Understanding the Roles of Sketching in Product Design

by

Min Hua

Dyson School of Design Engineering
Imperial College London

A thesis submitted for the degree of Doctor of Philosophy

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Originality Declaration

The development of the Combinator and Product Design Sketching textbook were accomplished in collaboration with Dr Ji HAN and Dr Yanming GE respectively. Except where otherwise stated, this thesis is the result of my own research. This research was conducted in the Dyson School of Design Engineering at Imperial College London between October 2015 and December 2019. All quotations have been distinguished by quotation marks, and the sources of all information have been specifically acknowledged. I certify that the thesis has not been submitted, either in whole or in parts, as consideration for any other degree or qualification at this or any other institute of learning.

Min Hua
April 2020
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Min Hua
April 2020
List of Publications

The following books and papers were published during this PhD research.

Books & Monographs

Journal Articles

Conference Papers
Abstract

Sketching is an essential part of the tradition and practice of design. However, despite the extensive literature on the subject, the roles of sketching in the design are still not fully understood. Therefore, this PhD study was carried out to understand the roles of sketching in the product design field and to develop the means to support the design sketching process. Hypotheses emerged from the review of the literature and led to three descriptive studies: a pilot study to identify the roles of sketching in design; a survey of design students; a survey of design professionals. Data collected from these studies were used to test and verify the hypotheses.

It was found that the major roles of sketching in design were related to design ideation and design communication. The comparison between design students and professionals showed that they tend to perceive the major roles of sketching differently, but shared similar opinions on the major roles of talking sketches, sketching expertise and as a practical supporting tool. In addition, an Ideation Segment Model was proposed, which describes the process that sketching ideas evolve into final design outcomes and locates the potential supporting tools in the sketching process.

Consequently, a practical supporting tool was developed to enhance understanding of design sketching, to provide external stimuli, and to improve sketching expertise. The supporting tool, entitled the PD-Sketching Primer and PD-Sketching Toolkit, was tested with education and positive feedback was received.

This research has contributed towards understanding the roles of sketching in design, e.g. it is the first empirical study of ‘non-working sketches’ in the design field. It has generated new knowledge and tools to support the design sketching process. This supporting tool is one of only a few resources designed to support sketching activity and creative performance in the product design field.
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# Nomenclature

## List of Abbreviations

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<thead>
<tr>
<th>Abbreviation</th>
<th>Full Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD</td>
<td>Computer-Aided Design</td>
</tr>
<tr>
<td>CAS</td>
<td>Computer-Aided Sketching</td>
</tr>
<tr>
<td>CPS</td>
<td>Combinational Pictorial Stimuli</td>
</tr>
<tr>
<td>CS&amp;E</td>
<td>Case Studies &amp; Examples</td>
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<tr>
<td>D</td>
<td>Demands</td>
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<td>D1</td>
<td>Descriptive studies 1 (pilot study with design students)</td>
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<tr>
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<td>Descriptive studies 2 (survey with design students)</td>
</tr>
<tr>
<td>D3</td>
<td>Descriptive studies 3 (survey with design professionals)</td>
</tr>
<tr>
<td>ED</td>
<td>Engineering Design</td>
</tr>
<tr>
<td>E1</td>
<td>Evaluation 1 (the evaluation of the PD-Sketching Primer)</td>
</tr>
<tr>
<td>E2</td>
<td>Evaluation 2 (the evaluation of the PD-Sketching Toolkit)</td>
</tr>
<tr>
<td>GAN</td>
<td>Generative Adversarial Network</td>
</tr>
<tr>
<td>GDP</td>
<td>Generic Design Process</td>
</tr>
<tr>
<td>GDs</td>
<td>General Demands</td>
</tr>
<tr>
<td>I</td>
<td>Introduction</td>
</tr>
<tr>
<td>ID</td>
<td>Industrial Design</td>
</tr>
<tr>
<td>IS</td>
<td>Ideation Segment</td>
</tr>
<tr>
<td>M</td>
<td>Mean</td>
</tr>
<tr>
<td>PD</td>
<td>Product Design</td>
</tr>
<tr>
<td>Q&lt;sub&gt;x&lt;/sub&gt;</td>
<td>Question x</td>
</tr>
<tr>
<td>R</td>
<td>Resources</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviations</td>
</tr>
<tr>
<td>SS</td>
<td>Sketching Skills</td>
</tr>
<tr>
<td>US</td>
<td>Understanding Sketching</td>
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<tr>
<td>W</td>
<td>Wishes</td>
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</tbody>
</table>

xx
List of Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f_i)</td>
<td>The weight assigned to the function (i)</td>
</tr>
<tr>
<td>(f_j)</td>
<td>The weight assigned to the function (j)</td>
</tr>
<tr>
<td>(M_1)</td>
<td>The overall quality score of an idea</td>
</tr>
<tr>
<td>(M_2)</td>
<td>The overall novelty score of an idea</td>
</tr>
<tr>
<td>(m/n)</td>
<td>The number of attributes</td>
</tr>
<tr>
<td>(S_i)</td>
<td>The score of attribute (i)</td>
</tr>
<tr>
<td>(S_j)</td>
<td>The score of attribute (j)</td>
</tr>
</tbody>
</table>

Nomenclature

The author proposed a nomenclature to describe the ID code, which was then assigned to each respondent in the prescriptive studies, which were used to identify their quotations. The respondents were coded in the form of XY0, i.e. two letters and one number. The first letter stands for their experience of design sketching (i.e. V: Very experienced; E: Experienced; L: Less experienced; N: Novice), the second letter stands for the occupation information of the respondents (i.e. S: Design students; D: Professional designers; A: Design academicians), and the number was assigned consecutively for differentiation.
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Chapter One: Introduction

1.1 Overview and research motivation

Freehand sketching has traditionally been central to the design-oriented disciplines, e.g. industrial design and engineering design (Craft and Cairns, 2009). Designers are commonly taught to think with their sketches to externalise concepts, communicate ideas and solve complex problems. Freehand sketching is often regarded as a fundamental skill in engineering design and many other design disciplines (Ferguson, 1992). Being skilful in sketching is believed by many professional designers as one of the most important vocational skills for design (Dong, Cifter and Fan, 2013). According to Uziak and Fang (2018), developing sketching expertise is important for design students as well as novice designers as it is a sense-making tool for design problems solving and expressing. In practice, sketching portfolios are widely used as a very important supporting material in both degree application for design schools and job application for design companies. These highlight the importance of sketching in both design industry and education. Thus, most designers are required to be able to make and interpret their sketches to support their design work. As a learned skill during design education, designers learn to think with sketches and keep practising on sketching until they become experts (Bilda, Gero and Purcell, 2006). Therefore, designers often place great emphasis on sketching. Thomas E. French (1918), in his pioneering textbook ‘A Manual of Engineering Drawing’, declared that “the designer must be able to sketch his ideas with a sure hand … it is the chief engineer’s method of design”. Tipping (1983) argued that sketching ability may be “the single most important factor in developing any general design ability”. Cross (1999) described sketching as “one of the particular tools that help designers to think.”

The use of sketching is clearly an important part of “the natural processes of designing” (Cross, 1999). Numerous studies have emphasized the importance of sketching and visual thinking in design (e.g. Goldschmidt, 1991; Cross, 1997, 2006; Suwa, Gero and Purcell, 1999; Sachse, Ro and Schu, 2003; Schütze, Sachse and Römer, 2003; Yusoff, 2007; Hua, 2019). For example, Nagai and Noguchi (2002) revealed that designers constantly translate non-visual textual information into visual graphical information. Suwa and Tversky (1997) suggested sketching is not simply an illustration of design cognition, but an important vehicle for the design thinking process. As Yusoff (2007) pointed out, “there perhaps is no better way for designers to express their thoughts than through sketching”. Although sketching is commonly accepted as an important tool for supporting the design process, the attempt to understand the importance is “something that has only recently become a subject of consideration and analysis by design researchers” (Cross, 1982). However, it is also recognised that some engineers and indeed chief engineers perform their roles without ever or rarely performing any sketching. This scenario is compounded by the
paperless environment associated with many engineering businesses and the use of CAD as the main tool for the definition of geometry in engineering. It may also be because the effective use of sketching requires a certain level of drawing skills which forms another barrier for some engineers to adopt sketching in their work (Uziak and Fang, 2018). In addition, some engineers do not even do design in their work and as such, they do not even have to sketch. For example, some engineers’ work is about performing regular testing and maintenance of equipment to keep them functioning as they should. In general, sketching is one of the various types of design representation methods in engineering design and engineers do not necessarily have to be good at sketching as they have other choices for design representation. It was also reported that sketching, in some cases, might not that important or supportive for design. For example, Cham and Yang (2005) conducted a study that explored the influence of sketching skills on the design outcomes, but “no notable relationship was found”. They suggested that “there are differences among the different types of sketching skills in the context of engineering design”. Bilda et al., (2006) questioned whether sketching is an essential part of conceptual design and conducted a think-aloud experiment with expert architects. The results showed that no significant difference was found between sketching and not sketching according to the assessments. Therefore, they proposed that sketching may not be essential for expert architects in the conceptual design stage. Such a problem is worth studying as it not only helps to understand the use of types of design representations in engineering design but also may bring us insights about the roles of sketching from the negative side as mentioned. However, this problem has not been the focus of the PhD research and therefore, will not be further discussed in this thesis.

Sketching has traditionally been considered as a means to ‘spur creative thinking’. In general, creativity can be defined as “the ability to imagine or invent something that is in some way novel and has potential value or utility” (see, for example, Childs et al., 2006). Creativity is believed to be a crucial element of design; however, it is also a very complex and multifaceted concept. This project mainly looked at one aspect of creativity in design, namely design ideation, which can be viewed as “the creative process of generating, developing, and communicating new ideas, where an idea is understood as a basic element of thought that can be either visual, concrete, or abstract” (Jonson, 2005). In particular, as several design researchers have pointed out, sketching is a core ideation tool in design, which can “promote the recognition of emergent features and properties of the design concept” (Cross, 1982). Sketching may help designers to make ‘lateral transformations’ in the solution space (Goel, 1995). It may also assist in the ‘dialectics’ sketching process, facilitating the dialogue between ‘seeing that’ and ‘seeing as’ (Goldschmidt, 1991). And sketching helps designers to find ‘unintended consequences’, which keep the exploration going in the ‘reflective conversation’ with the situation (Schon and Wiggins, 1992a). Jin and Benami (2010) recognized the iterative loops in sketching and described the sketching supported design ideation process as ‘generate–stimulate–produce cycles’. Sun et al., (2014) furthered this study by proposing the ‘inspiration generation-inspiration expression-visual feedback (sketching)’ model, which
explained how inspirations emerge and evolve in the loop and finally turn into the design outcomes.

Most of the above studies that refer to design sketching are conducted in the field of cognitive psychology and architectural/engineering design. Industrial design, a small but growing body of literature has emerged in the field. Bao, Faas and Yang (2018) and McGown, Green and Rodgers (1998a) suggested the importance of sketching in product design. Verstijnen et al. (1998) studied differences between skilled sketchers and unskilled sketchers among industrial design students. Chen, You and Lee (2003) explored the process of design thinking by the analysis of sketches at the early design stage. Pei (2009) proposes a classification system for sketching, based upon the need or intention of the designers while they are sketching. Subsequent work (Pei, Campbell and Evans, 2011) developed a design tool to improve the collaboration between industrial designers and engineering designers.

The exploration and understanding of the roles that sketching plays in the product design process are expected to bring important implications for both design education and design support systems development. However, the above studies are to some extent, scattered and disconnected from each other. In addition, the interplay between sketching and design creativity is always assumed, but still not well understood, which also provides the impetus for this research.

This research is, therefore, carried out to identify and understand the roles of sketching in supporting creative design work – the relationship between the product design process and several key types of sketching such as thinking sketch, talking sketch and non-working sketch. The focus is on how these different types of sketches interact with the designer, and in turn, to enhance a designer’s performance by facilitating their design process. Based on the findings, a PD-Sketching Toolkit was developed and tested during the study to facilitate the effective use of sketching in design.

1.2 Scope of research

In order to bring forward and give structure to the research, the research scope was narrowed down so that it may provide sufficient focus. Figure 1-1 shows the relevant research fields and sub-areas that are of interest in this thesis, which can help explain the scope of this research.

As previously discussed, the main focus of this study is to identify and understand the roles of sketching in product design. However, this topic can be related to a number of research fields that are too broad for a directed search. Therefore, the research scope of this study needs to be narrowed down to identify the specific areas of interest. As discussed in the previous section, designers commonly make extensive use of visual representation as a means for facilitating creative design thinking and design communication. Various types of design representations may be used in different stages of the design process, including mind maps, notes and annotations, diagrams,
collages, foam and CAD models, and especially sketches. Within design research, sketching has traditionally been viewed as an extremely useful representation tool for designers, especially for supporting design creativity (e.g. Goldschmidt, 1991; Suwa, Gero and Purcell, 1999; Do, 2002; Sachse, Ro and Schu, 2003; Gero and Sudweeks, 2012). These help to limit the research scope to sketching among various types of design representations. Existing studies and theories on exploring and understanding design sketching will be further discussed in Chapter 2.

Previous studies in design disciplines regarding the application of visual representation in design practice suggest that sketching can be used for multiple purposes throughout the design process (Akin and Lin, 1995; Van Der Lugt, 2001; Pei, 2009). Different types of sketches are found to be associated with different design stages and cognitive processes (Lawson, 2004). According to Pei (2009), designers tend to begin the design process with various relatively unstructured forms of sketches, such as the ‘ideation sketch’ in the early design phase. As the design develops, they turn to more structured forms of sketches, such as the “persuasive sketch” and “sketch rendering”. It was also observed the use of sketching in the late design stages (i.e. “detail sketch”), mostly dealing with sub-problems that emerged while detailing the product design. The conceptual design stage has always been viewed as the most important phase in the design process (French, 1971; Howard, Culley and Dekoninck, 2008; Self, Dalke and Evans, 2013; Sun, Xiang, Chai, et al., 2014). This is mainly because this design stage is closely related to design ideation. The design concepts and alternatives are mainly produced in this stage which provides the basis for later design development (French, 1971). In this stage, designers extensively use sketching to express their ideas and explore the design space (e.g. Cross, 1999; Bilda and Demirkan, 2003; Stones and Cassidy, 2010; Chu et al., 2017; Tedjosaputro et al., 2018). This helps to narrow the scope of research to the conceptual design within the product design process.

This research is carried out to understand the roles of sketching in design, but with a special focus on the role of supporting the creative design thinking process. The question of how designers think through sketching is still not fully understood which forms the main question encouraging researcher in design and cognition fields to further explore. Specifically, the relationship between sketching and design creativity has been established in various studies in creative cognition and design protocol studies (e.g. Do and Gross, 1996; Suwa, Gero and Purcell, 1998, 1999; Cross, 1999; Bilda and Demirkan, 2003; Yang, 2003; Van der Lugt, 2005; Stones and Cassidy, 2010; Self and Pei, 2014; Orthel and Day, 2016; Chu et al., 2017; Tedjosaputro et al., 2018). According to previous studies, sketching can be viewed as a mental activity relating to some key terms such as thinking, seeing, interpreting, visual thinking, and visual imagination. Tovey (1989) described thinking as “the way that our brains realize and order information and thoughts”. According to Gharib (2013), seeing and imagining are related concepts, seeing is receiving visual information from outside while imagining creates visual information inside the brains by using existing visual information. Visual thinking is believed to be essential in the process of organizing
visual information, and also to think and communicate with visual information. Sketching is used by designers to transfer their imagined visual information into drawing on paper (Do, 1998). This might be why sketching is often regarded as complementary to mental imagery. Studies conducted from the perspective of design cognition have tended to focus on visual thinking/imagery, i.e. the use of mental images in visual thinking and creativity. For example, Goldschmidt (1991) proposed the theory of “dialectic of sketching”, in which she broke down design thinking into observable “movements”. She viewed the sketching process as a special kind of dialectic between the “seeing as” and “seeing that”. Goldschmidt (2003) further described the sketching process by the concept of “interactive imaginary”. Schon and Wiggins (1992) proposed a similar cyclic backtalk loop of the sketching process as “reflective conversation”. This kind of mental iteration is suggested also in (Atman et al., 2007). These help to narrow down the scope to explore how sketching may support design creativity through facilitating the visual thinking process in design. This line of research will be further discussed in the next chapter.

The research scope of this study was narrowed down by focusing on sketching as a particularly potent tool for supporting visual expression and thinking in design, especially for the early conceptual design stage. In addition, the research is concerned with industrial design and engineering design. Specifically, the research focus is on product design.

![Figure 1-1 Limiting the scope of research](image-url)
1.3 Research aims and objectives

The aim of this research is two-fold. The first is to identify and understand the supporting roles of sketching for product design, especially for enhancing design creativity. This can be achieved by a good understanding of the functions of sketching, and designers’ preferences and requirements about sketching firstly, and then by finding out how sketching may support the design ideation process; the second is to develop supporting tools to enhance the use of sketching in product design. This could enhance the users’ understanding of sketching in product design and support aspects of the product design process through sketching, in particular, to support the design ideation process. This aim can be achieved by extracting information and data from three descriptive studies to capture requirements for the supporting tools firstly, and then adopting a user-centred design approach to develop the supporting tools which can meet these requirements. The specific objectives of this research project are:

- To gain a comprehensive understanding of the roles that sketching plays in industrial and engineering design.
- To explore the cognitive interplay between sketching and design creativity.
- To identify the requirements of product design, and the related fields of industrial and engineering design students and associated professionals for supporting the design sketching process.
- To develop a practical supporting tool for industrial and engineering designers to facilitate a more effective and creative design process through sketching.

1.4 Thesis structure

The structure of this thesis is presented in Figure 1-2. The eight chapters and appendices can be summarised as follows:

**Chapter 1, ‘Introduction’:** provides a brief overview of the research topic and scope; a description of the research aim and objectives; and a map of the thesis structure.

