

On the medium preferred to search for inspiration, all participants referred to the Internet. This comes in conformity with previous research (Gonçalves, Cardoso and Badke-Schaub, 2011; Mougenot, Bouchard, and Aoussat, 2008). Interestingly, using Internet as a resource to find all kinds of information, and as an inspirational medium, seems to be a recent approach and the favourite of the younger generations of designers. Past research showed that magazines were previously considered the traditional medium used by professional designers to gather information (Mougenot, Bouchard and Aoussat, 2006). In general, the participants indicated that browsing the Internet is one of the first steps while initiating a new design project. Participant F reported that one of the most important reasons for such intense use of Internet is based on its accessibility and availability:

> *"Well, it's the easiest access, you know? I'm not much of a magazine person… not that I have a big shelf full of magazines that I can go through. So, yeah, Internet is free and quick. A lot complete and really versatile".*

According to Kwasitsu (2003) and Hicks et al. (2002), *accessibility* and *availability* are some of the decisive criteria engineers and designers implicitly use to select information (other criteria include *relevance* and *reliability*, for instance). The information searched by the participants when using the Internet went from visual examples of current solutions, to textual information on the field of the problem, or general design websites (on the contemporary design trends, which are not necessarily related with the problem at hand) (Figure 5.4 d.). Six of the participants reported searching for similar solutions to the problem at hand in the earlier stages of the design process, especially during the task clarification phase. Existing search engines, such as Google, usually enable users (the participants of this study included) to explore a certain topic quickly enough to have an overview. Even when the design problem is not sufficiently framed nor the direction is clearly defined, it is possible to arrive at potentially relevant or unexpected information by trial and error. Participant A demonstrates this in the following quote:

> *"I like just typing the question in Google and go from one website to another. I think that's always a good way to find new things you didn't think about before. (…) I think… Google is my friend in that case".*

The participants expressed that they do not consider themselves inspired by existing solutions or do not seek them for that purpose. Alternatively, they present several reasons for attributing such priority to closely related stimuli: to obtain an overview of the context of the problem and information about which guidelines designers might follow; to narrow down the problem; to understand the disadvantages of the current products and use that knowledge to create better solutions; and to avoid "reinventing the wheel". Participant D elaborates on one of these reasons:

> *"I'd just go for images.google.com and flicker.com and I just type the subject I'm doing. And I really like the images that come on the screen because they instantly give some kind of idea of how the world perceives the term you are Googling".*

The analysis of the notebooks, reports and interviews indicated that there was limited active search for distantly related stimuli (which could be compared to between-domain stimuli). Some participants referred that they could find inspiration outside the scope of the problem, but mainly dependent on random encounters. A small number of participants tried to employ ideation methods that led them to explore distantly related stimuli. For instance, participant R used the Analogies method to establish relations between his design problem and a distant field, by transferring relationships from the source example into a possible solution. In this case, the target problem involved the lack of oxygen when an avalanche occurs and the medium-distant source was the type of oxygen equipment used by divers. Nevertheless, the use of distantly related stimuli via ideation methods was a rare practice across the participants.

### 5.6.4 Searching for inspiration in people

All participants referred that talking with people was also an inspiration source. Seven of the participants indicated that they gathered inspiration from discussions with fellow design students (see Figure 5.4 b.). Moreover, experts, coaches and users were other figures referred by the participants as inspirational. According to the participants, discussions with experts and users on the topic of the problem happened mainly during the task clarification phase, when the participants actively searched for further information that could help them identify and isolate the problem. On the other hand, conversations with colleagues and the course coach happened actively when the students were 'stuck' in their design process, but passive encounters and discussions also occurred frequently at different moments of their project. Through the analysis of the notebooks and interviews, it was possible to observe that external people, especially colleagues and the coach, directly influenced many initial ideas and even the final concepts. With this experiment, some of the participants were surprised to realize how influenced they were on the support provided by the coach and colleagues. Participant P indicates:

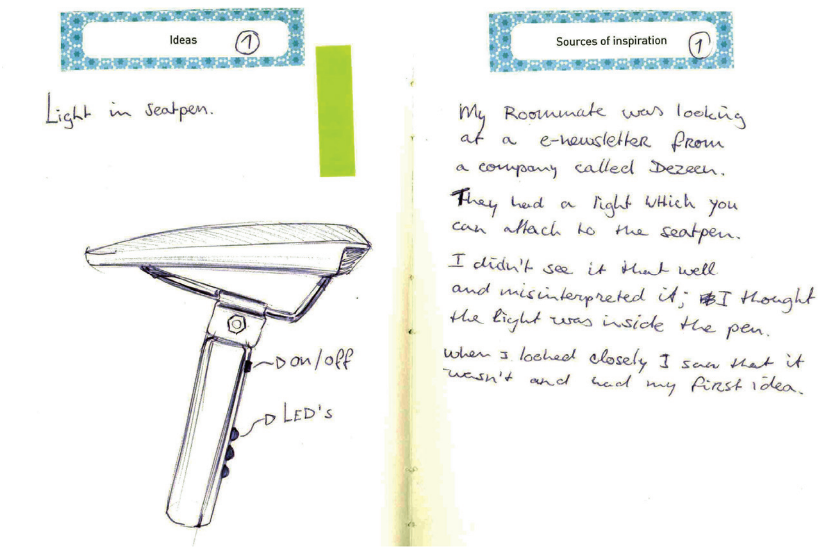
> *"(…) this is the first time I realize how much inspiration I get from a teacher. Because normally they say it, and I just accept it and use it as my own. I never realty think from where I got it from".*

The majority of the participants expressed that they missed the opportunity to discuss their ideas with colleagues in this individual project and that they preferred group work. This is consistent with the fact that this is one of the first individual projects of their Bachelor degree. Thus, they have no previous experience in managing all stages of the design process by themselves.

### 5.6.5 Advantages and disadvantages of reflecting on inspiration sources

When questioned on whether they reflected about their process and on the origins of their ideas, half of the novice designers reported not taking time for it. The other participants indicated that they occasionally have reflective moments, but normally unconsciously. These reflective moments were motivated by evaluative phases of their concepts, by exceptionally striking ideas or by their contemplative personalities, as reported by the participants. Due to the set up of this case study, the participants had to sketch their ideas and respective sources in their personal notebooks, which required an immediate moment of reflection. Figure 5.6 illustrates two pages of the personal notebook from one of the participants, displaying a sketched idea and its inspiration source. This task required an extra step in their design process and four of the participants reported that this reflective moment was disruptive. Active reflection, coincident with the generation of each idea, was considered to delay the flow of production of ideas, but not in a detrimental way. According to the participants, the immediate reflection on their inspiration sources did not affect their project, as strategies were employed to capture ideas without losing track of their inspiration sources.

Figure 5.6. Participant P's notebook page: on the left, the participant sketched the idea; on the right, the participant added a description of the idea's origin. The green sticker on the left page indicates that the participant considered the idea adequate to answer the problem.




**Idea 1:**
"Light in seatpen"

**Source of inspiration 1:**

"My roommate was looking at a newsletter from a company called Dezeen. They had a light which you can attach to the seatpen.
I didn't see it that well and misinterpreted it; I thought the light was inside the pen. When I looked closely I saw that it wasn't and I had my first idea".

Some participants chose to give shorter explanations or to jump the page meant for reflection on the inspiration sources and complete it later. Participants were asked to rate on a 1 to 5 Likert scale (1 = Strongly disagree; 2 = Disagree; 3 = Neither agree or disagree; 4 = Agree; 5 = Strongly agree) in how far they agreed that the reflection on their use of inspiration sources helped their design process. Conversely, the participants also rated how far they agreed that these reflective moments disturbed their design process. Although during the interviews some of the participants considered these immediate reflection moments as disruptive, the results on the ratings of the two Likert scales showed another perspective. On average, the participants rated that they generally disagreed that the reflection disturbed their design process ($\bar{x}$ = 1.88, SD = .991), and they generally agreed that it helped them ($\bar{x}$ = 3.63, SD = .518). In fact, the participants confirmed that reserving time to reflect throughout their inspiration process could benefit them. As possible advantages, participants indicated that this reflection helped them realize how much their ideas were dependent on the input of others, or raised the awareness that a more conscious choice of inspiration can help the development of their design process. Participant P indicated:

> *"Because [he] was thinking about inspiration, [he] may have got another idea".*

This reflects an unexpected but positive effect of reflecting on the inspiration sources. The reasons the participants presented to explain their limited reflection, specifically about where their ideas came from, were mainly dependent on the cognitive load this action requires. In regards to this, participant A replied:

> *"That's really easy not do it, it's a lot of thinking. (…) Yeah, I think maybe it could help realising the inspiration I searched, passively or unconscious. I think I realise it now already, that it could be interesting in a future project to search for inspiration in a more active way".*

Although it was indicated that reflection on the inspiration sources – at the moment of each generated idea – could be considered disruptive, participants raised concerns on the usefulness of reflection when the project is finished. Reflecting-in-action (as opposed to on-action [Schön, 1983]) might slow down the design process, but post-project reflection might not have immediate value, and learning experiences might not be incorporated in the next design project. This raises the important question of when is the most opportune moment to reflect on the design process.

### 5.6.6 Search and use of inspiration sources within several phases of the design process

The analysis of the interviews, together with the careful examination of the personal notebooks and reports, enabled the development of visual models portraying the design process of the participants in this project. Figure 5.7 illustrates the visualization of the design models of two participants: Participant P and R, which are used as cases in point.

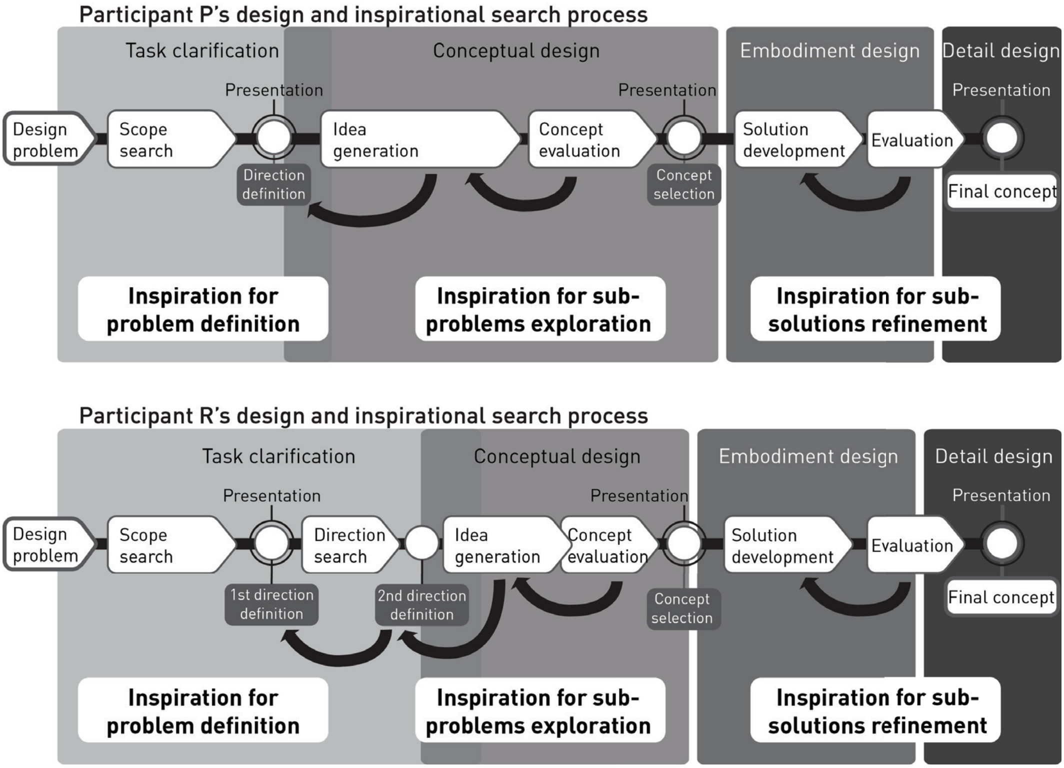
In this visualization, it is noticeable that both students went through the same general phases (task clarification, conceptual, embodiment and detail design) and the same three presentation moments, required by the coach of the course. However, participant P had a much shorter task clarification phase, as this student quickly arrived at a project direction, which he introduced in the first presentation. Participant R dealt with a longer task clarification phase, with iterative moments and constantly redefining the project direction, even after the first presentation. One first cycle of inspiration search was identified, which occurred in parallel with the task clarification phase. This first cycle of inspiration search, *Inspiration for (re)definition of the problem*, enabled the participants to explore and understand the problem, which is normally characterized by searching for contextual information and similar existing products. Other students mentioned undergoing a similar stage of inspiration search, as indicated by Participant F:

> *"It also happens in the 'finding a direction' part, I think. When you state the trends and developments in society (…). Because it's the basis, if you just think about what the company does and what happens, some solutions will come out".*

Participants P and R started the conceptual design phase at different times in the project, but in both cases there was overlapping with the previous phase. Participant P started generating ideas even during the task clarification, which extended the conceptual design phase from the first to the second presentation. Consequently, participant P produced many more ideas than participant R, who had a more condensed idea generation phase. With the constant search of information on the problem, participant R changed his direction even after the first presentation, to better refine it. During the analysis of the conceptual design phase of the participants' projects, another cycle of inspiration search was identified, in which the goal was to identify solutions for sub-problems of the main problem. In general, participants indicated that, while generating ideas, they are creating multiple ways to solve the problem, sub-dividing it in an approachable manner, as explained by participant T:

> *"I slowly built what the problem is, from the research I did, from the interviews [with users]. And at that time, after the first interview, I already made a list and I thought of 'pros' and 'cons' for the different problems. And also I started looking already for current solutions, before I had the next meeting".*

Figure 5.7. Participant P's and R's design process and the three moments of the inspiration process: Inspiration for problem definition; Inspiration for sub-problems; and Inspiration for sub-solutions.




Therefore, this cycle is referred as *Inspiration for exploration of sub-problems*, where participants searched for existing solutions, discussed their ideas with people (users, colleagues or coaches) or by encountering inspiration sources (mainly) passively. In the second presentation, the students had to opt for one concept and proceed with the embodiment and detail design. In these phases, which were not clearly distinguished in this project, the participants had to fully develop the chosen concept, by creating technical drawings and a three-dimensional model, estimating the production cost and retail price, materials and construction. Participant R had a slightly longer and diligent development of the concept than P. Once again, it was possible to recognise another cycle of inspiration search, in which the participants continued to search for inspiration, but for a different purpose. In the *Inspiration for refinement of sub-solutions phase,* the participants used inspiration sources to refine the chosen concept, to fully develop it. This is illustrated by the following quote from participant M, when referring to the later stages of his design process:

> *"I have my concept but I still don't know what's underneath here (…). I still need inspiration to solve those design problems. Although I have the main design concept, I still have a lot of things to figure out".*

Thus, in the *Inspiration for refinement of sub-solutions* phase, participants searched actively for, but also encountered passively, inspiration for sub-solutions that could help improve the final concept.
As a final remark, the differences in design process and final concept from participants P and R (from Figure 5.7) resulted in a difference in their final grades: Participant P obtained 6.5, while R achieved a 7.5 (on a 1 – very poor to 10 – excellent, grading scale).

## 5.7. Discussion

These findings concern the analysis of the design process of eight novice designers who took part in this course and study. General patterns emerged from these case studies, which might show similarities with other novice industrial designers. Considering these results, a flowchart was developed to illustrate the type of inspiration process that designers seem to experience in different phases of a design problem (Figure 5.8). This flowchart shows the cyclic processes that occur repeatedly when designers use inspiration sources to tackle a problem or a sub-problem. For each cycle of the inspiration process, different goals were identified, which depend on the phase of the design process: searching for inspiration sources to define the problem, to explore solutions for sub-problems and to refine the solution (by sub-dividing it). The inspiration process is initiated when the designer needs to answer a problem or part of it. The designer tries to make sense of the problem, by formulating it and (implicitly/explicitly) defining keywords that focus the attention on a specific direction. Designers search for inspiration sources according to these keywords, which are triggered by the individual formulation of the problem. Once the designer successfully defines keywords (by immediately thinking on how to approach a problem), the search for stimuli that match the keyword definition begins. However, whilst searching for the most appropriate stimuli the designer may arrive at unsuccessful results, in which case they can choose to continue searching for an appropriate stimulus or to change the keyword. With each selection of a stimulus, an analysis follows to assess if it corresponds to the designer's expectations. The designer can then choose whether the stimulus is incorporated and adapted to answer the problem at hand, or to store it (in the designer's memory or in a physical/digital collection) for another occasion. The last step is to adapt the stimulus in an effective manner to answer the goal of that specific cycle of the inspiration process, which could be to redefine the problem, to find solutions for a sub-problem or to refine a sub-solution. Each cycle will lead to a different reformulation of the problem. This process occurs multiple times during a design problem and it is normally an unconscious process. The novice designers in this study selected and used a number of inspiration sources without considering the impact in their outcomes. It is through reflection that designers can learn from experience and build on their expertise. However, novice designers are untrained in reflecting, as it is a difficult task and they are not encouraged to do so during their design projects. Reflection – on the design process as on the inspiration process – is essential to build expertise, but the moment when it should be applied within the design process still remains unclear. As the participants reported, reflecting on the process during the day-to-day project can be disruptive. Yet, reflecting at the end might not have direct impact because students can only apply improved practices or strategies in following projects, which might not be applicable or difficult to recall.

Considering these findings, it is recommended that reflection on the process

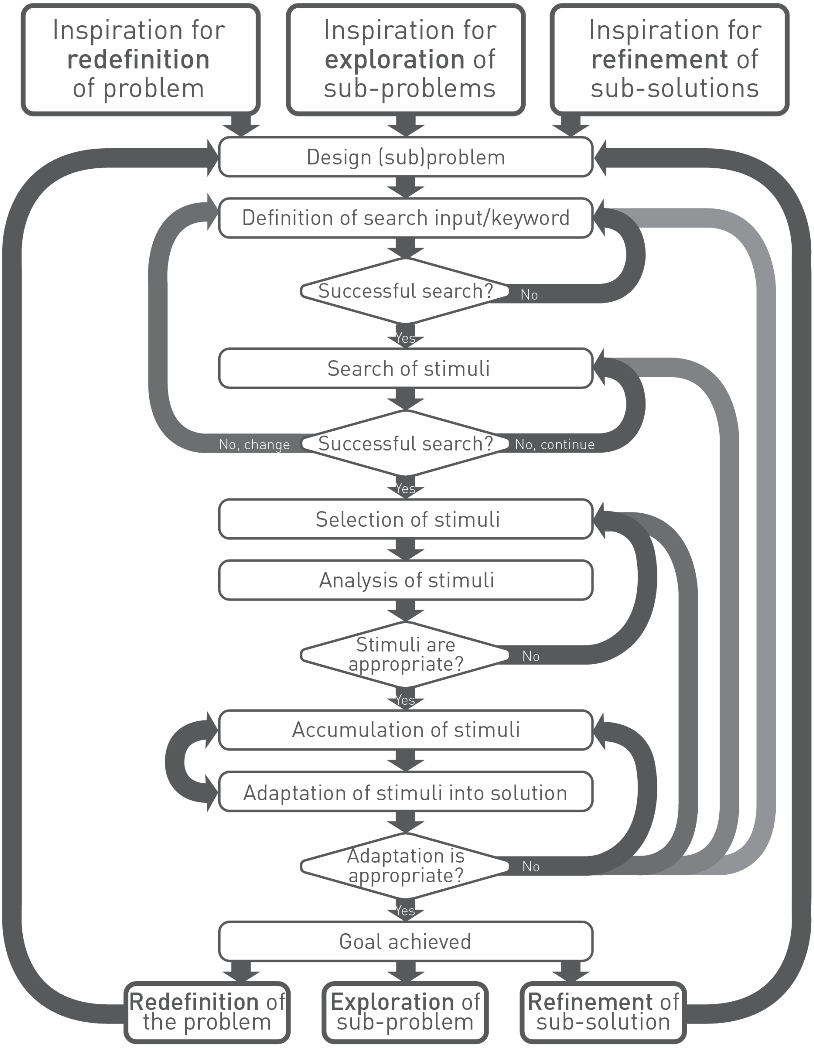



Figure 5.8. Flowchart of the inspiration process that could be observed at different moments of the design process (adapted from Eckert and Stacey, 2003).

should be applied after the conclusion of specific phases of the project, but before a new part of the problem is initiated. Furthermore, the results support that active reflection on the use of inspiration sources has a beneficial impact in the design process.

Another important aspect raised by this study is the focus on closely related stimuli (which could be compared to within-domain stimuli). The tendency to largely use this kind of stimuli when searching for inspiration might also be a reaction to the vagueness of the design brief. As the problem given to the participants enabled the exploration of any kind of field and led to very long task clarification phases, the participants relied on the search of similar products as soon as they decided on the their personal design directions. Due to the complexity of the problem, the participants spent an average of four weeks (of the ten weeks of the project) to grasp the problem and fully define their goal. However, research has extensively demonstrated the advantageous use of distantly related stimuli in creative design (e.g., Christensen and Schunn, 2007). Therefore, novice designers might be blocking their own creativity by the unreflective use of closely related stimuli in their inspiration processes. It was possible to observe that these novice designers were considerably dependent on external feedback from peers and coaches. In this bachelor programme, this project is one of the few courses which promotes individual work and until then, the participants had very little experience working alone in a design project. Relying only on their own skills seemed to be an unfamiliar situation, which most of the participants struggled with. This can be an indication of how novice designers are unprepared to work individually during a design project and how dependent they might be on external feedback. The initial years of design education in this bachelor programme focus on group work, which enables students to explore their role within a team, to learn how to negotiate and to improve their performance by relying on one another. However, personal skills and confidence are preferably practiced in individual projects and it seems that these students had little space to train these aspects. Arguably, this might indicate that the early years of design education should balance the quantity of group and individual projects, in order to promote the designers' full development.

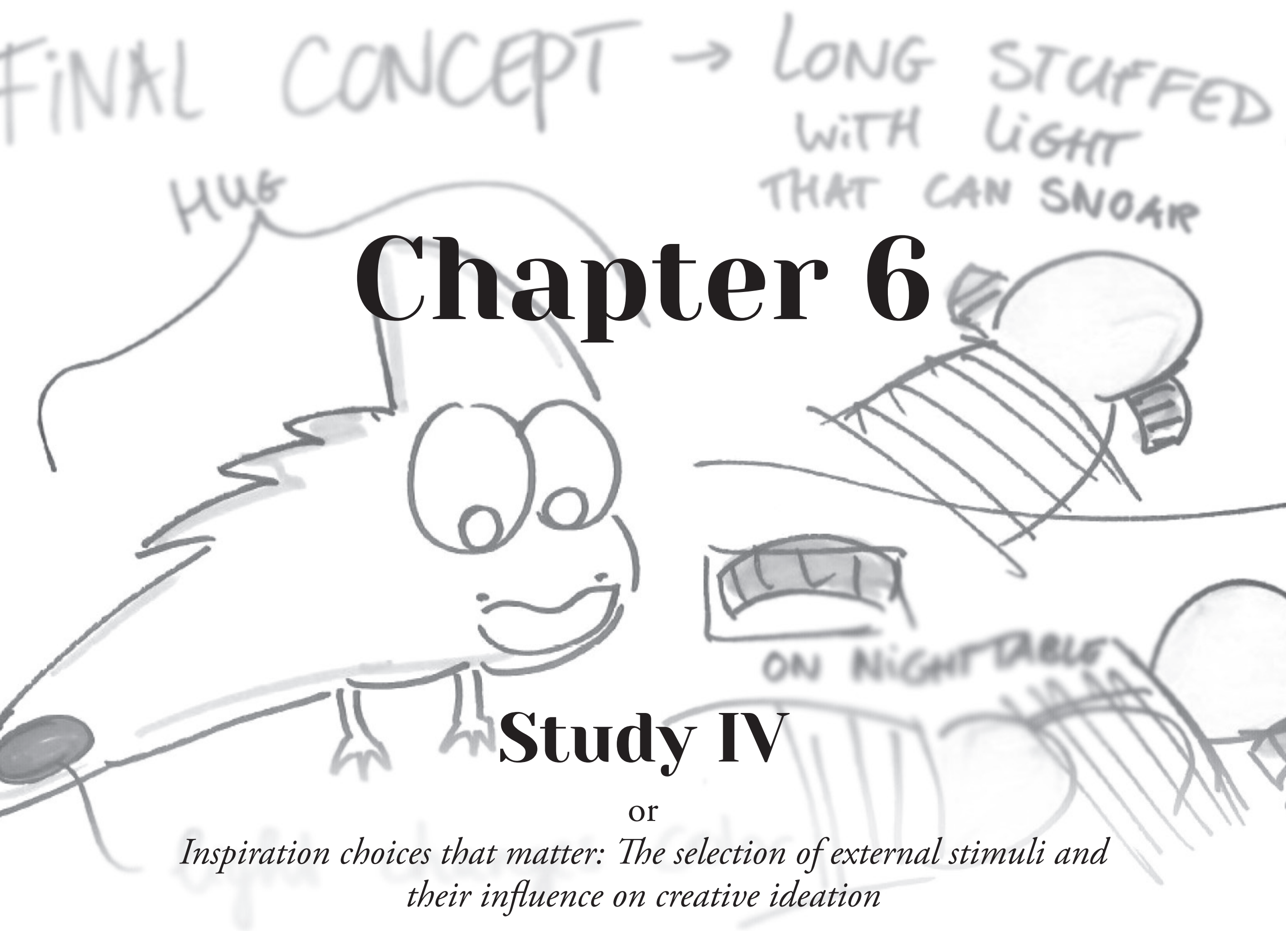
## 5.8. Conclusions

The goal of this chapter was to explore the processes designers undergo while searching and using potential inspiration sources for a design problem. By analysing different elements of novice designers' student work in combination with individual interviews, it was possible to describe their inspiration process within an existing design project. The inspiration process flowchart reveals the (mostly) unconscious procedures that underlie the process of encountering relevant stimuli – a process that is typically perceived as spontaneous and unstructured. Alternatively, the inspiration process is composed by specific steps and motivated by somewhat vague goals (to redefine the design problem; to solve a sub-problem; or to refine a sub-solution, as presented in Figure 5.8). In general, inspiration seems to be considered to be serendipitous and intuitive because designers tend to not reflect on their inspiration process.

To conclude, searching for inspiration sources seems to be a cyclic process that designers engage in multiple times during a design process, and which take different forms depending on the goal(s) driving such pursuit. This process can be better supported by active reflection, thus potentially enhancing the development of creative ideas. An understanding of the impact of the inspiration process in the early years of design education can promote the full development of designers' set of skills, by pinpointing the steps of the inspiration process where pitfalls might occur. Ultimately, a major challenge for designers lies in acquiring the mechanisms to conduct a timely and appropriate selection of functionally useful stimuli amongst the overwhelming diversity of available sources. Now that the inspiration process designers experience has been unfolded, the next steps of this research work are to investigate the selection of stimuli and which steps of this framework can be further supported to promote creative results. These are the aims of the next study, in Chapter 6.

Chapter 6 figure: Concept generated by participant from Study IV.

A version of this chapter, under the same name, is currently under review at the peer-reviewed Design Science journal




# Chapter 6

## Study IV

or

*Inspiration choices that matter: The selection of external stimuli and their influence on creative ideation*

*The previous chapter revealed which individual steps are involved in the inspiration process of designers, which is characterised by its cyclical nature within the design process. Nevertheless, much is still unknown about the inspiration process, especially because it is considered to result from pure serendipity. Thus, chapter 6 addresses designers' approaches when selecting external stimuli during the initial phases of a design process, in a quantitative and qualitative manner. This chapter presents an experimental study and follow-up interviews with 31 design masters students. Results indicate that searching for and selecting stimuli require high cognitive effort, which can be detrimental for design creativity. Furthermore, three important stages of the inspiration process were identified: keyword definition, stimuli search and stimuli selection. For each of these stages, it was possible to elaborate on how designers define keywords, which search approaches they use and what drives their selection of stimuli. Therefore, this chapter contributes to understanding how designers can be supported in their inspiration process in a more detailed manner.*

## 6.1. Rationale

In the well-known children's book, *Alice's Adventures in Wonderland* (1865), the author Lewis Carroll addresses a number of themes, such as the defiance of logic and the uncertainty of making right or wrong choices. About the latter, Carroll (1865, p. 56) wrote the following when Alice did not know how to proceed in her journey:

*"'Cheshire-Puss,' she began, rather timidly, as she did not at all know whether it would like the name (…) 'Would you tell me, please, which way I ought to go from here?'*

*'That depends a good deal on where you want to get to,' said the Cat.*

*'I don't much care where…' said Alice.*

*'Then it doesn't matter which way you go.' said the Cat."*

As Alice had to choose which road to take, designers usually have to choose which direction to follow while designing. However, contrary to Alice's adventures, design problems cannot be simply represented as a fork in the road, but rather as a criss-crossing of many possibilities, which might not be fully defined. During the development of a design project, designers have to deal with different levels of uncertainty. This is especially the case during the initial phases of the design process, commonly known as the fuzzy front end (Khurana and Rosenthal, 1997; Buijs, 2012). During that phase where it is often difficult to specify goals that clearly state the direction of a project, because of the ill-defined nature of design problems (Simon, 1973). In Alice's problem, she asks the Cheshire Cat where to go, trying to collect information, although without specifying a goal. In the design context, designers commonly seek information with the aim of defining and framing the design problem at hand, in order to bring clarity (Dorst and Cross, 2001; Goldschmidt, 1997; Gonçalves, Cardoso and Badke-Schaub, 2013). However, uncertainty can hamper designers, especially novices, whose attention focus tends to be less structured and might struggle to choose which information is the most relevant (Kavakli and Gero, 2002). Thus, designers might face the following crossroad: which information should they search for if they do not know yet which direction they should take? This can result in less experienced designers continuously searching for information,

hoping that eventually they will come across something relevant.
According to Ware (2008), our search mechanisms are systematic, but the goal of the search is not always clearly defined. Thus, several types of search procedures can take place when seeking information:
**Active search with purpose** refers to deliberately searching for particular information with a specific goal in mind. Examples of these practices are searching in the Internet or books for specific information, but can also include an intentional walk in a museum to observe an art piece (Eckert and Stacey, 2003).
**Active search without purpose** (or Ongoing search) refers to active search but without a specific intention to solve a problem at hand. The goal of this type of search is to update or expand one's knowledge on a topic (Wilson, 1997). Active search without purpose refers to designers' widespread routine of keeping informed about pertinent topics on their domain (Eckert and Stacey, 2003).
**Passive search** refers to random encounters with relevant information, which is consciously integrated in the design process, also known as serendipity (e.g., Keller, Pasman and Stappers, 2006). Although there is a conscious goal to solve a problem in this type of situations, the search process is not deliberate and occurs unintentionally. Even when the search query (or keyword) is not fully defined, our mind is open to recognise information, which could be somehow related to the current problem, and might fit a set of vague criteria (Ware, 2008; Wilson, 1997). This is similar to what Murty (2006) referred to as cold discoveries, i.e., the recognition of relevant information out-of-context (when the designer is not actively working in the problem). Murty (2006) reported that these moments of *cold discoveries* are more important in designing than it is usually acknowledged.
**Passive attention** refers to the moments when information is encountered but not consciously integrated in the context of an existing problem. This can occur while watching TV or talking with someone, for instance. In this situation, there is no urgent intention to solve a problem nor a conscious perception of the possible influence of a stimulus (Wilson, 1997).
Our constant state is one of passive attention, which can quickly change into a more alert or deliberate type of search of information. Therefore, all these types of search can develop into another, depending on the situation.