**Chapter 2, ‘Sketching for Design’:** reviews and summarises relevant literature on design sketching, highlighting insights relevant to this research topic and associated gaps in the knowledge base, and describes the need for understanding the supporting roles of sketching in design.

**Chapter 3, ‘Research Methodology’:** reviews a number of relevant research methodologies; describes the research methodology adopted for the study and how it has been designed; explains how the adopted research methodology addresses the research objectives.
Chapter 4, ‘Identifying the Roles of Sketching in Product Design: A Pilot Study’: describes a think-aloud experiment involving six design students in a toy design workshop in order to explore the way they use and their understanding of the role of sketching in the product design process, and presents the results of the experiment.

Chapter 5, ‘Understanding the Supporting Roles of Sketching for Design Students’: describes a survey of design students to understand their perceptions of the role of sketching in design; outlines their requirements regarding a supporting tool for the design sketching process, and presents the results of the survey.

Chapter 6, ‘Understanding the Supporting Roles of Sketching for Design Professionals’: describes a survey of professional designers to understand their perceptions of the role of sketching in design; also identifies their requirements regarding a supporting tool for the design sketching process, and presents the results of the survey.

Chapter 7, ‘Supporting Design Sketching: Development and Evaluation of A Practical Supporting tool’: describe the development of the toolkit based upon the findings from Chapter 4-6, and presents the feedback received from universities and training institutions on the toolkit.

Chapter 8, ‘Conclusions and Further Work’: summarises the research and proposes future work.
Figure 1-2 Outline of thesis
Appendices:

- Appendix A, ‘Interview topics for the pilot study’: describes the five topics and questions covered by the pilot study
- Appendix B, ‘Questionnaire for the design students’: contains a copy of the questionnaire used to investigate the understanding of design sketching among design students
- Appendix C, ‘Questionnaire for the design professionals’: contains a copy of the questionnaire used to investigate the understanding of design sketching among design professionals
- Appendix D, The ‘PD-Sketching Primer’: contains a copy of the booklet designed to convey the fundamentals of design sketching
- Appendix E, The ‘PD-Sketching Taxonomy Cards’: contains a copy of the whole set of design sketching taxonomy cards which were refined after the validation study.
- Appendix F, ‘Questionnaire for preliminary evaluation of PD-Sketching Primer’
Chapter Two: Sketching for Design

2.1. Introduction

This chapter provides a review of the identified roles of design sketching in the literature and explores a number of influences that might be available to be used as supporting tools for the design sketching process. It presents literature from various fields of design, including architecture, mechanical engineering, automotive, graphic, industrial, and product design. Specifically, the academic research concerning design sketching is mostly conducted in architectural design (e.g. Fraser and Henmi, 1993; Do, 1998, 2002; Lawson, 2006; El-khouly, 2015) and mechanical design (e.g. French, 1918; Ferguson, 1992; Shah et al., 2001; Schütze, Sachse and Römer, 2003; Yang, 2003; Booth et al., 2016). In addition, research in visual thinking and sketching has also been of interest to cognitive psychologists (e.g. Goldschmidt, 1991; Goel, 1995; Suwa, Gero and Purcell, 1998; Stubbs, 2006; Tversky and Suwa, 2009; Schön, 2017). Although these researchers are from different backgrounds and may study sketching from various perspectives, most of their works concerning design sketching were found to have a similar opinion on the role of sketching in the design process.

This chapter is organized into several sections. Section 2.2 provides a brief introduction to design sketching, reviewing literature that identifies the roles of sketching in supporting the design process (including the roles relating to design creativity) and the impact of the development of design visualization technologies on the use of sketching in today’s design contexts. Section 2.3 briefly discusses the design process and the stages involved, and further proposed a generic model of the product design process to facilitate research in this study. Section 2.4 discusses the types of sketches used in the design process and analysed the existing sketching taxonomies found in the literature. Section 2.5 discusses the interaction between design sketching and visual cognition in design. Section 2.6 and Section 2.7 discuss several major influences for the use of sketching in design, including sketching skill, the ability to effectively use sketching, the use of visual stimuli in the design sketching process and available digital supporting tools. In Section 2.8, the chapter ends with a reflection and summary of the chapter.

2.2. Design sketching

2.2.1. Defining design sketching

Sketching has traditionally been considered as an essential part of human creative activities. The primitive motivation for art and design is fulfilled through sketching generated by the cavemen millions of years ago. Friedman (1996) suggests that “design emerged 2.5 million years ago when our early ancestors began making tools
to reshape the environment”. In terms of design sketching, the specific time of its emergence is hard to trace, but it must be used by designers to support their work for a long time certainly long before the Renaissance. According to Cross (2006), he took Leonardo da Vinci as an example, whose sketches of various types of designs (e.g. engineering, interior and architectural design) suggests that sketching is not only a useful communication tool but also powerful thinking and reasoning tool for design.

Design sketching commonly refers to the freehand drawings or renderings generated by designers facilitating the design process. Due to the complicated nature of design activities, there is no universally accepted definition of design sketching. Numerous definitions of design sketching were proposed by researchers in the literature, in some areas of design (e.g. Industrial Design), design sketching is well defined as part of the various types of design representations, while in some areas (e.g. Art Design) drawing is less likely to be differentiated. For example, Lothrop (2012) defines design sketching as “the act of putting images on paper or other suitable surfaces to serve the purpose of planning a designed thing.” He further stressed the role of sketching that it could “assist in the creation of shared vision” among the team. Garner (2002) defines design sketching by making a comparison with art drawings and indicated that sketching can be used to “support the investigative and creative activities of designers’ works”. Tovey et al. (2003) share a similar opinion by describing that design sketching is different from “drawings from something that already exists or in front of the artist”, but to illustrate something new generated from the designers’ imagination. Tversky et al. (2003), from the domain of psychology, suggest design sketching can be used to “amplify a designer’s imagination and relieve limited-capacity of working memory.” The limited capacity of memory requires the designers to make records of fleeting ideas onto a piece of paper quickly before they disappear. Buxton (2010) supports this statement and describes design sketching as “...a quick way to generate and share many ideas in such a way that the ideas can generate more ideas.” His definition highlights the attributes of design sketching that should be quick, timely, informative and ambiguous so that it can record and convey design information to the designer for interpretation and imagination.

2.2.2. The general roles of design sketching

Designers often place great emphasis on sketching. One obvious reason suggested by Cross (2006) is that, before the high-performance 3D modelling software is applied in the field, design outcomes are normally presented in the form of rendering sketches (also known as presentation sketches, see Figure 2-1) to communicate with other involved parties, which is particularly useful for decision making by non-designers (e.g. the clients). In design education, designers are taught to think and work with their sketches since they were students. They are taught that sketching is an essential skill for designers, which can be helpful in many facets of design activities, including design concepts generation and expression, facilitating successful design collaboration, and solving complex problems (Hua, 2019). Craft and Cairns (2009) pointed out that sketching can be regarded as an essential part of design activity.
because it can support creative design thinking and enhance design collaboration. As Yusoff (2007) pointed out, "there perhaps is no better way for designers to express their thoughts than through sketching", no matter it is used to communicate ideas within themselves for stimulating their own thinking process, or to communicate with other people for facilitating design collaboration.

Figure 2-1. An example of a rendering sketch (Shimizu, 1990)

In design domains, sketching is believed to play important roles in the design process, and therefore numerous studies can be found in literature focusing on exploring and understanding the importance of sketching in design. For example, Cross et al. (1997) suggest that design sketching supports some of the high-level cognitive abilities required in design, including creativity, synthesis and problem-solving. Cross (2006) further describes sketching as a kind of ‘dialogue’ for designers in his book ‘Designerly Ways of Knowing’ and points out finished sketches can record and convey what designers “see in their mind”. Suwa, Gero and Purcell (1998) suggest that it is the use of sketching that allows visuospatial information to naturally emerge in designers’ perception. This visuospatial information extracted could, in turn, serve as ‘spatial models’ or ‘visual cues’ providing various supports for design (e.g. clarifying problem-structure, association abstract concepts, functional issues, and relevant past experiences). Lugt (2002) conducted four experimental meetings to explore the roles of sketching in idea generation meetings in design. He identified two functions of sketching that can support creative design communication within a design team, namely supporting reinterpretation of each other’s ideas in group activity and enhancing the access to earlier ideas by facilitating archiving and retrieval of design information. Schütze, Sachse and Römer (2003) presented an experimental investigation on the relationship between sketching and design outcomes and found designers did better in the assigned design task when allowed to sketch than when they were not. Specifically, sketching was proved to “have a positive impact on the
quality of the designed solution and the individual experience of the design process" (Schütze, Sachse and Römer, 2003). It was found that sketching can serve as an “aid for analysis, short-term memory and documentation”. In addition, Song and Agogino (2004) identified similar results through the product design courses, and they further pointed out the supporting role of sketching for the development and testing of design solutions, which is particularly useful for the identification of errors. Other functions of sketching found in the literature include: supporting the generation of design alternatives (Goldschmidt, 1991; Suwa, Gero and Purcell, 1999; Sachse, Ro and Schu, 2003); supporting technical discussion (Bly, 1988; Tang, 1989, 1991; Neilson and Lee, 1994); externalizing and visualizing problems (McKim, 1972; Woelfel, Krzywinski and Drechsel, 2013); facilitating cyclic talk-back loop (Schon and Wiggins, 1992b; Van der Lught, 2002; Goldschmidt, 2003); facilitating design reasoning (Do, 2002; Gero and Sudweeks, 2012); facilitating perception and translation of ideas (Suwa and Tversky, 1997; Tversky et al., 2003); revising and refining ideas (Suwa and Tversky, 1996; Tovey, Porter and Newman, 2003; Van der Lught, 2005). Some of these supporting roles are closely linked to design creativity and these roles will be further discussed in Section 2.2.3.

The above body of literature has explored the roles of the sketch which is produced during the design process. However, designers also sketch a lot outside the design process, just as Lawson (2012) points out: “Designers tend to draw habitually and certainly more often than just when designing”. Compared with the large body of literature on the working sketches, ‘non-working sketches’ has received little attention. Non-working sketches can be defined as a group of sketches that are produced by designers outside the design process. In this research, the design process consists of six stages which start from ‘defining the design task’ and end up with ‘design presentation & implementation’ (refer to Section 2.3.2). In practice, designers often produce even more sketches outside the design process. One of the main reasons is that, as a learned skill, expertise in design sketching requires plenty of practice. A number of empirical studies have identified the difference between skilled sketcher and unskilled sketcher (Suwa and Tversky, 1997; I. Verstijnen et al., 1998; Schütze, Sachse and Römer, 2003; Yang and Cham, 2007; Lawson, 2012). These studies firstly highlight that sketching skills can be a key influence on the effective use of sketching in design. Secondly, the findings suggest that the sketches produced by designers as practices in their spare time might have an impact on their design performance during the design process. This type of sketch is referred to as the ‘practising sketch’ in this study. The function of recording information through sketching has also been reported heavily in the design literature (Yang and Angeles, 2005; Cross, 2006; Self, Dalke and Evans, 2013; Hua, Huang and Childs, 2018). Some of the non-working sketches are rough and fast, which makes the sketches suitable for recording design-related information and ideas. The sketch notebook contains accumulated design information that could gradually turn into a personalized ‘database’, which might be of use for the designer in his future work. This type of sketch is referred to as the ‘storing sketch’ or ‘referential sketch’. In addition, the playing sketch was reported can bring ‘unintended consequences’ to support the
‘reflective conversation’ process (Schon and Wiggins, 1992), and the sketching process can be fun for designers enabling them to play with the sketches and ideas.

2.2.3. The roles of Sketching in supporting design creativity

Creativity is believed to be central to designers’ thinking and has a great influence on the success of design outcomes. Creativity can be defined as ‘the ability to imagine or invent something new of value’ (Childs et al., 2006) or ‘the ability to produce a novel and appropriate product’ (Kim et al., 2007). Although there is no universally accepted definition for creativity so far due to its complicated nature, ‘novelty’ and ‘appropriateness’ are the most commonly used terms for defining creativity in the design research field. Creativity is considered a vital element in design, which helps to initiate innovations, supporting problem-solving, and increasing a company’s market share (Sarkar and Chakrabarti, 2011).

In design sketching research, there is a large body of literature that has indicated the significant role of sketching in supporting design creativity (e.g. Do and Gross, 1996; Suwa, Gero and Purcell, 1998, 1999; Cross, 1999; Bilda and Demirkan, 2003; Yang, 2003; Van der Lugt, 2005; Stones and Cassidy, 2010; Self and Pei, 2014; Orthel and Day, 2016; Chu et al., 2017; Tedjosaputro et al., 2018). In a series of studies, Goldschmidt (e.g. Goldschmidt, 1991, 1992, 2003) has carefully analyzed protocols of design sessions and studied the use of design sketching in architectural design. Goldschmidt (1991) proposed the theory of ‘dialectic of sketching’ which first broke down design thinking into observable ‘movements’. She found the design sketching process alternated between ‘seeing-as’ and ‘seeing-that’ and back again through these movements in a cyclic manner, among which seeing-as is directly related to sketching as it involves the designer in ‘seeing’ new meanings in the sketches, and seeing-that involves non-figural arguments about the design. Analysis of the design protocols suggested that seeing-as and seeing-that arguments alternated in the design sketching process. In this way, designers could express their ideas through sketching and reinterpret the sketches to generate more design alternatives. Goldschmidt (1992) also found that designers commonly draw not one but a series of sketches during the design process. This “serial sketching” continually presents new shapes and relationships among shapes to the designer. Schon & Wiggins (1992) supported this statement by arguing that sketching was continually produced by designers to support the ‘reflective conversation’ process, which can bring ‘unintended consequences’ to designers as potential inspirations. According to Shah et al. (2001), designers can ‘read off’ from the sketches and obtain far more information than was invested in the initial sketches. These unanticipated relations and features could inspire designers to generate new ideas, or to refine and revise their previous ideas (Suwa and Tversky, 1997).

Sketching is extremely useful for recording fleeting design ideas as it can be rough and fast. As Hanks and Belliston (2006) pointed out, “creative ideas usually occur as fleeting thoughts in the mind and need to be captured quickly on paper before they
are lost”. Sketches do not require to be drawn with great details or to exact scale, especially those produced for supporting design ideation. It is typical for designers, to begin with, various relatively unstructured forms of sketches in the early-to-middle design phase. Purcell (1998) argues that “unstructured drawing or sketches are considered to play an essential role in generating creative outcomes”. Goel (1995) described the sketches produced in the early design phases as ‘dense and ambiguous’, and therefore, can bring a number of cognitive benefits for supporting the design ideation process. For example, these sketches can be created quickly allowing designers to easily manipulate the ideas (Jami J. Shah1, Noe Vargas-Hernandez, Joshua D. Summers, 2001). Also, sketching can be used as the ‘augmented memory devices’ to relieve designers’ cognitive load for facilitating a more fluent ideation process (Larkin and Simon, 1987). Goldschmidt (1994) argues that sketching in the early design stages can help designers to find the “potentially meaningful hints” and to define the problem space for facilitating the search of potential design solutions. In addition, Lothrop (2012) suggested that if a level of ambiguity is properly included in these rough sketches may lead to more or better ideas by inspiring new interpretations.

2.2.4. Technology and changing roles of design sketching

Previous studies showed that sketching was an essential part of the tradition and practice of design. In general, sketching is still vital in today’s design context even with the emergence of new design visualization technologies. However, the ability to use freehand sketching in design has been reported to have suffered a decline (Company et al., 2009; Veisz et al., 2012). The new generation of designers often are found to have inadequate experience in making freehand sketches and may have difficulty in effectively conveying design information graphically (Livshits and Sandler, 1999; Jonson, 2002; Rose, 2005). Company et al. (2009) indicate that the decline of sketching skills is “a consequence of a computer-centric teaching strategy”. For instance, some design textbooks are oriented towards forcing designers to alter their natural workflow and habits to fit the digitalized design environment. In fact, both business and design “have driven the need for the use of technology in the design process” (Lothrop, 2012), the changes that occur in the design sketching education is just a reflection of this trend.

With the introduction of Computer-Aided Sketching (CAS) software (e.g. Sketchbook, Illustrator, Photoshop) and Computer-Aided Design (CAD) software (e.g. Rhino, ProEngineer, Solidworks), designers could develop and communicate the design concepts in a medium ‘native to engineering’. Designers and technicians now could speak a similar language for product development by working on the same electronic file. In this way, designers could have more control over the final design and shorten the development cycle of the product (Lothrop, 2012). In addition, rendering skills are no longer a must for designers to deliver the presentation and sell design concepts to clients. With the help of CAS software, designers could present their designs with computer renderings, which look even more convincing than the real product to the
client and average consumer. Because of the use of CAS and CAD software, technical sketch and rendering sketch are almost no longer used among the new generation of designers. The roles of sketching and types of sketches used are changing due to the development of design visualization technology.

It was found that design students tend to give less time to the development of sketching abilities in school. As a result, design students’ abilities to think and visualize three-dimensionally are reported to be impaired (Lothrop, 2012). Alias et al (2002) identified a definitive correlation between sketching and spatial visualization abilities in a study of design students. Ulman et al. (1990) reported that a direct correlation was identified between the use of sketching in engineering designers’ thinking process and high levels of problems solving and fast design decision making. There is a common criticism of CAD is that it makes designers focus on details too early in the design process, while freehand sketching allows designers to concentrate on the essentials and capture their concepts quickly. More importantly, sketching is found to be more effective in supporting design creativity when compared with CAS/CAD software, especially in the early conceptual design stage of the design process. According to Ponn et al. (2004), initial design concepts are rarely modelled in CAD software because they often require exact geometrical information. As Veisz et al. (2012) pointed out “CAD can force your design to be more practical, which can limit creativity.” On the contrary, rough and quick sketching can play an important role at this stage recording the imagery and ideas that emerged in the mind of the designer, especially when the design tasks or problems are fuzzy and undefined. It is almost impossible for CAD software to quickly and accurately visualize designers’ thinking but requires specific input, which in turn highlight the need for sketching to facilitate the “loop involved each process to informing the other”. Therefore, freehand sketching still plays a number of important roles (e.g. recording and expressing fleeting ideas, supporting quick design evaluation, and facilitating the reinterpretation process to produce more design alternatives) in the design process, which will be further discussed in the following section.

2.3. The design process

The design process consists of a sequence of activities that aim to produce a new design solution or an improvement for an existing solution. It can be viewed as an approach for breaking down a large project into manageable chunks, which involves multiple iterations and redesigns of the final design outcomes. Take product design as an example, the product design process typically involves a number of stages before the products are delivered to be manufactured. Therefore, the design process can be viewed as a term that describes these sequences of design stages. In design domains, various procedural models have been proposed for systematic navigation and description of the design process (e.g. Jones, 1963; Archer, 1965; French, Gravdahl and French, 1985; Pugh, 1991; Dhillon, 1998; Cross, 2000; Dominick, 2001; Ulrich, 2003; Bousbaci, 2008; Clarkson and Eckert, 2010). Blessing et al. (1995 and
2012) compared design process models proposed in the literature and proposed a scheme to categorise these models, including stage-based models, activity-based models, solution-oriented models or problem-oriented models. This section concentrates on discussing the problem-oriented models which are considered to be more relevant to this research. This is because these models are developed by considering the design process as an investigation of a design problem and sketching is just the tool that commonly used by designers for supporting problem-solving during this process. The following paragraphs focus on four of the problem-oriented models, i.e. Jones’ model (1963), Archer’s model (1965), Cross’s model (2000) and Pahl and Beitz’s model (2013). These four models are widely accepted within the design research domains, which could be used to show a general but simple description of the design process.

2.3.1. Representative models of the design process

The model proposed by Jones (1963) is among one of the first descriptions of the design process. He described the design process in three stages: 1) ‘analysis’, 2) ‘synthesis’, and 3) ‘evaluation’, as shown in Figure 2-2. The model starts with the ‘Analyse’ stage, which focuses on defining and clarifying the design problem and then formulating the criteria. It follows a ‘Synthesis’ stage to explore possible solutions for the problem based on understanding gained in the first stage. In the last ‘Evaluation’ stage, designers evaluate those solutions and choose one to be implemented.

![Figure 2-2. Jones's (1963) model of the design process](image)

Archer (1965) proposed a similar model by incorporating external interactions (e.g. the training a designer received and his experience) and more details of design activities within each stage (e.g. observations, measurements and inductive reasoning in the ‘Analytical Phase’). As shown in Figure 2-3, Archer divided his model into three stages: 1) ‘analytical phase’, 2) ‘creative phase’, and 3) ‘executive phase’. Then, he further identified six design activities: programming to establish problems, data collection and storing, analysis of design problems, synthesis by outlining the design proposals, development of the prototypes and design communication for manufacturing. The basic structure and key features of these two models are similar, while Archer’s model better illustrates the flow of design activities held sequentially in the design process with more detailed information.
Cross (2000) presented a generic model (first published in 1994) of the industrial design process based on divergent and convergent design activities (see Figure 2-4). He described the design process in four phases: 1) ‘concept design’, 2) ‘development design’, 3) ‘detail design’, and 4) ‘manufacture’. According to this model, designers start with exploring the design problems and design space and then searching for inspirations for generating design concepts. The next two stages are about developing and refining the details of the initial design concepts through the cyclic iteration process and then evaluating the concepts to select appropriate design solutions for implementation. In the manufacturing phase, the selected design concepts or solutions are ready for manufacturing or to be embedded in a more complex product or system. This model better reveals the nature of design as it relates to several key features of the design and design process, e.g. dynamic requirements of the design process, divergence and convergence in design ideation and ambiguity of design representation associated with conceptual design. Specifically, the early-middle design phase starts from concept generation to development, design thoughts become clearer and design directions are developed during this design phase (Fish, 2004).
Pahl and Beitz (2013) proposed a more systematic model to explain the design process of the design of technical systems or products (Figure 2-5). They expressed the design process in four stages: 1) ‘clarification of task’, 2) ‘conceptual design’, 3) ‘embodiment design’, and 4) ‘detail design’. According to the model, the design process begins by gathering information and clarifying the design task, and then design concepts are generated based on the information. This is followed by an embodiment design stage to make the initial design concepts into more concrete solutions. After the principle solutions are created, the products are elaborated in more and more detail until the documentation is obtained, including the shape and colours of the product, materials, manufacture etc.

Figure 2-5. Pahl and Beitz’s (2013) model of the design process
The four models are summarised in Table 2.1. The next section focuses on developing a new generic model of the product design process.

### Table 2.1. Models of the design process

<table>
<thead>
<tr>
<th>1st Model (Jones)</th>
<th>2nd Model (Archer)</th>
<th>3rd Model (Cross)</th>
<th>4th Model (Pahl &amp; Beitz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis</td>
<td>Data collection and analysis</td>
<td>Concept design</td>
<td>Clarification of design task</td>
</tr>
<tr>
<td>Synthesis</td>
<td>Synthesis</td>
<td>Development design</td>
<td>Conceptual design</td>
</tr>
<tr>
<td>-</td>
<td>Development</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>Communication</td>
<td>-</td>
<td>Embodiment design</td>
</tr>
<tr>
<td>Evaluate</td>
<td>Solution</td>
<td>Detail design</td>
<td>Detail design</td>
</tr>
</tbody>
</table>

#### 2.3.2. Developing a generic model of the product design process

In the light of previous models (Table 2.1), it was proposed that the product design process could be described as a creative process that involves various design activities to transform initial ideas into real products through a number of stages, beginning with design problem definition and ending with manufacturing. The four design process models reviewed were developed by design researchers for understanding and illustrating the design process instead of studying design sketching. There is a need for developing a new model that is specifically designed for facilitating this study. This model should be able to illustrate the design process with a classification of design stages for locating types of sketches and to work as a framework for organising the analysis (e.g. see Section 2.4.2). Therefore, a Generic Design Process (GDP) model was proposed and adopted in this study (refer to Hua, Huang and Childs, 2018). In brief, this model presents the product design process in three main stages: early, middle and late, which can be further broken into the following sub-processes: define design task, conceptual design, development design, embodiment design, detail design, design presentation and manufacturing, which are briefly described as follows:

1. **Early design stage**
   - Define the design task. This stage is the starting point of the entire design process, which begins with an initial statement of the need and problem analysis.
   - Conceptual design. This stage is mainly associated with idea generation activities, i.e. searching, establishing and selecting suitable concepts to meet the design needs. Designers at this stage need to generate ideas based on form, function, features and aesthetic criteria.
2. Middle design stage
   - Development design. This stage involves a series of activities to develop the initial ideas and refine them through extensive use of sketches and models to establish the feasibility of the overall concept.
   - Embodiment design. This stage aims to produce a concrete form of a developed idea. Designers at this stage need to focus on creating a fixed layout with the most suitable configuration and evaluating it against technical and economic criteria.

3. Late design stage
   - Detail design. This stage defines the design solution through the specification of details, e.g. material, dimensions and assembly. This stage also supports the final testing and refinement before manufacture.
   - Presentation and Implementation. This stage contains only post-design activities, including presenting highly detailed design representation to clients, producing in small volumes for final testing and releasing the design to mass production.

This research is carried out to explore the roles of sketching in the product design field and this GDP model was proposed and used as a framework to organise the study. The conceptual design stage has always been viewed as the most important phase in the design process. This is mainly because this design stage is closely related to design ideation. The design concepts and alternatives are mainly produced in this stage which provides the basis for later design development (French, 1971). In this stage, designers extensively use sketching to express their ideas and explore the design space. Lottor (2013) thought this is why the conceptual design stage should be considered as the most demanding phase of design on designers. In comparison, other phases such as the manufacturing stage depend more on production engineers. This research investigated the use of sketching through the whole design process but also had a special focus on the early conceptual stage.

2.4. Design sketching taxonomy

Taxonomies can be useful in order to explore classifications and has been applied in the research to the roles of the sketch in design. To achieve a comprehensive understanding of the design sketch, various sketching taxonomies have been developed (Ferguson, 1992; Van der Lugt, 2005; Pipes, 2007; Schenk, 2007; Pei, 2009; Ullman, 2010; Pei, Campbell and Evans, 2011). Design sketches can be considered and classified from several perspectives, including their form, their shape, their purposes, as well as their applied design stages. For example, Ferguson (1992) classifies sketches according to their functions in the design process. Lught (2005) followed this research and added ‘storing sketch’ into the taxonomy. Pei (2009) proposes a taxonomy for the sketch, based upon the need or intention of the designers while they are sketching. Subsequent work (Pei, Campbell and Evans, 2011) developed a design tool to improve the collaboration between industrial designers and engineering designers. In this research, design sketches can be
roughly classified into two groups, i.e. the ‘working sketch’ and the ‘non-working sketch’. As their names suggest, the former refers to a group of sketches produced by designers in the design process, while the latter is produced in their spare time outside the design process.

2.4.1. Overview of the design sketching taxonomy

There exists an extensive literature on the design sketch, but few studies focus on reviewing the proposed sketching taxonomies. Schembri et al. (2015) provide a relatively complete summary of the existing sketch taxonomies, while a number of papers just provide a brief mention of one or several taxonomies related to their research. The available sketch taxonomies may be inaccessible for both designers and design researchers to use. For example, it is argued by Pei (2009) that the available sketch taxonomies are incomplete and fail to incorporate different design domains. Researchers also find it is hard to refer to a single taxonomy that can involve and describe the use of different types of sketches throughout the entire design process (Hua et al., 2018). Furthermore, although researchers such as Goldschimt (2003), Lugt (2005) and Lawson (2012) have identified several types of non-working sketches, which helped in expanding and refining the understanding of the design sketch, they did not integrate these non-working sketches into sketch taxonomy.

Taxonomy can be defined as the practice and science of classification. Eppler and Mengis (2011) point out that “Classifying empirical phenomena or theoretical contributions is a key step to building new knowledge, especially in the early stages of the research process”. Simon (2019) argued that “An early step toward understanding any set of phenomena is to learn what kinds of things there are in the set—to develop a taxonomy”. The design process can be viewed as an “evolution of different kinds of representations” (Goel, 1995). The different types of design sketches can be considered and classified from several perspectives (e.g. their form, purposes and level of complexity). According to the literature research, 20 sketch taxonomies were found in the relevant design fields. Table 2.2 gives an overview of the design sketching taxonomies found in the literature.
Table 2.2. A list of different sketch taxonomies found in the literature.

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Taxonomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crowe &amp; Laseau/1986</td>
<td>Basic drawings; Analytical drawings; Symbolic drawing</td>
</tr>
<tr>
<td>Tovey/1989</td>
<td>Diagrammatic drawings; Ideas sketches; Concept drawings; Measured drawings</td>
</tr>
<tr>
<td>Ullman et al. /1990</td>
<td>Support notation; Graphic representations</td>
</tr>
<tr>
<td>Radcliffe &amp; Lee /1990</td>
<td>Functional sketches; Geometric sketches; Pictorial sketches</td>
</tr>
<tr>
<td>Pugh/1991</td>
<td>Phase 1; Phase 2; Phase 3; Phase 4; Phase 5</td>
</tr>
<tr>
<td>Porter &amp; Goodman/1992</td>
<td>Orthographic projections; Axonometric drawings; Perspective drawings</td>
</tr>
<tr>
<td>Fraser &amp; Henmi/1993</td>
<td>Referential drawings; Diagrams; Design drawings; Presentation drawings; Visionary drawings</td>
</tr>
<tr>
<td>Ferguson/1994; Lugt/2005</td>
<td>Thinking sketch; Talking sketch; Prescriptive sketch; Storing sketch</td>
</tr>
<tr>
<td>Goel/1995</td>
<td>Lateral transformations; Vertical transformations</td>
</tr>
<tr>
<td>McGown et al. /1998</td>
<td>level 1; level 2; level 3; level 4; level 5</td>
</tr>
<tr>
<td>Ching/2003</td>
<td>Multi-view drawings; Praline drawings; Perspective drawings</td>
</tr>
<tr>
<td>Olofsson &amp; Sjöblén/2005</td>
<td>Ideation sketch; Explorative sketch; Explanatory sketch; Persuasive sketch</td>
</tr>
<tr>
<td>Menezes /2005</td>
<td>Orthogonal drawings; Axonometric drawings; Perspective drawings</td>
</tr>
<tr>
<td>Pipes/2007</td>
<td>Thematic sketch; Package-constrained sketch</td>
</tr>
<tr>
<td>E. Pei/2009</td>
<td>Personal sketch; Shared sketch; Persuasive sketch; Handover sketch</td>
</tr>
<tr>
<td>Yang/2009</td>
<td>Non-dimensioned sketch; Dimensioned sketch</td>
</tr>
<tr>
<td>Huet et al. /2009</td>
<td>Chronologically; Type of view; Subject</td>
</tr>
<tr>
<td>Lawson/2012</td>
<td>Presentation drawings; Instruction drawings; Consultation drawings; Experiential drawings; Diagrams; Fabulous drawings; Proposition drawings; Calculation drawings</td>
</tr>
</tbody>
</table>
2.4.2. Analysis of the existing sketch taxonomies

One of the key features of the design process is the use of a number of different types of sketches (Purcell and Gero, 1998). These different types of sketches are associated with different design stages and cognitive processes (Lawson, 2004). Based on this model, Pei (2009) proposes a sketch taxonomy, which organizes sketches according to their functions in specific design stages. According to him, designers tend to begin with various relatively unstructured forms of sketches, such as ‘ideation sketch’ in the early-to-middle design phase. As the design develops, they turn to more structured forms of sketches, such as “persuasive sketch” and “handover sketch”.

A generic model of the product design process is proposed in this study (Section 2.3.2). The selected nine sketch taxonomies are analyzed according to their applied stages in the design process (Table 2.3). It should be noted that only the taxonomy classifying sketches with regards to their applied design phases have been included. For example, the taxonomies presented by Ullman et al. (1990) and McGown et al. (1998) are not included, because Ullman et al. (1990) classified the Sketch based on the distinction between drawing and writing; McGown et al. (1998) developed their taxonomy based on the level of complexity of the sketching. The following sections will look at how each taxonomy could achieve its aim by analysing its functions along the design process.

Table 2.3 Analysis of sketch taxonomy according to their applied design phase

<table>
<thead>
<tr>
<th>Sketch taxonomy</th>
<th>Early design stage</th>
<th>Middle design stage</th>
<th>Late design stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Define the task</td>
<td>Conceptual design</td>
<td>Development design</td>
</tr>
<tr>
<td>Tovey/1989</td>
<td>√</td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Fraser &amp; Henmi/1994</td>
<td></td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Ferguson/1994; Lugt/2005</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Goel/1995</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olofsson &amp; Sjöblén/2005</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Pipes/2007</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yang/2009</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. Pei/2009</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lawson/2012</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Early to the middle design stage**

Design ideation is considered an essential part of the design process (Jonson, 2005) and is often synonymous with drawing (Orthel and Day, 2016). The design thinking literature emphasizes the importance of design sketch, design ideation and design communication for facilitating a creative and productive design process. Tovey (1989) classifies sketches according to their functions and corresponding forms. Diagrammatic drawings emphasize the abstract nature of the sketch, which helps in our understanding that rough sketches at the early design stage assists designers to convert a single idea into more than one potential design solutions. The idea sketch helps with the visualisation of the former generated design ideas. Fraser and Henmi (1993) suggested a taxonomy based on the characteristics of architectural drawings. Based on this research, Lawson (2012) tried to develop a more elaborate taxonomy with regards to the way in which knowledge is manipulated in designers’ minds. Both of these two taxonomies pay little attention to the early design stage, but they identified two types of sketches, namely ‘visionary drawings’ and ‘fabulous drawings’, which are believed to be associated with the design ideation process. Ferguson (1992) associated the thinking sketch and talking sketch within the early-to-middle design stage. The thinking sketch is used to assist the designer in focusing and guiding non-verbal thinking while the talking sketch is used for facilitating design communication. Similarly, Pei (2009) groups these two kinds of sketches as “personal sketch” and “shared sketch”. It should be noted that some differences exist in the meaning of thinking and talking sketches with personal and shared sketches. For example, the C-sketch (Jami J. et al., 2001) method requires designers to add or delete aspects of the sketch produced by team members in an agreed length of time, which do not incorporate time for discussion. Therefore it can be viewed as a type of shared sketch rather than a type of talking sketch. Goel (1995) used a cognitive approach to classify sketches and identifies two types of operation occurring in a design sketch, namely “lateral transformation” and “vertical transformation”. Lateral transformation refers to the movement from one idea to a slightly different idea. Vertical transformation is to step further to make a more developed and detailed sketch based on the original one. Olofsson and Sjolen (2005) classified sketches according to the need or intention of the designer while they are sketching. They put more emphasis on the initial stage of the design process, where the designer needs to understand the problem statement and starts to generate ideas. Pipes (2007) and Yang (2009) broadly grouped these two types of sketches respectively as thematic sketch and Non-dimensioned sketch. Pipes (2007) emphasises the aesthetic qualities of the sketch, while Yang (2009) focuses heavily on the role of the sketch as a representation of design thinking.

**Late Design Stage**

Design sketches produced in the late design stage mainly serve three purposes, i.e. improving the design details, selling design ideas and guiding manufacturing. Among all nine selected sketch taxonomies, only Pei (2009) sub-divided his taxonomy and defined a type of drawing named ‘technical drawing’ that can be applied at the detail
design stage. According to Pei (2009), a technical drawing is a complete and standardised way of design representation, which is capable of showing all the aspects of the built product and covering every detail for manufacture.