A number of research studies have investigated the impact that identifying, retrieving and transforming external stimuli can have on the generation of solutions (e.g., Yang, Wood and Cutkosky, 2005; Christensen and Schunn, 2007; Mougenot, Bouchard and Aoussat, 2008; Goldschmidt and Sever, 2010; Howard, Culley and Dekonick, 2010; Fu et al., 2013). However, little is known about how designers select external stimuli during the design process.

## 6.2. Research question

As introduced in chapter 2, section 2.2.6, this study aims to answer the following sub-research question: *Which processes do designers employ while searching and using external stimuli for a design problem?*

The aim of this study is to understand and explain designers' processes related to the selection of external stimuli while designing. In this context, *selection* of external stimuli is defined as the decision process of searching, selecting and retrieving stimuli to help answer and/or frame a problem.
Gaining insight into how designers select external stimuli can help understanding inspiration processes better, and finally to support design creativity. Thus, this research project can encourage the development of an empirical based intervention to influence professional practice and education in terms of designers' selection approaches of stimuli.
An experimental study was carried out where design students working individually had to generate ideas for a design problem. The designers were videotaped and interviewed, and their process and creative outcome (i.e. ideas generated) were analysed and evaluated. Section 6.3 elaborates on the methodology applied in this study and Sections 6.4 and 6.5 describe the quantitative and qualitative results, in this order. Sections 6.6 and 6.7 present the discussion and conclusions of this study and implications for design practice and education.

## 6.3. Research study

### 6.3.1 Set up of the study

The aim of this study was to investigate designers' selection approaches of potential inspiration stimuli during design ideation. The ideas generated during an ideation session and the process itself were analysed, in a quantitative and qualitative manner. In addition, each participant was interviewed to gather information on his or her selection of stimuli. In order to capture the participants' inspiration process, a 'search tool' was created - similar to a simple downsized version of an online search engine. This search tool included a visual and textual stimuli database to provide a range of possible sources for the designers to choose from, with 200 stimuli (100 images and 100 texts).

The participants of this study comprised 31 masters design students from an Industrial Design Engineering faculty. From the 31 participants, 17 were female and 14 were male, with an average age of 24 years. The participants reported having an average of five years studying design, and only four indicated previous professional experience.

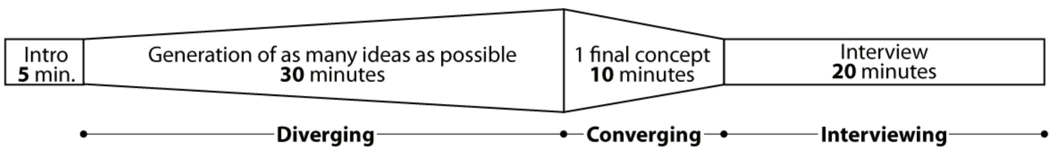
The experimental groups are the following:

**'Control' condition** (N=10): The participants did not have access to the search tool created or any other information, other than the design brief. They were also not aware of the existence of the search tool.

**'Unlimited' condition** (N=10): The participants received unlimited access to the search tool, at any point during ideation. Participants could search for as many keywords and choose to open as many stimuli as they wished.

**'Limited' condition** (N=11): The participants received limited access to the search tool. They could only search for one keyword and choose to open only one stimulus from the options available, during ideation (both diverging and converging phases).

Figure 6.1. Sequence of activities in the experimental session, which took on average one hour



The experimental session, which took on average one hour, was divided into three phases (see Figure 6.1) after the introduction. In the first phase – Diverging – participants were asked to generate as many different ideas as possible for 30 minutes. In the second phase – Converging – the goal was to elaborate on a final concept during 10 minutes. Finally, in the third phase – Interviewing – the participants were asked a number of questions related to their own inspiration searching behaviour, in a semi-structured interview.
All sessions took place in the same room, prepared for experimental purposes (plain white walls stripped of any information). Three cameras videotaped the participants, two focusing on the sketches generated and another capturing their general behaviour (Figure 6.2). The software Quick Time Player was used to digitally record the laptop screen and capture the participants' interaction with the search tool.

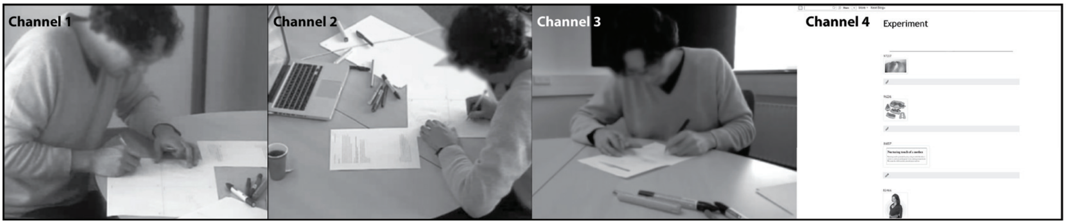



Figure 6.2. Four channels: channels 1-3 focus on the participant's work; channel 4 recorded the search tool.

Participants had to create as many different ideas as possible for the following design brief:
*"Learning to sleep alone at night is a challenge for children at young age. Normally, until the age of two, parents keep their children close and have them sleep in a crib in the parents' room or even in their own bed. However, it is recommended that children make the transition for their own room and bed. Having the kids waking up during the night and come into the parents' bed is quite common and it is a big problem for parents. No one sleeps and rests conveniently, the child doesn't conquer his/her fears and parents don't have their privacy.*
*Your task is to design a product to help children of young age (3 to 5 years old) sleep alone through the night, on their own bed."*
Additionally, the participants were asked to take into account the following requirements: *Safe for the child* and *comfortable*. A pre-test established that the brief was accessible and enabled the exploration of many different ideas, without

requiring detailed technical knowledge.

### 6.3.2 Search tool and stimuli

In both 'Unlimited' and 'Limited' conditions, participants were informed that they would have access to the laptop in front of them, to use a closed-circuit database specifically prepared for their design problem (not connected to the Internet). Additionally, they were informed that the search tool contained both pictures and pieces of text with closely or distantly related information and that the use of the search tool was not mandatory.

Unlike other studies that have investigated design information retrieval, where the goal was to create or test a computational tool (Yang et al., 2005; Mougenot et al., 2008; Setchi and Bouchard, 2010), this stimuli database and search tool were meant as a platform for studying the selection process of designers when searching for potential inspiration sources. The process of assembling stimuli for the search tool is explained in Appendix F.

In total, the search tool included 200 stimuli (100 images and 100 short texts) that were either distantly or closely related to the design brief. The 200 stimuli were clustered into 50 categories (e.g., 'Light' or 'Touch'). Each category contained two images and two short texts, each one being either closely or distantly related, as illustrated on Figure 6.3. In this example, four stimuli from the category 'Light' are represented.

**Star stickers to keep the dark away**

Glowing stars stickers are used to decorate children's rooms, on walls and ceilings. When the plastic stars are exposed to natural light during the day, they...

**Glowing animals: bioluminescence**

Bioluminescence is the production and emission of light by an animal, enabling it to glow in the dark. Bioluminescence functions go from attracting mates...

Figure 6.3. From left to right: closely related image; closely related text; distantly related image and distantly related text.

The tags (or meta-data) were manually generated, using a thesaurus. This process, although not mechanized, was considered to be comprehensive and enabled to identify an average of 62 keywords per pair of stimuli (M= 62.5; SD= 17.7). The same tags were attributed to both image and text from the same semantic level, to ensure that when the participants made a certain search query, both visual and textual counterparts would be shown. When a participant typed a keyword, a number of small thumbnails were displayed. In order to clearly see the stimulus, the participant needed to select it (i.e., click).

#### 6.3.3 Design protocol analysis

The design process of the students was investigated using protocol analysis. Thus, participants were requested to think aloud during problem solving. Verbal protocols have been considered a valuable method, which enable the analysis of aspects of the designers' thought processes with minimal disruption (Ericsson & Simon, 1993; Atman et al., 2005). However, this approach has also been criticized for it may affect participants' performance due to an increase in cognitive load (Chiu & Shu, 2010). To improve the validity of verbal protocol analysis, Lloyd, Lawson & Scott (1995) advocated that other methods should be added to the analysis, to obtain a richer perspective of the process and performance of the designer. Therefore, other types of enquiry were added to this study, namely their pen-and-paper outcome and interviews. The design protocols were analysed using the software INTERACT Mangold International, by coding segments of the participants' speech. The coding scheme used to analyse the participants design process can be found in Appendix G.

#### 6.3.4 Interview analysis

The 31 semi-structured interviews took place after the completion of the design problem and they varied between 20 to 50 minutes. The participants' sketches were used as visual elicitation material to retrieve information on certain topics of the interview (Crilly, Blackwell and Clarkson, 2006). Each interview was videotaped, transcribed and coded according to emergent categories, using the software Atlas.ti. The author of this thesis coded all interviews, whilst a second coder analysed a subset of the data using the same coding scheme. The two coders reached an agreement of 74,1%. Several coding iterations resulted finally into 57 codes, which were grouped into 14 categories and five main themes (Appendix H). Finally, two themes were considered to be the most relevant to discuss the topic of selection of stimuli for inspirational purposes. They are: *Selection of* *stimuli in the search tool* and *Reflection on inspiration sources.*

### 6.3.5 Analysis of the outcome in terms of creativity

The outcome of the design problem (Section 6.3.1) resulted in a set of ideas and one final concept, which was measured on the basis of creativity. A creativity score was defined based on the work of Dean et al. (2006) and Verhaegen et al. (2012) and adapted to the context of the design brief used in this study (Figure 6.4). All metrics, besides Fluency, Flexibility and Rarity, were rated on 1 to 10-point anchored scales, by two independent judges, both designers with a master degree, who were not aware of nature or goals of the study.

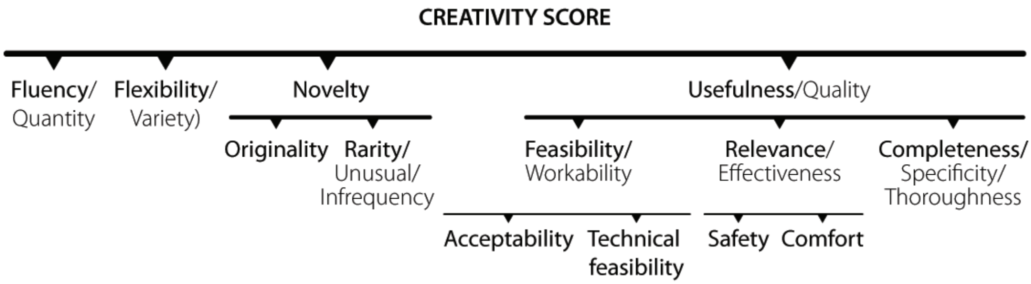



Figure 6.4. Composition of the overall creativity score (based on Deal et al., 2006 and Verhaegen et al., 2012).

**Fluency (Fl)** was measured by counting the number of ideas generated per participant. Two judges went through all ideas, in order to determine the total number of ideas. Following Dean et al. (2006), ideas that were not sufficiently clear, where their purpose and function (what the idea aimed to do and how) could not be understood, were discarded.

**Flexibility (Flex)** is defined as the ability to approach the problem in different ways, resulting in solutions which cover the exploration of many domains. Flexibility was analysed using a simplified variation of Shah, Vargas-Hernandez and Smith's (2003) proposed metric for variety (i.e., flexibility). Each idea was decoded in a tree-like structure (i.e., genealogy tree), with three levels – i.e. main function, working principle and detail, each with different weights. Three levels were considered sufficient instead of the proposed four (physical principle, working principle, embodiment and detail), as this design brief required no embodiment considerations. Thus, the following adapted formula was used to

calculate a flexibility score for each participant:
In this formula, $k$ refers to the level (main function, working principle or detail); $S_k$ is the score of the level, $b_k$ is the number of branch(es) in that level and, finally, $n$ refers to the total number of ideas per participant (Figure 6.5).

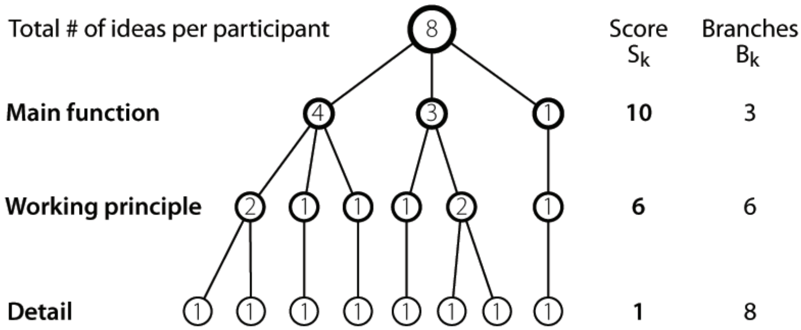



Figure 6.5. Example of a genealogy tree of the flexibility score for a participant with 8 ideas in total.

**Novelty (N)** is the degree to which an idea is original and uncommon. This was measured by computing two different metrics: originality and rarity.
**Originality (O)** refers to the degree to which an idea is new and surprising in the context of the 'outside' world.
**Rarity (Ra)** was rated differently than the other metrics, as it is the degree to which an idea emerges more or less frequently from within the pool of ideas generated by the participants. Thus, originality is different from rarity. The former is assessed within the realm of all existing ideas the judges might be aware of, whilst the latter is assessed only within the sample of ideas produced by the participants. Thus, rarity was measured by counting the occurrence of each idea, by clustering similar ones and distinguishing unique ones. The rarest idea would be produced by only one participant, whilst a common (not rare) idea would often re-emerge across the pool of ideas generated. In order to integrate *rarity* into the overall creativity score, the reoccurrence of each idea was then transformed into a 1-10 scale. This is demonstrated in Appendix C.
**Feasibility (F)** refers to whether an idea conforms to existing constraints and can be presently implemented. Feasibility considers two metrics: acceptability and technical feasibility.
**Acceptability (A)** is the degree to which an idea is socially, legally or politically acceptable. This measure was considered relevant for this design brief, as it

avoided ideas that would be disapproved legally or socially (such as giving sleeping pills to a child).

**Technical feasibility (TecF)** refers to the degree to which an idea can be manufactured and implemented, in technical and financial terms.

**Relevance (R)** reflects the degree to which an idea addresses the design problem. Considering the design brief of this study, relevance comprised two given requirements: safety and comfort. As explained in Section 6.3.1, the participants were asked to consider these two requirements when solving the design brief.

**Safety (S)** refers to how safe a product might be when using a given solution idea, in terms of physical and/or psychological well-being.

**Comfort (Cf)** refers to the physical/psychological comfort a solution ensures to the user.

Finally, **completeness (Cp)** of an idea refers to whether it contains all necessary details to be understood in a clear and concise manner.

The overall score of creativity is a function of the discrete metrics aforementioned, which results into the following formula:

$$Creativity = Flex + \frac{\left[ N\left(\frac{O + Ra}{2}\right) \times U \frac{\left[ F\left(\frac{TecF + A}{2}\right) + R\left(\frac{S + Cf}{2}\right) + Cp \right]}{3} \right]}{Fl}$$

This formula is adapted to the context of this specific design brief and to fit the circumstances of an idea generation problem (rather than another phase of the design process). Consequently, when considering other types of design problems or other process phases, the necessary components of creativity might differ and should be adapted to correspond to other studies' requirements. Novelty and Usefulness (arguably, the most important dimensions of creativity) were multiplied, as supported by Sarkar and Chakrabarti (2011). Novelty and Usefulness were decomposed into sub-components. Fluency, being an enumeration summarising all ideas, does not characterize an idea. In this equation, Fluency is used to relativise the function of Novelty and Usefulness, to make the creativity score comparable across participants. Furthermore, Flexibility is an additional dimension, which already considers the total number of ideas produced by participant when evaluating the categories for flexibility.

Arguably, some of these metrics weigh more than others, depending on the type of problem at hand, for instance. Thus, the following weights were attributed to the metrics (see Figure 6.6), which are in accordance with the problem used in this study. When considering past research, it is not clear how these metrics influence each other and it cannot be confidently assumed that this formula and weights are generally valid. Instead, further research is recommended to tailor this model to other design problems and requirements.

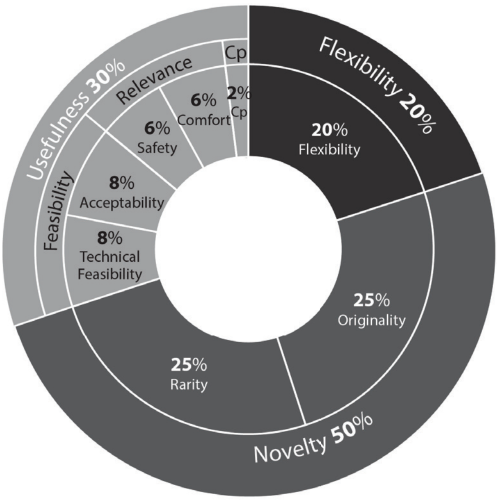



Figure 6.6. Creativity score, with different weights per metric, according to the design brief used in this study.

Therefore, Novelty and Usefulness are considered the most essential factors of creativity, as supported by many other studies (e.g., Stein, 1953; Lubart, 1994; Sawyer, 2006; Amabile, 1996; Hennessey and Amabile, 2010; Sarkar and Chakrabarti, 2007). Novelty has a higher weight than Usefulness, as it determines how creative an idea really is. If an idea is very useful, but not new or unexpected, it could hardly be considered being creative. Furthermore, Fluency and Flexibility are components of the formula as their contribution to creativity has been proposed by Guilford (1950) and determined by other studies (e.g., Casakin and Kreitler, 2005; Paulus, Kohn and Arditti, 2011). Flexibility is attributed a weight, whilst Fluency is considered as a relative dimension in relation to the other metrics and was not given a weight.
This combination of the aforementioned factors, including the different weights, resulted in the following creativity score:

$$\textbf{\textit{Creativity}} = \textbf{\textit{Flex}} \times 0.2 + \frac{\left[ \textbf{\textit{N}}\left(\frac{\textbf{\textit{O}} \times 0.25 + \textbf{\textit{Ra}} \times 0.25}{2}\right) \times \textbf{\textit{U}}\, \frac{\left[\textbf{\textit{F}}\left(\frac{\textbf{\textit{TecF}} \times 0.08 + \textbf{\textit{A}} \times 0.08}{2}\right) + \textbf{\textit{R}}\left(\frac{\textbf{\textit{S}} \times 0.06 + \textbf{\textit{Cf}} \times 0.06}{2}\right) + \textbf{\textit{Cp}} \times 0.02\right]}{3} \right]}{\textbf{\textit{Fl}}}$$

These weights are considered subjective but defendable because they were chosen according to literature and are related to the requirements of the design problem used in this study. Other weights were considered, but they led to a stable effect and did not alter the following results (Section 6.4).
Different metrics and formulae have been put forward by researchers in the field of design and engineering to be able to assess how creative an idea is. Thus far, there is no consensus in the literature on how creativity should be measured, neither on whether an overall score of creativity should be calculated (e.g., Dean et al., 2006; Kudrowitz and Wallace, 2013; Sarkar and Chakrabarti, 2011; Shah, Vargas-Hernandez and Smith, 2003). Although past research is acknowledged and was the basis for this creativity metric for some of its aspects, other formulae were considered unsuitable or too time-consuming to assess a large amount of 'quick and dirty' sketch ideas, as it was the case in this study.

## 6.4. Quantitative results: creativity score of the outcome

The following section presents the results of the designers' outcome (whilst the analysis of the process is discussed in detail in Section 6.5). Here, the quantitative results of the participants' outcome, with statistical analysis on singular and overall creativity metrics are presented, divided between ideas and final concepts.

### 6.4.1 Inter-rater agreement between judges

The inter-rater agreement between the judges was calculated with Pearson's correlation coefficient. The judges rated two sets of outcomes: *ideas*, which resulted from the diverging phase of the ideation; and *concepts*, from the converging phase. Rarity and Flexibility were not included in the analysis of the inter-rater reliability, since they were measured differently, by only one judge. Table 6.1 shows that the agreement between the two judges is sufficiently high (except regarding Completeness).

| | | |
|---|---|---|
| **Ideas** | Fluency | R (33) = .99, $p$ = .00 |
| | Originality | R (387) = .51, $p$ = .00 |
| | Acceptability | R (387) = .65, $p$ = .00 |
| | Technical feasibility | R (387) = .41, $p$ = .00 |
| | Safety | R (387) = .54, $p$ = .00 |
| | Comfort | R (387) = .41, $p$ = .00 |
| | Completeness | R (387) = .33, $p$ = .00 |
| **Concepts** | Fluency | not applicable |
| | Originality | R (33) = .73, $p$ = .00 |
| | Acceptability | R (33) = .87, $p$ = .00 |
| | Technical feasibility | R (33) = .86, $p$ = .00 |
| | Safety | R (33) = .51, $p$ = .01 |
| | Comfort | R (33) = .74, $p$ = .00 |
| | Completeness | R (33) = .69, $p$ = .00 |

$p$ < .01 (two tailed)

Table 6.1. Inter-rater reliability results across metrics.

### 6.4.2 Fluency

The total number of ideas created during the diverging phase was 387, across the three conditions. The total number of concepts created during the converging phase was 31 (as each participant had to create only one final concept). The 'Control' condition generated 145 ideas, the highest amount from all three groups, whilst both experimental conditions created exactly 121 ideas. A one-way between subjects ANOVA was conducted to compare the different conditions: no access to stimuli ('Control'), unlimited access to the search tool ('Unlimited') and limited access ('Limited'). No significant differences were found in regard to the amount of ideas generated by the three conditions [$F$(2, 28) = 1.106, $p$ = .35]. The means and standard deviations for all metrics can be found in Table 6.2 (Ideas) and Table 6.3 (Concepts).

### 6.4.3 Flexibility

A one-way ANOVA test showed that there was no significant difference between the three conditions regarding the Flexibility of ideas generated [$F$(2, 28) = 1.476, $p$ = .25]. In the same way as Fluency, Flexibility was computed as a characteristic, which is to be considered as one measurement across the whole range of ideas produced by each participant. Thus, there is no difference between ideas and concepts, regarding Flexibility.

### 6.4.4 Novelty: Originality and Rarity

Regarding ideas, there were no significant differences found for *Originality* between conditions [$F(2, 28) = 1.296$, $p = .29$], as determined by one-way ANOVA. However, there was a significant effect on *Rarity* for the three conditions [$F(2, 28) = 3.494$, $p = .04$].
Bonferroni's post-hoc test revealed that the 'Control' condition generated ideas that (within the sample of ideas produced) were significantly more rare (M = 6.88, SD = .62) than the 'Limited' condition (M = 5.81, SD = .80). Concerning the final concepts of the participants, no significant differences were found for *Originality* [$F(2, 28) = .499$, $p = .61$], nor for *Rarity* [$F(2, 28) = .501$, $p = .61$].

| IDEAS Individual creativity metrics | | Fluency | Flexibility | Novelty | | Usefulness | | | | | IDEAS Overall creativity score |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Originality | Rarity | Feasibility | | Relevance | | Complete-ness | |
| | | | | | | Accepta-bility | Tech. Feasibility | Safety | Comfort | | |
| Control | Mean | 6.43 | 7.04 | 4.98 | 6.88 | 8.26 | 8.08 | 7.89 | 7.17 | 5.39 | 1.51 |
| | SD | 1.84 | .97 | .84 | .62 | .60 | .56 | .53 | .50 | .41 | .22 |
| Unlimited | Mean | 5.29 | 7.75 | 4.46 | 6.06 | 8.32 | 8.14 | 7.82 | 7.48 | 5.38 | 1.67 |
| | SD | 2.24 | 1.26 | .75 | 1.33 | .50 | .65 | .49 | .42 | .71 | .28 |
| Limited | Mean | 5.24 | 7.69 | 4.92 | 5.81 | 8.24 | 8.02 | 7.67 | 7.47 | 5.22 | 1.65 |
| | SD | 2.03 | .84 | .79 | .80 | .56 | .67 | .47 | .43 | .76 | .19 |

Table 6.2. Means and standard deviations of ideas in each metric used to assess the overall creativity score (right). The statistical significantly different values are marked in red.

### 6.4.5 Usefulness: Feasibility, Relevance and Completeness

A one-way ANOVA demonstrated that the *Feasibility* of the ideas generated did not significantly differ across the three conditions: *Acceptability* [$F(2,2\ 8) = .063$, $p = .94$] and *Technical Feasibility* [$F(2, 28) = .94$, $p =. 91$]. Similarly, no differences were found on *Relevance*: *Safety* [$F(2, 28) = .581$, $p = .56$] and *Comfort* [$F(2, 28) = 1.477$, $p = .25$]. Additionally, no significant differences were found regarding the *Completeness* of ideas [$F(2, 28) = .254$, $p = .78$].
When focusing on the usefulness score of Concepts, there were again no significant differences between the three conditions: *Acceptability* [$F(2,2\ 8) =$

.618, *p* = .54]; *Technical Feasibility* [*F*(2, 28) = 1.437, *p* = .26]; *Safety* [F(2, 28) = .210, *p* = .81]; *Comfort* [*F*(2, 28) = .152, *p* = .86]; *Completeness* [*F*(2, 28) = 1.543, *p* = .23].

| **CONCEPTS** Individual creativity metrics | | **Fluency** | **Flexibility** | **Novelty** | | **Usefulness** | | | | | **CONCEPTS** Overall creativity score |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Since only 1 concept was created, Fluency and Flexibility of all ideas were used to measure the overall score of Creativity for **concepts.** | | Originality | Rarity | Feasibility | | Relevance | | Complete -ness | |
| | | | | | | Accepta- bility | Tech. Feasibility | Safety | Comfort | | |
| **Control** | **Mean** | **6.43** | **7.04** | **6.05** | **6.70** | **8.40** | **7.05** | **7.70** | **7.25** | **7.45** | **1.52** |
| | SD | 1.84 | .97 | 1.17 | 3.47 | 1.05 | 1.36 | 1.16 | 1.40 | 1.19 | .23 |
| **Unlimited** | **Mean** | **5.29** | **7.75** | **5.90** | **5.68** | **8.35** | **6.40** | **7.95** | **7.50** | **6.70** | **1.67** |
| | SD | 2.24 | 1.26 | 1.61 | 3.16 | .78 | 1.85 | .93 | 1.11 | .88 | .28 |
| **Limited** | **Mean** | **5.24** | **7.69** | **6.55** | **5.30** | **7.68** | **7.50** | **7.91** | **7.55** | **7.23** | **1.66** |
| | SD | 2.03 | .84 | 1.15 | 4.17 | 2.49 | 1.20 | .66 | 1.39 | .85 | .17 |

Table 6.3. Means values and standard deviations for the final concepts across all metrics, which were used to assess the overall creativity score (right).

### 6.4.6 Overall score of creativity

To compute the overall score of creativity, all metrics were calculated according to the weighted formula presented in section 6.3.5. An ANOVA showed that, regarding ideas created during the diverging phase, creativity did not differ significantly across conditions [*F*(2, 28) = 1.418, *p* = .26]. Regarding the creativity of final concepts, there were again no significant differences across conditions [*F* (2, 28) = 1.428, *p* = .26].

## 6.5. Qualitative results: design process and interviews

The second part of the results concerns the participants' processes. Two data sources are combined: the protocol analysis of the design process and the interviews, together with sketches and videos. From these analyses, a number of topics emerged, which are explained by including direct quotes from the participants.

### 6.5.1 Use of (and refusal to use) the search tool

This section presents general observations on the 'Unlimited' and 'Limited' participants' behaviour, particularly on the use of (or refusal to use) the search tool. The two treatment groups used the search tool mainly when they seemed to have run out of ideas during the diverging phase (first 30 minutes). Only three participants preferred to use the search tool during the converging phase (last 10 minutes) (See Table 6.4).

| CONDITION | USE OF SEARCH TOOL | | REFUSAL TO USE SEARCH TOOL |
|---|---|---|---|
| | Divergent phase | Convergent phase | |
| **Unlimited** (N=10) | 6 participants | 2 participants | 4 participants |
| **Limited** (N=11) | 11 participants | 1 participant | 0 participants |

Table 6.4. Use of the search tool across treatment conditions (diverging and converging phases).

Four out of ten participants from the 'Unlimited' condition opted for not using the search tool. These participants, who could be considered 'inspiration-avoiders', refused to use the tool even when they were unable to generate ideas, indicating that:

• They were aware of the possible negative influence of stimuli and did not want to be steered to think in specific ways.

• They preferred to rely on their own experience and internal stimuli.

• They considered the time of the session to be enough to continue generating ideas without assistance.

• They did not know the search tool beforehand and assumed it would be similar to existing search engines.

• They were unsure what to search for.