For the presentation and implementation stage, Tovey (1989) identified a type of sketch as ‘measured drawings’, which can be used closely with the ‘concept drawings’ to precisely present the design idea. This type of sketch is also known as ‘presentation drawings’ (Fraser and Henmi, 1993; Lawson, 2012), ‘persuasive sketch’ (Sjölen and Olofsson, 2005), ‘package-constrained sketch’ (Pipes, 2007) and ‘persuasive sketch’ (Pei, 2009). Ferguson (1994) defined a type of sketch named ‘prescriptive sketch’, which is used by engineers to provide instructions to the drafter at the last stage. This type of sketch is also known as ‘handover sketch’ (Pei, 2009) and ‘instruction drawings’ (Lawson, 2012).

**Outside the Design Process**

The taxonomy is the starting point for exploring unknown phenomena. To achieve a more comprehensive understanding of the design sketch, there is a need for establishing a holistic sketch taxonomy that can include the group of the non-working sketch. As the name suggests, the non-working sketch refers to the group of sketches that are produced by designers in their spare time outside the design process. However, according to our literature study, only three of the selected taxonomies have partially explored the roles of the non-working sketch. Lugt (2005) pointed out that a sketch also provides a means to store design ideas so that they can be revisited in the future. He named this type of sketch as storing sketch and combined it with Ferguson’s taxonomy as an improvement. Pei (2009) subdivided the personal sketch and identified two types of the sketch, namely ‘referential sketch’ and ‘memory sketch’. The purpose of a referential sketch is to record observations for future reference or as a metaphor and a memory sketch is used to help designers to recall thoughts and elements from previous work with the help of mind-maps, notes and text annotations. At last, Lawson (2012) noticed that designers tend to draw habitually in their spare time and most of them are prolific sketchers of the world around them. This is an important clue in revealing what designers know and how they think. To further this line of research, he classified this type of sketch as “experiential drawings”.

**2.4.3. Analysis of available sketch taxonomy**

To make the taxonomies accessible and feasible for design researchers to use in the design context as well as to assist in achieving a better understanding of the design sketch, they have to satisfy certain criteria. For example, numerous studies (Goldschmidt, 1991, 2003; Pugh, 1991; Schon and Wiggins, 1992a; Goel, 1995; Cross, 2006) revealed that sketching in the design process supports design creativity, e.g. supporting cyclic reinterpretation process, facilitating perception and translation of ideas and revising and refining ideas. These cognitive benefits are believed to be associated with different types of sketches applied in the different design stages. Therefore, a taxonomy that can be used for searching for numerous sketches and
their sequence may well provide further data and a good starting point for researchers to observe that particular phenomenon. Through reviewing the literature, criteria for improving design sketch taxonomy have been proposed as follows:

1. Whether the taxonomy helps to reveal the functions of the design sketch?
   - The sketch may promote the design process in multiple ways, including assisting design thinking, facilitating design commutation and collaboration and enhancing design creativity.

2. Whether the taxonomy helps to reveal the functions of drawing elements?
   - This line of research mainly focuses on the sketch outcomes, drawing elements and attributes. For example, the stylish sketches express wonderful or fantastic qualities of a product (e.g. fabulous drawings). Sketch taxonomies developed from this perspective may give design researchers insights into those aspects and their relationship with design.

3. Whether the taxonomy takes the whole design process into consideration?
   - The taxonomy should take a holistic overview of the whole design process concerning the application of different types of sketches. Existing taxonomies are always incomplete, which can be an obstacle for design research to get a fully rounded understanding of design sketch.

4. Whether the taxonomy includes the non-working sketches produced outside the design process?
   - Empirical evidence supports that the non-working sketch may also play a role in supporting the design process. To achieve a comprehensive understanding of the design sketch, researchers should consider the non-working sketches while developing a new taxonomy.

5. Whether the taxonomy demonstrates a hierarchy for sketches?
   - Design sketches are produced in the complex design context, which may apply in different stages and serves multiple purposes. This hierarchical structure may help design researchers to further the research in a way that has the potential to lead to a more detailed and in-depth understanding of the supporting value of the design sketch.
Table 2.4. Analysis of sketch taxonomies according to the criteria.

<table>
<thead>
<tr>
<th>Sketch taxonomy</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tovey /1989</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pugh /1991</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fraser &amp; Henmi/ 1994</td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferguson/1994; Lugt/ 2005</td>
<td>√</td>
<td></td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goel /1995</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Olofsson &amp; Sjölén/ 2005</td>
<td>√</td>
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<tr>
<td>Pipes /2007</td>
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<tr>
<td>Yang/ 2009</td>
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<tr>
<td>E. Pei /2009</td>
<td>√</td>
<td></td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Lawson/ 2012</td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>

Existing taxonomies have been screened based on the above criteria and the results are shown in Table 2.4. It is clear that few of the taxonomies can cover various types of sketches both in and outside the design process. Also, a few of them demonstrate a hierarchy for design sketches. This may cause confusion when studying a certain type of sketch with multiple functions. These problems are crucial for the study as taxonomy is an essential tool for exploring the roles of various types of sketches in design. Therefore, a new sketch taxonomy was developed to address the problems and facilitate the research of the project. Details can be found in Section 4.3.9.

2.5. Visual cognition and expression

Design sketching (as discussed in Section 2.2.1) is different from drawing of something that already exists (Tovey, Porter and Newman, 2003). Design sketching is a kind of representation of design ideas imagined in the mind of the designers. Therefore, design sketching is often considered as an extension of visual thinking and has been extensively studied in creative cognition, mental imagery, and design protocol studies (e.g. Kosslyn, 1980; Finke, 1990; Goldschmidt, 1991; Schon and Wiggins, 1992b; Goel, 1995; Do and Gross, 1996; Suwa and Tversky, 1996; I. M. Verstijnen et al., 1998; Schön, 2017). In fact, sketching can be viewed as both a form of thinking and the fundamental language of design (Botturi and Stubbs, 2008). It not only can be used as a tool to assist creative design thinking but also helps designers with communication and design collaboration (Goel, 1995). These major roles of sketching are always desirable in design, but the question that how designers think through sketching is still not fully understood. According to Shah et al. (2001), the primary drivers and barriers of design sketching are “visual thinking/imagery, provocative stimuli, and flexible representation”. Gharib (2013) divided sketching into two parallel parts, namely the “mental part”, and the “technical part”. The mental part
can be sub-divided into design thinking and imagination, while the technical part consists of sketching skills, tools, and behaviour. These insights gained from literature help providing the focus for the research and most related literature are reviewed and discussed in this and the following sections.

2.5.1. Enhancing design thinking

As a form of thinking, sketching serves the designer in various ways, i.e. the thinking sketch. In terms of creativity and cognition, two concepts recur in the literature, namely divergent thinking (e.g. lateral/vertical transformations) and cycles of generation and interpretation (e.g. reflective conversation). These two concepts are seen as cognitive benefits which sketching supports and which foster activities generative of creativity.

Numerous studies (Pugh, 1991; Goel, 1995; Liu, Chakrabarti and Bligh, 2003; Cross, 2006; Macomber and Yang, 2011) revealed that sketching in the design process supports divergent and convergent thinking. Pugh (1991), for example, points out that the early-to-middle design phase is characterized by "a continuing interplay between divergent and convergent design activities in order to generate appropriate design solutions". Cross (2006) suggests that the design process can be viewed as a convergent process, which also contains divergent thinking for the purpose of opening the search for new concepts. Cross (2000) furthered this line of research and established a generic model of the industrial design process based on divergent and convergent design activities. As is illustrated in Figure 2-3, while divergent thinking process promotes idea generation and exploration of alternatives, convergent thinking process will transform these ideas into more detailed and refined version.

Several important studies have explored how designers adopt specific cognitive strategies in the different design phases. Goel (1995), for example, identifies two types of strategies that occur in this divergent/convergent design process (i.e. lateral transformations and vertical transformations). Generally speaking, lateral transformations occur in the conceptual design phase and are associated with unstructured sketches; vertical transformations occur during the development design phase and are associated with more detailed and precise drawings. He also points out that sketching is "a particular form of symbol system", which is characterized by semantic denseness and by ambiguity, and it is these aspects of sketching which allow lateral transformation to occur. Goel concludes that sketching is associated with preliminary design because it is a symbol system that is dense and ambiguous and consequently facilitates the lateral transformations that are an essential aspect of this phase of the design process.

Other researchers have also proposed such cyclical models of re-interpretation, each with a slightly different connotation. Schön and Wiggins (1992) argue that the path leading to the final design cannot be foreseen, but need to be dynamically explored step by step. Sketching serves as a tool during this process, helping designers to put their ideas down on paper and inspecting them. In this way, designers see new
features and relations that suggest ways to refine and revise their former ideas, and thereby are driven to draw again. They describe these designers’ cyclic activity as reflective ‘conversation’ with sketches, which is “the essence of early design processes”.

Based on Schon and Wiggins’ work (1992), Tversky et al. (2003) examined what information architects ‘think of’ and ‘read off’ from their own freehand sketches. Also, Suwa et al. (1997) explored sketches to find how they can be a good medium for a reflective conversation. The serial studies of design protocols revealed insights on different aspects of the design activity. For example, while designers are sketching, they proceed by a “seeing, moving and seeing again” behavioural sequence. Sketches are interpreted by designers, “transforming the previous sketches by adding, deleting, modifying or replacing certain parts”. This reflective ‘conversation’ leads to the generation of related sketches, which may further support both the idea generation and development process.

Goldschmidt (1991) also points out that designers transform their designs in a cyclic manner. She proposes a dialectic type of argumentation between ‘seeing-as’ and ‘seeing-that’ to illustrate this mechanism. Goldschmidt points out that, while making idea sketches, designers use two types of reasoning in rapid oscillation. One type is based on analogical or metaphorical thought, dealing with extracting new meaning from the sketch. She describes this kind of reasoning as seeing as. The other type, seeing that, deals with the design consequences of this newly acquired meaning of the sketch.

### 2.5.2. Enhancing design collaboration

As a kind of language, sketching is essential for communicating ideas, both with ‘self’ and others (Temple, 1994), i.e. the talking sketch. Robbins (1994) points out that sketching has both a monologic and dialogic function. As monologue, the language of sketching helps designers with the thinking process for generating and developing design ideas. As dialogue, the language of sketching serves as a medium to communicate with others. Here, we mainly focus on the sketches used as the dialogue, especially the way in which it supports creative group discussion.

The collaborative sketching promoted design collaboration in multiple ways. The presence of collaborative sketching encouraged interactivity between the participants (Heiser, Tversky and Silverman, 2004), enhancing their communication and feedback of the collaboration. Designers largely use sketching as the main way to illustrate their ideas during the early design stages. Through sketching, designers can employ visual symbols, communicate features, exchange opinions, and explain thoughts during the design process (Pei, Campbell and Evans, 2009) using a fast and efficient way for sharing and discussing complex ideas. Heiser, Tversky and Silverman (2004) suggested that sketching may serve as a ‘shared focus of attention’, ensuring all of the participants focus on the same task. It also helps to simplify the communication in a way that allows the ‘efficient gestures’ to convey design information instead of
‘cumbersome language’. Gestures are an inevitable and natural element of speaking. For example, a pointing gesture may establish the focus of attention, by participants pointing to the relevant part of sketching.

As a way of communication, sketching also enables the ‘audience’ to reply rapidly to contribute to that idea (Shah et al., 2001). When working in a group, designers can generate ideas by not only reflecting on their own sketching but also receiving feedback from other participants. Especially, when participants are in the face-to-face condition, they not only look at a shared sketch but also add their own ideas and assessment to it. Through this feedback loop, design evaluation and reinterpretation are made. In particular, this reinterpretation cycle, as discussed in the former section, is often considered as a key ingredient of creativity (Schön, 2017). The function of inviting the reinterpretation cycle is especially relevant for the idea generation process. It may lead to novel directions for idea generation, facilitating both the exploration and expansion of the idea space. Lugt (2005) argues that this type of support has also been observed in the collaborative design process. Designers exhibit more “reinterpretation cycles and reuse of ideas” in group meetings through sketching. The ambiguity in a sketch is believed to be beneficial for communicating design ideas as ambiguity could facilitate creativity by enabling the reinterpretation process (Schon and Wiggins, 1992b; Goel, 1995; Casakin and Goldschmidt, 1999). Designers can find unintended configurations of ambiguous sketch elements, which can bring active interest in new possibilities and chances for triggering new insights (Casakin and Goldschmidt, 1999). In addition, the ambiguity in a sketch helps to maintain the non-fixedness in design, which can influence “the development of a shared understanding of the design and provide space for further designing” (Minneman, 1991). Therefore, designers may find ambiguity useful for maintaining a wider space of possibilities in design communication.

2.6. Sketching ability and skill

Although sketching may have the many advantages described in the preceding sections (Section 2.2.2 and Section 2.2.3), it was found that designers often benefit to different degrees from the use of sketching (Shah et al., 2001). Lawson (2006) points out that design is a highly “complex and sophisticated” work, which requires designers to “use their utmost ability of thinking and sketching skill to propose a design solution”. In general, sketching is often viewed as the fundamental language of designers (Botturi and Stubbs, 2008). In this sense, proficiency in this language may have an impact on both the design process and outcome. Therefore, to fully utilize sketching in design, designers need to have qualified sketching skills and the abilities to use sketching in the appropriate way. There are, however, only a small body of literature that has explored the roles of sketching skills in design. Related studies are reviewed in the following paragraphs.

Larkin and Simon (1987) suggested that effective use of sketching in design might come with practice and experience. Suwa and Tversky (1997) studied differences
between professional architects and students while they were asked to design a museum under certain constraints. According to protocol studies, it was found that experienced architects are better than students at reading abstract features and relationships from their sketches. They found that professional architects could generate more interpretations than students and have better skills in transformative reasoning. In their experiment, more functional inferences were made by professional architects from their own sketches than students did. As Goldschmidt (1991) suggests that, while unskilled sketchers can only “use sketching to represent an image held in the mind”, skilled sketchers can use sketching to manipulate the images generated in the mind as if the sketch talked back to the designer.

Verstijnen and Hennessey (1998) suggest two mental processes are essential in the creative design process, namely ‘combining’ and ‘restructuring’. Their research tried to prove these two processes are influenced by sketching skills, which in turn will affect designers’ creative performance. However, the results show that the combining process is easy to perform in mental imagery while the restructuring process is difficult so that only the restructuring process is supported by sketching. The result is confirmed by the fact that only experts are aided in performing it by sketching.

Sketching as a design activity has also been linked to design outcome. Schütze, et al (2003) found that designers who were allowed to sketch while facing a design task produced a higher quality solution than those who were not allowed to sketch. It was found that good sketching skills could improve the quality of the solution and shortens the process of finding a solution. Song and Agogino (2004) observed and explored the relationship between the amount of 3-dimensional perspective sketching and design outcomes. Yang (2003) found that the quantity of dimensioned drawings created early in the design cycle is significantly linked with the design outcome. Subsequent work (Cham and Yang, 2005) explored how sketching expertise may influence sketching fluency and design outcome. They suggest that the content of a sketch is mainly depending on the interplay between the ability and the demand for sketching. Results show that skilled sketchers tend to draw more while they are designing and a positive correlation can be found between sketching fluency and design outcome. Specifically, there were positive correlations between the total number of freehand sketches and project grade, and between the number of perspective sketches and the ranking given by the independent judges. According to Hanks and Belliston (2006), sketching fluency is a key driving force for design creativity. They suggested that creative ideas usually occur as fleeting thoughts in the mind and need to be captured quickly on paper before they are lost. Thus, sketches need to be produced quickly, so that allows the designer to easily manipulate the ideas. Goldschmidt (2003) also highlighted the importance of sketching expertise (especially sketching fluency) in design. She argued that sketching expertise was indispensable for a designer in the search of design solutions and was one of the most significant parts of the design process. She classified sketching ability into two independent components, namely ‘the ability to sketch fluently’ and ‘a good command of the system of orthogonal projections’. A skilled sketcher has therefore been defined as someone “who can make and
manipulate representations fast and with great ease while choosing the most appropriate projections”. In particular, sketching fluency requires designers to be able to “use sketching without having to spare attention to the actual production processes”. This sketching ability is crucial due to the ‘mileage’ effect that designers can expect from their investment in the sketches by revisiting concepts made earlier for new design rationale.

### 2.7. Visual Stimuli as Inspiration

Designers commonly use multiple methods to enhance their creative design process, many of which try to come up with creative ideas through adopting visual stimuli as external supports (Eckert and Stacey, 2003; Goldschmidt, 2015; Hua et al., 2019). Throughout the design process, especially in the early design stage, designers can be exposed to vast collections of visual stimuli, which are believed associated with design creativity (Goldschmidt, 2015). Design creativity can be defined as the ability ‘to develop something new of value’ (Childs et al. 2006), which is a vital element in the design. Design studies have provided evidence in support of the view that the use of external stimuli can have an impact on design creativity in many ways, e.g. by offering new information/knowledge (Agogué et al., 2011), eliciting emotion (Mougenot et al., 2010), building far connections among irrelevant elements (Gassmann and Zeschky, 2008) and making analogies from accumulated experience (Goldschmidt and Smolkov, 2006a). Therefore, designers are used to searching for visual stimuli serving as important triggers for idea generation.

Numerous research programmes have been carried out to explore the supporting roles visual stimuli play in the design ideation process (Finke, 1990; Henderson, 1998; Dahl and Moreau, 2002; Goldschmidt and Smolkov, 2006a; Goldschmidt and Sever, 2011; Gonçalves, Cardoso and Badke-Schaub, 2014; Borgianni, Rotini and Tomassini, 2017; Hua, 2019). Sun et al. (2014) suggested that visual stimuli can enhance design creativity by offering additional information (e.g. new information from other domains or details of related products). Chang et al. (2016) suggested that the student creative performance, particularly on expressiveness and functionality, was evidently improved by espousing to 3D-CAD representations. It was also reported that design thinking can be triggered through the use of stimuli, which activate memory in specific patterns that support both divergent and convergent thinking process (Goldschmidt, 2015). Besides the roles of stimuli in design, the taxonomy of stimuli also attracted much attention from many researchers. Various types of stimuli like images, words, videos, sounds and even designer’s own sketches were reported to help support design creativity, e.g. “inferring unexpected information” (Goldschmidt, 2015) or “recording ideas for future reference” (Hua, Huang and Childs, 2018). Empirical evidence shows that the effective use of visual stimuli can enhance the ideation process across various dimensions of creativity, especially for quantity and variety (Guo and McLeod, 2014; Bacciotti, Borgianni and Rotini, 2016; Hua et al., 2019). In this sense, the method of presenting stimuli to designers (e.g. content and format) should be carefully
studied and designed so that designers can make the best of the stimuli for boosting their creativity. However, little attention has been paid to explore how stimuli should be delivered to designers during the design process. Only a few studies can be found in the literature, for example, the relevance of stimuli to the design tasks was found might influence the originality of design ideas (Gassmann and Zeschky, 2008) and the timing of stimuli delivery could affect the quality of conceptual sketching (Tseng et al., 2008). This question is crucial to the effective use of stimuli because previous studies also have indicated that ill-presented stimuli can lead to lower design efficiency or even harm creative production (Goldschmidt and Smolkov, 2006a; Siangliulue et al., 2015; Hua et al., 2019).

2.7.1. Previous Research on Visual Stimuli

Finke (1990) in his pioneering work ‘Creative Imagery: Discoveries And Inventions in Visualization’ reported a series of experiments to explore the interplay between mental imagery and external visual stimuli. In the experiments, a set of 15 forms were shown to the subjects, from which three randomly selected forms would be named and presented on each trial. Once the forms had been named, the subjects were asked to close their eyes and try to mentally combine the forms into a recognizable design. The subjects were asked to synthesize the forms in two minutes and then to draw the design outcomes on paper. These sketches were then rated by judges from the perspective of practicality and originality. According to the results, the subjects scored higher in creativity when they received the specified interpretive categories after completing their forms, whereas the subjects scored lower when they were free to choose interpretive categories at any time. These results indicate that receiving unexpected stimuli and delaying the exposure to stimuli after the ‘pre-inventive structures’ are completed can enhance creative performance. These findings suggest the importance of the way that stimuli are accessed (e.g. their types, forms, and timing of delivery).

Finke and his associates revealed that people can benefit from external stimuli and manipulate them in imagery to make novel and meaningful combinations (Finke and Slayton, 1988; Finke, 1990). Their experiments opened up a new perspective of research based on the insight of mental synthesis, which also inspired many other researchers to take it further. For example, Goldschmidt and her colleagues subsequently reported several important studies which contributed to the literature on creative mental synthesis. In the first, Goldschmidt and Smolkov (2006) carried out an empirical study that experimentally tested how different types of stimuli and their presence in the designers’ working environment can affect design outcomes. The results suggest that the presence of stimuli can influence the quality and originality, only when designers are facing an ill-structured design problem. The effect of stimuli may vary due to the types of design problems and environmental factors. In the second study, Goldschmidt and Sever (2009 and 2011) switched their research attention to only focus on textual stimuli and their role in supporting creative design performance. They found that the reading of different types of texts containing ideas
can be inspiring and enhances the originality and creativity of designs. Compared with pictorial stimuli, fewer studies have been done to explore the impact of textual stimuli on design creativity. These studies (Goldschmidt and Litan Sever, 2009, 2011) found in the literature prove that, like pictorial stimuli, textual stimuli also play a role in the ideation process and have a positive effect on the rated creativity of design outcomes.

One reason why design researchers choose to pay more attention to pictorial stimuli is that designers have traditionally been considered as visualizers (Mednick, 1962) and they acknowledge a clear preference for pictorial stimuli over textual or any other types (Muller, 1989; Henderson, 1998; Hanington, 2003; Gonçalves, Cardoso and Badke-Schaub, 2014). Numerous researchers have reported the superior effect of pictorial stimuli over textual ones, especially when it related to form and function design (Paivio, Rogers and Smythe, 1968; Lutz and Lutz, 1977). Pictorial stimuli are believed to be more efficient than textual stimuli because pictures are easier to memorise and connect to semantic memory than texts, which means less cognitive effort is needed for accessing and storing pictures, and combining them with previous knowledge into novel combinations (Sarkar and Chakrabarti, 2008; Ware, 2010).

According to Paivio’s (1968) dual coding theory, people can process information in both verbal (which includes text or audio) and non-verbal (images and sounds) channels, and these two channels can work either independently or synergistically. Thus, some information can only be processed in texts or pictures, while other information is better delivered in a combinational way than any modality alone (Paivio, Rogers and Smythe, 1968; Ware, 2010). Malaga (2000) reported an experiment in which participants were asked to produce new ideas for a given design task. Textual, pictorial and hybrid stimuli were provided as sources of inspiration for participants. The results showed that pictorial stimuli elicited more creative ideas than textual or hybrid stimuli. Borgianni et al. (2017) performed a very similar experiment but adopted different creativity metrics for evaluation. Their results show that stimuli fashions play a limited role in the ideation outcomes, and hybrid stimuli rated slightly higher on the creativity test than the other two kinds of stimuli. The shared insight among all of these studies is that not only the stimuli themselves, or their relevant attributes, can have an impact on the creative performance, but also the way to deliver them to the ideators can play a significant role in the creative design process. Therefore, an experiment was carried out to test if and how combinational pictorial stimuli can influence the creative design performance (see Section 7.6.3).

2.7.2. Forms of Combinational Pictorial Stimuli Delivery

There is empirical evidence to show that combined images can be used as effective stimuli for supporting creativity (Rothenberg and Sobel, 1980, 1981; Eckert and Stacey, 2003; Ward and Kolomyts, 2010; Han, Shi and Childs, 2016; Han et al., 2018; Hua et al., 2019). Rothenberg (1980) proposed that ‘homospatial thinking’ was a specific cognitive process operating in creativity that could be enhanced by the fusion of sensory images. This theory was supported through his research into the
superimposed visual stimuli. A series of experimental studies (Rothenberg and Sobel, 1980, 1981; Rothenberg, 1986) were carried out to test and compare the effectiveness of different forms of combinational visual stimuli, i.e. ‘superimposed images’, ‘separated images’ (two slide images juxtaposed side by side) and ‘combined-composite images’, in supporting creative homospatial process, the results showed that superimposed images could facilitate the production of literary metaphors and rated higher on creativity than the other two forms of combinational images. He further explained that perceived images were intentionally superimposed or fused during the creative homospatial thinking process, which helped the ideators to “generate new and integrative ideas and products, such as literary metaphors”. The study of homospatial thinking provides the basis for many combinational stimuli generation methods and the applications in a number of CAD tools development (Joshi et al., 2012; Sylla et al., 2014; Han, Shi and Childs, 2016; Yilmaz et al., 2016).

For example, Joshi et al. (2012) developed a visual media named ‘cliplets’ which could generate ‘juxtaposed still images’ and ‘dynamic images’ (video segments), whilst Sylla et al. (2014) designed a physical-digital book aiming to “unleash children’s creativity” by supporting the ‘collation process’, which could juxtapose two images to create a new image with a different meaning. Other combinational methods proposed by researchers may include ‘animated views’, ‘explicit encodings’, ‘conjunction’ and ‘concatenation’ (Dormann, 1994; Gleicher et al., 2011; Alper et al., 2013).

Two forms of image combination methods (i.e. juxtaposing and superimposing) were redesigned and provided for delivering pictorial stimuli to designers involved in our study (Figure 2-6). According to Ward and Kolomyts (2010), juxtaposing and superimposing, two basic ways for generating combinational images, have been considered as effective stimuli for creativity. In this study, the first method ‘juxtaposing’ is to crop images first and then to merge them next to one another and the second method ‘superimposing’ is to make images semi-transparent and then to superimpose them on one another. For example, Figure 2-6 shows the original images of a hairdryer and a conch shell, and their juxtaposed image and superimposed image. The optimal way to deliver visual stimuli for creative inspiration should make the best of pictorial stimuli and avoid the potential cognitive fixation caused by it. Previous studies have indicated that presenting complete pictures of design examples as a source of inspiration may lead to design fixation (Jansson and Smith, 1991; Purcell and Gero, 1991, 1996). However, subsequent studies found a new method to reduce design fixation by only presenting partial pictures of design examples (Cheng, Mugge and Schoormans, 2014). Therefore, the images collected for generating juxtaposed images in this study were cropped first prior to the juxtaposition. In addition, the two methods (i.e. juxtaposing and superimposing) were randomly used to avoid the einstellung effect on designers, whose mind might be blocked because of the overexposure to just one type of stimuli combination (Borgianni, Rotini and Tomassini, 2017).
2.7.3. Supporting tools

A number of emerging ideation software and online platforms were reported to be useful in supporting designers’ searching behaviour and creative performance. Many of these tools do not actually generate ideas (Childs, 2013), but stimulate the users by providing external stimuli to designers while they are working (Hua et al., 2019). For instance, Bacciotti, Borgianni and Rotini (2016) proposed a method and implemented it in software (i.e. ‘iDea’) for idea generation, which provides users with a group of textual stimuli called general demands (GDs) as triggers for idea generation. Shi et al. (2017) developed a web-based data-driven creativity tool called ‘B-Link’, which can produce a visual map relating to the inputs for inspirations or further insights. More recently, Chen et al. (2019) proposed an AI image synthesis tool, which employs the Generative Adversarial Network (GAN) to produce synthesised pictorial stimuli for enhancing design creativity. As Wang and Nickerson (2017) point out: “Creativity support systems are important not only because they offer help to practitioners, but also because they are where theories of creativity become manifest”. Therefore, based on the study conducted by Han et al. (2016 and 2018) and Hua et al. (2019), a user-adaptive CAD system structure was developed by the authors. This resulted in ‘Combinator V2.0’, a computer-based creativity tool for generating combinational pictorial stimuli, which was adopted for facilitating the research. The interface and an example of the use of Combinator are as shown in Figure 2-7.
2.8. Summary and discussion

As discussed in previous sections, sketching can be considered as an essential part of the design process. A clear understanding of the roles of design sketching might be of use for both design education and practice. Therefore, a literature study was carried out and the four most relevant areas in the design sketching literature were reviewed, namely 1) understanding the roles of sketching in design, 2) the sketching taxonomy, 3) visual cognition and expression of design sketching, and 4) supports for the use of design sketching. Over the years, numerous studies have been carried out, attempting to reveal the roles of sketching in design. However, despite the extensive literature on the subject, the roles of sketching in creative design work may not have been fully understood.

The current status of sketching studies features a lack of integration. These reviewed bodies of literature are somewhat scattered and disconnected from each other. In particular, individual sketching and collaborative sketching seem to be far apart. There may be a more natural and obvious connection between divergent thinking and creativity. While the cognitive creativity literature highlights the importance of divergent/lateral transformations, the equally important role of convergent/vertical transformations has been ignored. Numerous researches have been carried out to explore the interplay between sketching and the design process, and its influence on design outcomes, but we still know very little about how inspirations can evolve to the final outcomes through the sketching process. In addition, sketching skill may also play a role in the creative design process. However, the understanding of its roles in design is basic and lacks detailed insights. This is a question that has not been fully addressed in the research literature to date, and which needs to be explored in a more detailed way in this project.

In order to get a comprehensive understanding of the roles that sketching plays in design, only focusing our study on the design process is not enough, we also need to take the non-working sketches into consideration. This PhD project will move beyond the state of the art by combining several current research streams together. In addition, this project will shed light upon the unknown roles of those sketches which are produced by designers, not during the design process, but in their spare time (i.e. the non-working sketches). This further integration is crucial, not only to identify the functions of non-working sketching but also to give us a relatively complete picture of the field.
Chapter Three: Research Methodology

The literature reviewed in Chapter 2 highlighted the lack of in-depth understanding of the roles (e.g. how sketching cognitively supports the design ideation process) that sketching plays in the design process. Therefore, this PhD research was carried out to better understand the roles. This chapter describes the research methodology adopted for the study, which is based upon a critical review of general research methodologies. The methodology is composed of three phases, namely:

1. Development of hypotheses (to provide logic node and research focus for the study);
2. Descriptive studies (to identify and understand the roles of sketching in supporting design process);
3. Prescriptive studies and evaluation (to develop a practical supporting tool for enhancing design performance through sketching).

3.1. General research methodologies

At the moment, there is no common view as to how design research should be carried out, and discussion about “what constitutes design research and how it is distinct from or similar to other disciplines are still very much ongoing” (Blessing and Chakrabarti, 2009; Robson, 2011; Cash, 2018; Hatchuel et al., 2018). This research focused on understanding the roles that sketching plays in design, especially for supporting design creativity and hence involves the exploration of designers’ cognitive modes and sketching activities. Insights gained from the exploration were used to develop sketching supporting tools for design practitioners and academics. Therefore, design research, cognitive science and pedagogy studies are believed to be relevant. In order to find the appropriate research methodology for this study, a number of research methodologies from multi-fields were reviewed (Rummel and Ballaine, 1963; Eckert, Stacey and Clarkson, 2003; Blessing and Chakrabarti, 2009; Robson, 2011). These research methodologies are briefly introduced and discussed in the following paragraphs.

Rummel and Ballaine (1963) proposed a general procedure for scientific research. This research methodology was generated in line with research findings of the human thinking process, which is comprised of six steps:

1. Selection of the topic or problem for investigation;
2. Definition and differentiation of specific aspects of the topic;
3. The framing of hypotheses to facilitate the preparation of logical study design;
4. Collection of pertinent data;
5. Analysis and interpretation of the data;
6. A written report of the research study.

Robson (2011), in his book ‘Real World Research’, proposed a research methodology with five elements to social scientists and practitioner-researchers:
1. The purpose of the study: exploratory, explanatory, descriptive;
2. The research strategy: case studies, experiment, survey;
3. The type of research being carried out: qualitative or quantitative;
4. The data collection techniques to be used: interviews, ethnography, checklist etc.
5. The analysis approach to be used: coding and clustering, qualitative analysis.

Although there is an ongoing discussion on what methodology really means, it is generally related to planning the research, by sequence or by elements. Therefore, two typical design research methodologies were reviewed, one featuring the sequence and the other featuring the element. These two research methodologies are more concerned with design research when compared with the previously discussed two general research methodologies. They are briefly described in the paragraphs that follow.

Blessing et al. (1995, 2009) proposed a ‘Design Research Methodology’ (DRM) featuring a four-stage process:
1. Criteria formulation: identification of the criteria for success and the measurable criteria;
2. Descriptive study I: analysis of the existing design process aiming to discover relations between the measurable criteria and the design process;
3. Prescriptive study: insights gained in the descriptive study I are adopted to develop design supporting tool;
4. Descriptive study II: the design supporting tool is tested experimentally to determine whether it works as intended and whether it actually impacts the measurable criteria.

Eckert et al. (2003) proposed an integrated design research framework that contains eight elements in a spiral, including empirical studies of design behaviour; evaluation of empirical studies; development of theoretical understanding; evaluation of tools and procedures; introduction of tools and procedures to industry; evaluation of dissemination of tools and procedures. The framework emphasises iterative evaluation. It was suggested that individual research projects could start with any of the elements and contain any number of these eight elements.
3.2. Designing a research methodology

This study aims to integrate two main strands of research: the improvement of understanding of design sketching and the development of a practical supporting tool. These strands are closely linked and should, therefore, be considered together to achieve the overall aim of design research. Figure 3-1 illustrates the overall aim, objectives and facets of design.

![Diagram of Design research: aim, objectives and facets of design](image)

Figure 3-1 *Design research: aim, objectives and facets of design* (Blessing, Chakrabarti and Wallace, 1995)

The design of the research methodology was inspired by DRM proposed by Blessing and Chakrabarti (2009). Since there are few common research methodologies grounded within the industrial/engineering design research field (Blessing and Chakrabarti, 2009; Stompff, 2012), the lack of methodological development has become a major barrier for design researchers to "responding to key research questions about the nature of design phenomena and develop effective design theory" (Wacker, 2008; Cash, 2018). DRM is one of the few available research methodologies specifically developed for design research, which provides a common framework as well as method/tools for facilitating the investigation in the design field (Laursen, 2017). According to Blessing and Chakrabarti (2009), DRM consists of two main strands, i.e. developing an understanding of the existing situation, and developing supporting tools to improve the situation. The aim of this research, as previously mentioned, is both to understand and support the use of sketching in design. Therefore, DRM was considered as an appropriate methodology for this research and was adapted to take the lead for framing the overall study design. Specifically, the design of the methodology in this study was not only based on DRM, but also with specific references to Rummel and Blaine’s (1963) methodology (for the formulation
of research hypotheses) and the research framework proposed by Eckert et al. (2003) (for iterative evaluation). In addition, Robson's framework (2011) was employed to help select methods during each stage of the research. The proposed research methodology in this study consisted of three stages, i.e. ‘development of hypotheses’, ‘descriptive studies’, and ‘prescriptive studies and evaluation’.

![Figure 3-2 Research methodology](image)

### 3.2.1 Development of hypotheses

The aim of this study was to identify and understand the roles sketching plays in supporting creative design work and to develop the means to enhance designers’ creative performance. For this research, it was difficult to start with any measurable criteria. Thus, following the methodology proposed by Rummel and Ballaine (1963), a number of hypotheses were developed to facilitate logical study design and also provide a focus for the exploratory process. A study into understanding the criteria and their relationships with the research problems was carried out. Once sufficient understanding had been gained, testable hypotheses were developed and then tested accordingly. The literature review and analysis led to the formulation of five hypotheses, and the justification of each hypothesis was based on studies on roles, application, classification, mechanism and supporting methods of design sketching (Section 2.2-2.7), as well as research findings from comparable fields such as architectural design and graphic design. The initial hypotheses and their corresponding justifications are listed as follow.