Although they avoided to search for stimuli in the session, these participants reported later that inspiration search is part of their usual design process. Conversely, all 11 participants from the 'Limited' condition decided to use the search tool. Two types of search behaviour could be observed: whilst the four 'Unlimited' participants who refused to search for inspiration could be considered 'inspiration-avoiders' in the context of this experiment, the remaining participants from the 'Unlimited' and 'Limited' conditions could be defined as 'inspiration-seekers'. Contrary to 'inspiration-avoiders', 'inspiration-seekers' preferred to surround themselves with as much information as they could find. With only one selection, it was sometimes necessary for the 'Limited' participants to make the most of a stimulus and 'force fit' it into the context of the problem. Participant L4 ('Limited' condition) reported the following:

> *"I would have wasted many things [stimuli] that I used, actually. (…) Actually I would have not used these kind of inputs, if I had the chance to change them over and over, I would have wasted them".*

Additionally, even thought the imposed limitation required a higher effort in selecting one search input and one stimulus, all 11 participants from the 'Limited' condition were positive about its usefulness. In fact, using the search tool in a limited way was appraised as a way to save time in stimuli searching.

### 6.5.2 Formulating keywords in the search tool

The interviews also enabled to investigate how designers initiated a stimuli search. Using as a starting point previous research on designers' inspiration processes (Gonçalves et al., 2013), the initial phases of the search process were addressed, especially three moments: definition of search input, search of stimuli, and selection of stimuli (Figure 6.7).

At the beginning of every design process, designers implicitly and/or explicitly define directions that guide their search, which are operationalized by using 'keywords'.

All participants considered that some keywords became prevalent throughout the session, opening possible directions to solve the problem. However, there were differences across conditions regarding how explicitly participants defined keywords. Participants in the 'Limited' condition were more cautious and took longer in the selection of keywords and made more explicit decisions than the 'Unlimited' condition. Ultimately, these participants regarded the option of using the search tool as a 'trump card' to be used as a last resort, especially when they ran out of ideas. Conversely, participants in the 'Unlimited' condition quickly decided on keywords, not explicitly relating it to a search goal.

The 'Limited' condition participants typed, in total, 16 keywords, from which ten were successful (i.e., the search tool produced results). On the six occasions participants typed keywords that were not included in the search tool they were allowed to change it. There were 29 search inputs in the 'Unlimited' condition, from which 20 were successfully associated with the data in the search tool. Figure 6.8 shows the keywords (in bold) most frequently selected by each treatment condition.

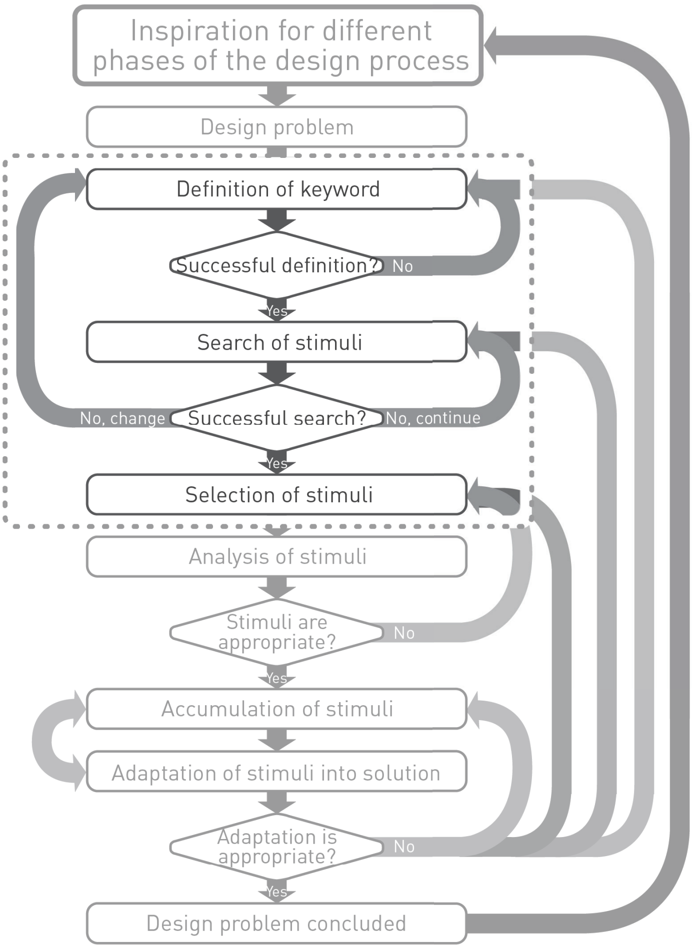



Figure 6.7. Simplified version of designers' inspiration process flowchart, adapted from Gonçalves et al. (2013). A complete version of this flowchart can be found in chapter 5, figure 5.8

When both treatment conditions ('Limited' and 'Unlimited') are added together, 'fear' was the most chosen search input (22.75%, selected by five participants). When clustering synonyms of the most common words, 'children' was equally highly chosen (22.75%, selected by five participants, taking into account the terms 'kid' and 'toddler'), but also 'sleep' (13.64%, selected by three participants, considering the term 'kids sleeping') and finally 'stuffed toy' (13.64%, chosen by three participants, including the terms 'teddy'). In the 'Unlimited' condition, closely related keywords were chosen most frequently and earlier in the participants' search for stimuli. Other keywords, which could be considered distantly related to the design brief, were chosen later. In the 'Limited' condition, a similar amount of closely and distantly related keywords were selected.

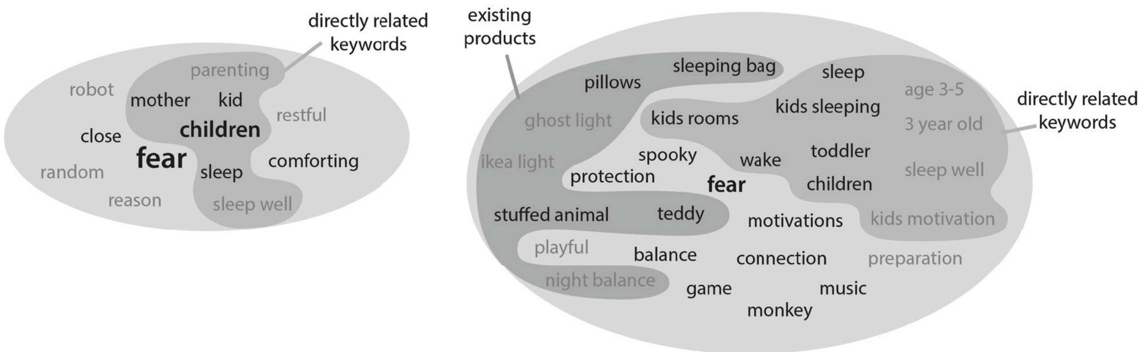



Figure 6.8. Search inputs chosen by the 'Limited' (left) and 'Unlimited' (right) conditions.

### 6.5.3 Forcing a strike of inspiration

A number of participants across treatment conditions reported to want to be struck by inspiration, in a random way, especially because finding useful distantly related stimuli was difficult for them. Especially in the case of two participants (from the 'Unlimited' and 'Limited' conditions), using 'random' as a keyword in Internet search engines is an acknowledged strategy, in order to increase the chances of coming across inspiration. In this manner, they are able to find unrelated stimuli that they subsequently try to force fit into their project. Participant U11 ('Unlimited') explains:

> *"If I was really stuck and couldn't generate ideas anymore, I think I would search for just a random image and then try to use that in any way to solve my problem. So it's basically a random stimulus as an image (…) I just type in 'random image' on Google. It works because you get images you don't know."*

This behaviour was also visible during the experiment, as one participant from the 'Limited' condition chose to search for the word 'random' in the search tool. This did not produce any results and the participant was authorized to choose another search input. Although most Internet search engines require a keyword to initiate a query, searching for stimuli in the Internet was considered by eight participants (one from 'Control', three from 'Unlimited' and four from 'Limited') as passive search, due to the unlimited amount of information it contains. This is also a possible explanation for the refusal to use the search tool (Section 6.5.1), as participant U4, from the 'Unlimited' condition, who intentionally did not use it, revealed:

> *"Yeah, I don't know, what do I type? And see images for what, as inspiration? (…) Then I would look into the Internet, but not for my final product. I prefer books and yeah. It's not the format, but I don't know exactly what to search there."*

This suggests that U4's hesitation about using the search tool might have to do with not knowing what to search for.

### 6.5.4 Most selected stimuli from the search tool

In alignment with previous findings (e.g., Muller, 1989; Henderson, 1999; Gonçalves et al., 2014), the participants expressed a preference for using visual stimuli for inspirational purposes, despite textual stimuli also being used during the experiment. These novice designers seemed to be aware of how potentially useful distantly related stimuli might be for ideation, as shown also by Ozkan and Dogan's findings (2013). However, they appeared to struggle to formulate keywords that could allow them to reach for more distant (stimuli) domains. There were striking differences between the treatment conditions regarding the selection of stimuli, which are visualised in Figure 6.9. Participants in the 'Unlimited' condition selected a variety of images and text (in total, 48 images and 27 texts). On the other hand, the majority of those in the 'Limited' condition selected textual stimulus, in their only opportunity to use the search tool (8 out of 11 participants). The six participants from the 'Unlimited' condition who used the search tool selected (clicked) a total of 75 stimuli entities. From this selection of stimuli entities: 34 (i.e., 45.3%) were closely related images; 20 (26.7%) were closely related texts; 14 (18.7%) were distantly related images; and only 7 (9.3%) were distantly related texts. Besides designers' preference for visual stimuli, the 'Unlimited' condition's substantial use of images is also due to expectations of their inspirational value. This is illustrated by participant U8 ('Unlimited'):

> *"I don't expect to get inspiration from it [text]. I expect to get more inspiration from images."*

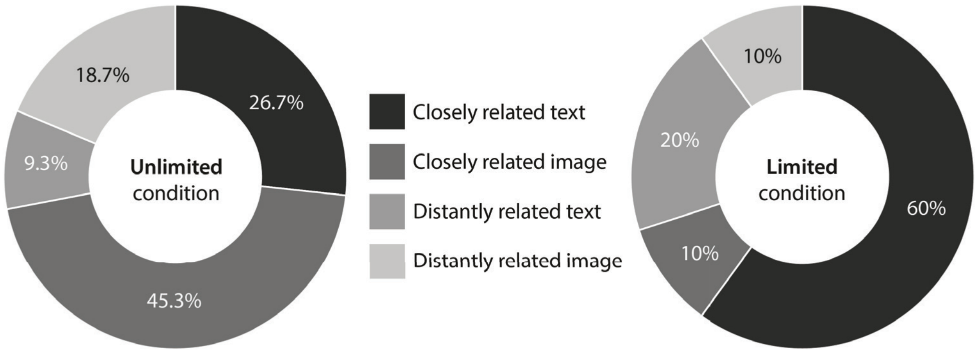



Figure 6.9. Numerical proportion of the 'Unlimited' (Left) and 'Limited' (Right) conditions' selection of stimuli.

In the 'Limited' condition, there were 10 selected (clicked) stimuli. From these: 6 (60%) were closely related text; 2 (20%) were distantly related text; 1 (10%) was a closely related image; and 1 (10%) was a distantly related image. As a result of the restricted tool use of the participants in the 'Limited' condition, they adopted a different search strategy when compared to those in the 'Unlimited' condition. Participants in the 'Limited' condition reported that their goal was to select a stimulus that could provide them with the highest exploitation value, to create as many ideas as possible with the one option they had. In an attempt to increase the chances of success in their restricted search, participants in the 'Limited' condition went against their general preferences for visual stimuli and opted to use textual stimuli instead, because they believed it could provide additional information.

### 6.5.5. Most used stimuli for ideas generated

This section compares in how far the stimuli selected for idea generation corresponds to the stimuli used by the participants. For this purpose, ideas were considered to be 'directly' influenced by a stimulus when the form, function and physical principle were transferred without transformation of the idea

(Figure 6.10). Conversely, ideas were considered to be 'indirectly' influenced by a stimulus when form and function were transferred, but transformed, or when only the principle was transferred (Figure 6.11). This analysis included not only the selected stimuli but also stimuli that happened to influence the participants even without selection, when the thumbnail was already sufficient to develop an idea.

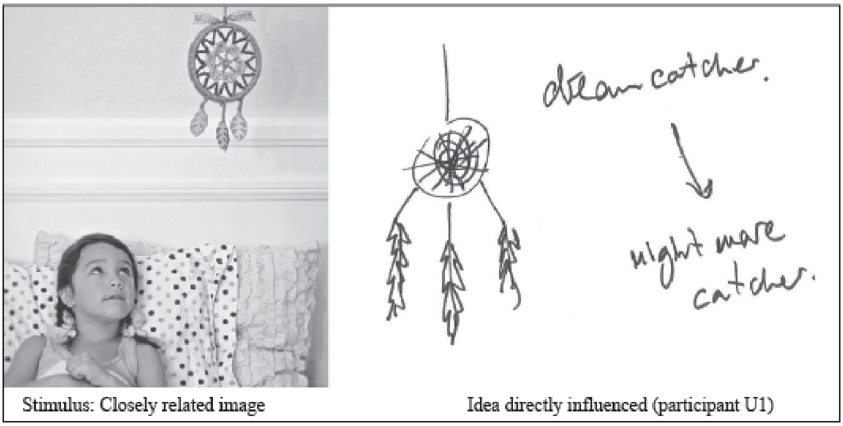



Figure 6.10. Example of participant's U1 idea, which was directly influenced by a closely related image.

In the 'Unlimited' condition, ideas were influenced by 27 stimulus entities (36% of the 75 stimuli selection). From the 27 stimuli used by the 'Unlimited' group, 12 were direct influences, whilst the remaining 15 stimuli were indirect influences.

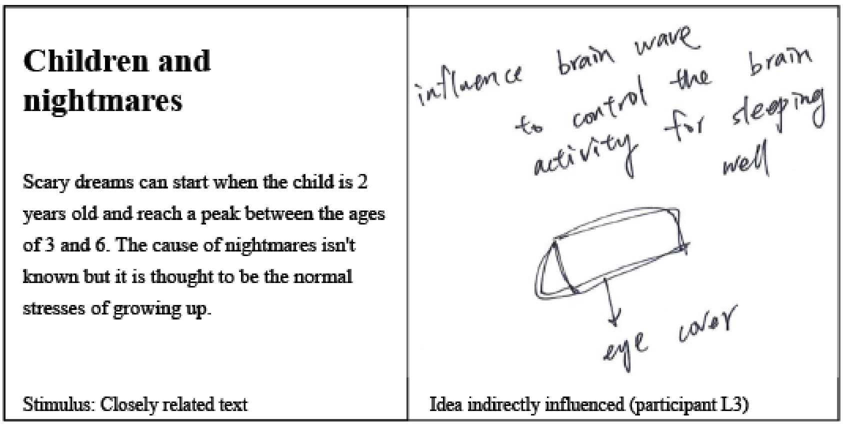



Figure 6.11. Example of participant's L3 idea, which was indirectly influenced by a closely related text.

The 'Limited' condition' ideas were influenced by 20 stimuli, which means that ten other stimuli inadvertently influenced participants' ideas without selection. From these 20 stimuli, 17 were indirect influences and only three were considered to be direct influences by the participants.

### 6.5.6. Reasons for stimuli selection

By asking participants about their reasons for choosing certain stimuli, it was possible to identify a number of drivers that motivated the selection of stimuli. Designers first need to decide on the keywords to find appropriate stimuli and only then they decide on whether they want to use a particular stimulus for designing. Table 6.5 indicates the number of participants, per treatment condition, who based their stimuli selection on each driver.

*Selection based on relevance* – With this driver, stimuli were selected (or dismissed) depending on how appropriate it was perceived to be in relation to the problem at hand (Kwasitsu, 2003; Hicks et al., 2002). This driver brought into focus familiar stimuli and it was dependent on the design problem being solved. Participant U1 ('Unlimited') reported on how easy it was to choose a relevant stimulus, as there was a clear connection with the design brief:

> *"I immediately thought of the connection, it just rang with me, it was a very natural thing. (…) That's why there was an inspiration."*

When focusing on relevance, there was a tendency to overlook distantly related stimuli, as the links between stimuli and target were not obvious or immediately available.

| Drivers for stimuli selection | UNLIMITED (N=10) | LIMITED (N=11) |
|---|---|---|
| Relevance | 6 | 2 |
| Recognition | 4 | 5 |
| Verification | 5 | 0 |
| Reliability | 1 | 1 |
| Curiosity | 3 | 7 |

Table 6.5. Number of participants per treatment condition and their use of selection drivers.

*Selection based on recognition* – These selections were based on whether the participants recognised or were already aware of the content of a stimulus. However, selections based on recognition did not usually result in generation of ideas. This, to some extent, explains the considerable number of selections of the 'Unlimited' condition, reported in Section 6.5.5. Selections based on recognition occurred also in the 'Limited' condition, as reported by participant L2:

> "Here there was 'Children afraid clowns' [closely related textual stimulus] and I was afraid of clowns as well. I have always wondered why and now I know why".

In general, *recognition* was an important motivator to select stimuli (or to overlook it) and it could be compared to *Experience with source* (one possible determinant for information selection, identified by Kwasitsu, 2003). Selection based on *recognition*, though, is different from selection based on *relevance*: A stimulus could be considered relevant because it was recognised to be appropriate to the problem. However, *recognition* is independent of the context of the problem and can occur even when a stimulus is considered irrelevant. Selections based on *recognition* also led to misinterpretations, with participants hoping to obtain a certain stimulus and receiving unexpected information. This resulted either in fortuitous encounters, with the stimulus being considered useful, or, especially in the 'Limited' condition, these misunderstandings led to frustration and disappointment with the search tool.

*Selection based on verification* – Another reason for selection is based on the need to verify ideas generated or decisions made. *Verification* became important at later stages of their process (mainly in the 'Unlimited' condition), when they had already generated some ideas and needed to validate them. In general, it can be assumed that *verification* as a driver occurs mainly in the converging phases of the design process. As an example of this, participant U7 ('Unlimited') indicated:

> "And you should do more research to know which kind of stimulus works for children now, because I don't have experience with children. And it takes a lot more research."

*Selection based on reliability* – With this driver, selection was based on how reliable a stimulus appeared to be. Choosing a stimulus was dependent on the appearance of formality or how grounded on factual information it appeared to be, as explained by participant L5 ('Limited'):

> *"The term 'co-sleeping' was quite new for me, I thought I just had found something scientific, something that is used by authorities."*

*Reliability* can be compared to *Authenticity* or *Credibility* as factors that influence the selection of information (respectively, Hicks et al., 2002; Wilson, 1997).

*Selection based on curiosity* – Contrary to selections based on *relevance, verification* and *recognition*, some participants selected stimuli specifically because they were unfamiliar to them, eye-catching or unexpected. Participant L11 ('Limited') reported:

> *"This one was the only thing I didn't expect that should be there."*

Selections driven by *curiosity* in the 'Unlimited' condition were very brief, with just enough time to click and open the image/text. In the 'Limited' condition, these selections were more strategic, chosen to provide new and unexpected information. In general, unexpected stimuli selected by curiosity were also distantly related to the brief, thus entailing a higher effort of adapting the information into a solution.

## 6.6. Discussion

The goal of combining in a single study quantitative and qualitative methods was to establish a connection between input, process and output. Although the statistical analysis of the participants' outcome was predominantly non-significant, the qualitative analysis of the interviews and design process provided interesting insights on the initial phases of the inspiration process. As indicated in section 6.2, the aim was to answer the following research question: *How do designers select external stimuli and how does it influence creativity in the design process?* The research question is answered in the following five sub-sections: the process of searching is elaborated in Section 6.6.1; the selection and retrieval of stimuli is explained in Sections 6.6.2 and 6.6.3; Section 6.6.4, discusses how the stimuli selected by the participants influenced their idea generation; finally Section 6.6.5 presents an overall analysis of the inspiration process, based on the results.

### 6.6.1. Inspiration avoiders and inspiration seekers

In this study, two distinct inspiration behaviours were observed: there were participants who were inspiration seekers, and those who were inspiration avoiders. The reactance theory (Brehm, 1966) offers a possible explanation for the difference between 'inspiration-avoider' and 'inspiration-seeker' behaviour. Reactance can occur when a person's perceived freedom is limited, such as when 'Limited' participants' search processes were restricted to only one search input and only one selection. When a behavioural freedom is externally restricted or eliminated, people tend to desire their lost freedom even more and try to reinstate it. According to Brehm (1966), there are two possible manifestations of the occurrence of reactance behaviour: (1) to try to restore the lost/endangered freedom and (2) to perceive it to be more attractive than before. When questioned about whether they would have used the search tool had there been no limitations, on either the amount of search inputs or stimuli chosen, all participants from the 'Limited' condition expressed the importance of the inclusion of inspiration search in the creation of ideas. Thus, the participants in the 'Limited' condition considered the search tool as more appealing than those in the 'Unlimited' condition, who had no restrictions. Furthermore, the 'Limited' participants also tried to restore that option by taking advantage of the stimulus they selected. On the other hand, it is possible that the participants' awareness of being in an experimental setting may have biased their behaviour. Nevertheless, the results do not support that being inspiration seeker or avoider is any better than the other. The 'Control' condition had no access to stimuli and thus, these participants could not be considered either inspiration avoiders or seekers. However, they were able to create ideas regardless of lacking external stimuli.

### 6.6.2. Drivers for inspiration search

Five drivers for inspiration search were revealed in the analysis of the designers' processes. Again, differences were found between 'Unlimited' and 'Limited' conditions. 'Unlimited' participants selected stimuli by their *relevance*, because they were *recognisable* and enabled *verification* of their ideas. This explains, to some extent, why these participants might have made less efficient use of the search tool (see Section 6.5.5): selections based on *recognition* and *verification* usually did not lead to idea generation. Many 'Unlimited' participants were constantly browsing for additional stimuli without incorporating them in ideas. Furthermore, these drivers, especially *relevance*, offer an explanation on why there were so many ideas directly influenced by stimuli in the 'Unlimited' condition. By being relevant to the problem at hand, the chosen stimuli were often also closely related. Thus, there were more superficial similarities between ideas and stimuli, which were considered less rare than the ones created by the 'Control' condition.

The 'Limited' condition' selections were mostly driven by *curiosity* and *recognition*. Whilst recognition as a driver enabled participants to be more confident in their stimuli selection (as they were already experienced with the source), selections driven by *curiosity* aimed to access unknown information and exploit the potential value of the stimulus. This reveals that the 'Limited' condition had to select stimuli more strategically than the 'Unlimited', hoping to find stimuli that could help them generate as many ideas as possible. However, selections driven by curiosity usually led to unexpected stimuli, normally distantly related to the brief, which are considered to be more difficult to implement than closely related ones (e.g., Christensen and Schunn, 2007; Ozkan and Dogan, 2013). Therefore, the higher cognitive effort of perceiving, transferring and transforming distantly related stimuli into the context of the brief might have led the participants in the 'Limited' condition to develop less unique ideas.

### 6.6.3. Random active search of stimuli

The majority of designers in all conditions seemed to recognise the positive influence distantly related stimuli can have as potential inspiration sources. However, one of the challenges of using distantly related stimuli is the difficulties in recognising what could be relevant or inspiring. When there are no strict time constraints in a project, activities such as a walk in the park or 'people watching' can lead to these random passive encounters with inspiration sources. When time is limited, though, as it is frequently in design studios, designers can adopt alternative methods to support fruitful encounters with different types of stimuli. In this study, a possible alternative was observed, which was the use of search engines as a medium to provoke opportunistic encounters with stimuli and to take advantage of any relevant information in this way (Seifert et al., 1995). These results coincide with findings by Herring et al. (2009) and Mougenot et al. (2008), who indicated that the Internet can be used as a brainstorming tool, to come up with keywords designers initially did not think of. Similarly, participants in this study interpreted the search tool as passive search, which enabled them to stumble upon potentially inspiring stimuli. This behaviour might be caused by the uncertainty of not knowing what to search for. Without having a specific direction, designers might be dependent on randomly finding relevant stimuli in an opportunistic manner, which shows that even the process of defining a search input can be uncertain. Furthermore, the results show that there is another type of search designers engage in, in addition to the ones presented in the section 6.1: *Random Active Search*. This type of search is characterized by being active and intentional but without a specific goal. Table 6.6 summarises the five types of search approaches designers might follow to find stimuli, organized into three criteria: whether there is a problem at hand to solve (and the search is motivated by the problem); whether the search for stimuli is intentional; and whether designers know what they want to find.

Table 6.6. Five types of search for information, for inspiration purposes.

| SEARCH TYPOLOGIES | | Problem to solve? | Intention to search? | Know keyword to search? |
|---|---|---|---|---|
| Active | Active search with purpose | ✔ | ✔ | ✔ |
| | Active search without purpose | N/A | ✔ | N/A |
| | **Random active search** | ✔ | ✔ | ✖ |
| Passive | Passive search (serendipity) | ✔ | ✖ | ✖ |
| | Passive attention | N/A | ✖ | N/A |

The results indicate that the issue of not being able to reach more distantly related stimuli is a knowledge problem, not a motivational one. These novice designers did want to incorporate distantly related stimuli, under the assumption that it can lead to more creative ideas. Although they were motivated, they could not simply reach disparate domains because they did not know what to search for. For this purpose, they devised a strategy that enabled them to actively force passive encounters with stimuli.

#### 6.6.4. Influence of the chosen stimuli in idea generation

Surprisingly, the 'Control' condition, who received no stimuli, generated ideas that were considered to be more unique (rare) than the 'Unlimited' and 'Limited' conditions. There were no further differences between any of the three conditions. This indicates that, although the 'Unlimited' participants' process was very different from the 'Limited' one, their selection of stimuli and its influence were not sufficient to lead to more unique ideas. In fact, it can be argued that the added complexity of choosing keywords and stimuli might have hampered the designers' creative outcome. In the 'Unlimited' condition, the long periods of time participants spent within the search tool while browsing through stimuli reduced their ideation time. In the 'Limited' condition, extra cognitive effort could have resulted from the longer period reflecting on the process and on keywords to use in the search tool.

The null influence of stimuli in the treatment conditions contradicts previous studies (e.g., Casakin and Goldschmidt, 2000; Goldschmidt and Smolkov, 2006) and challenges the notion that using external stimuli is more beneficial to ideation and creativity than when no stimuli are present. However, the set up of this study might also be the reason for these results. Related literature have mainly focussed on the inclusion of only one stimulus when comparing to other conditions, whilst the present study allowed the participants to either select an unlimited amount of stimuli or to choose only one stimulus. The process of searching and choosing stimuli was more complicated and, thus, less inspiring than not having stimuli at all. On the other hand, designers do spend large amounts of time searching for stimuli, mainly in the Internet (Mougenot et al., 2008; Gonçalves et al., 2014) and the 'Unlimited' condition coincides with usual design situations. Therefore, designers who usually keep searching for stimuli online for endless hours might be hindering their own creativity, instead of supporting it.

### 6.6.5. Elaboration of designers' inspiration process

Building on the previously mentioned framework of designers' inspiration process, adapted from Gonçalves et al. (2013) and based on Eckert and Stacey (2003), it was possible to elaborate on the initial three phases of the inspiration process, which are the most relevant for this study (Figure 6.12).

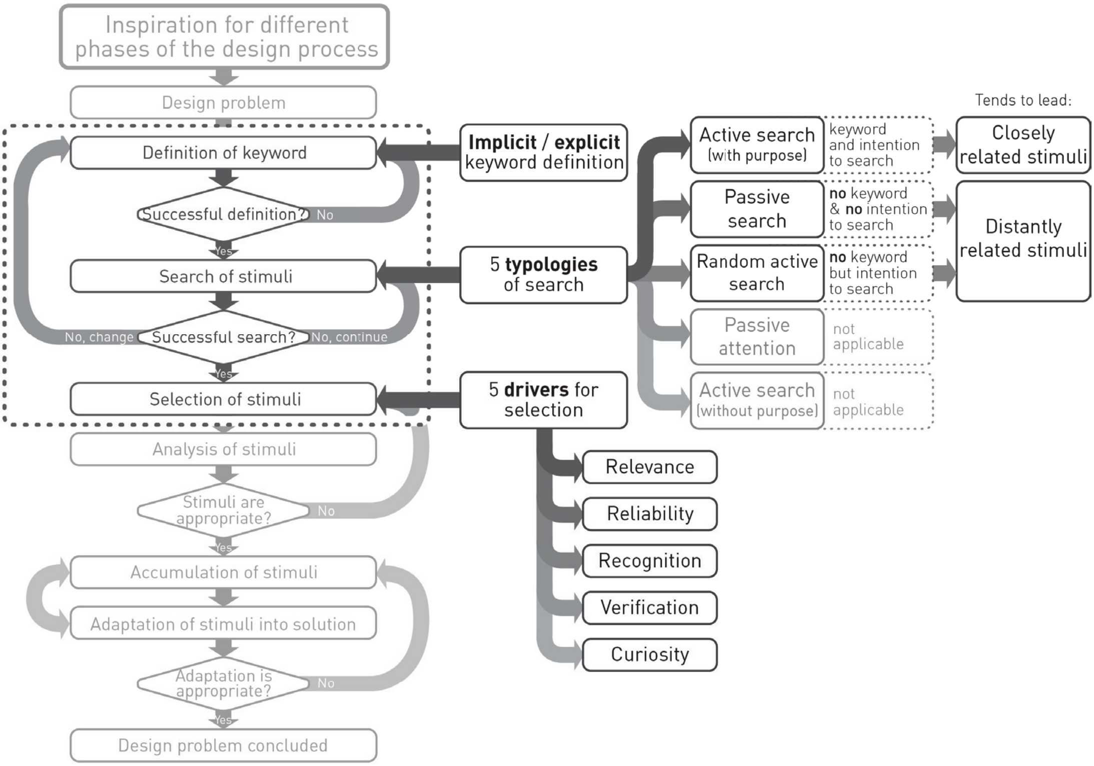



Figure 6.12. Focus on three phases of the inspiration process: definition of keywords, search and selection of stimuli.