**Hypothesis 1:** There is a need to get a better understanding of the roles of sketching in the product design field.

**Justification:** Sketching is believed to play essential roles in the design process, however, the attempts to identify and understand these roles is something that has only recently raised attention from design researchers (Cross, 2006; Bouchard, Duchamp and Bouchard, 2013; Hua, 2019). Despite the growing body of literature in the field, the roles of design sketching are still not fully understood. For example,
Suwa and Tversky (2002) pointed out that little research has been done to empirically examine how designers cognitively interact with their own sketches. Min et al. (2018) identified that non-working sketches have not been carefully studied yet. In addition, the reviewed bodies of literature (Chapter 2) are somewhat scattered and disconnected from each other. The lack of integration of the research in the field was identified as a barrier to gain a comprehensive understanding of sketching in design.

**Hypothesis 2:** The perception of design sketching may be different for designers with different expertise.

**Justification:** As discussed in Chapter 2, numerous studies (Goldschmidt, 1991; I. Verstijnen et al., 1998; Casakin and Goldschmidt, 1999; Kavakli and Gero, 2001) have suggested that the ability to cognitively interact with sketches may vary from design students to professional designers. In addition, some studies (Suwa and Tversky, 1997; I. M. Verstijnen et al., 1998; Yang and Cham, 2007; Corremans, Corremans and Coppens, 2017; Corremans, Vaes and Coppens, 2018) also indicated that sketching expertise may play a role in supporting the design process. These findings imply that different levels of sketching expertise and experience may influence the use and perception of design sketching. Design students and professionals can have a different understanding of the roles of sketching in design.

**Hypothesis 3:** Understanding the cognitive interplay between sketching and design ideation process may be of use to both design academics and practitioners.

**Justification:** The empirical studies focusing on design sketching carried out in the field of industrial design, engineering design and architectural design all show concern about the cognitive mechanism of design sketching (Goldschmidt, 1991; Goel, 1995; Suwa and Tversky, 1997; Cross, 1999; Bilda and Demirkan, 2003; Sun, Xiang, Yang, et al., 2014; Schön, 2017; Bao, Faas and Yang, 2018). This suggests that exploring how designers cognitively interact with their sketches may be of use to design researchers. Numerous sketching tools were generated, based on the findings captured through researches, which may be of use to design academics and practitioners.

**Hypothesis 4:** External stimuli and sketching instruction can be helpful in supporting the design sketching process.

**Justification:** Designers commonly use external stimuli to support design ideation processes. Numerous studies have indicated that the adoption of external stimuli may serve as important triggers for idea generation (e.g. Benami and Jin, 2002; Goldschmidt and Litan Sever, 2009; Guo and McLeod, 2014; Bacciotti, Borgianni and Rotini, 2016; Borgianni, Rotini and Tomassini, 2017; Hua et al., 2019). In addition, sketching ability was proved to be associated with design creativity (Shah et al., 2001; Bouchard, Aoussat and Duchamp, 2006; Tedjosaputro et al., 2018). As a learned skill, designers need to be trained under proper instruction to develop their sketching ability. Therefore, the adoption of external stimuli and sketching instruction can be two effective methods for supporting the design sketching process.
Hypothesis 5: Effective support of design sketching is critically dependent on the presentation of supporting materials.

Justification: Many supporting software and books for teaching sketching are available, but the perceived effectiveness of the use of sketching in practical design work varies greatly among different designers. This raises the question of whether the supporting materials have been effectively delivered to designers. Pei (2009) propose a classification system for design sketches and a set of taxonomy cards were developed to enhance the collaboration between industrial designers and engineering designers. This suggests that the ineffective use of design sketching was due to a lack of appropriate supporting tools, and the form of tools should be developed in sympathy with the culture of a specific design field (Dong, 2004).

Hypothesis 1 set a basic postulate for the study. Hypothesis 1, 2 and 3 are closely related to the first research aim, i.e. to identify the major roles and the mechanism that sketching in supporting creative design work. Hypothesis 2 was developed based on the findings from the literature study that the levels of sketching expertise and experience may influence the perception and the use of sketching in design. It was an important supplement as which would bring us insights for developing a versatile tool for both design students and professionals. Hypothesis 4 and 5 were developed following the second research aim, i.e. to develop a practical supporting tool for product designers to enhance their sketching process and design performance. Hypothesis 4 was developed based upon designers’ top favourable influences identified from the literature. It is about the use of visual stimuli and sketching instruction, which is believed to be important for enhancing designers’ creative performance. Hypothesis 5 makes assumptions of the content and format of a practical supporting tool for creative design work through sketching. These five hypotheses were tested and verified throughout the research project.

3.2.2 Descriptive studies

As the roles of sketching in design were not well understood at the beginning of this research project, it was decided to dedicate a significant amount of time to exploratory studies during the descriptive stage. The descriptive stage consisted of three studies: 1) a pilot study on the roles of sketching in supporting creative design thinking; 2) a survey on the perception of sketching with design students; 3) a survey on the perception of sketching with design professionals. The following paragraphs give a brief introduction to each study, a summary of the results from the 3 descriptive studies, and a summary of the characteristics of the descriptive studies. The method and result of each descriptive study are discussed further in Chapter 4, 5 and 6.

Pilot study

The pilot study, which is reported in Chapter 4, aimed to identify the roles of sketching in supporting individual creative performance in design work. The research methods consist of think-aloud experiments and follow-up interviews were employed, which
were suitable for examining the cognitive process of the human being (Ericsson and Simon, 1984). A group of 6 design students were invited to participate in the study. All of them were asked to think out loud while they are working on a design task for 50 minutes. Their sketching activities were videotaped. Standard research ethics and data protocols were considered and followed. After the design task, they were required to report what they have been thinking of while drawing each stroke of their sketches. Finally, the creative design episodes (refer to Section 4.3.10) were segmented and encoded, and the data was analyzed. Findings gained from the pilot study were related to the findings from the literature reviewed.

Survey of design students

The survey of design students (79 in total) is presented in Chapter 5, which aimed to identify and understand the roles of sketching perceived by design students in supporting the design ideation process. According to Robson (2011), surveys work best with standardised questions which can be clearly perceived by different respondents. Therefore, a questionnaire was initially designed for the survey with design students. Both qualitative data and qualitative data were collected through the use of rating scales and comments. Students from both industrial design background and engineering design background were involved in this survey and their understanding of the roles of sketching in design was compared. The findings were related to the findings from the pilot study and the literature reviewed.

Survey on design professionals

The survey of professionals (51 in total, from both design and other related fields) is presented in Chapter 6, which is a complementary study to the survey of design students and aimed to explore the roles of sketching perceived by design professionals in supporting design ideation process. An adjusted questionnaire was designed for this survey to make it more relevant to professional designers. Both qualitative data and qualitative data were collected and analyzed using the same methods as the previous survey. The perceptions of design professionals regarding the roles of sketching in design were compared to those of design students and professionals from other fields. The findings were related to the findings from the pilot study and the literature reviewed.

Results of descriptive studies

The pilot study and the two surveys revealed that there was a lack of good understanding of design sketching in the industrial design field. The types of sketches used in today’s design context have changed and the existing sketching taxonomies feature a lack of both integrity and accuracy (Hua et al., 2018). 79 design students and 51 professional designers were involved in the two surveys respectively. According to the results, design students and professionals tended to have different opinions on the roles of sketching in design, i.e. they share different opinions on the importance of sketching ability to designers. This implies the importance of sketching instruction for novice designers. In addition, both design students and professionals
were found to rely heavily on pictorial stimuli. These findings highlighted the lack of appropriate supporting tools for design sketching and led to the identification of two important ways to enhance the roles of sketching in design, i.e. 'sketching instruction' and 'external stimuli'. Through interviews and surveys, the five hypotheses were tested and verified, and the requirements regarding a practical supporting tool for design sketching were generated.

**Summary: characteristics of the descriptive studies**

A brief summary of the characteristics of the three descriptive studies is presented in Table 3.1:

<table>
<thead>
<tr>
<th></th>
<th>Study 1: Pilot study with design students</th>
<th>Study 2: Survey of design students</th>
<th>Study 3: Survey of design professionals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of research</td>
<td>Qualitative</td>
<td>Qualitative and quantitative</td>
<td>Qualitative and quantitative</td>
</tr>
<tr>
<td>Data collection</td>
<td>Think aloud experiment and follow-up interview</td>
<td>Online questionnaire (closed questions with rating scales and open questions for comments)</td>
<td>Online questionnaire (closed questions with rating scales and open questions for comments)</td>
</tr>
<tr>
<td>Participants</td>
<td>6</td>
<td>79</td>
<td>51</td>
</tr>
<tr>
<td>Data analysis</td>
<td>Qualitative analysis</td>
<td>Qualitative analysis and statistical analysis</td>
<td>Qualitative analysis and statistical analysis</td>
</tr>
<tr>
<td>methods</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3.2.3 Prescriptive studies and evaluation

Based on the requirements captured from the descriptive studies, the means of enhancing the use of sketching in the design process was developed, i.e. the **PD-Sketching Primer** and the **PD-Sketching Toolkit**. The **PD-Sketching Primer** is an awareness-raising tool developed in a form of a booklet; the **PD-Sketching Toolkit** is a toolkit developed to further address the understanding problem and providing external stimuli and sketching instruction (refer to Section 7.4 and 7.5). The development of the **PD-Sketching Primer** and the **PD-Sketching Toolkit** comprised three steps:
1. The exploration of methods to enhance the supporting roles of sketching, which was based on Hypothesis 4: *External stimuli and sketching instruction can be helpful in supporting the design sketching process*;

2. The development of the PD-Sketching Primer (refer to Section 7.3), which was based on Hypothesis 1: *There is a need to get a better understanding of the roles of sketching in the design field*.

3. The development of the PD-Sketching Toolkit, which incorporated the feedback on the PD-Sketching Primer booklet and aims to provide a practical supporting tool for design sketching.

Each step provided input to the next step, i.e. extracted data for design sketching were included in the PD-Sketching Primer booklet, and the booklet was included in the PD-Sketching Toolkit. Accordingly, the feedback on the PD-Sketching Primer informed the development of the PD-Sketching Toolkit. The development of practical supporting tools followed a systematic engineering design process, featuring conceptualization, embodiment, and detailing (Pahl and Beitz, 2013).

The Kirkpatrick Model (Donald, James and Wendy, 2016) and Design Ideation Metrics (Shah, Smith and Vargas-Hernandez, 2003) were used to evaluate the PD-Sketching Primer and PD-Sketching Toolkit. The Kirkpatrick Model is a widely used framework for evaluating new methods, tools and training programmes. It was used for the overall evaluation of the sketching supporting tools (details see Table 3.2), and data was collected in respect of reaction, learning, behaviour and validation, as follows.

- **Reaction:** how did the participants like the PD-Sketching Primer and PD-Sketching Toolkit;
- **Learning:** what did the participants learn from the PD-Sketching Primer and PD-Sketching Toolkit;
- **Behaviour:** what changes in participants' design performance resulted from learning the PD-Sketching Primer and PD-Sketching Toolkit;
- **Validation:** the fulfilment of the aims of the PD-Sketching Primer and PD-Sketching Toolkit.
### Table 3.2 Characteristics of evaluation

<table>
<thead>
<tr>
<th></th>
<th>Evaluation of the PD-Sketching Primer</th>
<th>Evaluation of the PD-Sketching Toolkit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data collection methods</td>
<td>Questionnaire and interview</td>
<td>Controlled experiment, online/offline comments, conference presentation, observation and interview</td>
</tr>
<tr>
<td>Participants</td>
<td>24 (preliminary evaluation)</td>
<td>19 (preliminary evaluation)</td>
</tr>
<tr>
<td></td>
<td>13 (formal evaluation)</td>
<td>12 (formal evaluation i)</td>
</tr>
<tr>
<td></td>
<td>13 (formal evaluation)</td>
<td>36 (formal evaluation ii)</td>
</tr>
<tr>
<td>Data analysis methods</td>
<td>Qualitative analysis and statistical analysis</td>
<td>Qualitative analysis and statistical analysis</td>
</tr>
</tbody>
</table>

### 3.3. Summary

This section has described the methodology adopted for the research, which was primarily based on the framework of DRM (Blessing, Chakrabarti and Wallace, 1995; Blessing and Chakrabarti, 2009), with references to a number of other research methodologies (Rummel and Ballaine, 1963; Eckert, Stacey and Clarkson, 2003; Robson, 2011). Table 2 summarises the methodology according to its research phases and purposes, specific studies carried out and expected results.
<table>
<thead>
<tr>
<th>Research phase and general-purpose</th>
<th>Studies and key methods</th>
<th>Expected results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Development of hypotheses</strong></td>
<td>Literature review and analysis</td>
<td>Five research hypotheses formulated (refer to Section 3.2.1)</td>
</tr>
<tr>
<td>-to focus the study</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Descriptive studies</strong></td>
<td>• Pilot study (think-aloud experiment and follow-up interview)</td>
<td>• The main roles of design sketching were identified</td>
</tr>
<tr>
<td>-to identify and understand the roles of sketching</td>
<td>• Survey on design students (questionnaire)</td>
<td>• Main requirements were identified for the practical supporting tool</td>
</tr>
<tr>
<td></td>
<td>• Survey on design professionals (questionnaire)</td>
<td>• Research hypotheses tested and supporting evidence obtained</td>
</tr>
<tr>
<td><strong>Prescriptive studies and evaluation</strong></td>
<td>• Development of supporting tool: <em>PD-Sketching Primer</em> and <em>PD-Sketching Toolkit</em></td>
<td>• Feedback on the supporting tool was collected</td>
</tr>
<tr>
<td>-to develop a practical supporting tool for enhancing design creativity through sketching</td>
<td>• Evaluation of the supporting tool (questionnaire, interview, observation and experiment)</td>
<td>• Further evidence to support the research hypotheses were obtained</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Future work identified</td>
</tr>
</tbody>
</table>
Chapter Four: Identifying the Roles of Sketching in Product Design: A Pilot Study

4.1. Introduction

This chapter describes the findings that emerged from the pilot study. The pilot study was conducted to identify the roles of sketching in supporting the design process. Some of the hypotheses generated in Chapter 3 were tested and verified through the pilot study. The research objectives of the pilot study were to:

- develop a better understanding of sketching in today’s design context, e.g. identify the types of sketches used and their roles in design
- identify important issues related to design sketching, e.g. the cognitive interplay between design sketching and design ideation
- collect data to test and verify the research hypotheses
- determine the direction of further studies

The research methods consisted of think-aloud experiments and follow-up interviews, which were suitable for examining the cognitive process of the human being (Ericsson and Simon, 1984). A group of five design students were invited to participate in the study. All of them were asked to think out loud while they are working on a toy design task for 45 minutes. This design challenge was part of the curriculum. Their sketching activities were videotaped. After the design task, a follow-up interview was carried out to further collect the data. Each interview was recorded and transcribed. Finally, the creative design episodes were segmented and encoded, and the data was analyzed. The findings that emerged from the pilot study were related to those from the literature study.

4.2. Setting-up of the experiment

4.2.1. Participants

The experiment was carried out following a toy design workshop at the Zhejiang Normal University. In total, 33 third-year students with design background attended the workshop and they were divided into five groups. A two-day study was undertaken during the workshop and subjects were selected from each of the five groups. They were the students who were responsible for sketching in the group. The task and
procedure were informed with the subjects before the experiment. These subjects vary in terms of sketching experience, from three years to six years, please refer to Table 4.1.

Table 4.1 Profile of the participants

<table>
<thead>
<tr>
<th>ID code</th>
<th>Background</th>
<th>Years of sketching experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student A</td>
<td>Industrial design</td>
<td>3</td>
</tr>
<tr>
<td>Student B</td>
<td>Industrial design</td>
<td>3</td>
</tr>
<tr>
<td>Student C</td>
<td>Industrial design</td>
<td>6</td>
</tr>
<tr>
<td>Student D</td>
<td>Industrial design</td>
<td>3</td>
</tr>
<tr>
<td>Student E</td>
<td>Engineering design</td>
<td>4</td>
</tr>
</tbody>
</table>

4.2.2. Task and procedure

The task set was to design a toy that may help in stimulating children’s creativity. The description was simple, the desired toy designs would be able to serve as open-ended tools, which could spark kids’ imagination and inspire them to create, including stories, drawings, songs, strategies, methods to play, and more.

The participants were asked to join the design session one at a time in a quiet room without any interruptions, as one can be influenced by others in the group (Perttula and Sipilä, 2007). Each participant was given a brief introduction and 10 min before the experiment started to get familiar with the sketching tools and requirements of the think-aloud experiment. Then, the participants were asked to sketch and work on the assigned design task lasted for 45 min. The duration was long enough for participants to design for the task and finish the sketching (Christensen, 2010; Chan et al., 2011). After the design task, a follow-up interview was carried out to further explore the participants’ perceptions on a number of the major issues related to design sketching. Interviews lasted between 8 to 29 minutes with an average of 15, as some of the interviewees were more articulate than others.

4.2.3. Method of data collection

The empirical study utilized a qualitative research methodology, incorporating think-aloud protocols, sketch observation and follow-up interviews of participants during a product design workshop. The think-aloud method was adopted aiming to reveal how designers interact with their sketches to facilitate the design process. However, as Branch (2000) points out, “behind the decisions that were made were often explained in the Think After”. Therefore, the follow-up interview method was adopted to further explore why the participants used sketching in the exact way they do. Observations were used to obtain detailed information by being close to the field.
of study. The five participants were asked to work on the task for 45 min while sketching on paper. All sessions were recorded on two video cameras. One camera captured the general movements and gestures of the participants while the other focused on the paper to record the participants’ sketching process (Figure 4-1 and Figure 4-2). Standard ethical protocols were adopted for the study.

![Figure 4-1. Recording approach used during the observation process](image1)

![Figure 4-2. Participant in the experiment and examples of the sketches](image2)

After the sketching process, individual interviews were conducted with the participants. The interviews comprised open-ended questions that allowed respondents to fully describe their personal experiences relating to a number of important issues about design sketching, e.g. the influence of sketching on design ideation, the supporting roles of sketching skills in design and strategies they employed for selecting types of sketches. A number of questions were generated according to each topic of interest so that to provide a common reference for the interview (Appendix A). The general interview topics are listed below.
• General understanding of design sketching
• The importance of sketching and sketching expertise in design
• The influence of sketching on design ideation
• The students’ preferences about sketching
• The use of non-working sketches

These topics were used as a guide for organising the interviews but were not rigidly constrained to the sequence of contents presented in the guidelines (Appendix A). This was reported can be helpful for creating a relaxed atmosphere that would encourage informative responses (Dong, 2004). Each interview was audio-taped with approval and notes were taken throughout the sessions.

4.2.4. Method of analysis

The data in the form of sketches, video records of the sketching process and the audio records of the follow-up interview were collected for analysis. To aid analysis, some data were presented to the participants in follow-up interviews. Transcripts of the session were summarized according to each participant in a spreadsheet, which was double-checked by the author and his co-researchers independently so that to ensure the accuracy of the transcription. The research materials, as recorded in the think-aloud experiments and interviews, were collected as data and analyzed with the coding and clustering method. Transcriptions were coded with short words or phrases and then data labelled with the same code grouped into clusters. For example, all data labelled with ‘non-working’ were grouped. Since the pilot was an exploratory study aiming to identify the basic issues on the topic and form the framework for future study, no pre-existing coding scheme was adopted. The coding was developed according to the author’s subjective judgement on the importance of the data and the relevance to the topics of interest. For example, the objective recurrence of the data was taken into consideration as high frequency of mentions in the form of self-report, comments and answers to the questions can be viewed as a measure of importance.

4.3. Results and findings

This section presents the results and findings from the pilot study. In total, five participants were involved in the experiment and the follow-up interview. The findings are briefly presented according to each participant (Section 4.3.1- 4.3.5) and then according to the six main topics (Section 4.3.6- 4.3.11) covered in the study.
### 4.3.1. Student A

**Table 4.2 Main points of Student A**

| Awareness | • Sketching should be used at the early and late stage of the design process, mainly for recording design ideas and convey them to colleagues and clients  
• For the very early stages, she preferred text-based tools to freehand sketching  
• Sketching skills, especially a good control of lines & structure, are very important for supporting fluent design thinking and its expression. It even gives me a sense of accomplishment when the audience could understand my concept |
| General functions | • Use sketching to express her thoughts  
• Use sketching to ‘sell’ designs to the clients  
• Use sketching to “find the details” |
| Creative functions | • She was taught to use existing design examples as references, mainly for expanding thoughts and appearance design  
• Sketching skills could influence the state of design ideation. She felt worried in the design process when she was a novice sketcher, but later she became more confident and even got a “sense of achievement” during the process due to her improvement in sketching skills.  
• Quick sketching skill is very important as it helps the ideation process more fluent and recording of fleeting ideas  
• Her own sketches could bring her unexpected outcomes or features which might inspire her to generate new ideas, but this does not happen very often  
• Sketching helps her to create the design details step by step through the sketching process |
| Types of sketches used | • Defining sketch, memory sketch, idea sketch, coded sketch, explanatory sketch and instruction sketch |
| Supporting tools | • Thinking tools were found to be useful  
• Image search platforms |
| References | • The knowledge gain from the internet  
• Design examples found from the internet  
• Related objects found in daily life |
| Sketching habits | • Heavy use of thinking tools and annotations  
• Search for images and examples on the internet  
• Keep images, examples and sketches for future use |
| Design process | • Briefing – analysis – start sketching – concept generation – inspiration from memory – concept development – concept presentation |
## 4.3.2. Student B

**Table 4.3 Main points of Student B**

| Awareness | • Sketching is about “finding possible solutions” and appearance and detail design  
• Sketching skills are believed to have a great influence on design and students who “have good sketching skills are always admired by others in my class”  
• “Good sketching offers an advantage over your competitors because it is a powerful tool for design presentation” |
| --- | --- |
| General functions | • Use sketching to clarify the design task  
• Use sketching to record design-related materials for future reference |
| Creative functions | • She likes to use ‘doodles’ for multiple purposes, e.g. inspiring sensibilities, arousing association of ideas and breaking through fixation  
• Sketching facilitate the reflective thinking process |
| Types of sketches used | • Playing sketch, idea sketch, development sketch, storing sketch, practising sketch and storyboard sketch |
| Supporting tools | • Image search platforms  
• Search engines (e.g. Google and Baidu)  
• Sketching classes or training sessions could be quite useful, especially for beginners  
• Books |
| References | • Images found from websites like Behance and Pinterest  
• Her sketch notebook  
• Related knowledge  
• Living creatures like animals |
| Sketching habits | • She usually starts sketching with ‘doodling’ randomly on the paper  
• She usually copies good sketches to improve her sketching skills |
| Design process | • Briefing – start sketching – inventing associations – concept generation – inspiration from memory – concept development – evaluation and iteration – concept presentation |
### 4.3.3. Student C

**Table 4.4 Main points of Student C**

<table>
<thead>
<tr>
<th>Awareness</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Sketching is a “visual tool” for designers, it is most useful for</td>
<td>solving design problems related to appearance and details</td>
</tr>
<tr>
<td>• Sketching could help to “find the temperament” for a product,</td>
<td>for example, I use soft and smooth lines while sketching</td>
</tr>
<tr>
<td>• The quality of design presentation, including sketches, may influence</td>
<td>people’s judgement on the design</td>
</tr>
<tr>
<td>• She thinks sketching skills have little influence on her design</td>
<td></td>
</tr>
<tr>
<td><strong>General functions</strong></td>
<td></td>
</tr>
<tr>
<td>• Use sketching to clarify the design task</td>
<td></td>
</tr>
<tr>
<td>• Use sketching to explore the appearance and design details</td>
<td></td>
</tr>
<tr>
<td>• Use sketching to support design communication and further improvement</td>
<td>before 3D modelling</td>
</tr>
<tr>
<td>• Use sketching to facilitate comparison between design alternatives</td>
<td></td>
</tr>
<tr>
<td>• Use sketching to stimulate design interest</td>
<td></td>
</tr>
<tr>
<td>• Use sketching to organise the design process</td>
<td></td>
</tr>
<tr>
<td><strong>Creative functions</strong></td>
<td></td>
</tr>
<tr>
<td>• Use various types of visual stimuli (e.g. cartoon images, sketch</td>
<td>and design examples, and videos) as inspirations</td>
</tr>
<tr>
<td>• Receive feedback from colleagues based on the sketches,</td>
<td>which sometimes can be inspiring</td>
</tr>
<tr>
<td><strong>Types of sketches used</strong></td>
<td></td>
</tr>
<tr>
<td>• Defining sketch, idea sketch, development sketch, explanatory sketch,</td>
<td>detail sketch, storing sketch and playing sketch</td>
</tr>
<tr>
<td><strong>Supporting tools</strong></td>
<td></td>
</tr>
<tr>
<td>• Image search platform (e.g. Pinterest, Baidu Image and Hua Ban)</td>
<td></td>
</tr>
<tr>
<td>• Image and video APPs</td>
<td></td>
</tr>
<tr>
<td>• Mind maps</td>
<td></td>
</tr>
<tr>
<td>• Her sketch notebook</td>
<td></td>
</tr>
<tr>
<td><strong>References</strong></td>
<td></td>
</tr>
<tr>
<td>• Images searched online</td>
<td></td>
</tr>
<tr>
<td>• Videos found on Hitnology</td>
<td></td>
</tr>
<tr>
<td>• Her storing sketches</td>
<td></td>
</tr>
<tr>
<td>• Marine animals</td>
<td></td>
</tr>
<tr>
<td>• Text-based information</td>
<td></td>
</tr>
<tr>
<td><strong>Sketching habits</strong></td>
<td></td>
</tr>
<tr>
<td>• Search visual stimuli (i.e. images and videos) online as inspiration</td>
<td>through the whole sketching process</td>
</tr>
<tr>
<td><strong>Design process</strong></td>
<td></td>
</tr>
<tr>
<td>• Briefing and analysis - concept generation - search images</td>
<td></td>
</tr>
<tr>
<td>• start sketching - search videos - concept generation - 3D modelling</td>
<td></td>
</tr>
<tr>
<td>• determine the design scheme</td>
<td></td>
</tr>
</tbody>
</table>
### 4.3.4. Student D

#### Table 4.5 Main points of Student D

| Awareness | - The concept can be fuzzy at the early stage of the design ideation process, but sketching can help to show these concepts visually  
  - Sketching is a personalized way of expression, it reflects your style and taste which is of great value for a designer  
  - Sketching skills are very important which gives her incentives (e.g. sense of self-satisfaction) to design and to communicate with others |
|---|---|
| General functions | - Use sketching to visualise design concepts  
  - Use sketching to evaluate the design alternatives  
  - Use sketching to convey the aesthetic feeling  
  - Use sketching to facilitate design communication |
| Creative functions | - She likes to work on the design task generating ideas and sketching on paper  
  - She was inspired by some elements recalled from memory, i.e. two videos, a story and two computer games  
  - When she is stuck during the ideation process, she stops and starts to draw something else she like, even if the sketches are not relevant to the task, can be helpful for breaking through the design fixation  
  - Sketching is essential for recording the fleeting ideas |
| Types of sketches used | - Warming-up sketch, defining sketch, idea sketch, development sketch, playing sketch, practicing sketch and fabulous sketch |
| Supporting tools | - Thinking tools, e.g. mind map  
  - Digital sketching tools, e.g. graphics tablet  
  - Sketching tools may influence her sketching state |
| References | - Visual stimuli, e.g. videos and images  
  - Stories  
  - Music |
| Sketching habits | - Use a warm-up sketch before the design process  
  - Listen to the music while sketching  
  - Drawing something randomly when getting stuck with the idea generation |
| Design process | - Warm-up sketching – define & clarify the design task – concept generation – inspiration from memory – concept development – concept presentation |
# 4.3.5. Student E

<table>
<thead>
<tr>
<th>Table 4.6 Main points of Student E</th>
</tr>
</thead>
</table>
| **Awareness**                     | • Design sketching *“should be simple and quick”*
|                                   | • The importance of sketching skills may vary due to different context of use, for example, it is essential for making quick records but not very important for design communication as long as the involved parties could understand the design concept |
| **General functions**             | • Use sketching to clarify the design task
|                                   | • Use sketching to explore the appearance design
|                                   | • Use sketching to visualize design concepts |
| **Creative functions**            | • Sketching different things during the design process to shift focus or change the direction of thinking, which are believed to be beneficial for idea generation
|                                   | • Use various types of visual materials as inspirations
|                                   | • Sketching supports reflective thinking |
| **Types of sketches used**        | • Idea sketch, development sketch, explanatory sketch, detail sketch, practicing sketch and presentation sketch |
| **Supporting tools**              | • School classes
|                                   | • Image search platforms
|                                   | • Search engine
|                                   | • Personal database |
| **References**                   | • Visual materials (e.g. videos, images, computer games, and sketch and design examples)
|                                   | • Related knowledge
|                                   | • Physical product at hand |
| **Sketching habits**             | • A frequent change of sketching subjects during the design process
|                                   | • She likes to sketch at the night
|                                   | • Listen to music or even TV play while sketching |
| **Design process**               | • Briefing and analysis – concept generation – inspiration from memory – concept development and refinement – implementation |
4.3.6. Basic awareness of design sketching

From this section, the findings will be presented according to the five topics covered in the pilot study. The findings are tabulated and presented in Tables 4.7 - 4.17. The left column in the tables presents a summary of relevant comments or observations, and the right column uses a quantitative measure to show the frequency of occurrence. Regardless of the number of occurrence of any contributing factor identified in the pilot study, it was only counted once. There were five participants involved in the study, and therefore, the maximum number of possible frequency is five.

The findings on basic awareness of design sketching (Table 4.7) are derived from the data in the cluster entitled ‘Awareness’ (Table 4.2 – 4.6). The top three mentioned ‘awareness’ are related to sketching skills, idea generation and communication. It was found that four out of five participants believed that the use of sketching can strongly influence their idea generation process. Only one participant thinks differently and said: “I just draw what comes to my mind and not sure whether sketching could be viewed as a driver.” Four participants gave positive comments on design sketching, among which three of them thought sketching skills are important for designers and may have a strong influence on design, while the other one thought the importance of sketching may vary (e.g. sketching skills is essential for recording ideas but not very important for design communication). There are also four participants who thought sketching is useful for explaining design concepts, among which two participants suggested communicating ideas through sketching gives them a sense of accomplishment and satisfaction.
Table 4.7 Identified awareness of design sketching

<table>
<thead>
<tr>
<th>Awareness</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sketching is useful for supporting idea generation</td>
<td>4</td>
</tr>
<tr>
<td>Sketching skills is believed to have a strong influence on the design</td>
<td>4</td>
</tr>
<tr>
<td>Sketching is useful for explaining design concepts to others</td>
<td>4</td>
</tr>
<tr>
<td>Sketching is an effective way to make quick records of ideas</td>
<td>3</td>
</tr>
<tr>
<td>Sketching is an effective way to make a design presentation</td>
<td>3</td>
</tr>
<tr>
<td>Sketching is motivating for designers (e.g. sense of accomplishment and satisfaction)</td>
<td>3</td>
</tr>
<tr>
<td>Sketching is a visual tool for the designer to visualize their concepts</td>
<td>2</td>
</tr>
<tr>
<td>Sketching is full of fun which makes me happy</td>
<td>2</td>
</tr>
<tr>
<td>Sketching is useful for appearance and detail design</td>
<td>2</td>
</tr>
<tr>
<td>Sketching is used in the early and late design stage</td>
<td>2</td>
</tr>
<tr>
<td>Sketching is useful for supporting fluent design think</td>
<td>1</td>
</tr>
<tr>
<td>Sketching is about “finding possible solutions”</td>
<td>1</td>
</tr>
<tr>
<td>Sketching is a personalized way of expression that reflects your style and taste</td>
<td>1</td>
</tr>
<tr>
<td>Sketching is a way to “find the temperament” for a product</td>
<td>1</td>
</tr>
</tbody>
</table>

4.3.7. The supporting roles of sketching in design

This section presents the results of the identified supporting roles of sketching in design (Table 4.8) derived from the data in the cluster of ‘General functions’ and ‘Creative functions’ (Table 4.2 – 4.6). In addition, Section 4.3.6 presents the findings on the basic awareness about sketching which aims to answer several basic questions about the perceptions of sketching, e.g., “what is design sketching?”, “what is design sketching about?” and “what are some characteristics of the desired design sketching?” This was naturally related to functions of sketching in design for some participants (e.g., Student A and C). Inevitably there is an overlap between these two sections, but no conflict was found. The section incorporates the related data presented in Section 4.3.6 as a complementary data source. The most frequently mentioned functions were all related to design ideation, i.e. four participants thought sketching was useful in “supporting idea generation” and “recording the fleeting ideas”. There were also three participants who thought sketching could help “breaking through design fixation”. Other important functions (mentioned three times) of sketching in design includes “clarify design task”, “support appearance and detail design” and “support design communication with colleagues”.