The 'Definition of keyword' was observed to be an essential step, which normally happens implicitly. It is through these keywords that pattern-finding mechanisms in the brain are adjusted to focus on the most relevant stimuli for the problem at hand. When these triggers are recognised, associations between information already stored in the brain and external stimuli can lead to the creation of new meanings (Mednick, 1962). Initially, most search keywords aim to collect contextual information of the problem, which tends to be closely related, and only later remote associations can be established. The keyword definition influences the remaining steps of the inspiration process, as it directs which kind of stimuli can be found. Concerning the 'Search of stimuli', one more type of search was identified – *Random Active* – besides the four aforementioned (Section 6.1).

Figure 6.12 emphasises *Active, Passive* and *Random Active Search* typologies, as they refer to searches motivated by existing problems (*Passive Attention* and *Ongoing Search* might occur independently of a problem). Whilst *active search* is intentional and occurs mainly to obtain specific information (to frame the problem), *passive* and *random active search* tend to result in unexpected encounters with stimuli. These types of search coincide in the lack of a specific keyword to guide the search and differ in intentionality. With *passive search*, designers either miss or stumble upon inspiration, without much control on the result, whilst *random active search* refers to intentional active search but without a specific keyword/direction. This influences the selection of stimuli, which can be unconsciously motivated by five drivers. Depending on the designers' goals and on the phase of the design process, certain drivers can become prominent. These drivers also influence the type of stimuli found.

## 6.7. Conclusions

In this chapter, the inspiration process of design students has been described, analysed, and evaluated by identifying how they search, select and retrieve external stimuli for inspirational purposes. Designing requires, among others, a continuous switch between information stored in the memory and external stimuli (Norman, 1993; Ware, 2008). Internal and external stimuli enable us to describe, analyse and understand the world, which makes them powerful reasoning aids (Ware, 2008). Understanding how designers choose external stimuli enables design creativity to be better supported and, in tandem, to adapt innovation efforts to the real need of information and to avoid unstructured Internet search.

A number of findings were unveiled. The results highlighted the importance of carefully considering the stage of which keywords are defined, when designers are trying to come up with appropriate terms to initiate their search process. This is the initial step of the inspiration process, which has not been thoroughly considered by previous research. Furthermore, the study revealed the search typologies novice designers go through intuitively without reflection, to be able to search stimuli from further domains. And finally, it was possible to identify some of the possible drivers that motivate designers in their selection of stimuli. These are relevant findings because each step of the inspiration process can now be tackled individually, to better support it in general.

To close the circle and return to the example of *Alice's Adventures in Wonderland*, when the destination is to achieve creative results, knowing which 'road' to take is important, as it determines the following steps of the inspiration process. By reflecting on the use of external stimuli, designers can potentially make more efficient choices instead of blindly chancing upon an unlimited diversity of available sources. In this way, the key for a more effective search for inspiration lies on designers' awareness of their own inspiration process. Thus, they can redirect their attention focus, to be able to recognise the potential value of keywords (formulated to initiate a search) and drivers (to select stimuli), which could otherwise be dependent on pure chance. However, designers are prone to engage in the process of causing random encounters with potential inspiration sources. Presently, Internet search engines (the most common medium to obtain stimuli) require keywords to initiate a search, but they are still used as a brainstorming tool to be able to access further directions (Herring et al., 2009; Mougenot et al., 2008). This process can continue for a considerable time as it is either based on chance or trial and error. To increase the efficiency of finding relevant distantly related stimuli, computational tools could be developed to support a less time-consuming search of stimuli with different levels of sematic distance to the problem domain, to fit different phases of the design process. However, previous research on computational tools and their usefulness for retrieval of analog or bio-inspired stimuli assume designers know what to search for and thus, how to actually initiate their search (Linsey, Markman and Wood, 2012; Vattam et al., 2010). In such studies, retrieval of stimuli was considered the most difficult stage in order to successfully use analogies or bio-inspired stimuli. However, the challenges associated with the formulation of keywords when initiating a search process would precede the retrieval of external stimuli. Although existing computational tools support the retrieval of stimuli, they do not aid in the process of framing the problem, defining directions and formulating appropriate keywords. By clarifying which steps designers go through in the inspiration process, another important stage was recognised – defining keywords – which, until now, has been disregarded from current computational tools, and should thus be considered in future developments. This requirement was, to some extent, recognised by recent studies on existing software tools supporting analogical and biomimetic design (e.g., Vattam and Goel, 2011; Töre Yargin and Crilly, 2015). Particularly, these studies recommend that the development of software tools should enable several modes of accessibility, such as browsing, but also other forms of data categorisation. These alternative modes of accessibility could support designers even when they do not clearly know what they are looking for.

These findings are relevant for design education and practice, as they provide insights into how designers come across stimuli, how they select them and how these might influence design creativity.

Finally, a number of limitations need to be considered. The set up of this study involved triangulation of methods by combining quantitative and qualitative analysis. Although the number of participants is considered adequate for a qualitative analysis, it is limited for a statistical analysis, which indicates that these statistical results might not be easily generalised. Nevertheless, this study enabled an in-depth analysis of designers' inspiration process.

On the other hand, further avenues for future research emerge from this study. It would be interesting to investigate the influence of added cognitive efforts of formulating keywords and selecting external stimuli in a larger sample of participants. This would provide insights on the difference between 'given' and 'intentionally retrieved' stimuli and their influence on the creative outcome. Moreover, it would be relevant to investigate the usefulness of certain selection drivers in relation to the creative design outcome. This would enable the development of computational tools that could support designers' search, selection and retrieval of stimuli, even when the goal is uncertain or unknown. Finally, the combined creativity score developed in this study could be used by other researchers, in order to explore and compare creativity across different studies and design problems. Although there is an essential need to develop a way how to assess and compare design creativity across various persons, situations and studies, the evaluation of a creativity measurement is still a big challenge, for which there seems no agreement in sight.

Chapter 7 figure:
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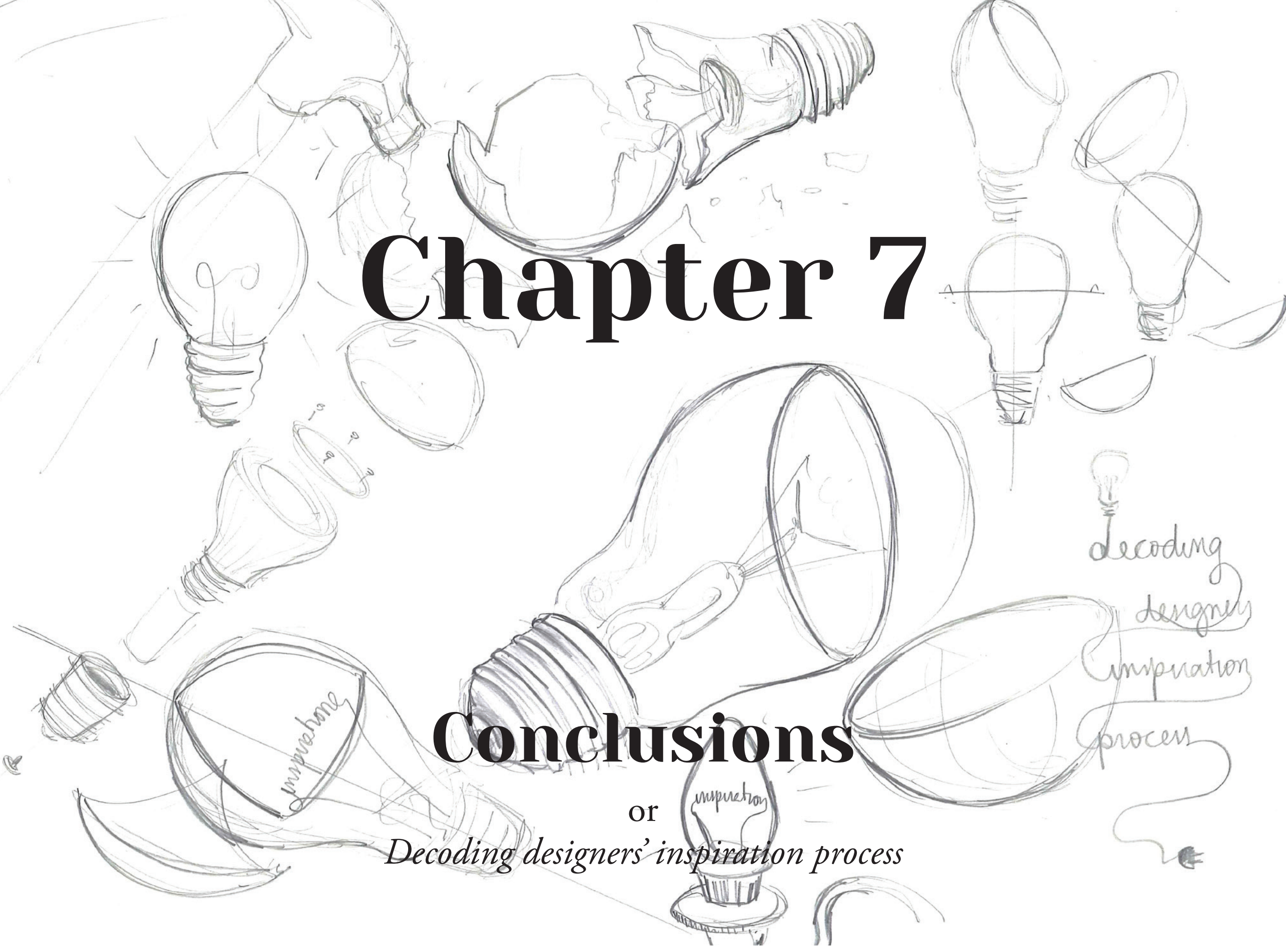



# Chapter 7

## Conclusions

or

*Decoding designers' inspiration process*

*Each individual empirical study, previously presented in chapter 3, 4, 5 and 6, addressed the research questions, which were initially proposed in the Introduction (Chapter 1). In the final chapter of this thesis, the answers for each sub-question are summarized and the main findings are identified. As a last reflection, this chapter strives to decode designers' inspiration process, by discussing the most important insights in relation to relevant design theory literature. Finally, implications and recommendations for design practice and education conclude this work.*

The goal of this doctoral thesis was to investigate how designers are influenced by external stimuli, to strengthen designers' creative outcome. This was achieved by approaching the topic of inspiration process in an 'input-output' system, by addressing first which 'input' designers search for and use in their usual design projects (Chapter 3, in reference to Study I). Subsequently, the emphasis was on 'output', i.e., the influence external stimuli ('input') has on the designers' 'output' (Chapter 4, in reference to Study II). Finally, the inspiration process itself was analysed, in order to access designers' implicit procedures while searching, selecting and implementing external stimuli in the context of a design problem (Chapters 5 and 6, respectively Studies III and IV). The four studies that compose this thesis collectively contribute to existing theories on the influence of external stimuli within the context of design creativity. The final chapter of this thesis recapitulates the most important findings, framing them in relation to the present body of knowledge and by formulating a model of designers' inspiration process. This chapter (and thesis) is concluded with reflections and suggestions for future research, as well as with recommendations for design education and practice.

## 7.1. Summary of findings

This section presents an abridged version of the main findings, which are discussed under each sub-research-question. Figure 7.1 illustrates how each sub-question relates to the main research question, and the different focal points they approached. For convenience, Figure 7.1 also includes an indication of the empirical studies that addressed each sub-question.

### 7.1.1. What are the external stimuli designers search for during idea generation?

Chapter 3 identified the types of stimuli and ideation methods student and professional designers mostly prefer. Although there were specific differences between student and professional designers, in general, their behaviour towards stimuli and use of methods was similar. Despite the virtually unlimited number of available stimuli, designers have a rather limited range of external stimuli preferences. Regarding the representation type, student and professional designers showed a higher preference for visual stimuli, as in accordance with many other studies (Mougenot, Bouchard and Aoussat, 2008; Hannington, 2003; Henderson, 1999; Tovey, 1992; Muller, 1989). However, whilst images are the dominant preference for design students, professionals ascribe as much preference to images as to objects. Textual stimuli, on the other hand, are often overlooked as a potential inspiration material. This restricted use of non-pictorial stimuli (despite evidence suggesting text is a valid alternative to encourage creativity [Goldschmidt and Sever, 2010; Chiu & Shu, 2007, 2012]) was the motivation to investigate the usefulness of textual stimuli in design ideation (explored in Chapter 4). The designers in this study also showed to be restricted in their use of stimuli content, mostly preferring design or problem-related information (examples of competitor products or similar solutions on Internet). Although this type of closely related information is relevant to understand the problem and its context, it can also be linked to design fixation behaviours.

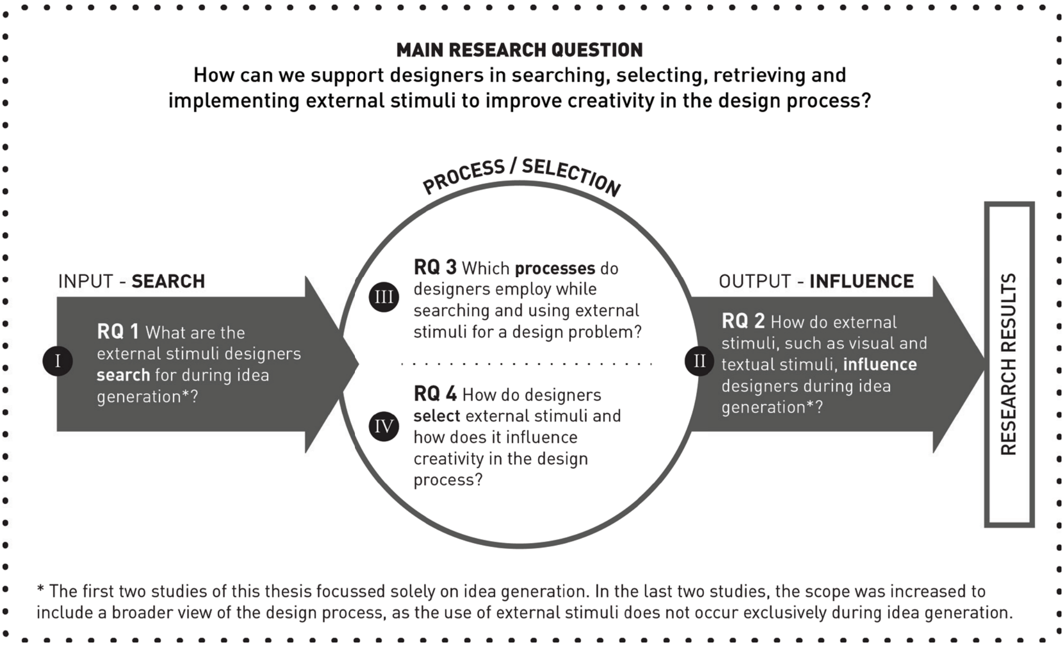
Designers' preference on ideation methods was also investigated, which revealed a striking preference for brainstorming (especially by student designers). This suggests a limited use of methods for different phases of the design process, which could otherwise enhance a more thorough exploration of the solution space. An important difference between student and professional designers is that the latter group has a more balanced set of inspiration preferences. Both in the representation type of stimuli and ideation methods, student designers tend to stick to only one approach, ignoring any benefits that other stimuli or methods could provide. Conversely, professional designers have a slightly larger range of creative approaches, to cover different goals within the design process.

Thus, designers seem to be hijacking their own creativity, by using the most readily available methods and stimuli (i.e., easily accessible visual stimuli, which are closely related to the problem). Especially in the case of professional designers, this behaviour can be explained as a reflected economical approach to the inspiration process. Considering the hectic environment in design practice, where deadlines get tightened, professional designers tend to reuse available precedents and to avoid 'reinventing the wheel', as a cognitive economy strategy (Visser, 1996; Pasman, 2003; Goldschmidt, 2003). On one hand, using readily available methods and stimuli may be beneficial, especially if reflection is involved. This strategy reduces the risk of venturing into something new, where quality cannot be guaranteed (contrary to reusing solutions, which have been proved over and over). On the other hand, this strategy streamlines the creative process and puts creative exploration at risk.

Finally, a number of assumptions were also verified, laying the foundation for the remaining empirical chapters of this thesis: firstly, the Internet was considered to be the most preferred source of information (although it could also be regarded as a medium); secondly, both students and professionals considered inspiration search to be most important during idea generation.

Considering how similar design professionals' preferences were to the students', the differences in performance might lie in their distinct cognitive processing. In conclusion, the type of stimuli used for inspiration does not solely predict how creative a solution can be, but it might rather be supported by how stimuli are transformed to generate innovative solutions.

Figure 7.1. Overview and structure of this thesis, in relation to the main research question and sub-questions.




### 7.1.2. How do external stimuli, such as visual and textual stimuli, influence designers during idea generation?

Chapter 4 describes a large-scale experimental study with 137 design students, in seven conditions, where the goal was to investigate the usefulness of visual and textual stimuli (with three levels of semantic distance) during idea generation. The influence of closely related, distantly related and unrelated stimuli, both in visual and textual forms, were investigated in relation to three creativity factors: fluency, originality and flexibility. The main finding resulting from this study was the understanding that the usefulness of inspiration stimuli varies in a *curvilinear pattern.* Considering semantic distance as a continuum, closely related stimuli lie on one side of the spectrum, where there is a tendency to adhere to similar solutions, which can hinder the exploration of the solution space. The other side of this continuum comprises unrelated stimuli, where it is difficult to recognise the relevance of too distant stimuli. Along this continuum, between stimuli that are either too close or too far, lies an 'optimal' range of semantic distance, an inspiration peak where more creative results can be achieved. This pattern was identified, at different levels, in both visual and textual stimuli portraying distantly related semantic distance.

Furthermore, these findings support that textual stimuli, even though the least preferred representation type by designers (chapter 3), should not be disregarded as potential inspiration material. In fact, distantly related textual stimuli led to the highest creative output when compared to visual stimuli (albeit not always significantly).

Although textual stimuli are strongly supported in this thesis as relevant external stimuli for design idea generation, this does not mean that other types of stimuli should be dismissed. Designers' almost exclusive preference and use of pictorial stimuli seems to come from an implicit assumption that images can be more inspirational than any other representation type. Nevertheless, the influence of visual stimuli in design has been associated with dual-effects in design creativity (Cai, Do, and Zimring, 2010; Perttula and Liikkanen, 2006), with both beneficial and detrimental effects. Thus, this thesis supports the notion that one must choose adequately when and how to use different types of representational stimuli. During the initial phases of Problem Definition/Task Clarification and Conceptual phase, closely related images, especially when portraying existing similar products, might not be the most beneficial to be able to generate creative ideas. However, this type of information can still be meaningful, as it establishes a benchmark position for what already exists in the market.

### 7.1.3. Which processes do designers employ while searching and using inspiration sources for a design problem?

Chapter 5 reported on a case study involving eight Bachelor design students, during the development of their final Bachelor design project. In the course of 10 weeks, the students were followed and their process and outcome were collected periodically.

The main finding resulting from this case study was the development of a flowchart that represents designers' inspiration process throughout a design project, where the main steps were identified. This is a cyclic process that occurs several times at different phases of the design process, driven by three main goals: searching for inspiration sources to define the problem (*Inspiration for problem definition)*, to explore solutions for sub-problems (*Inspiration for sub-problems exploration*) and to refine the solution by sub-dividing it (*Inspiration for sub-solutions refinement*) (See figure 5.8 in chapter 5). Therefore, stimuli search and use takes place at multiple occasions during a design process (not only in the early stages) and, depending on the goal of the inspiration cycle, the type and content of stimuli changes. Each cycle leads to a different reformulation of the problem or of the solution.

Being largely an unconscious process, the findings from this study reveal that inspiration is perceived as spontaneous and unstructured because designers tend not to reflect on their inspiration process. Encouraging active reflection on the inspiration process during the early years of design education can help designers make better use of available stimuli for the design problem at hand.

### 7.1.4. How do designers select external stimuli during idea generation and how does that influence creativity in the design process?

Chapter 6 describes the combined experimental study and interviews with 31 design students, which explores the selection process of stimuli for inspirational purposes. Considering the inspiration process flowchart described in Chapter 5 (figure 5.8), specific phases responsible for the selection of stimuli during ideation were elaborated. They are: Definition of keyword; Search of stimuli; and Selection of stimuli. By focussing on these three phases of the inspiration process, it was possible to understand how designers come across diverse stimuli and how they become relevant to the development of creative ideas. The findings from chapter 6 revealed that the issue of using stimuli successfully in design begins with the formulation of keywords for each cycle of the inspiration process, as designers tend to have difficulties in finding appropriate keywords for search. Furthermore, typologies for stimuli search were identified, distinguished by three criteria: whether the search is motivated by a problem at hand; whether the search for stimuli is intentional; and whether designers know what they want to find. Finally, five drivers that motivate designers in stimuli selection were identified: relevance; recognition; verification; reliability and curiosity. These drivers tend to become prominent according to the goal and phase of the inspiration and design process, besides being able to influence the type of stimuli selected. Together, these findings brought in-depth knowledge on the specific steps designers encounter when using external stimuli for inspirational purposes.

## 7.2. The inspiration process decoded

A complex network of influences plays a part in the designer's context. Some of these influences lie at the level of the individual designer or in relation to a team; other influencing components come from the characteristics of the problem at hand, the design process or solution being designed; and finally, they can also relate to the organisational context (Badke-Schaub et al., 2010). Evidently, within these factors, an important influence is information.

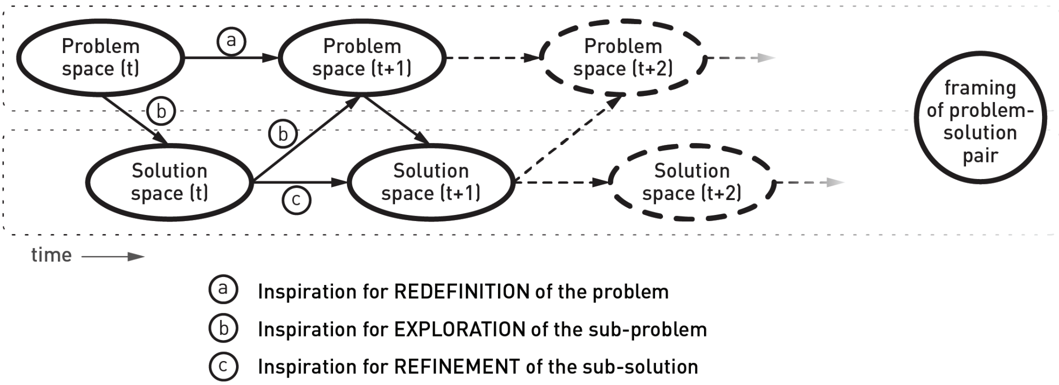
To investigate the influence of stimuli in design, a number of theoretical concepts were relevant and provided the context for the conclusions of this research project: it follows a designer-centred methodology approach (Badke-Schaub, 2007; Badke-Schaub et al., 2010; Badke-Schaub, Daalhuizen and Roozenburg, 2011), borrows its framework from Wilson's general model of information behaviour (Wilson, 1997) and it hinges on Schön's reflective practice theory (Schön, 1983).

From the four empirical chapters here presented, a common denominator seems

to be present, either in an explicit or implicit manner: the value of reflection within the inspiration process in design. Schön's critical work on the reflective practitioner (1983) is then a natural starting point to discuss the inspiration process in design and understand how can it be better supported.
Schön developed his constructivist perspective of design as a 'reflective practice' as a response to Simon's positivist theory of design (1969). Although paradoxical perspectives, both theories have been co-habiting in the discussion of design methodology, as they enable different interpretations of the design practices, depending on the 'paradigmatic' lens used (Dorst, 1997; Dorst and Dijkuis, 2005).
Schön described design process in terms of its mechanisms, composed by the following four activities: *naming, framing, moving* and *evaluating*. *Naming* refers to the identification of the issues to be tackled; *framing* indicates the step where these issues are understood within a constructed perspective; while *moving*, the designer acts according to the previous *naming* or *framing*; and finally, *evaluating* refers to the assessment of the previous activities, which could result in different *moves*, in the problem *reframing* or even in the *naming* of different entities.
In this way, Schön (1983) considers design as a reflective conversation, an iterative process between the designer and the situation, supported by these four activities. While designing, the designer constructs his/her vision of the problem (by *naming, framing* it and making *moves*) and the problem 'talks back' (when the designer *evaluates* his/her actions). Here lies the root of Schön's reflective practice: phenomenology. Phenomenology is based on the idea that there is an interaction between the person and the object (world/situation), where the person creates a subjective interpretation of the object and the latter influences how the person perceives reality. This comes in direct disagreement, for instance, with the rational problem-solving paradigm (Simon, 1969), which has its foundations in positivism and an objective interpretation of reality.
In the reflective practice perspective, the design problem is not fixed (again, contrary to Simon's rational problem-solving [1969]). The design process can rather be understood as co-evolving together, where several rounds of iteration contribute not only to the development of the solution but also to the interpretation of the problem. This relates to the concept of co-evolution of the

design problem and solution (Maher and Poon, 1996; Maher, 2000; Dorst and Cross, 2001; Wiltschnig, Christensen and Ball, 2013). The co-evolution model, firstly presented by Maher (1994; Maher and Poon, 1996) distinguishes between two design spaces: the problem space, which includes its initial formulation, requirements and constraints; and the solution space, where possible solution structures can be developed. Figure 7.2 illustrates how the problem and solution space evolve over time, by interacting in the following manners (note that t refers to time in point, while t+1 is a subsequent moment of the timeline):
*Problem space (t) to problem space (t+1):* a horizontal move within the problem space, which results in the evolution of the definition of the problem.
*Problem space (t) to solution space (t)*: a downward diagonal move from the problem to the solution space, where an idea emerges from the requirements.
*Solution space (t) to problem space (t+1)*: an upward diagonal move from the solution to the problem space, which refers to a change of the problem framing caused by a solution that did not fulfil the requirements.
*Solution space (t) to solution space (t+1)*: a horizontal move within the solution space, where an idea evolves over time.
Thus, designers keep iterating between their interpretation of the design brief and the development of solutions, until they can pair a solution with the problem. As indicated in figure 7.2, this eventually results in a framing of a problem-solution pair (Schön, 1983; Dorst and Cross, 2001).

Figure 7.2. Co-evolution in design, and the potential influence of inspiration goals in each move between problem and solution space.




In their study on co-evolution, Dorst and Cross (2001) recognised that information can be a trigger to move between and across spaces. As part of their set up, participants could ask for information about the problem and, in this process, one stimulus became particularly relevant to them. That stimulus triggered the participants to create new requirements, which spurred the evolution of the problem space and, consequently, the solution space. The influence of stimuli in the co-evolution model was not studied or recognised in prior or subsequent studies on this topic. Nevertheless, it is possible to propose that stimuli can support diagonal and horizontal moves within and between the problem and solution space, as demonstrated in figure 7.2.

The three main goals for the inspiration process revealed by the findings of Study III (Chapter 5, and previously mentioned in section 7.1.4) can then be mapped into the co-evolution model. As illustrated in figure 7.2, designers can move across the problem space when their aim is to search for stimuli to reframe the problem (*a* – inspiration for redefinition of the problem). Furthermore, searching for stimuli to expand the interpretation of the sub-problem (*b* – inspiration for exploration of the sub-problem) can result in diagonal moves from problem to solution space (or vice versa). This cycle of the inspiration process is characterised by generating alternatives to parts of the problem, which was previously subdivided to be more manageable. Thus, both (sub)solutions and (sub)problems evolve together. Finally, designers can move horizontally across the solution space by searching for stimuli that can support their development until completion (*c* – inspiration for refinement of sub-solutions).

As Adams, Turns and Atman (2003, p.292) stated:

> *"Information cannot be gathered meaningfully unless the problem is understood but you can't understand the problem without gathering information about it".*

It is through reflecting-in-action (see 2.2.1) that designers can adapt to the inherent uncertainty of the design problem and elaborate their understanding of its framing, a process characterized by Schön (1983) as 'back-talk'. Whenever designers encounter unexpected information, new opportunities for reflecting-in-action and 'back-talk' emerge and a new frame of the (sub)problem or (sub) solution might be defined.

To consolidate the findings from this thesis, an inspiration process model was developed, illustrated in Figure 7.3. This model integrates the previous findings presented by the inspiration process flowchart (Chapter 5, figure 5.8. and Chapter 6, figure 6.12) and proposes a comprehensive overview of the inspiration process, in relation to the many steps designers experience every time a need for stimuli arises. Iterations occur frequently between steps, but for simplification, they were not included in this model (to observe possible iterations within phases, please see the flowchart in figure 5.8).

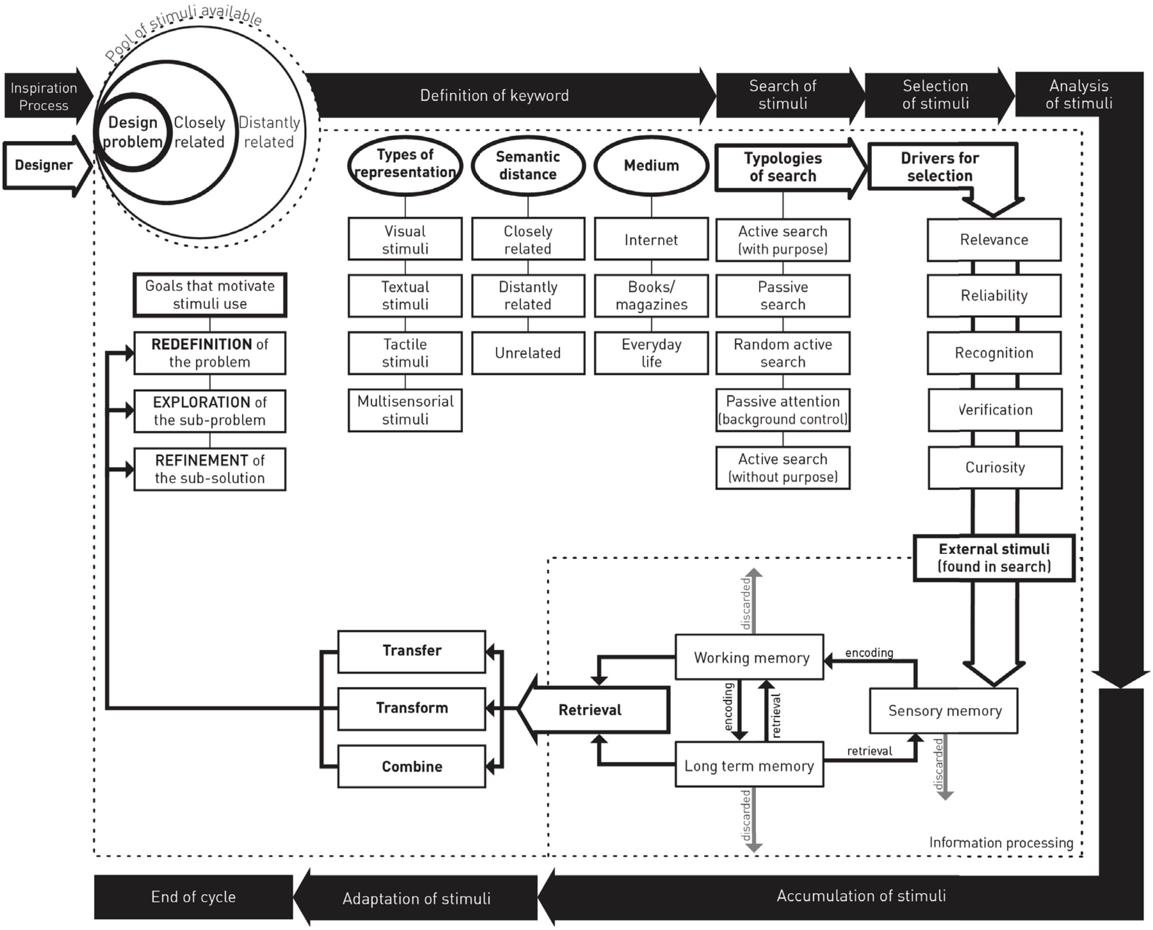



Figure 7.3. Inspiration process model, within the context of creative problem solving in design.

When a designer encounters a design problem (or a sub-problem), this normally entails a specific context. Within this context, some information is immediately available and close at hand, while other needs to be explored in distant domains.

Thus, the designer needs to understand which information is missing and explore possible directions in order to interpret the problem. This defines the pool of stimuli available. Depending on the type of problem (or sub-problem) being tackled, three main goals can motivate the use of stimuli in design. For instance, the designer might need to *redefine* the problem, or to *explore* a sub-problem, or even to *refine* a (sub)solution. During a design process, and independently of the specific phase a designer is tackling at the moment, several cycles of inspiration use can occur. Consider a designer in the conceptual design phase (as defined by Pahl and Beitz in their 1984 four phase model). Although the designer is mainly engaged in the generation of ideas, he or she may need to redefine the problem definition by changing its requirements. In that sense, the designer is motivated to initiate a cycle of the inspiration process with the goal to redefine the problem (or its parts). In the same way, the designer might need to search for stimuli that supports him/her in the exploration of alternatives or even in the refinement of a solution. Therefore, the phases or goals of the inspiration process do not necessarily match with specific phases of the design process. Instead, the inspiration process occurs multiple times during the development of a design project.

Several variables can be considered in the process of searching, selecting, retrieving and implementing stimuli in design. For instance, stimuli can be differentiated in terms of types of representation (for instance, visual or textual stimuli), in terms of semantic distance (closely or distantly related), or in terms of medium (whether stimuli is found in the Internet, or a book) [1]. These variables are not a step of the inspiration process but stimuli characteristics designers can encounter.

The inspiration process starts with the **definition of a keyword**. As elaborated in chapter 6 (sections 6.5.2 and 6.6.5), the results of Study IV revealed that defining keywords normally occurs implicitly, as designers do not always know what they are searching for. The way one defines a keyword to start a search for

*1 Other variables might be also influential but they were not within the focus of this thesis.*

stimuli (either to search online, to leaf through a book or to ask a colleague about a topic) influences the following steps of the inspiration process. For instance, vague keyword definitions might require several iterations until the designer finds something relevant.

The inspiration process continues with **searching for stimuli.** This can be accomplished by following different typologies of search, such as: active search with purpose; passive search; random active search (a type of search recognised from the findings from chapter 6, specifically sections 6.6.3 and 6.6.5); passive attention; or active search without a specific purpose. These typologies are organised into three criteria: whether the search of stimuli was motivated by a problem presently being tackled by the designer; whether the search for stimuli was intentional (rather than just caused by chance); and whether the designer has explicitly defined a keyword.

Subsequently, designers need to **select stimuli** from the virtually unlimited pool of information available, a step of the inspiration process that occurs mostly unconsciously. According to results from Study IV, stimuli selection is guided by certain drivers, which depend from the goal of the stimuli search or the phase of the design process (see sections 6.6.2 and 6.6.5). They are: relevance; reliability; recognition; verification; and curiosity. Together with the selection of stimuli, the designer immediately **analyses** the potential of the stimulus to achieve the initial goal of the inspiration process.

In this manner, stimuli go through a process of being encoded, stored and later retrieved from memory (**accumulation of stimuli**). The information processing model is a well-accepted cognitive theory, which explains that stimuli are processed in three stages: the sensory memory, the working memory and, finally, long-term memory (e.g., Atkinson and Schiffrin, 1968). Stimuli arrive first in the sensory memory, as simple impressions. If they are selected as meaningful, they are encoded into the working memory, by establishing links with existing memories (non-meaningful stimuli are discarded from sensory memory). While sensory memory mostly functions unconsciously, working memory processes stimuli consciously, encoding them from sensory memory and retrieving associations from long-term memory (Jonides, Lacey and Nee, 2005). Once stimuli have been encoded (matched within meaningful categories), they can be stored indefinitely (or until stimuli are forgotten, i.e., discarded). Since stimuli have been encoded by meaning, establishing associations with other similar meaningful memories, it is possible then to retrieve stimuli from long-term memory (and from working memory). Although a complex system, processing and retrieving stimuli can take a split second.

A retrieved stimulus can then be **adapted** into the context of the problem at hand, by a process of *transfer, transformation or combination*[2] (Rosenman and Gero, 1993; Gero, 1994; 2000; Goldschmidt, 2001; Eckert and Stacey, 2003). *Transfer*, as a process of stimuli adaptation, occurs when a stimulus (the source) is transferred from a domain to the context of the design problem (the target). The transfer can be literal, i.e., close to the domain of the problem, where only superficial features of the stimulus are mapped and transferred to the target solution. On the other hand, stimuli can also be transferred from distant domains. In this case, structural similarities are recognised and mapped from a potential stimulus in relation to the target context, and the transfer requires further transformation to be successfully integrated as a solution (see section 2.2.5 and 2.3.4, as the process of transfer can be compared to analogical reasoning).
Stimuli could also be target of a process of *transformation*. This occurs when the stimulus mutates into a solution insofar that only some similarities are recognised. As explained in the previous paragraph, the adaptation of stimuli into

*2 Other processes have been proposed by Rosenman and Gero (1993) and Gero (1994, 2000) to explain creative designing. They were: combination, transformation, analogy, emergence and first principles. In this way, Gero (2000) aimed to model, from an artificial intelligence perspective, possible procedures responsible for creative designing – and not necessarily how stimuli are incorporated in a design solution. Thus, for the context of this thesis, only three of processes were selected: combination, transformation and transfer (analogy can be considered a transfer from either very close or very far domains, to the target). Emergence and first principles were excluded, as they were not dependent on the use of stimuli.*

a target context can initially involve a process of transfer, but transformation is only achieved when it results in a mutation of structure variables (Gero, 2000). Thus, transformation could involve analogical but also associative reasoning (Mednick, 1962), where links between distant stimuli are established, which might lead to free association of ideas.

Finally, stimuli can also be *combined*, where two (or more) stimuli are added and integrated into a new solution. According to Gero (2000), combination of stimuli might result from the composition of features at the function, behaviour or structural levels.

By undergoing transfer, transformation or combination (or even a combination of these processes), stimuli can be adapted to the problem context, which concludes the cycle of the inspiration process. Therefore, one of the initial goals might have been achieved: either the (sub)problem was redefined, the (sub) problem was explored or a (sub)solution was refined.

To bring this to the previously described co-evolution theory of problem and solution, the use of stimuli has the potential to support moving from the problem space to the solution space (and vice-versa), until a problem-solution pair is framed (Dorst and Cross, 2001; Schön, 1983). As mentioned before, this is an iterative process, which occurs multiple times during a design project, for different phases. This thesis proposes that the inspiration process can be supported by recognising and reflecting on its individual steps, in order to promote a more creative use of external stimuli in design.

## 7.3. Contributions and implications for design practice and education

There is a strong relationship between creativity and knowledge: one cannot be creative or generate creative solutions without the support of prior knowledge or experience (Weisberg, 1999). When encountering a new design problem, characterized by its uncertainty and ill-definition (Simon, 1973), designers rely heavily on information, which eventually can become stimuli and influence their design process (Adams, Turns and Atman, 2003). Therefore, investigating the influence of stimuli in the design process is important for the purpose of supporting the development of innovative products and services. The collection of findings gathered in this thesis contributes to design practice and education for the following reasons:

**The influence of external stimuli in design creativity**

The impact external stimuli have in the development of creative solutions in design problem solving has been investigated and revealed to be essential for creativity, especially when uncertainty is high (Chapters 4, 5 and 6, respectively Studies II, III and IV). The crucial impact of external stimuli on creativity gives clear indications that design educators should pay further attention to how student designers search and handle stimuli in project-based courses. These findings can be used to support the preparation of student designers in their inspiration process, by educating them on the potential influence of different stimuli on design problems with diverse levels of uncertainty.

**Designers' preferences on external stimuli**

The thesis describes designers' main preferences for stimuli representation types, medium for search and information gathering practices. In this way, it revealed the limited use of inspiration resources designers prefer and use, especially during idea generation (Chapter 3, Study I). By obtaining this knowledge, it is possible now to raise awareness in design education and practice on the need to reflect on the inspiration process. Furthermore, other types of stimuli were also recognised, besides the ones mostly used by designers, as advantageous to creativity. Namely, textual stimuli, which were demonstrated to be the least preferred type of stimuli representation by designers, should be considered as potential inspiration sources (Chapter 4, Study II).

**A multi-faceted exploration of the inspiration process**

This investigation incorporated a varied sample of research methods, which enabled an exploration of a multitude of procedures that can be used to examine the influence of stimuli in design. This resulted in a rich understanding of the phenomena discussed in this thesis, approached from different angles, which can be used as a starting point for future research.

**The relevance of reflection in the inspiration process**

Mapping the inspiration process of designers brought to light the multiple individual steps responsible for the use of stimuli in design. Moreover, reflection was identified as a crucial element in inspiration use, which can support better use of stimuli in design. By encouraging reflection also in how ideas come about and result from inspiration sources, it is possible to prepare designers for a more efficient inspiration process. By isolating specific steps of the inspiration process, future research can address possible pitfalls connected to the use of stimuli and promote focussed solutions to tackle them.

**Tool development**

The findings from this thesis represent initial suggestions to inform the development of computational tools, such as search engines, to support designers' search, selection and retrieval of stimuli. A follow up of this research project could be to implement these suggestions in tools that present *"the right information in the right forms"* (Töre Yargin and Crilly, 2015). Likewise, the findings may be used to support and inform the development of ideation methods, workshops or even educational courses.

**Coping with the inspiration process**

For professional (and student) designers, pragmatic recommendations can be retrieved to employ in their practice in order to enhance their creative development of solutions (they are discussed in Section 7.4). Regarding design education, these findings can be used to teach our students to cope with uncertainty in design problems and the daunting task of finding relevant stimuli in a world of virtually unlimited information.

## 7.4 Recommendations for design practice and education

The findings summarised in this chapter entail many possible guidelines to support design practice and education. The following section elaborates on how the main themes of this thesis can be employed to better support the development of creative solutions in design.

**Stimulating reflection on inspiration use during the design process**

The first empirical study of this thesis revealed that professional designers engaged in possibly detrimental practices to creativity, such as relying too much on existing examples and avoiding 'reinventing the wheel', as a cognitive economy strategy. Past research demonstrated that design practitioners are able to build their own expertise by reflecting-on-action, the process by which the designer is able to self-analyse previous strategies and decisions and learn from them (Schön, 1983). Reflection on the inspiration process becomes even more important when limited amount of time is reserved for searching relevant information to support the design process. Thus, reflecting-on and in-action – the capacity to readjust one's strategy or decisions when unexpected situations arise (Schön, 1983) become crucial for practitioners when dealing with external stimuli. Findings from Study III (chapter 5) highlighted that, although design novices learn how to reflect on their design process, they do not usually reflect on the source of their ideas. Thus, this thesis recommends increasing the focus on the inspiration process during the early years of design education.

**Giving an opportunity to other representational stimuli**

Images in general are undoubtedly powerful to communicate ideas, to seize one's attention and to efficiently share knowledge between team members. However, these are not the characteristics relevant for the process of searching, finding and adapting stimuli into a solution or problem context. In this way, there is no immediate reason to justify the predominant use of pictorial stimuli by both professional and student designers. Thus, it is important to consider other representation types of stimuli, such as textual. For instance, by considering textual information for inspirational purposes, one is able to find alternative formulations of keywords, which can lead to the exploration of different ways to reframe the problem context.

**Giving an opportunity to distantly related stimuli**

When considering the use of distantly related stimuli for inspirational purposes, it emerged from the findings (Chapter 6) that the issue of not being able to reach more distantly related stimuli is a knowledge problem, not a motivational one.

Novice designers are, in general, well aware that distantly related stimuli can be useful for the generation of analogies and metaphors. The key to reach such stimuli is found in the formulation of keywords, which guide the subsequent search for information. To support it, novice designers can make use of generative methods, such as mindmaps to uncover possible directions that compose the main problem and sub-problems, or frame creation (Dorst, 2015), which is concerned mainly with the reframing of the problem in different approaches and not necessarily in the generation of ideas.

**Reflecting while applying the inspiration process**

The use of distantly related stimuli does not solely guarantee the development of creative solutions. Ultimately, the inspiration process includes several interdependent phases, which should be covered:

A) **Formulate keywords to initiate a search as explicitly as possible.** The chosen keywords guide subsequent searches and frames how one interprets the problem (or sub-problems). Thus, it is recommended to explore alternative keywords. Several ideation methods can be used for this purpose, such as: mindmaps, analogies or metaphors creation (van Boeijen et al., 2013). Even simple techniques of free association (Sherwin, 2010) or an online Thesaurus can be useful tools to map possible keywords to support stimuli search.

B) **Search stimuli in any available medium** (for instance, Internet, books/magazines, daily life or experience, contacts with experts, colleagues or users). Stimuli search can take many forms, depending on three criteria: existence of a design problem at hand; intentionality of the search; and certainty of search goal or keyword. The more intentional a search is and the more certainty one has in relation to the search goal, the more efficient the search can become. Several search cycles occur during the design process, motivated by different goals, which can change throughout the project. In this way, some stimuli search can be motivated by a need to clarify a knowledge gap; or because the designer needs a different perspective; or even motivated by the need to solve one particular issue of a on-going solution. By reflecting on the current goal to achieve, designers can choose a more appropriate search medium.

C) **Choose stimuli by following one or more possible drivers for selection:**

motivated by relevance, reliability, recognition, verification or curiosity. These drivers are often implicit and tend to hedge the designer into specific types of stimuli. By reflecting on what motivates stimuli selection, a designer is able to structure the inspiration process, so he/she is not dependent on trial and error or relying on blindly chancing upon appropriate stimuli. Serendipity can, of course, occur and it is beneficial to sudden insights on the resolution of a problem. Nevertheless, designers can potentially become more efficient by reflecting on drivers that motivate their stimuli selection.

D) **Analyse how appropriate the stimuli are for the (sub)problem at hand.** As demonstrated in chapter 4, there is a sweet spot for inspiration when considering semantic distance. Between very closely-related and very distantly-related (or unrelated) stimuli lies an optimal semantic distance range of stimuli, which supports the exploration of non-obvious stimuli, yet establishes sufficient cues to relate with the problem at hand. Other considerations might be important when considering stimuli's appropriateness, but they were not the focus of this thesis. To consider whether the stimuli are appropriate to solve the (sub) problem at hand, one should review the motivation for searching and selecting a stimulus. When the goal is to create a point of reference of existing solutions (benchmarking), it is wise to look at closely-related stimuli. Nevertheless, if the objective is to ideate and explore different directions, it is better to discard closely-related and instead use distantly related stimuli. In the same way, consider also other representation types in addition to visual stimuli. The findings here presented showed the relevance of using textual stimuli for inspirational purposes, but other representation types can also be considered (e.g., three-dimensional).

E) **Adapt the stimuli to the solution** (or the context of the problem, to reformulate it). Adaption of stimuli might not be immediate but rather involve a preceding step of storing stimuli in the working memory or long-term memory, by a process of encoding and retrieval (or discard, when the stimulus is considered unsuitable). In order to adapt a stimulus (the source) into the context of the solution (the target), properties from both elements need to be mapped and matched. The next step of adaptation is either transfer, transform or combine properties from the source into the target context.

F) Verify whether the reached solution (which can include also the reformulation of the problem, sub-problem or part of the final solution) was appropriately answered by the requirements of the design problem. Considering the phase of the design process, other cycles of inspiration might be necessary and can now be initiated. One of three possible goals can be reached: redefinition of the problem; reorientation of the sub-problem; or refinement of the sub-solution.

## 7.5 Limitations of this research

In every empirical chapter, a number of limitations were presented, which referred specifically to each research method. In addition to these, the following general limitations were identified.

**Narrow stimuli focus**

The type of stimuli investigated in this thesis is, by itself, a limited sample of available sources. Regarding their representation type, this research work exclusively addressed pictorial and textual stimuli (and only investigated three-dimensional representations in Study I). When considering their semantic distance, three levels were explored: closely related, distantly related and unrelated stimuli.

**Limited generalisation of participants sample**

Initially, this doctoral research implicitly aimed to investigate the inspiration process in design under a general lens. The main research question follows this wide perspective, where the goal was to understand the phenomenon of inspiration considering the overall population of designers. Thus, study I was conducted to collect information from two different groups of interest: student and design practitioners. However, this general focus across expertise levels was not consistently achieved throughout the development of the later studies. In three out of four studies, the participants sample comprised only novice designers, students from either the Master or Bachelor programmes of the Industrial Design Engineering faculty, of the Technical University of Delft. A number of reasons were responsible for this change in focus. Firstly, there was a methodological motivation: the set up of these studies would encounter many difficulties and delays if design practitioners would be chosen as participants. On the other hand, novice designers were readily available and able to participate in the studies, with minor amounts of preparation required to manage their coordination, which expedited data collection. Furthermore, it became apparent with the results from study I that reflection in the inspiration process was an important determinant, especially in the case of novice designers (who are not usually aware of their inspiration practices). This indicated that it would be more beneficial to investigate design students' inspiration process in detail, in order to improve their use of stimuli in design. Nevertheless, this does not mean that an in-depth analysis of expert designers' inspiration process should not be conducted in the future. The shift towards a more specific focus on design novices' inspiration process reflects a possible mutual contribution between design education and research. By being able to reflect on the students' inspiration strategies, the thesis can contribute to design education and, consequently, to the design practitioners of the future.

Even so, one possible limitation of this research project (and an opportunity for future work) is its generalisation onto other levels of design expertise, such as expert designers.

**Scope of the inspiration process**

The development of the studies reported in this thesis led to the natural exploration of certain aspects of the inspiration process. The steps of the inspiration process that received greater attention in this research project were the definition of keyword/search input; search of stimuli; selection of stimuli and, to some extent, the adaptation of stimuli in the design process. Nevertheless, other steps of the inspiration process were identified, but not fully explored within the scope of this research project. These were: the analysis of stimuli and the accumulation of stimuli (but not immediate adaptation of stimuli in the design process). Furthermore, other steps involved in the inspiration process might have been overlooked.

## 7.6. Recommendations for future research

The scope of this investigation was on decoding of specific aspects of the inspiration process, namely, particular issues of the search, selection and influence of stimuli in a design process. A number of parallel avenues for future research were identified throughout the development of this thesis, which were not fully explored within its scope. Thus, this section proposes possible developments to give continuation to the existing body of work on the inspiration process of designers:

**Support in the development of computational tools**

The findings collected in this thesis suggested that designers might not be fully supported by existing search engines to find stimuli. Existing Internet search engines and even computational tools resulting from research on analogical thinking and bio-inspired design assume that designers know what to search for (e.g., Linsey, Markman and Wood, 2012; Vattam et al., 2010). However, findings from study IV (Chapter 6) revealed that search engines and tools do not presently support an important stage of the inspiration process – keywords definition (i.e., framing keywords to initiate the search for stimuli). Some online databases, such as Ask Nature (http://www.asknature.org/), support search for keywords by function (strategies used by organisms in nature), which enable search for biomimicry purposes. However, existing tools or search engines do not usually support keyword definition or the possibility to reframe the problem (Chakrabarti et al, 2005; Töre Yargin and Crilly, 2015). In a review of existing studies on the development and evaluation of software tools supporting analogical and biomimetic design, Töre Yargin and Crilly (2015) built a list of requirements focused on the user (designers who might want to find stimuli). In their revision, they recognised that a number of requirements are not consistently being fulfilled, either considering the information content (what and how stimuli are provided) or in terms of interaction (how do designers arrive and interact with stimuli). One important interaction guideline is accessibility, i.e., how stimuli can be retrieved. According to Töre Yargin and Crilly (2015) and Vattam and Goel (2011), tools should enable browsing, besides the usual keywords searching. In this way, when designers do not have a clear keyword to search for, browsing could provide the opportunity to find relevant stimuli accidentally. Browsing supports active random search, whilst searching requires keywords, which designers do not necessarily have defined before starting stimuli search (as

discussed in Chapter 6 and section 7.1.4).
Among the recommendations of Tore Yargin and Crilly (2015), another is the restoration of previous searches. Restoration, or the possibility to return back to earlier attempts of inspiration search could be beneficial to enhance reflection. By recording or documenting previous searches, designers could have the possibility to review their steps. This could have several benefits: designers could pursue different search directions without the risk of losing an earlier train of thought. Moreover, designers, especially novices, could reflect back on their steps, as a learning moment to improve their inspiration process. Furthermore, the rationale of how one idea could be better communicated to colleagues or clients, by providing the links of stimuli that influenced the solution.
Thus, considering the conclusions of this thesis and guidelines to support computational tools (Töre Yargin and Crilly, 2015), efforts should be implemented to continue developing computational tools to fully support keyword definition search, selection and retrieval of stimuli for creative problem solving. In this way, existing search engines (such as Google, Bing or Yahoo!), analogical and biomimetic software tools (e.g., Chakrabarti et al., 2005; Vattam and Goel, 2011) could consider enhancing users' experience by supporting the search for stimuli, even when the goal of search is uncertain or ambiguous.

**Co-evolution triggered by stimuli influence**

Despite being identified as a relevant issue in design research, co-evolution of the problem and solution has only been explored or followed-up by a small number of studies (Maher and Poon, 1996; Poon and Maher, 1997; Dorst and Cross, 2001; Wiltschnig, Christensen and Ball, 2013). In Dorst and Cross' study (2001), the authors came across a possible link between design information and co-evolution. That is, a particular type of information provided with the design brief seemed to have triggered a particular type of framing of the problem and solution. However, no other developments have explored the influence of stimuli in the co-evolution of the problem and solution. Future research on the topic of inspiration in design could then consider the exploration of the influence of stimuli in the co-evolution of the problem and solution. This is relevant as it would clarify how designers create ideas, supported by the use of stimuli, by continually evolving their problem and solution space.

**Influence of reasoning types in the inspiration process**

Future research should also be able to converge onto the specific reasoning types that support the inspiration process in general. In this thesis, associative, analogical and metaphorical reasoning types were only approached briefly but it may be relevant to investigate the inspiration process within the bigger context of a specific thinking reasoning. Different types of reasoning perhaps have different influences on how stimuli are used and how they influence the design process.

**Inspiration process across other levels of expertise**

This investigation can be continued by exploring the role of expertise in the use and influence of external stimuli in design. An initial step was made in this thesis, but much more can be explored, especially concerning how expert designers select, use and are influenced by external stimuli.

**Influence of stimuli in collaborative settings**

Future studies are recommended to investigate the influence of external stimuli in design teams. It remains uncertain whether the inspiration process flowchart developed in this thesis (considering the individual designer as the unit of analysis) would differ when considering the social context of designers collaborating together or with other stakeholders.

**Implementation of findings**

Future research should focus as well on the dissemination and implementation of these findings in different manners, such as via the development of workshops to education or to design practice or through their integration in existing ideation methods. Computational tools, gamification and application software are also important trends, which can also be considered to disseminate the findings from this thesis.

## 7.7. Breaking through the myth of inspiration

The issue of inspiration has, since ancient times, been surrounded by myth. Nowadays, you just have to make a quick online search for 'how to find inspiration' to find apparent miraculous solutions for the lack of creativity (normally involving a list of tips of at least 10 steps). Those promised answers are normally vague and non-explanatory, such as 'try new things', 'take a long shower' or even 'watch your cat or dog in nature'. Although these strategies, to some extent, can lead to insightful states of mind that can support creativity, they are definitely not efficient, especially considering the limited time practitioners have in their daily life to cope with lack of 'inspiration'. This thesis attempts to break through the mysticism of inspiration and to bring clarity to a mostly unconscious process: the inspiration process. The inspiration process, i.e., the searching, selecting, retrieving and implementing of stimuli in design, can be used for more than just creating ideas. Stimuli can also be useful at several stages of the design process, by supporting the definition of the problem context, by exploring the problem and solution space and, indeed, by developing and refining solutions. By investigating specific elements involved in the search and use of external stimuli, this thesis is able to answer what designers use, how is it used and how it influences their creative outcome. Thus, designers' inspiration process can be now better supported. This thesis hopefully contributes to improve our understanding of the role of inspiration in design and creativity in general.

# Bibliography

A

Adams, R., Turns, J., & Atman, C. (2003). Educating effective engineering designers: The role of reflective practice. *Design Studies*, 24, 3, 275-294.

Agogué, M., Kazakçi, A., Hatchuel, A., Le Masson, P., Weil, B., Poirel, N., & Cassotti, M. (2014). The impact of type of examples on originality: Explaining fixation and stimulation effects. *Journal of Creative Behavior*, 48(1991), 1–12.

Ahmed, S., Blessing, L., & Wallace, K. (1999). The relationships between data, information and knowledge based on a preliminary study of engineering designers. In *Proceedings of ASME 1999 Design Theory and Methodology*, DETC99, Las Vegas, Nevada, USA.

Ahmed, S., Wallace, K., Blessing, L., & Moss, M. (2000). Identifying differences between novice and experienced designers (keynote address). In *Proceedings of Engineering Design Conference EDC2000*, Brunel University, Uxbridge, London, UK: Professional Engineering Publishing, 97 – 106.

Ahmed, S., & Wallace, K. (2004). Identifying and supporting the knowledge needs of novice designers within the aerospace industry, *Journal of Engineering Design*, 15(5), 475 – 492.

Ahmed, S., & Christensen, B. T. (2009). An In Situ Study of Analogical Reasoning in Novice and Experienced Design Engineers, *Journal of Mechanical Design*, 131, 111004.

Akin, Ö., & Akin, C. (1996). Frames of reference in architectural design: Analysing the hyperacclamation (A-h-a-!). *Design Studies*, 17(4), 341–361.

Allen, M. S. (1962). *Morphological creativity*. Englewood Cliffs, NJ: Prentice-Hall.

Allen, R. D., Hicks, B. J., & Culley, S. J. (2000). Integrating electronic information for the design of mechanical systems: The designers perspective. *4th World Multi-Conference on Systematics, Cybernetics and Informatics*, 2, 266– 271.

Allen, T. (1966). Studies of the problem-solving process in engineering design. *IEEE Transactions on Engineering Management*, 13, 72 – 83.

Amabile, T. (1982). Social psychology of creativity: A consensual assessment technique. *J. Personal. Soc. Psychol.*, 43, 997–1013

Amabile, T. (1983). *The social psychology of creativity*. New York, Springer-Verlag.

Amabile, T. (1996). *Creativity in context: Update to the social psychology of creativity*. Boulder, CO: Westview Press.

Ansburg, P. I., & Hill, K. (2003). Creative and analytic thinkers differ in their use of attentional resources. *Personality and Individual Differences*, 34, 1141–1152.

Archer, L. B. (1965). Systematic method for designers, The Design Council, London, UK. Reprinted in N. Cross (ed.) (1984). *Developments in design methodology*, John Wiley, Chichester, UK.

Arciszewski, T. (1998). ARIZ 77 - An innovative design method. *Methods and Theories*, 22, 796-820.

Arnheim, R. (1969). *Visual thinking*, University of California Press, Berkeley and Los Angeles.

Athavankar, U. A. (1997). Mental imagery as a design tool. *Cybernetics & Systems: An International Journal*, 28(1), 25–42.

Atkinson, R. & Schiffrin, R. (1968). Human memory: A control system and its control processes. In K. Spence (Ed.), *The psychology of learning and motivation* (vol. 2). New York: Academic Press.

Atman, C. J., Chimka, J. R., Bursic, K. M., & Nachtmann, H. L. (1999). A comparison of freshman and senior engineering design processes. *Design Studies*, 20(2), 131–152.

Atman, C. J., Cardella, M. E., Turns, J., & Adams, R. (2005). Comparing freshman and senior engineering design processes: an in-depth follow-up study. *Design Studies*, 26(4), 325–357.

**B**

Badke-Schaub, P. (2007). Creativity and innovation in industrial design: wishful thinking?, *J. Design Research*, 5(3), 353-367.

Badke-Schaub, P., Cardoso, C., Daalhuizen, J. Lauche, K., Jalote-Parmer, A., Neumann, A. (2010). Solving an unresolvable puzzle? How to support the designer in context. In *Proceedings of design research in the Netherlands 2010 symposium.*

Badke-Schaub, P., Daalhuizen, J., & Roozenburg, N. (2011). Towards a designer-centred methodology - Descriptive considerations and prescriptive reflections. In H. Birkhofer (Ed.), *The Future of Design Methodology* (pp. 229–237). London: Springer-Verlag.

Ball, L., & Christensen, B. (2008). Analogical reasoning and mental simulation in design: two strategies linked to uncertainty resolution. *Design Studies*, 30(2), 169–186.

Ball, L., Ormerod, T., and Morley, N. (2004). Spontaneous Analogising in Engineering Design: A comparative analysis of experts and novices, *Design Studies*, 25(5), 495 – 508.

Baya, V. (1996). *Information Handling Behavior of Engineers in Conceptual Design: Three Experiments*, Ph.D. Dissertation, Stanford University, California.

Boden, M. (1990). *The creative mind: myths and mechanisms*. London: Weidenfeld and Nicolson, 32-35.

Boden, M. (Ed.)(1994). *Dimensions of creativity*. Cambridge, MA: MIT Press.

van Boeijen, A., Daalhuizen, J., Zijlstra, J., & van der Schoor, R. (2013). *Delft design guide*. Amsterdam: BIS Publishers.

Bonnardel, N., & Marmèche, E. (2005). Towards supporting evocation processes in creative design: A cognitive approach. *International Journal of Human-Computer Studies*, 63(4-5), 422–435.

Brehm, J. (1966). *A theory of psychology reactance*. New York: Academic.

Brown, R., & Mcneill, D. (1966). The "tip of the tongue" phenomenon. *Journal of Verbal Learning and Verbal Behavior*, 5, 325–337.

Brown, T. (2008). Design thinking. *Harvard Business Review*, 86(6), 84–92, 141.

C

Cai, H., Do, E. Y.-L., & Zimring, C. M. (2010). Extended linkography and distance graph in design evaluation: an empirical study of the dual effects of inspiration sources in creative design. *Design Studies,* 31(2), 146–168.

Cardoso, C., Badke-schaub, P., & Luz, A. (2009). Design fixation on non-verbal stimuli: The influence of simple vs rich pictorial information on design problem-solving. *Proceedings of the ASME 2009 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, IDETC/CIE 2009* (Vol. 31, pp. 1–8). San Diego, California, USA.

Cardoso, C., & Badke-Schaub, P. (2011). The influence of different pictorial representations during idea generation. *The Journal of Creative Behaviour,* 45(2), 130-146.

Carrol, L. (1865). *Alice's Adventures in Wonderland* (1998 ed.). London: Penguin Books

Casakin, H., & Goldschmidt, G. (1999). Expertise and the Use of Visual Analogy: Implications for Design Education. *Design Studies*, 20(2), 153–175.

Casakin, H. & Goldschmidt, G. (2000). Reasoning by visual analogy in design problem solving: The role of guidance. *Journal of Planning and Design: Environment & Planning B*, 27, 105-119.

Casakin, H. (2004). Visual Analogy as a Cognitive Strategy in the Design Process: Expert Versus Novice Performance. *Journal of Design Research*, 4(2).

Casakin, H. (2005). Design aided by visual displays: a cognitive approach. *The Journal of Architectural and Planning Research*, 22, 250-265.

Casakin H. and Kreitler, S. (2005). The nature of creativity in design: Factors for assessing individual creativity, in *Studying Designers International Conference 2005*, Provence University, Aix-en-Provence, 87-100.

Casakin, H., & Kreitler, S. (2006). Self-assessment of creativity: Implications for design education. In *Engineering and Product Design Education Conference* (pp. 1–6). Salzburg, Austria.

Casakin, H. P. (2007). Metaphors in Design Problem Solving : Implications for Creativity. *International Journal of Design,* 1(2), 21–33.

Casakin, H. (2011). Metaphorical reasoning and design expertise: A perspective for design education. *Journal of Learning Design*, 4(2), 29–38.

Casakin, H. (2011). Associative Thinking As a Design Strategy. In *International Conference on Engineering Design, ICED 11*. Copenhagen, Denmark.

Casakin, H., & Kreitler, S. (2011). The cognitive profile of creativity in design. *Thinking Skills and Creativity,* 6(3), 159–168.

Chakrabarti, A., & Khadilkar, P. (2003). A measure for assessing product novelty. In *Proceedings of the International Conference on Engineering Design 2003*. Stockholm, Sweden.

Chakrabarti, A., Sarkar, P., Leelavathamma, B., & Nataraju, B. (2005). A functional representation for aiding biomimetic and artificial inspiration of new ideas. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 19(2), 113 - 132.

Chakrabarti, A. (2006). Defining and supporting design creativity. In *International Design Conference - Design 2006* (479–486).

Chambers, D. & Reisberg, D. (1985). Can mental images be ambiguous? *Journal of Experimental Psychology: Human perception and performance*, 11, 317 – 328.

Chan, J., Fu, K., Schunn, C., Cagan, J., Wood, K., & Kotovsky, K. (2011). On the effective use of design-by-analogy: The influences of analogical distance and commonness of analogous designs on ideation performance. In *International Conference on Engineering Design ICED'11.*

Chan, J., Dow, S. P., & Schunn, C. D. (2014). Do the best design ideas (really) come from conceptually distant sources of inspiration? *Design Studies*, 36, 31–58.

Cheng, P., Mugge, R., & Schoormans, J. (2014). A new strategy to reduce design fixation:

Presenting partial photographs to designers. *Design Studies,* 35, 374 – 391.

Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in problem solving In: R. J. Sternberg (Ed.) *Advances in the psychology of human intelligence* (Vol. 1). Hillsdale, NJ: Erlbaum.

Chiu, I., & Shu, L. H. (2007). Using language as related stimuli for concept generation. *Artificial Intelligence for Engineering Design Analysis and Manufacturing*, 21(2), 103–121.

Chiu, I., & Shu, L. (2010). Potential limitations of verbal protocols in design experiments. In *ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2010*, 1–10.

Chiu, I., & Shu, L. H. (2012). Investigating effects of oppositely related semantic stimuli on design concept creativity. *Journal of Engineering Design,* 23(4), 271–296.

Christensen, B. T., & Schunn, C. D. (2007). The relationship of analogical distance to analogical function and preinventive structure: the case of engineering design. *Memory & Cognition*, 35(1), 29–38.

Christiaans, H. & Dorst, K. (1992). Cognitive models in industrial design engineering: a protocol study. In D. L. Taylor and D. A. Stauer (eds.), *Design Theory and Methodology – DTM92,* American Society of Mechanical Engineers, New York, USA.

Christiaans, H., & Van Andel, J. (1993). The effects of examples on the use of knowledge in a student design activity: the case of the "flying Dutchman." *Design Studies*, 14(1), 58–74.

Chrysikou, E. G., & Weisberg, R. W. (2005). Following the wrong footsteps: Fixation effects of pictorial examples in a design problem-solving task. *Journal of Experimental Psychology-Learning Memory and Cognition*, 31(5), 1134–1148.

Cila, N. (2013). *Metaphors we design by: The use of metaphors in product design*. PhD Thesis, TU Delft, The Netherlands.

Court, A., Culley, S. & McMahon, C. (1993). The information requirements of engineering designers, In *Proceedings of the International Conference on Engineering Design*, The Hague, 1708 – 1716, August 17 – 19, 1993.

Court, A., Culley, S. & McMahon, C. (1993). The information requirements of engineering designers. In: *Proceedings of the International Conference of Engineering Design* 1993.

Court, A. W. (1995). *Modelling and classification of information for engineering designers*. Ph.D. Thesis in Mechanical Engineering. Bath, University of Bath.

Court, a W., Culley, S. J., & Mcmahon, C. a. (1997). The influence of information technology in new product development: Observations of an empirical study of the access of engineering design information. *International Journal of Information Management*, 17(5), 359–375.

Craik F., & Lockhart, R. (1972). Levels of processing: A framework for memory research, *Journal of Verbal Learning and Verbal Behavior*, 11, 671-684.

Crilly, N., Blackwell, A. & Clarkson, P.J. (2006). Graphic elicitation: using research diagrams as interview stimuli. *Qualitative research*, 6(3), 341-366.

Crilly, N. (2009). The structure of design revolutions: Kuhnian paradigm shifts in creative problem solving. *Design Issues,* 26(1), 54-66.

Crilly, N. (2014). Design fixation : a call for qualitative research. In *Design Creativity Workshop 2014,* University College London, London, UK, June 22, 2014.

Crilly, N. (2015). Fixation and creativity in concept development: The attitudes and practices of expert designers. *Design Studies*, 38, 54–91.

Cross, N. (1994). *Engineering design methods: strategies for product design*. Chichester, UK: John Wiley.

Cross, N. (1997). Descriptive models of creative design: application to an example. *Design Studies*, 18(4), 427–440.

Cross, N. (2004). Expertise in design: an overview. *Design Studies*, 25(5), 427–441.

Cross, N. (2006). *Designerly Ways of Knowing*. London: Springer-Verlag.

**D**

Daalhuizen, J., Badke-Schaub, P. & Batill, S. (2009). Dealing with uncertainty in design practice: Issues for designer-centered methodology. In *Proceedings of ICED'09, International Conference on Engineering Design*, Standford, CA, USA.

Daalhuizen, J., & Badke-Schaub, P. (2011). Why do design methods not promote excellent designers?. In *Proceedings of IASDR 2011*, Delft, The Netherlands.

Dahl, D. W., & Moreau, P. (2002). The Influence Thinking and During Value New of Analogical Ideation Product. *Journal of Marketing Research*, 39(1), 47–60.

Darke, J. (1979). The primary generator and the design process. *Design Studies*, 1(1), 36–44.

Dean, D., Hender, J., Rodgers, T. & Santanen, E. (2006). Identifying quality, novel and creative ideas: constructs and scales for idea evaluation. *Journal of the Association for Information Systems*, 7, 10, 646-699.

DeBono, E. (1968). *New think: The use of lateral thinking in the generation of new ideas*. New York: Basic.

Diehl, M., & Stroebe, W. (1987). Productivity loss in brainstorming groups: Toward the solution of a riddle. *Journal of Personality and Social Psychology*, 53, 497–509.

Diehl, M., & Stroebe, W. (1991). Productivity loss in idea-generating groups: Tracking down the blocking effect. *Journal of Personality and Social Psychology*, 61(3), 392–403.

Dörner, D. (1978). *Self-reflection and problem solving*. In F. Klix (Ed.), Human and artificial intelligence. Berlin: Deutscher Verlag der Wissenschaften.

Dorst, K., & Dijkhuis, J. (1995). Comparing paradigms for describing design activity. *Design Studies*, 16(1992), 261–274.

Dorst, K. & Cross, N. (2001). Creativity in the design process: co-evolution of design problem-solution, *Design Studies*, 22, 425-437.

Dorst, K. (2015). *Frame creation – Create new thinking by design*, The MIT Press, Cambridge, MA, USA.

Dreyfus, H. & Dreyfuss, S. (1986). *Mind over Machine: the power of human intuition and expertise in the era of the computer*, Basil Blackwell, Oxford.

Dunbar, K. (1997). How scientists think: On-line creativity and conceptual change in science. *Creative Thought: An Investigation of Conceptual*, 1–22.

E

Eastman, C. (2001). New Directions in Design Cognition : Studies of Representation and Recall. In C. Eastman (Ed.), *Knowing and Learning to Design: Cognition in Design Education* (pp. 1–46). Atlanta, USA: Elsevier.

Eckert, C., & Stacey, M. (1998). Fortune favours only the prepared mind: Why sources of inspiration are essential for continuing creativity. *Creativity and Innovation Management*, 7(1), 1–12.

Eckert, C. M., & Stacey, M. K. (2000). Sources of inspiration: A language of design. *Design Studies*, 21(5), 523–538.

Eckert, C. M., Stacey, M. K., & Clarkson, P. J. (2000). Algorithms and inspirations: Creative reuse of design experience. In *Proceedings of the Greenwich 2000 symposium: Digital creativity* (1-10).

Eckert, C., & Stacey, M. (2003a). Sources of inspiration in industrial practice : The case of knitwear design. *Journal of Design Research,* 3.

Eckert, C., & Stacey, M. (2003b). Adaptation of Sources of Inspiration in Knitwear

Design. *Creativity Research Journal,* 15(4), 355–384.

Eckert, C., Stacey, M., & Earl, C. (2003). Ambiguity is a double-edged sword: similarity references in communication. In I*nternational Conference on Engineering Design ICED'03.*

Eckert, C., Stacey, M., & Earl, C. (2005). References to past designs. In J. Gero, & N. Bonnardel (Eds.), *Studying designers* (3-21). Sydney, Australia: Key Centre of Design Computing and Cognition.

Encyclopedia Brittanica (2014). Alfred Bernhard Nobel. [Online] Available from: http://www.britannica.com/EBchecked/topic/416842/Alfred-Bernhard-Nobel [Accessed: 24th February 2015].

Erickson, K.A., Krampe, R.T., & Clemens, T. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review,* 100(3), 363–406

Ericsson, K. & Simon, H. (1993). *Protocol analysis: verbal reports as data*, Cambridge, Massachusetts: The MIT Press.

Estes, Z. & Ward, T. B. (2002). The emergence of novel attributes in concept modification. *Creativity Research Journal,* 14, 149-156.

Evans, M. and Pei, E., *ID Cards*, Loughborough University, 2010. ISNB: 9781907382352.

**F**

Finke, R. (1996). Imagery, creativity, and emergent structure. *Consciousness and Cognition,* 5(3), 381–93.

Flick, U. (2011). *Introducing research methodology: A beginner's guide to doing a research project*, London: Sage Publications Ltd.

Forceville, C. (2012). Creativity in pictorial and multimodal advertising metaphors. In R. H. Jones (Ed.), *Discourse and creativity* (pp. 113-132). Harlow: Pearson.

Frankenberger, E. & Badke-Schaub, P. (Ed.).(1999) Empirical studies of engineering design in Germany [Special Issue], *Design Studies*, 20(5).

French, M. (1985). *Conceptual design for engineers.* London, UK: The Design Council/ Springer-Verlag.

Frensch, P. & Sternberg, R. (1989). Expertise and intelligent thinking: When is it worse to know better? In: R. J. Sternberg (Ed.) *Advances in the psychology of human intelligenc*e (Vol. 5, 157-188). Hillsdale, NJ: Erlbaum.

Fu, K., Chan, J., Cagan, J., Kotovsky, K., Schunn, C., & Wood, K. (2013). The meaning of "near" and "far": The impact of structuring design databases and the effect of distance of analogy on design output. *Journal of Mechanical Design,* 135(2), 021007.

G

Gabora, L. (2002). Cognitive mechanisms underlying the creative process. *Proceedings of the Fourth Conference on Creativity & Cognition - C&C '02*, 126–133.

Gentner, D. (1983). Structure-Mapping: A Theoretical Framework for Analogy. *Cognitive Science*, 7(2), 155–170.

Gentner, D., & Markman, A. B. (1997). Structure mapping in analogy and similarity. *American Psychologist,* 52(1), 45–56.

Gero. J. (1994). Computational models of creative design processes. In T. Dartnall (ed) *Artificial intelligence and creativity.* Dordrecht, NL: Kluwer Academic.

Gero, J. (1996). Creativity, emergence and evolution in design. *Knowledge-Based Systems*, 9, 435–448.

Gero, J. S. (2000). Computational Models of Innovative and Creative Design Processes. *Technological Forecasting and Social Change*, 64(2-3), 183–196.

Gerstberger, P. & Allen, T. (1968). Criteria used by research and development engineers in the selection of an information source. *Journal of Applied Psychology,* 52, 272 – 279.

Gick, M. L., & Holyoak, K. J. (1980). Analogical Problem Solving. *Cognitive Psychology*, 12, 306–355.

Goel, V. (1995). *Sketches of thought*, MIT Press, Cambridge, MA.

Goldschmidt, G. (1991). The dialectics of sketching. *Creativity Research Journal*, 4(2), 123–143.

Goldschmidt, G. (1995) Visual displays for design: Imagery, analogy and databases of visual images. In A. Koutamanis, H. Timmermans & I. Vermeulen (Eds.), *Visual databases in architecture: Recent advances in design and decision-making* (pp. 53–76). Aldershot, UK: Avebury Press.

Goldschmidt, G. (1997). Capturing indeterminism: Representation in the design problem space. *Design Studies*, 18, 441–455.

Goldschmidt, G. (2001). Visual analogy - a strategy for design reasoning and learning. In C. Eastman, W. Newsletter, & W. McCracken (Eds.), *Design knowing and learning - Cognition in design education.* New York: Elsevier, 199–219.

Goldschmidt, G. (2003). Cognitive economy in design reasoning. In U. Lindemann (Eds.) *Human behaviour in design*, Springer Verlag, Berlin, 53 – 62.

Goldschmidt, G., & Smolkov, M. (2006). Variances in the impact of visual stimuli on design problem solving performance. *Design Studies,* 27(5), 549–569.

Goldschmidt, G., & Sever, A. L. (2010). Inspiring design ideas with texts. *Design Studies,* 32(2), 139–155.

Gonçalves, M., Cardoso, C. and Badke-Schaub, P. (2013) Through the looking glass of inspiration: Case studies on inspirational search processes of novice designers, in: *Proceedings of the International Association of Societies of Design Research, IASDR 2013*, Tokyo, Japan.

Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2014). What inspires designers? Preferences on inspirational approaches during idea generation. *Design Studies*, 35(1), 29–53.

Guilford, J. (1950). Creativity. *American Psychologist,* 5, 444–454.

Gordon, W.J.J. (1961), *Synectics: The development of creative capacity.* New York: Harper and Row.

Guilford, J. (1967). *The nature of human intelligence.* New York: McGraw-Hill.

Guo, B. (2011). The scope of external information-seeking under uncertainty: An individual-level study. *International Journal of Information Management,* 31(2), 137–148.

H

Hanington, B. (2003). Methods in the Making: A Perspective on the State of Human Research in Design. *Design Issues*, 19(4), 9–18.

Hatchuel, A., Le Masson, P., & Weil, B. (2011). Teaching innovative design reasoning: How concept–knowledge theory can help overcome fixation effects. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 25(01), 77–92.

Heisig, P., Caldwell, N., Grebici, K. & Clarkson, P. (2010). Exploring knowledge and information needs in engineering from the past and for the future – results from a survey. *Design Studies*, 31, 499-532.

Hekkert, P., Snelders, D. & van Wieringen, P. (2003). 'Most advanced, yet acceptable': Typicality and novelty as joint predictors of aesthetic preference in industrial design, *British Journal of Psychology,* 94, 111-124.

Helms, M., Vattam, S. S., & Goel, A. K. (2009). Biologically inspired design: process and products. *Design Studies*, 30(5), 606–622.

Henderson, K., (1999). *On line and on paper: visual representations, visual culture, and computer graphics in design engineering*, 1-14, Chap. 1 (Cambridge MIT Press, Cambridge MA).

Hennessey, B.  & Amabile, T. (2010). Creativity. *Annual Review of Psychology,* 61, 569–98.

Herring, S. R., Chang, C.-C., Krantzler, J., and Bailey, B. P. (2009). Getting Inspired! Understanding how and why examples are used in creative design practice. In: *Proceedings of CHI 2009 - Design Methods*, 87–96.

Hey, J., Linsey, J., Agogino, A., & Wood, K. (2008). Analogies and metaphors in creative design. *International Journal of Engineering Education*, 24(2), 283-294.

Hicks, B. J., Culley, S. J., Allen, R. D., & Mullineux, G. (2002). A framework for the requirements of capturing, storing and reusing information and knowledge in engineering design. *International Journal of Information Management*, 22, 263–280.

Howard, T. J., Culley, S. J., & Dekoninck, E. (2006). Information as an input into the creative process. In *International Design Conference - Design 2006* (pp. 549–556). Dubrovnik, Croatia.

Howard, T. J. (2008). *Information management for creative stimuli in engineering design*. Ph.D. Thesis, Bath, University of Bath.

Howard, T. J., Culley, S. J., & Dekoninck, E. A. (2010). The use of Creative Stimuli at early stages of Industrial Product Innovation. *Research in Engineering Design*, 21(4), 263–274.

Howard, T. J., Culley, S., & Dekoninck, E. (2011). Reuse of ideas and concepts for creative stimuli in engineering design. *Journal of Engineering Design*, 22(8), 565–581.

## J

Jansson, D. G., & Smith, S. M. (1991). Design fixation. *Design Studies*, 12(1), 3–11.

Jastrow, J. (1899). The mind's eye. *Popular Science Monthly*, 54, 299 – 312.

Jonides, J., Lacey, S., & Nee, D. (2005). Processes of working memory in mind and brain. *Current Directions in Psychological Science*, 14, 2-5.

## K

Kahneman, D. (2003). Maps of bounded rationality: Psychology for behavioral economics. *The American Economic Review,* 93(5), 1449-1475.

Kahneman, D. (2011). *Thinking, fast and slow.* London, UK: Pinguin Books.

Kalogerakis, K., Lu, C., & Herstatt, C. (2010). Developing Innovations Based on Analogies: Experience from Design and Engineering Consultants. *Journal of Product Innovation Management*, 27, 418–436.

Kavakli, M., & Gero, J. S. (2002). The structure of concurrent cognitive actions: A case study on novice and expert designers. *Design Studies,* 23(2002), 25–40.

Kayser, T. A. (1994). *Building team power: How to unleash the collaborative genius of work teams.* New York: Irwin.

Keller, A. I., Pasman, G. J., & Stappers, P. J. (2006). Collections designers keep: Collecting visual material for inspiration and reference. *CoDesign*, 2(1), 17–33.

Keller, I., Sleeswijkvisser, F., Vanderlugt, R., & Stappers, P. (2009). Collecting with Cabinet: or how designers organise visual material, researched through an experiential prototype. *Design Studies*, 30(1), 69–86.

Kelley, T., & Littman, J. (2001). *The art of innovation: Lessons in creativity from Ideo, America's leading design firm*. New York: Doubleday.

Khurana, A., & Rosenthal, S. (1997), Integrating the fuzzy front end of new product development, *Sloan Management Review*, 38 (2), 103-20.

Kohn, N. W. (2008). *An examination of fixation in brainstorming.* Texas A&M University.

Kudrowitz, B., Te, P., & Wallace, D. (2012). The influence of sketch quality on perception of product-idea creativity. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing,* 26, 267–279.

Kudrowitz, B. M., & Wallace, D. (2013). Assessing the quality of ideas from prolific, early-stage product ideation. *Journal of Engineering Design,* 24(2), 120–139.

Kuhlmann, D. (2011). Biomorphism in architecture: Speculations on growth and form. In P. Gruber, D. Bruckner, C. Hellmich, H-B. Schmiedmayer, H. Stachelberger, I. Gebeshuber (eds.) *Biomimetics - materials, structures and processes. Biological and medical physics, Biomedical engineering.* Springer-Verlag, Berlin Heidelberg.

Kuhn, T. (1970). *The structure of scientific revolutions.* Chicago, IL: The University of Chicago Press.

Kwasitsu, L. (2003). Information-seeking behaviour of design, process and manufacturing engineers. *Library & Information Science Research,* 25, 459 – 476.

**L**

Lawson, B. (1979). Cognitive strategies in architectural design. *Ergonomics*, 22(1), 59 - 68.

Lawson, B. (2004). Schemata, gambits and precedent: some factors in design expertise. *Design Studies*, 25(5), 443–457.

Lawson, B. & Dorst, K. (2009). *Design expertise*. Oxford: Architectural Press.

Liikkanen, L. A., & Perttula, M. (2006). Contextual cueing and verbal stimuli in design idea generation. In J. S. Gero (Ed.), *Design Computing and Cognition '06* (1st edition, 619–631). Springer.

Liikkanen, L., & Perttula, M. (2008). Inspiring design idea generation: insights from a memory-search perspective, *Journal of Engineering Design*, 1–1.

Linsey, J., Wood, K., & Markman, A. (2008). Increasing innovation: Presentation and evaluation of the WordTree Design-by-Analogy Method. *ASME IDETC Design Theory and Methodology Conference*, New York, NY.

Linsey, J., Tseng, I., Fu, K., Cagan, J., Wood, K., & Schunn, C. (2010). A Study of Design Fixation, Its Mitigation and Perception in Engineering Design Faculty. *Journal of Mechanical Design*, 132(4), 041003.

Linsey, J. S., Markman, A. B., & Wood, K. L. (2012). Design by Analogy: A Study of the WordTree Method for Problem Re-Representation. *Journal of Mechanical Design*, 134(4), 041009.

Lloyd, P., & Scott, P. (1994). Discovering the design problem. *Design Studies*, 15(2), 125–140.

Lloyd, P., Lawson, B., & Scott, P. (1995). Can concurrent verbalization reveal design cognition? *Design Studies*, 16(2), 237–259.

Lopez-Mesa, B., & Vidal, R. (2006). Novelty metrics in engineering design experiments. *In International Design Conference - Design 2006* (pp. 557–564).

López-Mesa, B., Mulet, E., Vidal, R., & Thompson, G. (2011). Effects of additional stimuli on idea-finding in design teams. *Journal of Engineering Design,* 22(1), 31–54.

Lubart, T. (1994). Creativity. In E. C. Carterette & M. P. Friedman (Series Eds.) & R. J. Sternberg (Vol. Ed.), *The handbook of perception and cognition:* Vol. 12. Thinking and problem solving. New York: Academic Press.

Luchins, A., & Luchins, E. (1959). *Rigidity of behavior: A variational approach to the effect of Einstellung* (471–575). Eugene, Oregon, USA: University of Oregon Books.

van der Lugt, R. (2005). How sketching can affect the idea generation process in design group meetings. *Design Studies*, 26(2), 101–122.

# M

MacCrimmon, K. R. & Wagner, C. (1994). Stimulating ideas through creative software. *Management Science*, 40(11), 1514–1532.

Madsen, K. H. (1994). A guide to metaphorical design. *Communications of the ACM*, 37(12), 57-62.

Maher, M. L. (1994). Creative design using a genetic algorithm. *Computing in Civil*

*Engineering*, 2, 2014-2021.

Maher, M. Lou, & Poon, J. (1996). Modeling Design Exploration as Co-Evolution. *Microcomputers in Civil Engineering*, 11(3), 195–209.

Maher, M. L. (2000). A model of co-evolutionary design. *Engineering with computers*, 16, 195-208.

Malaga, R. A. (2000). The effect of stimulus modes and associative distance in individual creativity support systems. *Decision Support Systems*, 29(2), 125–141.

Marsh, R., Ward, T., & Landau, J. (1999). The inadvertent use of prior knowledge in a generative cognitive task. *Memory & Cognition*, 27(1), 94–105.

Mather, M., Shafir, E., & Johnson, M. (2003). Remembering chosen and assigned options. *Memory & Cognition*, 31, 422-433.

McAlpine, H., Hicks, B. J., Huet, G., & Culley, S. J. (2006). An investigation into the use and content of the engineer's logbook. *Design Studies*, 27(4), 481–504.

Mednick, S. A. (1962). The associative basis of the creative process. *Psychological Review,* 69(3), 220–232.

Mete, F. (2006). The creative role of sources of inspiration in clothing design. *International Journal of Clothing Science and Technology*, 18(4), 278–293.

Michalko, M. (2006). *Thinkertoys: A handbook of creative-thinking techniques*. Berkeley, CA: Ten Speed Press.

Morewedge, C., & Kahneman, D. (2010). Associative processes in intuitive judgment. *Trends in Cognitive Sciences*, 14, 435-440.

Mougenot, C., Bouchard, C., & Aoussat, A. (2008). Inspiration, images and design: an investigation of designers' information gathering strategies. *Journal of Design Research*, 7(4), 331–351.

Mougenot, C., & Wanatabe, K. (2010). Verbal stimuli in design creativity: A case study with Japanese sound-symbolic words. In T. Taura & Y. Nagai (Eds.), *Design creativity 2010* (pp. 231–238). London: Springer Verlag.

Moss, J. (1966). Measuring creative abilities in junior high school industrial arts. *American Council on Industrial Arts Teacher Education*. Washington, DC:

Muller, W. (1989). Design discipline and the significance of visuo-spatial thinking. *Design Studies*, 10(1), 12–23.

Mumby, H. (1989). Reflection-in-action and reflection-on-action, *Education and culture*, vol. 09, Iss. 1, Article 4.

Murphy, G. (2002). *The big book of concepts*. Cambridge, MA: MIT Press.

Murty, P. (2006). Discovery processes in designing, (PhD thesis). The University of Sydney, Sydney, Australia.

N

Neumann, A., Badke-Schaub, P., & Lauche, K. (2009). Show me what you've got – The influence of combined sketching on idea. In M. Norell Bergendahl, M. Grimheden, L. Leifer, P. Skogstad & U. Lindemann (Eds.), *Proceedings of the international conference on engineering design, ICED09* (pp. 191–198). Stanford, CA, August 2009.

Nickerson, R. (1999). Enhancing creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (392–430). NewYork: Cambridge University Press.

Nonaka, I. (1991). The knowledge-creating company. *Harvard Business Review,* 69, 96-104.

Norman, D. (1993). *Things that make us smart: Defending human attributes in the age of the machine.* Addison-Wesley Longman Publishing Co., Inc. Boston, MA, USA.

Norman, D., & Verganti, R. (2014). Incremental and radical innovation: Design research vs. technology and meaning change. *Design Issues*, 30(1).

Novick, L. (1988) Analogical transfer, problem similarity, and expertise. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 14(3), 510-520.

O

Oehlberg, L., Lau, K., & Agogino, A. (2009). Tangible interactions in a digital age: Medium and graphic visualization in design journals. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 23(03), 237.

Olofsson, E., and Sjolen, K. (2005). *Design Sketching*. Klippan, Sweden: Design Books AB.

Osborn, A. (1953). *Applied imagination: Principles and procedures of creative problem solving*. Charles Scribners Sons. New York.

Osborn, A., Rona, G., Dupont, P., & Armand, L. (1971). *The constructive imagination: How to take advantage of its ideas, principles and process of the creative thought and brainstorming*. Paris: Dunod.

Oriakhi, E. V, Linsey, J. S., & Peng, X. (2011). Design-by-analogy using the wordtree method and an automated wordtree generating tool. In *International Conference on Engineering Design, ICED'11*.

Ortony, A., Vondruska, R. J., Foss, M. A. & Jones, L. E. (1985). Salience, similes, and the asymmetry of similarity. *Journal of Memory and Language*, 24, 569- 594.

Oxford University Press (2015) *Oxford Dictionaries*. Retrieved November 5, 2015 from: http://www.oxforddictionaries.com/definition/english/stimulus

Oxman, R. (1990). Prior knowledge in design: a dynamic knowledge-based model of design and creativity. *Design Studies*, 11(1), 17–28.

Oxman, R. E., & Oxman, R. M. (1992). Refinement and adaptation in design cognition. *Design Studie*s, 13(2), 117–134.

Ozkan, O., & Dogan, F. (2013). Cognitive strategies of analogical reasoning in design: Differences between expert and novice designers. *Design Studies,* 34(2), 161–192.

# P

Paivio, A. (1971). *Imagery and verbal processes*. Holt, Rinehart and Winston, New York.

Paivio, A. (1983). Empirical case for dual coding. In J. Yuille (Ed.) *Imagery, memory and cognition*. Lawrence Erlbaum Associates, Hillsdale, NJ.

Pasman, G. (2003). *Designing with precedents.* (PhD thesis). TU Delft, The Netherlands.

Paton, B. & Dorst, K. (2011). Briefing and reframing: A situated practice. *Design Studies*. 32, 573-587.

Paulus, P., Brown, V., & Ortega, A. (1996). Groups creativity. In R. Purser, & A. Montuori (Eds.), *Social creativity in organizations*. Cresskill, NJ: Hampton Press.

Paulus, P. (2000). Groups, teams and creativity: the creative potential of idea generating groups. *Applied Psychology,* 49(2), 237-262.

Paulus, P. B., Kohn, N. W., & Arditti, L. E. (2011). Effects of quantity and quality instructions on brainstorming. *Journal of Creative Behavior*, 45(1), 38–46.

Pei, E., Campbell, I., & Evans, M. (2011). A taxonomic classification of visual design representations used by industrial designers and engineering designers. *Design Journa*l, 14(1), 64–91.

Perkins, D. (2000). *Archimedes's bathtub – the art and logic of breakthrough thinking.* WW Norton & Company, New York, USA.

Perttula, M., & Liikkanen, L. (2006). Exposure effects in design idea generation: unconscious conformity or a product of sampling probability? *NordDesign 2006* (Vol. pp, pp. 1–14). Reykjavik, Iceland.

Perttula, M., & Sipila, P. (2007). The idea exposure paradigm in design idea generation.

*Journal of Engineering Design*, 18(1), 93–102.

Petre, M. (2004). How expert engineering teams use disciplines of innovation. *Design Studies,* 25(5), 477-493.

Pohl, G., & Nachtigall, W. (2015). *Biomimetics for architecture and design: Nature - Analogies - Technology*. Springer International Publishing, Switzerland.

Poon, J., & Maher, M. L. (1997). Co-evolution and emergence in design. *Artificial Intelligence in Engineering,* 11(3), 319–327.

Popovic, V. (2004). Expertise development in product design – strategic and domain-specific knowledge connections. *Design Studies,* 25(5), 527-545

Punch, K. F. (2005), *Introduction to social research – Quantitative & qualitative approaches,* London: Sage Publications Ltd.

Purcell, T., & Gero, J. (1992). Effects of examples on the results of a design activity. *Knowledge-Based Systems*, 5(1), 82–91.

Purcell, T., & Gero, J. (1996). Design and other types of fixation. *Design Studies*, 17(4), 363–383.

Plucker, J. & Beghetto, R. (2004). Why creativity is domain general, why it looks domain specific, and why the distinction does not matter, In R. Sternberg, E. Grigorenko & J. Singer (Eds.), *Creativity – From potential to realization*, American Psychological Association, Washington, DC.

R

Rhodes, M. (1961). An analysis of creativity. *Phi Delta Kappan*, 42, 305–310.

Ridding, R. & Cheema, I. (1991). Cognitive Styles: An Overview and Integration. *Educational Psychology,* 11(3/4), 193–216.

Rietzschel, E., Nijstad, B., & Stroebe, W. (2006). Productivity is not enough: a comparison of interactive and nominal brainstorming groups on idea generation and selection. *Journal of Experimental Social Psychology*, 42, 244-251.

Rittel, H. & Webber, M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, 4(2), 155-169.

Rosenman, M. & Gero, J. (1993). Creativity in design using a design prototype approach. In J. Gero & M. Maher (eds.) *Modelling creativity and knowledge-based creative design.* New Jersey, USA: Lawrence Erlbaum.

Runco, M. (2007) *Creativity. Theories and themes: research, development, and practice.* Elsevier Academic Press, London, UK.

Runco M. & Albert R. (2010). Creativity research. In: J. C. Kaufman & R. J. Sternberg (Ed.) *The Cambridge Handbook of Creativity,* Cambridge University Press.

Runco, M. & Jaeger, G. (2012). The Standard Definition of Creativity. *Creativity Research Journal*, 24(1), 92–96.
Sachs, A. (1999). 'Stuckness' in the design studio. *Design Studies*, 20, 195 – 209.

**S**

Sarkar, P., & Chakrabarti, A. (2007). Development of a method for assessing design creativity. In *International Conference on Engineering Design, ICED'07* (Vol. 390, 1–12). Paris, France.

Sarkar, P., & Chakrabarti, A. (2008). The effect of representation of triggers on design outcomes. *Ai Edam,* 22(02), 101–116.

Sarkar, P., & Chakrabarti, A. (2011). Assessing design creativity. *Design Studies,* 32(4), 348–383.

Sawyer, R. (2006). *Explaining Creativity: The Science of Human Innovation.* New York: Oxford University Press.

Schön, D. (1963). *Displacement of concepts,* Tavistock, London, UK.

Schön, D. (1983). *The reflective practitioner: How professionals think in action*, New York: Basic Books.

Seifert, C. M., Meyer, D., Davidson, N., Patalano, A., & Yaniv, I. (1995). Demystification of cognitive insight : Opportunistic assimilation and the prepared-mind hypothesis. In *The Nature of Insight*, 71 –124.

Setchi, R., & Bouchard, C. (2010). In search of design inspiration: A semantic-based approach. *Journal of Computing and Information Science in Engineering,* 10(3).

Shah, J. J., Kulkarni, S. V, & Vargas-Hernandez, N. (2000). Evaluation of idea generation methods for conceptual design: Effectiveness metrics and design of experiments. *Journal of Mechanical Design,* 122(December), 377–384.

Shah, J., Vargas-Hernandez, N., & Smith, S. (2003). Metrics for measuring ideation effectiveness. *Design Studies,* 24, 111–134.

Sherwin, D. (2010). *Creative workshop: 80 challenges to sharpen your design skills.* HOW books.

Simon, H. (1973). The structure of ill structured problems. *Artificial Intelligence,* 4(3-4), 181–201.

Simon, H. (1969). *The sciences of artificial.* MIT Press, Cambridge, MA.

Simonton, D. K. (1984). *Genius, creativity, and leadership.* Cambridge University Press.

Simonton, D. K. (2012). Taking the U.S. patent office criteria seriously: A quantitative three-criterion creativity definition and its implications. *Creativity Research Journal,* 24(2-3), 97–106.

Simsarian, K. T. (2003). Take it to the next stage: the roles of role playing in the design process. In *Proceedings of CHI* (1012-1013).

Smith, S., & Blankenship, S. (1991). Incubation and the Persistence of Fixation in Problem Solving. *The American Journal of Psychology*, 104(1), 61–87.

Smith, G. J. (1998). Idea-generation techniques: a formulary of active ingredients. *Journal of Creative Behavior,* 32(2), 107-133.

Smith, S. (1995). Getting into and out of mental ruts: A theory of fixation, incubation, and insight, in R.J. Sternberg and J. Davidson (eds), *The nature of insight,* Cambridge: MIT Press, 121-149.

Smith, S. (2003). The constraining effects of initial ideas. In P. B. Paulus and B. A. Nijstad (Eds.), *Group Creativity.* New York, NY: Oxford University Press (15 – 31).

Smith, S., & Linsey, J. (2011). A three-pronged approach for overcoming design fixation, *Journal of Creative Behavior,* 45(2), 83-91.

Smith, S. M., & Ward, T. B. (2012). Cognition and the creation of ideas. In K. J. Holyoak & R. G. Morrison (Eds.), *The Oxford Handbook of Thinking and Reasoning,* 456 – 474.

Sobek, D. K. (2002). Preliminary Findings from Coding Student Design Journals. In *Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition*.

Spink, A. (1996). A multiple search session model of end-user behaviour: an exploratory study. *Journal of the American Society for Information Science,* 46, 603 – 609.

Stanovich, K. & West, R. (2000). Individual differences in reasoning: Implications for the rationality debate. *Behavioral and Brain Sciences,* 23, 645-665.

Stark, L.-J., & Perfect, T. (2008). The effects of repeated idea elaboration on unconscious plagiarism. *Memory & Cognition,* 36(1), 65–73.

Stein, M. (1953). Creativity and culture. *Journal of Psychology,* 36, 31-322.

Sternberg, R. (Ed.) (1988). T*he nature of creativity: Contemporary psychological perspectives.*

Cambridge University Press.

Sternberg, R. J., & Lubart, T. I. (1999). The concept of creativity: Prospects and paradigms. In: R. J. Sternberg (Ed.), *Handbook of creativity* (Vol. 1, pp. 3–15).

Stroebe, W., & Diehl, M. (1994). Why groups are less effective than their members: On productivity loss in idea generating groups. In Stroebe, W, & Hewstone, M. (Eds.) *European review of social psychology,* Vol. 5 (271-304). Chichester: Wiley.

Suwa, M., & Tversky, B. (2003). Constructive perception: A metacognitive skill for coordinating perception and conception. *Twenty-Fifth Annual Conference of the Cognitive Science Society,* 1140–1145.

T

Tardif, T. & Sternberg, R. (1988). What do we know about creativity? In: R. J. Sternberg (Ed.), *The nature of creativity,* (429 – 440). New York: Cambridge University Press.

Taylor, D. W., Berry, P. C., & Block, C. H. (1958). Does group participation when using brainstorming facilitate or inhibit creative thinking? *Administrative Science Quarterly*, 3(1), 23-47.

Tenpenny, P., Keriazakos, M., Lew, G., & Phelan, T. (1998). In Search of Inadvertent Plagiarism. *The American Journal of Psychology,* 111(4), 529–559.

Tobin, D. R. (1998). *The knowledge-enabled organization*. New York: AMACOM.

Töre Yargin, G., & Crilly, N. (2015). Information and interaction requirements for software tools supporting analogical design. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 29(2), 203 - 214.

Torrance, E. (1962). *Guiding creative talent.* Englewoods Cliffs, NJ: Prentice-Hall.

Tovey, M. J. (1992). Intuitive and objective processes in automotive design. *Design Studies,* 13(1), 23-41.

Tseng, I., Moss, J., Cagan, J., & Kotovsky, K. (2008). The role of timing and analogical similarity in the stimulation of idea generation in design. Design Studies, 29(3), 203–221.

Tseng, W. S. W., & Ball, L. J. (2010). How uncertainty helps sketch interpretation in a design task. In T. Taura & Y. Nagai (Eds.), *Design Creativity 2010*, 257-264. London: Springer.

Turner, B. T. (1978), *Senior Clayton fellowship final report: Information for engineering design work.* London, UK: The Institution of Mechanical Engineers.

V

Vasconcelos, L. A., & Crilly, N. (2015) Inspiration and fixation: questions, methods, findings, and challenges. (Unpublished manuscript submitted to *Design Studies*).

Vattam, S., Wiltgen, B., Helms, M., Goel, A. K., & Yen, J. (2010). DANE: Fostering Creativity in and through Biologically Inspired Design. In T. Taura & Y. Nagai (Eds.), *Design Creativity 2010* (pp. 125 – 122). London: Springer-Verlag.

Vattam, S., & Goel, A. (2011). Foraging for inspiration: Understanding and supporting the online information seeking practices of biologically inspired designers. *Proc. ASME 2011 Int. Design Engineering Technical Conf. Computers and Information in Engineering Conference,* 177 - 186, Denver, CO: ASME.

Verhaegen, P.-A., Vandevenne, D., Peeters, J., & Duflou, J. R. (2012). Refinements to the variety metric for idea evaluation. *Design Studies,* 1–21.

Visser, W. (1996). Two functions of analogical reasoning in design: A cognitive psychology approach. *Design Studies,* 17, 417–434.

Viswanathan, V., & Linsey, J. (2013). Examining design fixation in engineering idea generation : the role of example modality. *International Journal of Design Creativity and Innovation,* 1(2), 109–129.

W

Wallas, G. (1926). *The art of thought.* London: Cape.

Ward, T. (1994). Structured imagination: the role of category structure in exemplar generation. *Cognitive Psychologoy,* 27(1), 1-40.

Ward, T. (1998). Analogical distance and purpose in creative thought: mental leaps versus mental hops. In K. J. Holyoak, D. Gentner, & B. N. Kokinov (Eds.), *Advances in analogy research: Integration of theory and data from the cognitive, computational, and neural sciences* (pp. 221-230). Sofia, Bulgaria: New Bulgarian University Press.

Ward, T. B., Patterson, M. J., & Sifonis, C. M. (2004). The Role of Specificity and Abstraction in Creative Idea Generation. *Creativity Research Journal,* 16(1), 1–9.

Ware, C. (2008). *Visual thinking: For design.* Burlington, MA: Elsevier (Morgan Kaufmann).

Weisberg, R. (1999). Creativity and knowledge: A challenge to theories. In: R. J. Sternberg (Ed.) *Handbook of creativity,* Cambridge: Cambridge University Press.

Weisberg, R. (2006). *Creativity: Understanding Innovation in Problem Solving, Science*, Invention and the Arts. John Wiley and Sons, Inc., New Jersey.

Wilson, T. D. (1997). Information behaviour: an interdisciplinary perspective. *Information Processing & Management,* 33(4), 551–572.

Wiltschnig, S., Christensen, B. T., & Ball, L. J. (2013). Collaborative problem-solution co-evolution in creative design. *Design Studies,* 34(5), 515–542.

Y

Yang, M. C., Wood, W. H., & Cutkosky, M. R. (2005). Design information retrieval: a thesauri-based approach for reuse of informal design information. *Engineering with Computers,* 21(2), 177–192.

Youmans, R. (2011). The effects of physical prototyping and group work on the reduction of design fixation. *Design Studies*, 32(2), 115–138.

Youmans, R., & Arciszewski, T. (2012). Design Fixation : A Cloak of Many Colors. In J. Gero (Ed.), *Design Computing and Cognition '12* (pp. 1–18). Springer.

Youmans, R., & Arciszewski, T. (2014). Design fixation: Classifications and modern methods of prevention. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 28(02), 129–137.

Z

Zahner, D., Nickerson, J. V., Tversky, B., Corter, J. E., & Ma, J. (2010). A fix for fixation? Rerepresenting and abstracting as creative processes in the design of information systems. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 24, 231.

Zeng, L., Proctor, R. W., & Salvendy, G. (2011). Can Traditional Divergent Thinking Tests Be Trusted in Measuring and Predicting Real-World Creativity? *Creativity Research Journal*, 23(1), 24–37.

# Summary

Every great invention, innovative design or visionary art piece ever created started in the same way: with a blank canvas. This limitless white page can be quite daunting, especially when you do not know how to start. However, you never begin a new project with a completely clean slate: besides memories, past experiences and general knowledge, all of us are constantly surrounded by information, which can have a profound influence in our daily lives.
Designers, just like other problem solvers, often find inspiration for their solutions in the myriad of stimuli they encounter. By walking down the street, by talking with a friend, by casually overhearing something on the radio or in any other situation, they can stumble upon something meaningful that can steer part of an idea into a concrete solution. Nevertheless, these random encounters with inspiration are unpredictable. When they are required to consistently deliver creative solutions, designers can become stuck or fixated, unable to continue generating ideas. And because inspiration is not a step-wise process that can be neatly followed by a method, nobody knows whether a stimulus found by chance may lead to an insight and, subsequently, to the development of a novel and practical solution.
Although this is a process that designers naturally, and often unconsciously experience in practice, research on design inspiration has not gained much traction so far. This thesis aimed to address that, to better support the inspiration process of designers and thereby promote the development of creative solutions.
The research question that guided this thesis was the following: *How can we support designers in searching, selecting, retrieving and implementing external stimuli to improve creativity in the design process?*
The main research question was divided into the following sub-questions, to enable a more structured approach to this research:
1. What are the external stimuli designers ***search*** for during idea generation?
2. How do external stimuli, such as visual and textual stimuli ***influence*** designers during idea generation?

3. Which ***processes*** do designers employ while searching and using external stimuli for a design problem?
4. How do designers ***select*** external stimuli and how does it influence creativity in the design process?

Provisional responses to these sub-questions contributed to the development of a model of the inspiration process of designers, which expands on how designers use and are influenced by stimuli in design. Thus, the ultimate goal of this thesis was to encourage design creativity, by enabling designers in education and in practice to become more aware of their inspiration process.

Each sub-question reveals an aspect of the inspiration process not yet covered by empirical research, and four studies were conducted to address these gaps (found in chapters 3, 4, 5 and 6).

This thesis is structured in the following way:

***Theoretical investigation***

**Chapter 1** describes an initial introduction to the phenomenon of inspiration, together with the relevance of this topic for design practice and education. Furthermore, it also explains the research methodology that was adopted, by elaborating on how the research question was answered with the four empirical studies. Since this thesis is about designers and for designers (in practice, research and education), it follows a designer-centered methodology (Badke-Schaub, Daalhuizen and Roozenburg, 2011). The chapter concludes with an overview of the main themes and a thesis outline.

**Chapter 2** reviews meaningful theoretical streams of literature, relevant for the study of inspiration in design, by including concrete definitions of inspiration in relation to information, inspiration sources and stimuli. This chapter is divided into four main sections. Firstly, inspiration and the use of inspiration sources are framed in relation to the design process, as one possible strategy to cope with uncertainty. The second section provides a comprehensive overview of main findings regarding the use of stimuli and their influence on creativity. Subsequently, creativity is the main issue discussed in the third section of chapter 2. This includes a definition of creativity, main responsible cognitive processes and a revision of possible metrics to evaluate creativity. Chapter 2 concludes with a fourth section on the detrimental influence of external stimuli on creativity, reviewing such phenomena as design fixation.

***Empirical investigation***

**Chapter 3** initiates the empirical section of this thesis, by focusing on the first of the sub-research questions: What are the external stimuli designers search for during idea generation? The first study explores the types of stimuli and ideation methods student and professional designers prefer. A questionnaire with 103 students and 52 practitioners revealed that designers across different levels of expertise have a rather limited range of inspiration preferences. Both student and professional designers demonstrated a striking preference for visual stimuli when searching for inspiration, as well as design and problem-related stimuli. Moreover, designers' preference on ideation methods could also be considered restrictive, especially in the case of student designers, who prefer brainstorming over other methods. Thus, designers might be hijacking their own inspiration approaches. By favoring the most readily available ideation methods and stimuli, which several research studies have linked to potentially inferior creative output, designers might be creating barriers to their own creativity. As these findings provided information on designers preferences on types of stimuli and ideation methods, Study I was the starting point for the following three studies.

**Chapter 4** introduces Study II, which was motivated by the following sub-research question: How do external stimuli, such as visual and textual stimuli influence designers during idea generation? The aforementioned study I revealed that, when comparing visual and textual stimuli, designers often overlook textual stimuli (preferring visual ones), despite the empirical evidence pointing out text as a potential alternative to stimulate creativity (Goldschmidt and Sever, 2010; Chiu & Shu, 2007, 2012). This motivated Study II, an experimental study with 137 design students that investigated the usefulness of visual and textual stimuli, across three levels of semantic distance, during ideation. Thus, it was also possible to explore how closely related, distantly related and unrelated stimuli influence creativity. The main finding from Study II revealed that there seems to be a curvilinear pattern regarding the usefulness of sematic distance of stimuli in relation to creativity. When considering semantic distance of stimuli in a continuum, starting from closely related towards unrelated stimuli, there seems to be a potential inspiration peak. More specifically, using distantly related stimuli (in relation to the context of the design problem being tackled) can be more beneficial to attain creative results than when stimuli are semantically too close or too far. This curvilinear pattern was observed when using visual and textual stimuli. Moreover, a comparison between the influence of visual and textual stimuli on creativity revealed that text is beneficial as potential inspiration source. Designers usually disregard textual stimuli as a potential stimuli type (as demonstrated in chapter 3, study I) but these results indicate that designers can benefit from alternating between images and text.

**Chapter 5** explores the third sub-research question: Which processes do designers employ while searching and using external stimuli for a design problem? For this purpose, a case-study approach was chosen for Study III, to enable an in-depth analysis of the inspiration process of eight design students, during a period of 10 weeks. By collecting process and outcome data periodically, it was possible to develop a flowchart to represent the designers' inspiration process. The findings from Study III revealed that the inspiration process occurs cyclically within the design process, within different phases, and three main goals motivate inspiration use: Inspiration for problem definition; Inspiration for sub-problems exploration; and Inspiration for sub-solutions refinement. Depending on these goals, inspiration cycles occur multiple times during the design process, which leads to reframing of the problem or the solution.

**Chapter 6** expands on the findings of the previous study, emphasising the selection process of inspiration sources in design. Study IV sought to answer the last of the sub-research questions: How do designers select external stimuli and how does it influence creativity in the design process? This study combines a quantitative and qualitative approach, as it was set up as an experimental study followed by interviews with 31 design students. This resulted in the further development of the inspiration process flowchart, started with Study III (Chapter

5). More specifically, it was possible to identify the mechanisms behind three phases of the inspiration process, namely: Definitions of keywords; Search of stimuli; and Selection of stimuli. Besides contributing to the understanding of what it entails to use inspiration sources, study IV revealed that, although designers are motivated to use stimuli from distant domains, they find it difficult to know what to search for (i.e., defining keywords). Thus, to promote serendipity, designers engage in different search typologies, which were identified in this study. Finally, the following five drivers for selection of stimuli were distinguished: relevance; recognition; verification; reliability and curiosity.

***Conclusion, implications and recommendations***

**Chapter** 7 concludes this thesis with a summary of the main findings and the discussion of an overall model of the inspiration process. This model complements the many findings from this thesis in relation to a number of theoretical concepts, such as Schön's reflective practice theory (Schön, 1983) and the co-evolution model in design (Maher and Poon, 1996; Maher, 2000; Dorst and Cross, 2001; Wiltschnig, Christensen and Ball, 2013). A discussion of the inspiration model under these theoretical perspectives revealed that reflection is an essential element to support designers in their search, selection, retrieval and implementation of external stimuli, in order to promote creativity in design. Furthermore, the last sections of chapter 7 elaborate on contributions and implications for design practice and education, possible recommendations to take the findings from this thesis forward, and possible research caveats to take into consideration. This chapter rounds off by suggesting several avenues for future research, such as the development of computational tools to support the inspiration process and the exploration of stimuli usefulness across collaborative settings.

# Samenvatting

Iedere grote uitvinding, innovatief ontwerp of visionair kunstwerk dat ooit gecreëerd werd begon op eenzelfde manier: met een leeg canvas. Deze oneindige witte pagina kan ontmoedigend overkomen, vooral wanneer iemand niet weet hoe te ermee te beginnen. Echter, je begint nooit een nieuw project met een volledig lege lei: los van herinneringen, ervaringen uit het verleden en algemene kennis, zijn we allemaal constant omringd door informatie, welke een diepgaande invloed kan hebben op ons dagelijks leven.

Ontwerpers, net zoals andere probleemoplossers, vinden vaak inspiratie voor hun oplossingen in de massa stimuli die ze tegenkomen. Door over straat te wandelen, tegen een vriend te praten, toevallig iets op de radio op te vangen of in elke andere situatie, kunnen ze iets waardevols tegenkomen dat een deel van een idee naar een concrete oplossing kan leiden. Desalniettemin, zijn deze toevallige ontmoetingen met inspiratie onvoorspelbaar. Wanneer van hen vereist wordt om constant creatieve oplossingen op te leveren, kunnen ontwerpers vast of gefixeerd geraken, verhinderd om verder ideeën te genereren. En omdat inspiratie geen stap voor stap proces is dat netjes gevolgd kan worden met een model, weet niemand of een stimilus die bij toeval gevonden wordt kan leiden tot een inzicht en, opeenvolgend, tot de ontwikkeling van een nieuwe en praktisch toepasbare oplossing.

Hoewel dit een proces is dat ontwerper van nature en vaak onbewust ervaren in praktijk toepast, heeft onderzoek naar ontwerp inspiratie tot nu toe nog niet veel voeten aan grond gekregen. Dit proefschrift heeft dit als doel, om zo het inspiratie proces van ontwerpers beter te ondersteunen en daarbij ook de ontwikkeling van creatieve oplossingen te bevorderen. De onderzoeksvraag die als leidraad dient voor dit proefschrift in was de volgende: Hoe kunnen we ontwerpers ondersteunen in het zoeken, selecteren en implementeren van externe stimuli om creativiteit in het ontwerpproces te verbeteren?

De hoofd onderzoeksvraag werd onderverdeeld in de volgende sub-onderzoeksvragen, om een meer gestructureerde aanpak toe te laten :

1. Wat zijn de externe stimuli waar ontwerpers naar op zoek zijn tijdens ideegeneratie?

2. Hoe beïnvloeden externe stimuli, zoals visuele en tekstuele stimuli ontwerpers tijdens ideegeneratie?
3. Welke processen gebruiken ontwerpers wanneer ze externe stimuli zoeken en gebruiken bij een ontwerpprobleem?
4. Hoe selecteren ontwerpers externe stimuli en hoe beïnvloedt dit creativiteit in het ontwerpproces?
Voorlopige resultaten op deze sub-vragen droegen bij tot de ontwikkeling van een model van het inspiratieproces van ontwerpers, welk uit de doeken doet hoe ontwerpers stimuli gebruiken en erdoor beïnvloedt worden. Aldus, het uiteindelijke doel van dit proefschrift was om creativiteit in het ontwerpen aan te moedigen, door ontwerpers, in onderwijs en in de praktijk, toe te laten meer gewaar te worden van hun inspiratieproces.
Elke sub-vraag belicht een aspect van het inspiratieproces dat tot op heden nog niet door empirisch onderzoek gedekt werd, en vier studies werden ondernomen om deze leemtes aan te pakken (terug te vinden in hoofdstukken 3, 4, 5 en 6).
Dit proefschrift is gestructureerd op de volgende manier :

***Theoretisch onderzoek***
**Hoofdstuk 1** beschrijft een initiële introductie tot het fenomeen van inspiratie, samen met de relevantie van dit onderwerk voor het ontwerpen in praktijk en educatie. Bovendien, legt het ook de onderzoeksmethodiek uit die werd aangenomen, door uit te wijden over hoe de onderzoeksvraag beantwoordt werd met vier empirische studies. Aangezien dit proefschrift handelt over ontwerpers en gericht is naar ontwerpers (in de praktijk, onderzoek en onderwijs), volgt het een ontwerp-gecentreerde methodologie (Badke-Schaub, Daalhuizen en Roozenburg, 2011). Het hoofdstuk eindigt met een overzicht van de belangrijkste thema's en een samenvatting van het proefschrift.
**Hoofdstuk 2** bespreekt zinvolle theoretische takken van de literatuur, relevant voor de studie naar inspiratie in het ontwerpen, door concrete definities van inspiratie in relatie tot informatie, inspiratiebronnen en stimuli op te nemen. Dit hoofdstuk is onderverdeeld in vier hoofddelen. Ten eerste, worden inspiratie en het gebruik van inspiratiebronnen gekaderd in relatie tot het ontwerpproces, als een mogelijke strategie om onzekerheid te behandelen. Het tweede deel voorziet een uitvoerig overzicht van de belangrijkste bevindingen rondom het gebruik van stimuli en hun invloed op creativiteit. Vervolgens wordt creativiteit als

belangrijkste kwestie behandeld in het derde deel van hoofdstuk 2. Dit omvat een definitie van creativiteit, de belangrijkste cognitieve processen en een herhaling van mogelijke maatstaven om creativiteit te evalueren. Hoofdstuk 2 eindigt met een vierde deel over de schadelijke invloed van externe stimuli op creativiteit en bespreekt fenomenen zoals ontwerp fixatie.

***Empirisch onderzoek***

**Hoofdstuk 3** leidt het empirische deel van dit proefschrift in, door te focussen op de eerste sub-onderzoeksvraag: Wat zijn de externe stimuli waar ontwerpers naar op zoek zijn tijdens ideegeneratie? Het eerste onderzoek verkent de soorten stimuli en methoden voor ideegeneratie die verkozen worden door studenten en professionele ontwerpers. Een vragenlijst met 103 studenten en 52 professionals bracht aan het licht dat ontwerpers met verschillende niveaus van expertise een behoorlijk beperkt scala van inspiratie voorkeuren hebben. Zowel studenten als professionele ontwerpers vertoonden een opvallende voorkeur voor visuele stimuli wanneer op zoek naar inspiratie, idem voor ontwerp en probleem-gerelateerde stimuli. Bovendien, zou de voorkeur van ontwerpers voor bepaalde ideegenererende methodes ook beperkend beschouwd kunnen worden, vooral in het geval van student-ontwerpers, welke brainstorming boven andere methodes verkiezen. Zo doende, zou het kunnen dat ontwerpers hun eigen inspiratie aanpak kapen. Door de makkelijkst voor handen zijnde ideegeneratie methode en stimuli te verkiezen, welke verschillende onderzoeken verbonden hebben aan mogelijke minderwaardige creatieve output, werpen ontwerpers mogelijk barrières op voor hun eigen creativiteit. Aangezien deze vondsten informatie over de voorkeuren van types stimuli en ideegeneratiemethoden opleverden, was Onderzoek I het startpunt voor de volgende drie onderzoeken.

**Hoofdstuk 4** leidt Onderzoek II in, welk gedreven werd door de volgende sub-onderzoeksvraag: Hoe beïnvloeden externe stimuli, zoals visuele en tekstuele stimuli ontwerpers tijdens ideegeneratie? Het reeds besproken Onderzoek I onthulde al dat, wanneer visuele en tekstuele stimuli vergeleken worden, ontwerpers vaak de tekstuele stimuli over het hoofd zien (ze verkiezen visuele), ondanks het feit dat empirisch bewijs laat zien dat tekst een mogelijk alternatief is om creativiteit te stimuleren (Goldschmidt and Sever, 2010; Chiu & Shu, 2007, 2012). Dit leidde Onderzoek II in, een experimenteel onderzoek met 137 studenten dat het nut van visuele en tekstuele stimuli onderzocht, over drie niveaus van semantische afstand, tijdens de ideegeneratie. Zo doende, was het ook mogelijk om te verkennen hoe nauw gerelateerde, ver gerelateerde of niet gerelateerde stimuli creativiteit beïnvloeden. De belangrijkste vondst uit Onderzoek II bracht aan het licht dat er een curvilineair patroon blijkt te zijn tussen het nut van de semantische afstand van stimuli in relatie tot creativiteit. Wanneer semantische afstand van stimuli in een continuüm beschouwd wordt, startende van nauw gerelateerd tot ver gerelateerde stimuli, lijkt er een potentiële piek in inspiratie te bestaan. Meer specifiek, ver gerelateerde stimuli (in relatie tot de context van het ontwerpprobleem dat aangepakt wordt) gebruiken, kan gunstiger zijn om creatieve resultaten te bereiken dan wanneer semantisch niet gerelateerde of te nauwe gerelateerde stimuli gebruikt worden. Dit curvilineair patroon werd geobserveerd wanneer visuele en tekstuele stimuli gebruikt werden. Bovendien, een vergelijking tussen de invloed van visuele en tekstuele stimuli op creativiteit bracht aan het licht dat tekst nuttig is als een mogelijke bron van inspiratie. Ontwerpers negeren gewoonlijk tekstuele stimuli als een mogelijk type van stimuli (zoals gedemonstreerd in hoofdstuk 3, onderzoek I) maar deze resultaten tonen aan dat ontwerpers kunnen profiteren van afwisseling tussen afbeeldingen en tekst.

**Hoofdstuk 5** verkent de derde sub-onderzoeksvraag: Welke processen gebruiken ontwerpers wanneer ze externe stimuli zoeken en gebruiken bij een ontwerpprobleem? Hiervoor werd een case-study aanpak gekozen voor Onderzoek III, om toe te laten een diepteanalyse van het inspiratieproces van acht ontwerpstudenten te voeren tijdens een periode van 10 weken. Door periodiek data van het proces en resultaten te verzamelen, was het mogelijk om een flowchart te ontwikkelen die het inspiratieproces van de ontwerpers voorstelt. De resultaten van Onderzoek III brachten aan het licht dat het inspiratieproces cyclisch voorkomt binnen het ontwerpproces, binnen verschillende fases, en drie hoofddoelen motiveren het gebruik van inspiratie: inspiratie voor probleemdefinitie, inspiratie voor verkenning van deelproblemen; en inspiratie voor de verfijning van deeloplossingen. Afhankelijk van deze doelen, komen inspiratiecycli verscheidene malen voor in het ontwerpproces, welke leiden tot het herformuleren van het probleem of de oplossing.

**Hoofdstuk 6** gaat verder met de resultaten van de vorige studie, de nadruk leggende op het selectieproces van inspiratiebronnen in het ontwerpen. Onderzoek IV zocht naar antwoorden op de laatste van de sub-onderzoeksvragen:

Hoe selecteren ontwerpers externe stimuli en hoe beïnvloedt dit creativiteit in het ontwerpproces? Deze studie combineert een kwantitatieve en een kwalitatieve aanpak, aangezien ze opgezet was als een experimentele studie gevolgd door interviews met 31 ontwerpstudenten. Dit resulteerde in de verdere ontwikkeling van de inspiratie proces flowchart, gestart tijdens Onderzoek III (Hoofdstuk 5). Meer specifiek, was het mogelijk om de mechanismes achter de drie fases van het inspiratieproces te identificeren, namelijk: Definitie van kernwoorden, Zoektocht naar stimuli; en Selectie van stimuli. Buiten het bijdragen tot het inzicht naar wat het inhoudt om inspiratie bronnen te gebruiken, bracht Onderzoek IV aan het licht dat, hoewel ontwerpers gemotiveerd zijn om stimuli van afgelegen domeinen te gebruiken, vinden ze het moeilijk om te weten waar naar te zoeken (bvb, definiëren van kernwoorden). Zo doende, om serendipiteit aan te moedigen, gebruiken ontwerpers verschillende zoek-typologiën, welke geïdentificeerd werden in dit onderzoek. Als laatste werden de volgende vijf drijfveren voor selectie van stimuli onderscheiden: relevantie, herkenning, verificatie, betrouwbaarheid en nieuwsgierigheid.

***Conclusie, implicaties en aanbevelingen***

**Hoofdstuk** 7 concludeert dit proefschrift met een samenvatting van de belangrijkste vondsten en de discussie van een algemeen model van het inspiratieproces. Dit model vult de vele vondsten van dit proefschrift aan in relatie tot een aantal theoretische concepten, zoals Schön's reflectieve gebruik theorie (Schön, 1983) en het co-evolutiemodel in ontwerpen (Maher en Poon, 1996; Maher 2000; Dorst en Cross, 2001; Wiltschnig, Christensen en Ball, 2013). Een discussie over het inspiratie model ten opzichte van deze theoretische perspectieven liet zien dat reflectie een essentieel element is om ontwerpers te ondersteunen in hun zoektocht, selectie, terug ophalen en implementatie van externe stimuli, ten einde creativiteit in het ontwerpen te vergroten. Bovendien, gaan de laatste secties van hoofdstuk 7 dieper in op de bijdragen aan en implicaties voor ontwerpen in de praktijk en in educatie, mogelijke aanbevelingen om de vondsten uit dit proefschrift verder te zetten, en mogelijke onderzoekslimieten om in overweging te nemen. Dit hoofdstuk eindigt met suggesties voor mogelijk toekomstig onderzoek, zoals de ontwikkeling van computer hulpmiddelen om de het inspiratieproces de ondersteunen en de verkenning van de nuttigheid van stimuli binnen samenwerkingsverbanden.

## Appendix A – Example of questionnaire for professional designers

1. For how long have you been working as a professional designer?

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2. How long are you working in this company?

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3. Where did you do your studies?

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4. What is your educational background?

□ Industrial Design
□ Design Engineering
□ Mechanical Engineering
□ Artistic Design
□ Other

5. Do you look for sources of inspiration (e.g., nature, art, other solutions for the same problem) when you design? (only one option can be selected)

○ Always
○ Often
○ Sometimes
○ Rarely
○ Never

6. During the design process, how important is inspiration for you? (only one option can be selected)

○ Very important
○ Moderately important
○ Neutral
○ Slightly important
○ Not at all important

7. Which of these stimuli is more important for you during the design process?

(please evaluate each stimuli from 'Very important' to 'Not at all important')

| | Very important | Moderately important | Neutral | Slightly important | Not at all important |
|---|---|---|---|---|---|
| **Images** (photographs, drawings) | ○ | ○ | ○ | ○ | ○ |
| **Objects** (mock-ups, proto-types, commercial products) | ○ | ○ | ○ | ○ | ○ |
| **Text** | ○ | ○ | ○ | ○ | ○ |

8. When is inspiration most important to you?

□ All the time

□ Once I get the brief

□ During problem analysis

□ During idea generation

□ During conceptual design

□ During embodiment and detail design

□ In discussion with co–workers

□ In discussion with clients

9. Which of the following techniques and tools do you use in order to get inspired? (please consider how frequent do you use each technique/tool, from 'Always' to 'Never'.)

| | Always | Often | Sometimes | Rarely | Never |
|---|---|---|---|---|---|
| Collage | ○ | ○ | ○ | ○ | ○ |
| How to's | ○ | ○ | ○ | ○ | ○ |
| Mind map | ○ | ○ | ○ | ○ | ○ |
| Brainstorming | ○ | ○ | ○ | ○ | ○ |
| Synectics | ○ | ○ | ○ | ○ | ○ |
| Function Analysis | ○ | ○ | ○ | ○ | ○ |
| Morphological Chart | ○ | ○ | ○ | ○ | ○ |
| Roleplaying | ○ | ○ | ○ | ○ | ○ |
| Storyboard | ○ | ○ | ○ | ○ | ○ |
| Scenarios | ○ | ○ | ○ | ○ | ○ |

| | | | | | |
|---|---|---|---|---|---|
| Checklists | ○ | ○ | ○ | ○ | ○ |
| Context mapping | ○ | ○ | ○ | ○ | ○ |
| Metaphors | ○ | ○ | ○ | ○ | ○ |
| Analogies | ○ | ○ | ○ | ○ | ○ |
| Other? ________________ | ○ | ○ | ○ | ○ | ○ |

10. In which age group are you?
○ 21 – 30 years old
○ 31 – 40 years old
○ 41 – 50 years old
○ over 51 years old

11. What is your gender?
○ Female
○ Male

## Appendix B - Glossary of ideation methods

*Analogies:* Based on analogical reasoning, analogies enable the transfer of concepts, principles or features from the source example to solve problems creatively. The design solution and initial example (or source analogue) therefore share common characteristics, such as shape, functions or principles. By using analogies, it is possible to approach a design problem from a different perspective, by finding a distantly related concept in order to establish parallels, and transform it to fit the problem. Analogies are best used during idea generation, as this method enables the production of creative ideas.
*Brainstorming*: Created by Osborn (1953), this method seeks the generation of a large quantity of ideas in a short period of time, without considering – at this stage – their utility, feasibility or importance. There are four principles underlying brainstorming: 1 – quantity is wanted; 2 – premature criticism is avoided; 3 – freewheeling is welcomed; 4 – combination and improvement of ideas is desired. This method is usually carried out at the beginning of idea generation.
*Checklists:* As the name suggests, this is a collection of questions with a specific

focus, which enable a systematic development of concepts. It can be used at the beginning of a design process (to explore a problem and redefine it), during the idea generation phase (to explore alternatives to solving a specific problem) or at a later stage (to lead a concept to completeness).

*Collage:* is a visualisation technique made from collecting and combining of visual representations from different sources (e.g., magazines). The main purpose of collages is to create a homogeneous palette and visual impression of a context, target group or visual appearance of a concept, for instance. Collages can promote the visualisation of the designer's idea to others and identify design criteria for the subsequent phases of the design process. It is normally applied at the beginning of idea generation.

*Context mapping:* This is a user-centred design technique based on the experience of the user as an expert. This method requires the active participation of users. The method is aimed at enabling designers to understand the context of a specific situation (and types of user) through the observation of several layers of social, emotional, cultural or physical aspects in relation to a product/service. Context mapping normally comprises the use of cultural probes, videos and several interviews with users. This method can be used at different stages of the design process, but it is especially beneficial at the initial steps of the idea generation phase.

*Function analysis:* This method enables, through an abstraction exercise, analysis and development of the future function structure of a new product. Function analysis alters the perspective in which one approaches a problem, as it encourages looking from the interior to the outside of an artefact/system, or from the abstract to the specific. This method is based on what the product should do and how could it do it. It is normally employed at the beginning of the idea generation phase and often precedes the use of morphological charts.

*How to's:* By writing down problem statements in the form of 'how to …', this method enables the generation of a wide variety of perspectives on the problem. Consequently, this stimulates people to think creatively and to have an overview of the problem at hand. This method is most helpful at the beginning of the idea generation process.

*Metaphors:* Metaphors are a design method that is more appropriate for the earlier phases of the design process, and is specifically helpful for problem framing and definition. Metaphors enable the understanding of the design problem from different perspectives, by creating comparisons with another concept or situation. The differences between metaphors and analogies are often unclear, though they do have different goals. Metaphors are expected to provide meaning and perspective about a design problem; analogies enable the creation of ideas by mapping common structures/principles between the source analogue and the target solution.

*Mind map:* This method makes it possible to have a visual overview of a problem at hand that shows the relationship between a central theme and its ramification of important factors or ideas. Using associations, mind maps help to identify which are the main topics and sub-topics of a problem and to create a structure. It is most helpful at the beginning of the idea generation process. However, it can also be used at a later stage of the design process, for instance, at the problem analysis phase, to identify the positive or negative characteristics of a devised concept.

*Morphological chart:* This method enables the generation of ideas through an analytical and systematic procedure of combining components and functions. These functions and sub-functions can be pre-defined by employing a function analysis prior to a morphological chart. The latter is organised by a matrix of functions and components and each sub-function is meant to be combined. Each combination results in a new solution to the problem. This method is best applied at the beginning of the idea generation phase, after the function analysis method, and it is most suitable for the engineering design field.

*Roleplaying*: This method is based on the re-enactment of the tasks of interaction involving the situation of the problem at hand. This allows the designer to get 'into the users' shoes' and reach a better overview of which interactions are there and what could be developed. This method can therefore be used throughout the design process, depending on the expected goal.

*Scenarios:* Similar to storyboards, scenarios help designers and other stakeholders to grasp the context and use of a product, with a focus on the users. Scenarios are representative of authentic situations, as they normally derive from data collection during contextual enquiring sessions. The use of scenarios is especially beneficial in perceiving the interaction of user and product and can be used in several phases of the design process.

*Storyboards:* This is a tool for both designers (to understand the context, timing and use of a product) and external stakeholders (as it also provides a quick and easy visual description of a product in use). As it can be used with different goals in mind, storyboards can be developed at different stages of the design process. Therefore, depending on the intended aim, storyboards can entail different levels of refinement, being rougher and incomplete if it is meant to clarify the context for the designer or more detailed for a presentation to a client.

*Synectics:* Created by Gordon and Prince (1976), this is a comprehensive creative method, which contains techniques for problem analysis, idea generation and the selection stage. It is based on the use of analogies, as it helps people to dissociate from the original context, subsequently returning to it and trying to force fit novel concepts into the basic problem. Synectics is most appropriate for use in highly complex problems, as it is composed of several steps: 1 – analysis of the problem; 2 – reformulate problem statement (purge or shredding the known); 3 – find a relevant analogy; 4 – force fit solutions to the problem statement.

*TRIZ* (not included in questionnaire): This method is essentially based on logic and on the analysis and comparison of existing patents with the problem at hand. TRIZ does not have space for intuition. By systematically and repeatedly analysing patterns that might exist between patents in different fields, it is expected to lead to innovative solutions. These novel ideas contain transformed parts or principles of patents previously acknowledged as good solutions.

*Forward steps* (not included in questionnaire): As with TRIZ, forward steps is considered a logical method (Shah et al., 2003). It is can be applied by systematically creating and analysing variations of first ideas (which can initially be created in an unsystematic way).

## Appendix C - Explanation of formula for Originality and Rarity scores

As defined in Sections 4.5 (Study II) and 6.3.5 (Study IV), some metrics related to novelty were evaluated by statistical infrequency. In chapter 4, where there was no overall score for creativity, originality of ideas was measured by statistical infrequency. Thus, original ideas were considered to be inversely correlated to the probability of being generated by the participants: the fewer times an idea was reproduced by participants, the more original it was.
In chapter 6, an overall creativity score was developed and several metrics were refined. Consequently, originality was defined differently from rarity, but both metrics combined form a score of novelty. In this case, rarity was measured differently than the (revised) originality and other metrics: whilst the remaining metrics were scored in a 1-10 scale, Rarity was measured by statistical infrequency. In order to integrate rarity into the overall creativity score, the reoccurrence of each idea was transformed into a 1-10 scale, using the following linear equation: $Y = 10 – [Z (x – 1)] / xmax – 1$

This formula is based on two conditions:
When the number of occurrences of an idea is equal to the maximum number of occurrences, the rarity score of the idea is 1. That is to say, the most frequently occurring idea will score 1 in rarity.
$Y = 1 = a \times xmax + b$
When the number of occurrence is equal to 1, the rarity score of the idea is 10. In other words, the least frequently occurring idea will score 10 in rarity.
$Y = 10 = a \times 1 + b$
This enables to transform the rarity score into a 1 to 10 scale and to include it as part of the overall creativity score.

## Appendix D – Interview questions Study III

(next page)

**Background information**

**1)** How old are you?

**2)** Where do you come from?

**3)** How many years of design education did you have until now?

**4)** We would like to know more about your perception on your design skills. Could you please grade yourself (by circling the numbers below) on a scale from 1 (low) to 5 (high) on the following aspects:

| | [low] | | | | [high] |
|---|---|---|---|---|---|
| Analysing the problem | 1 | 2 | 3 | 4 | 5 |
| Innovative Ideas | 1 | 2 | 3 | 4 | 5 |
| Sketching | 1 | 2 | 3 | 4 | 5 |
| Conceptualisation | 1 | 2 | 3 | 4 | 5 |
| Detailing | 1 | 2 | 3 | 4 | 5 |
| Creativity | 1 | 2 | 3 | 4 | 5 |
| Ergonomics | 1 | 2 | 3 | 4 | 5 |
| Mechanics of materials | 1 | 2 | 3 | 4 | 5 |
| Aesthetics | 1 | 2 | 3 | 4 | 5 |

**5)** Please, fill in the online creativity test.

**Overview of the project**

**6)** Could you please explain how did you carry out your project?

**7)** Could you describe your design process and compare it with your usual design process?

**7.1)** If your process was different than usual, can you give me an example of how your design process is?

**7.2)** Which kind of design methods do you use (in this project and normally)?

**Analysis on inspiration sources**

**8)** In general, which kind of inspiration do you search for? (try to answer it in the format "Where/What/When/Who/How")

**9)** How do you find inspiration (Actively/Passively)?

**10)** Do you reuse inspiration?

**11)** Did you get inspired by your own ideas? Could you give an example?

**12)** Do you ever reflect on from where did your ideas come from?

**12.1)** How does that influence/change the final outcome?

**12.2)** When do you reflect?

**12.3)** Do you ever change the inspiration to build a better story for your concepts?

**Reflection on the experiment**

**13)** This reflection on the relation between inspiration sources and idea generation **helped** my design process during this project.

| **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|
| Strongly disagree | Disagree | Neither agree or disagree | Agree | Strongly agree |

**14)** This reflection on the relation between inspiration sources and idea generation **disturbed** my design process during this project.

| **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|
| Strongly disagree | Disagree | Neither agree or disagree | Agree | Strongly agree |

# Appendix E – Coding scheme interviews Study III

| **Theme** | **Category** | Code |
|---|---|---|
| INSPIRATION PROCESS | Inspiration: what | Preference for closely related stimuli<br>Preference for visual stimuli<br>Preference for Internet as medium<br>Internet use to explore context<br>Search queries formulated as questions<br>Search queries closely related to the problem at hand<br>Personal experience as stimuli<br>Originality vs "don't reinvent the wheel"<br>Inspiration for different moments of the design process |
| | Inspiration: who | Over-reliance on coach (colleagues/friends)<br>Confidence on experts and users' opinions<br>Inspiration by misunderstandings |
| | Inspiration: when | Ubiquity influence of inspiration sources<br>Use of inspiration across all phases of the design process, with different goals<br>Using inspiration from users<br>Building from ideas from others |
| | Inspiration: where | Internet predominance<br>Limited use of magazines and books<br>Everyday life |
| | Active and passive inspiration | Active inspiration related to the resolution of (sub-)solutions<br>Passive inspiration related to the understanding of (sub-)problems<br>Ongoing search (active inspiration search without a problem at hand)<br>Active search provoked by creative blocks |
| | Inspiration reuse | Recognition of reusing inspiration |
| | Information | Excessive vs insufficient information<br>Perks/drawbacks from too much info<br>Uncertainty on what to search for<br>Information vs inspiration |

| Theme | Category | Code |
| --- | --- | --- |
| DESIGN PROCESS | Process | Ambiguous/Vague problem definition<br>Coping with ambiguity with information<br>Lack of structure/externally imposed requirements |
| | Methods | Use of 'mindmaps' in Task Clarification phase<br>Use of 'How to's' in Task Clarification & Concept Design phases<br>Use of methods for educative purposes<br>Unstructured use of methods |
| | Idea generation | Primary generator<br>Reuse of ideas by combination<br>(Use of closely/distantly related stimuli) |
| | Concept selection | Time-dependent concept-selections<br>Selections based on implicit self-imposed criteria<br>Selections based on external considerations (company/users)<br>Subjective decision-making methods |
| | Creativity blocks | Recognition of feeling stuck<br>Stuckness caused by vague design brief<br>Coping strategies |
| | Sketching | Explorative "dooling"<br>Initial exhaustion of obvious ideas<br>Relation between types of sketches and audience/medium (report vs notebook) |
| | Prototyping | Drawbacks of prototyping: premature conceptualisation & delays<br>Perks of prototyping: knowledge on problem/user & supports iteration |
| REFLECTION | Perception of skills | Uncertainty vs confidence<br>Adoption of different roles in group work<br>Competences development |
| | Reflection | Lack of reflection in usual design process<br>Disruptive reflection<br>Stimulative reflection |

## Appendix F – Creation of search tool and stimuli for Study IV

The search tool used a closed-circuit database, which used the existing platform www.blogger.com. In order to build the database of the search tool, several requirements were considered. The search tool enabled:
• a more controlled environment to run the experiment, compared to existing search engines (but similar enough to maintain a high ecological validity);
• the creation of meta-data (not visible to the participants), embedded in the stimuli;
• the search for keywords, by using meta-data;
• to randomly display stimuli retrieved by the participants;
• to display multiple stimuli at the same time;
• the modification of the size of the stimuli displayed;
• to partially display stimuli, so participants can have only an impression of the stimulus.
The process of assembling such a large quantity of stimuli required 5 phases of preparation, which are succinctly presented in Figure A1.

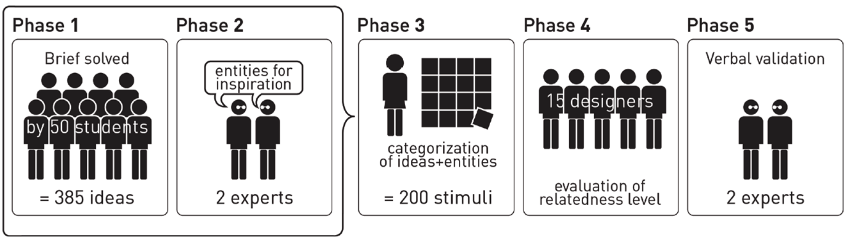


Figure A.1. Overview of the creation process of the stimuli for the search tool used in this study.

During Phase 1, 50 Master students developed ideas for the design brief, resulting in 385 ideas. Phase 1 also enabled us to pre-test the design brief to evaluate whether it was sufficiently accessible and open for exploration. In Phase 2, two design experts, who were unaware of the solutions created in the Phase 1, devised entities (situations, products or actions) associated with the resolution of the brief, aiming to assemble possible associations or directions that one could use as inspiration source. The experts of Phase 2 were a professional product designer with five years of experience and a fellow design researcher, who were unaware of the goals of this study. In Phase 3, the author of this thesis clustered the entities resulting from Phases 1 and 2, in order to create 50 main categories (e.g., 'Communication'). For each category, four stimuli were created or found: two pictures and two texts with two levels of semantic distance to the topic of 'children sleeping alone at night', closely related and distantly related. This process resulted in 200 total stimuli. The remaining phases were reserved to evaluate the stimuli. In Phase 4, 15 designers rated the semantic distance of the stimuli, regarding the topic of helping children to sleep alone at night, in three levels: closely related; distantly related; or unrelated. The goal was to validate whether the 200 stimuli adequately conveyed the intended level of semantic distance. When the professional designers could not reach perfect agreement, alternative stimuli were found. During Phase 5, the initial two experts from Phase 2 were asked to evaluate the semantic distance level of alternative stimuli and verbal validation was reached. Finally, there were a total of 200 stimuli.

## Appendix G – Coding scheme used to analyse designers' process for Study IV

(next page)

| **Theme** | **Category** | Code |
|---|---|---|
| ANALYSIS | Problem<br>Process | Considering requirements<br>Reflecting on complexity of problem<br>Reflecting on process<br>Formulating direction<br>Planning<br>Using method |
| IDEA GENERATION | Diverging<br>Converging | Creating idea<br>Elaborating idea<br>Combining idea<br>Evaluating idea<br>Rejecting idea |
| STIMULI SELECTION | Deliberate<br>Unconscious/ Latent | Selecting close related image<br>Selecting close related text<br>Selecting distant related image<br>Selecting distant related text<br>Selecting keyword |
| INFLUENCE OF IDEAS | Direct influence<br>Indirect influence | Based on previous idea<br>Based on experience<br>Based on environment<br>Based on existing solution<br>Based on stimuli |
| OPERATIONAL ACTIVITIES | | Writing<br>Sketching<br>Talking<br>Reading<br>Looking at sketches<br>Using tool<br>Scrolling<br>Typing |

## Appendix H – Coding scheme used to analyse designers' interviews for Study IV

| Theme | Category | Code |
|---|---|---|
| PREFERENCES AND MOST USED STIMULI | Need for inspiration | Needing inspiration<br>Not knowing what is inspiration<br>Needing to be original<br>Evaluating skills (positively or negatively)<br>Thinking associatively |
| | Most used types of content | Using inspiration from brief<br>Using inspiration with focus on form<br>Using inspiration from past experiences<br>Using inspiration from users<br>Building from ideas from others |
| | Most used medium | Using magazines and books<br>Using internet |
| | Most used type of stimuli representation | Using visual stimuli<br>Using textual stimuli<br>Using other types of stimuli |
| | Most used semantic distance | Using closely related stimuli<br>Using medium related stimuli<br>Using distantly related stimuli<br>Having difficulties on using distant stimuli |
| COPING WITH CONSTRAINTS | Conscious perception of constraints | Being constrained by time limitation<br>Feeling stuck<br>Feeling stuck in 1st idea |
| | Coping with constraints | Applying coping strategies<br>Applying methods<br>Working in group/brainstorming<br>Reusing ideas / iterating<br>Evaluating reuse of ideas negatively<br>Evaluating reuse of ideas positively<br>Rejecting ideas<br>Creating "stupid" ideas with a goal |

## Appendix H – Coding scheme used to analyse designers' interviews for Study IV (continuation)

| **Theme** | **Category** | Code |
|---|---|---|
| STAGES OF THE INSPIRATION PROCESS (WITHIN THE DESIGN PROCESS) | Inspiration process | Using inspiration for problem definition<br>Using inspiration for problem solution<br>Using inspiration for solution refinement<br>Using inspiration in the diverging phase<br>Using inspiration in the converging phase |
| USE AND SELECTION OF STIMULI IN THE SEARCH TOOL | Generation of keywords | Generating keywords<br>Generating 1st keyword easily<br>Generating keywords with difficulty |
| | Usefulness of the search tool | Finding stimuli especially useful<br>Evaluating usefulness of chosen keyword<br>Evaluating usefulness of search tool<br>Evaluating limitation of inspiration search |
| | Avoidance to use the search tool | Avoiding using the search tool<br>Accepting using the search tool |
| | Reasons for selection of stimuli | Selecting based on relevance<br>Selecting based on recognition<br>Selecting based on verification<br>Selecting based on reliability<br>Selecting based on curiosity |
| REFLECTION ON INSPIRATION SOURCES (ACTIVE AND PASSIVE) | Reflection on source of ideas | Not reflecting<br>Consciously reflecting<br>Unconsciously reflecting<br>Reflecting when?<br>Evaluating reflection on inspiration negatively<br>Evaluating reflection on inspiration positively |
| | Passive vs active inspiration | Using passive inspiration<br>Using active inspiration |

# About the author

Milene Gonçalves was born on March 31st, 1985 in Faro, Portugal. She obtained her Bachelor and Master degree (with high honours) in Product Design at FA-UTL, in Lisbon, Portugal. During her Bachelor program, Milene spent five months at Delft University of Technology as an Erasmus exchange student. For her Master project, she investigated the relevance of designers as 'cultural artefacts creators' in the development of cultural identities and in the extension of lasting bonds between people and their objects. After her Master graduation, in 2009, she was a research assistant at the Centro de Estudos Florestais, in Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Portugal.

In 2010, Milene received a doctoral grant by the Foundation for Science and Technology (FCT - Portugal). Subsequently, she started her Ph.D. research at the Department of Product Innovation Management of Delft University of Technology, where she investigated the influence of external stimuli on the creative work of designers. Her research interests include inspiration sources, creativity, design methodology, cognition and sketching. In tandem with her research functions, Milene was involved in many teaching activities, especially as a design and research coach, at the bachelor and master level.

**Journal publications**

Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2014) What inspires designers? Preferences on inspirational approaches during idea generation, *Design Studies, 35*(1).

Gonçalves, M., Cardoso, C. and Badke-Schaub, P. (2013) Inspiration peak: Exploring the semantic distance between design problem and textual inspirational stimuli, *International Journal of Design Creativity and Innovation, 1*(4).

**Conference publications**

Al-Shorachi, E., Sasasmit, K., & Gonçalves, M. (2015). Creativity intervention: Using storytelling and math problems as intervening tasks for inducing incubation. In *International Conference on Engineering Design, ICED15* (pp. 1–10). Milan, Italy.

Gonçalves, M., Cardoso, C. and Badke-Schaub, P. (2013) Through the looking glass of inspiration: Case studies on inspirational search processes of novice designers, in *IASDR*

*2013*, Tokyo, Japan.

Gonçalves, M., Cardoso, C. and Badke-Schaub, P. (2012) Find your inspiration: Exploring different levels of abstraction in textual stimuli. *The 2nd International Conference on Design Creativity, ICDC 2012,* 18-20 September, Glasgow, UK.

Cardoso, C., Gonçalves, M. and Badke-Schaub, P. (2012) Searching for inspiration during idea generation: Pictures or words? *12th International Design 2012 Conference, Design 2012,* May 21-24, Dubrovnik, Croatia.

Gonçalves, M., Cardoso, C. and Badke-Schaub, P. (2012) How far is too far: Using different abstraction levels in textual and visual stimuli. *12th International Design 2012 Conference, Design 2012,* May 21-24, Dubrovnik, Croatia.

Gonçalves, M., Badke-Schaub, P. and Cardoso, C. (2011) Searching for inspiration during idea generation, In *Proceedings of International Association of Societies of Design Research, IASDR'11,* October 31 – November 4, Delft, The Netherlands.

Gonçalves, M., Cardoso, C. and Badke-Schaub, P. (2011) Around you: how designers get inspired. In *Proceedings of International Conference on Engineering Design, ICED'11,* August 15-18, Copenhagen, Denmark.