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Table 4.8 Identified functions of design sketching

<table>
<thead>
<tr>
<th>Functions</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use sketching to record the fleeting ideas</td>
<td>4</td>
</tr>
<tr>
<td>Use sketching to support idea generation</td>
<td>4</td>
</tr>
<tr>
<td>Use sketching to define and clarify the design task</td>
<td>3</td>
</tr>
<tr>
<td>Use sketching to breakthrough design fixation</td>
<td>3</td>
</tr>
<tr>
<td>Use sketching to support the appearance design</td>
<td>3</td>
</tr>
<tr>
<td>Use sketching to support detail design</td>
<td>3</td>
</tr>
<tr>
<td>Use sketching to support design communication with colleagues</td>
<td>3</td>
</tr>
<tr>
<td>Use sketching to visualise design concepts</td>
<td>2</td>
</tr>
<tr>
<td>Use sketching to get designers motivated for design</td>
<td>2</td>
</tr>
<tr>
<td>Use sketching to facilitate the reflective thinking process</td>
<td>2</td>
</tr>
<tr>
<td>Use sketching to support fluent design and thinking process</td>
<td>2</td>
</tr>
<tr>
<td>Use sketching to activate related memory and experience</td>
<td>2</td>
</tr>
<tr>
<td>Use sketching to support design evaluation</td>
<td>2</td>
</tr>
<tr>
<td>Use sketching to record design-related materials for future reference</td>
<td>1</td>
</tr>
<tr>
<td>Use sketching to support design presentation</td>
<td>1</td>
</tr>
<tr>
<td>Use sketching to generate unexpected outcomes/features as inspiration</td>
<td>1</td>
</tr>
<tr>
<td>Use sketching to express designers’ thoughts</td>
<td>1</td>
</tr>
<tr>
<td>Use sketching to support the design development process</td>
<td>1</td>
</tr>
<tr>
<td>Use sketching to expand designers’ thoughts</td>
<td>1</td>
</tr>
<tr>
<td>Use sketching to organise the design process</td>
<td>1</td>
</tr>
<tr>
<td>Use sketching to convey the aesthetic feeling</td>
<td>1</td>
</tr>
</tbody>
</table>

4.3.8. Influences of design sketching

The analysis of ‘influences of design sketching’ is mainly based on the data selected from the cluster entitled ‘Supporting tools’, ‘References’ and ‘Habits’ (Table 4.2 – 4.6). In addition, it also incorporates the data relating to ‘Awareness’ and ‘Functions’. A number of supporting factors were identified, including:

- Vision-related influences (Table 4.9)
- Sound-related influences (Table 4.10)
- Internal influences (Table 4.11)
- Contents of the influences (Table 4.12)
- Formats of supporting tools (Table 4.13)
- Approaches to learning (Table 4.14)
- Other identified influences (Table 4.15)

### Table 4.9 Vision-related influences

<table>
<thead>
<tr>
<th>Summary of findings</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Images</td>
<td>5</td>
</tr>
<tr>
<td>Sketches</td>
<td>4</td>
</tr>
<tr>
<td>Videos</td>
<td>4</td>
</tr>
<tr>
<td>Computer games</td>
<td>2</td>
</tr>
<tr>
<td>Texts</td>
<td>2</td>
</tr>
<tr>
<td>Music</td>
<td>2</td>
</tr>
<tr>
<td>Doodles</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 4.10 Sound-related influences

<table>
<thead>
<tr>
<th>Summary of findings</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Music</td>
<td>2</td>
</tr>
<tr>
<td>Randomly played background sound</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 4.11 Internal influences

<table>
<thead>
<tr>
<th>Summary of findings</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sketching skills</td>
<td>4</td>
</tr>
<tr>
<td>Emotional factors</td>
<td>3</td>
</tr>
<tr>
<td>Understanding of design sketching</td>
<td>1</td>
</tr>
<tr>
<td>The ability to use sketching</td>
<td>1</td>
</tr>
<tr>
<td>Sketching experience</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 4.12 Contents of the influences

<table>
<thead>
<tr>
<th>Summary of findings</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design examples</td>
<td>5</td>
</tr>
<tr>
<td>Other related visual materials (e.g. design sketches)</td>
<td>4</td>
</tr>
<tr>
<td>Irrelevant visual materials (e.g. animals)</td>
<td>4</td>
</tr>
<tr>
<td>Related knowledge</td>
<td>3</td>
</tr>
<tr>
<td>Related information</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 4.13 *Identified types of supporting tools*

<table>
<thead>
<tr>
<th>Summary of findings</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image search platforms (e.g. Behance and Pinterest)</td>
<td>5</td>
</tr>
<tr>
<td>Thinking aids</td>
<td>3</td>
</tr>
<tr>
<td>Sketch notebooks</td>
<td>3</td>
</tr>
<tr>
<td>Search engines (e.g. Google and Baidu)</td>
<td>2</td>
</tr>
<tr>
<td>Books</td>
<td>1</td>
</tr>
<tr>
<td>Digital sketching tools (e.g. graphics tablet)</td>
<td>1</td>
</tr>
<tr>
<td>Mobile APPs</td>
<td>1</td>
</tr>
<tr>
<td>CAD/CAS systems</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.14 *Identified approaches to learning*

<table>
<thead>
<tr>
<th>Summary of findings</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning on the job</td>
<td>3</td>
</tr>
<tr>
<td>School classes</td>
<td>2</td>
</tr>
<tr>
<td>Self-taught</td>
<td>2</td>
</tr>
<tr>
<td>Training sessions</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.15 *Other identified influences*

<table>
<thead>
<tr>
<th>Summary of findings</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objects (e.g. product at hand)</td>
<td>2</td>
</tr>
<tr>
<td>Stories</td>
<td>1</td>
</tr>
</tbody>
</table>

Consequently, the major influences of design sketching according to the frequencies of mentions included:

- Vision-related influences (21 mentions in total)
- Contents of the influences (17 mentions in total)
- Supporting tools (14 mentions in total)

4.3.9. Development of a new design sketching taxonomy

This section presents the findings on design sketching taxonomy, which are derived from the data in the cluster of *‘Types of sketches used’* (Table 4.2 – 4.6). Ferguson’s taxonomy (1992) is widely accepted and has been instrumental in helping to characterize sketches. It was adapted as a framework for classifying and organising the identified types of sketches. The aim of the analysis was three-fold. Firstly, to
identify the major drawbacks that limit the effective implementation of existing sketching taxonomies in design; secondly, to identify the types of sketches that designers tend to use in today’s design context; and thirdly, to develop a new taxonomy for current design researchers and practitioners. In total, 12 problem categories were identified. By adopting a coding and clustering technique, the results were then condensed into a matrix based on recurrence and importance. These 12 problem categories can be further categorized into the following three distinct headings:

1. Problem Category A–Lack of hierarchical structure. Ferguson’s taxonomy has its limitations, as one type of sketch may serve multiple purposes at different stages in the design process. The revised taxonomy should sub-divide the original sketch category with a hierarchical structure to address this point.

2. Problem Category B–Out of date. Due to the impact of technological changes in the last 20 years, several types of sketches have been replaced by CAD software, including the prescriptive sketch identified by the original taxonomy.

3. Problem Category C–Lack of integrity. Due to overlooking the non-working sketch, the original taxonomy is incomplete and fails to involve several important types of sketches, such as fabulous, practising and playing sketches.

According to the video recordings and collected sketches, eleven types of sketches used in the design task were identified i.e. idea sketch, development sketch, explanatory sketch, playing sketch, defining sketch, detail sketch, instruction sketch, storyboard sketch, logbook sketch, coded sketch, and warming-up sketch. These types of sketches emerged from the many different ways that participants used sketching in the design process. Analysis of the results enabled confirmation of the preferences and choices of design students when they are sketching during a product development process. According to the analysis of the interview transcripts, another two types of sketches were identified which are normally used for facilitating the design commutation, namely presentation sketch and fabulous sketch. In addition, it also helped us to confirm the existence of three types of sketches found in the literature, namely practicing sketch, storing sketch and memory sketch.

In total, 16 different types of sketches were identified according to the findings from the literature study and pilot study (Table 4.16). The most frequently used types of sketches were related to design ideation, i.e., idea sketch for supporting idea generation (five times) and development sketch for supporting idea development (four times). Other four commonly used types of sketches occurred three times each, they were defining sketch (used to defined and clarify the design task), explanatory sketch (used to share and explain design concepts to other designers), practicing sketch (extensively produced by designers for improving their sketching skills) and playing sketch (enabling designers to play with sketches and ideas).

<table>
<thead>
<tr>
<th>Table 4.16 Types of sketches identified in the pilot study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of sketches</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Idea sketch</td>
</tr>
<tr>
<td>Development sketch</td>
</tr>
<tr>
<td>Explanatory sketch</td>
</tr>
<tr>
<td>Playing sketch</td>
</tr>
<tr>
<td>Defining sketch</td>
</tr>
<tr>
<td>Detail sketch</td>
</tr>
<tr>
<td>Instruction sketch</td>
</tr>
<tr>
<td>Storyboard sketch</td>
</tr>
<tr>
<td>Logbook sketch</td>
</tr>
<tr>
<td>Coded sketch</td>
</tr>
<tr>
<td>Warming-up sketch</td>
</tr>
</tbody>
</table>

64
<table>
<thead>
<tr>
<th>Sketch Type</th>
<th>Coding</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idea Sketch</td>
<td>LS, VS</td>
<td>5</td>
</tr>
<tr>
<td>Development Sketch</td>
<td>LS, VS</td>
<td>4</td>
</tr>
<tr>
<td>Explanatory Sketch</td>
<td>LS, VS</td>
<td>3</td>
</tr>
<tr>
<td>Practicing Sketch</td>
<td>LS, FI</td>
<td>3</td>
</tr>
<tr>
<td>Playing Sketch</td>
<td>VS</td>
<td>3</td>
</tr>
<tr>
<td>Defining Sketch</td>
<td>LS, VS</td>
<td>3</td>
</tr>
<tr>
<td>Detail Sketch</td>
<td>LS, VS</td>
<td>2</td>
</tr>
<tr>
<td>Storing Sketch</td>
<td>LS, FI</td>
<td>1</td>
</tr>
<tr>
<td>Instruction Sketch</td>
<td>LS, VS</td>
<td>1</td>
</tr>
<tr>
<td>Presentation Sketch</td>
<td>LS, FI</td>
<td>1</td>
</tr>
<tr>
<td>Fabulous Sketch</td>
<td>LS, FI</td>
<td>1</td>
</tr>
<tr>
<td>Storyboard Sketch</td>
<td>LS, VS</td>
<td>1</td>
</tr>
<tr>
<td>Coded Sketch</td>
<td>LS, VS</td>
<td>1</td>
</tr>
<tr>
<td>Memory Sketch</td>
<td>LS, FI</td>
<td>1</td>
</tr>
<tr>
<td>Warming-up Sketch</td>
<td>VS</td>
<td>1</td>
</tr>
<tr>
<td>Logbook Sketch</td>
<td>VS</td>
<td>1</td>
</tr>
</tbody>
</table>

**Coding of the content:** LS: Literature Study; VS: Videos & Sketches; FI: Follow-up Interview

The hierarchical classification in Figure 4-3 illustrates the arising framework for the newly developed taxonomy. According to the roles sketches play in design, this study first broadly classifies sketches as thinking sketch, talking sketch and non-working sketch, then they are sub-classified into 16 types of sketches, each of which is now described.

![Design Sketches Diagram](image)

**Figure 4-3: Framework of the classification of product design sketches**

**Thinking sketches**
Thinking sketch refers to a group of sketches that designers use to support their individual thinking process. According to Ferguson (1992), engineers use the thinking sketch “to focus and guide nonverbal thinking”. The group of thinking sketch comprise defining sketch, memory sketch, idea sketches, coded sketch, development sketch and logbook sketch. The purpose of a defining sketch is to help the designer to define and clarify the task. This stage is the starting point of the entire design process, which begins with an initial statement of the need and problem analysis. The memory sketches are used by designers to expand their thoughts and recall elements from previous work with the help of mind-maps, notes and text annotations. The idea sketch helps designers with the visualization of their thoughts and design ideas. It emphasizes the abstract nature of sketch, which tends to be used at the early design stage to assist designers in converting a single idea into more than one potential design solutions. The coded sketch is a kind of informal representational drawings as a means to categorise information, which is usually used “to show an underlying principle or scheme” (Pei, 2009). The aim of a development sketch is two-fold, first is to evaluate and select those ideas generated in the former stage, and second is to develop the ideas by investigating their appearance, proportion and scale in greater detail than an idea sketch. The logbook sketch can be viewed as an external memory device, which is the collection of sketches produced in the design project and can record the design information for future reference.

**Talking sketches**

Talking sketches are used for facilitating design communication. They encourage discussion and build a common understanding of the design idea among the involved parties. According to the different parties they serve, i.e., designers, engineers and clients, this group of talking sketches can be further divided into five categories as explanatory sketch, instruction sketch, presentation sketch, fabulous sketch, detail sketch and storyboard sketch. The explanatory sketch is used to quickly and effectively convey the design intent or features with other designers across the team. Ferguson (1992) describes the instruction sketch as the means for an engineer “to direct the drafter in making a finished drawing”. However, this type of sketch is produced by CAD tools instead of freehand. It has evolved into a type of informal coded representation or sketches for designers to communicate technical details such as mechanisms, manufacturing and dimensions with engineers. Presentation sketches are rendered and realistic sketches to help designers to communicate the show formal proposals of design concepts with clients, which often employ the use of colour/tone to enhance detail for realism. The fabulous sketch is used to present design ideas in a way that intend to express their wonderful, fantastic or emotional qualities. Lawson (2012) suggested that: “they tend to represent something that could not exist in reality. They thus suspend disbelief and criticism and realism. This characteristic seems to be important in assisting the development of creative thought in some of its stages.” Detail sketch tends to be large-scale drawings used to provide a detailed description of a part of a product that “may be included in less detail” on a presentation sketch. It presents all the information required for design communication.
about the design and manufacturing details, which may include information about
detailed form design, structure design, dimensions, surface finish specifications, and
material specifications. Storyboard sketch is often used by designers to provide “a
visual description of the use of a product”, which helps people from different
backgrounds can ‘read’ and understand the design concepts in their implementation
contexts (Stappers and Van der Lelie, 2011). It helps designers to describe the
interaction between user and product, portrays the product in the context, and
illustrates the use with compelling or interesting stories.

Non-working sketches

The non-working sketch can be defined as a group of sketches that are produced by
designers outside the design process in their spare time. As Lawson (2012) points out:
“Designers tend to draw habitually and certainly more often than just when designing”.
Empirical evidence supports that the non-working sketch may also play a helpful role
in the design process. The non-working sketch group comprises storing sketch,
practising sketch, playing sketch and warming-up sketch. The storing sketch is
produced for recording images of inspirations or interesting observations for future
reference as a metaphor. Compared with the logbook sketch, the storing sketch is
less formal and a designer can use it to record almost anything that interests he/her,
e.g. ideas, cartoons, scenery or even living creatures. As a learned skill, expertise in
sketching requires lots of practice. Therefore, practising sketch often is extensively
undertaken by designers for the purpose of improving their sketching skills. The
playing sketch is produced by designers in their spare time simply for fun which
enables designers to ‘play’ with the sketches and ideas. The warming-up sketch tends
to be produced at the initial stage of the sketching process, which may help the
designer to quickly enter the drawing state. A summary of the various types of
sketches discussed in this section is shown in Table 4.17. Sketching examples of the
16 identified types of sketches are presented in Figures 4-4 to 4-18. The sketching
examples presented are mainly selected from the sketching textbook ‘Product Design
Sketching’ written by the author (Ge and Hua, 2016), while the rest of the examples
found in other sources are also included (i.e. Sjölen and Olofsson, 2005; Tjalve,
Andreasen and Schmidt, 2016; Hua, Huang and Childs, 2018).
<table>
<thead>
<tr>
<th>Sketch Category</th>
<th>Sub-category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinking Sketch</td>
<td>Defining Sketch</td>
<td>Helps the designers to define and clarify the design task</td>
</tr>
<tr>
<td>Memory Sketch</td>
<td>Used by designers to expand their thoughts and recall elements from previous work</td>
<td></td>
</tr>
<tr>
<td>Idea Sketch</td>
<td>Promotes idea generation and exploration of alternatives with simple line drawings</td>
<td></td>
</tr>
<tr>
<td>Coded Sketch</td>
<td>The informal coded representation used for categorizing information to demonstrate an underlying principle or scheme</td>
<td></td>
</tr>
<tr>
<td>Development Sketch</td>
<td>Used to evaluate design ideas and further investigate the appearance, proportion and scale in greater detail</td>
<td></td>
</tr>
<tr>
<td>Logbook Sketch</td>
<td>Drawing records produced in the design process and contains the project information for future reference</td>
<td></td>
</tr>
<tr>
<td>Talking Sketch</td>
<td>Explanatory Sketch</td>
<td>Encourages discussion, produced to share and explain an idea to other designers</td>
</tr>
<tr>
<td>Instruction Sketch</td>
<td>Informal sketches for facilitating design communication with engineers regarding technical points</td>
<td></td>
</tr>
<tr>
<td>Presentation Sketch</td>
<td>Rendered and realistic sketches to help designers to communicate the design concept with clients</td>
<td></td>
</tr>
<tr>
<td>Fabulous Sketch</td>
<td>Used to present design ideas in a way that intend to express wonderful or fantastic qualities</td>
<td></td>
</tr>
<tr>
<td>Detail Sketch</td>
<td>Illustrates detailed information on components of products to facilitate detailed communication or further improvement</td>
<td></td>
</tr>
<tr>
<td>Storyboard Sketch</td>
<td>Describes interaction between user and product and portrays the use in the context</td>
<td></td>
</tr>
<tr>
<td>Non-working Sketch</td>
<td>Storing Sketch</td>
<td>Drawings produced outside the design process and record images of ideas and interesting observations</td>
</tr>
<tr>
<td>Practicing Sketch</td>
<td>Extensively produced by designers for the purpose of improving their sketching skills</td>
<td></td>
</tr>
<tr>
<td>Playing Sketch</td>
<td>Simply produced by designers for fun, enabling them to play with sketches and ideas</td>
<td></td>
</tr>
<tr>
<td>Warming-up Sketch</td>
<td>Produced as a warm-up exercise for designers to quickly enter the drawing state</td>
<td></td>
</tr>
</tbody>
</table>
Figure 4-4. Sketch example of ‘Defining Sketch’ (Sjölen and Olofsson, 2005)

Figure 4-5. Sketch example of ‘Memory Sketch’ (Ge and Hua, 2016)
Figure 4-6. Sketch example of ‘Idea Sketch’ (Ge and Hua, 2016)

Figure 4-7. Sketch example of ‘Coded Sketch’ (Tjalve et al., 1979)
Figure 4-8. Sketch example of ‘Development Sketch’ (Ge and Hua, 2016)

Figure 4-9. Sketch example of ‘Explanatory Sketch’ (Ge and Hua, 2016)
Figure 4-10. Sketch example of ‘Instruction Sketch’ (Ge and Hua, 2016)

Figure 4-11. Sketch example of ‘Presentation Sketch’ (Ge and Hua, 2016)
Figure 4-12. Sketch example of ‘Fabulous Sketch’ (Ge and Hua, 2016)

Figure 4-13. Sketch example of ‘Detail Sketch’ (Ge and Hua, 2016)
Figure 4-14. Sketch example of ‘Storyboard Sketch’ (Ge and Hua, 2016)

Figure 4-15. Sketch example of ‘Logbook Sketch’ (Ge and Hua, 2016)
Figure 4-16. Sketch example of ‘Storing Sketch’ (Ge and Hua, 2016)

Figure 4-17. Sketch example of ‘Practicing Sketch’ (Ge and Hua, 2016)
Figure 4-18. Sketch example of ‘Playing Sketch’ (Hua, Huang and Childs, 2018).

Figure 4-19. Sketch example of ‘Warming-up Sketch’ (Ge and Hua, 2016)
4.3.10. The sketching habits

Through the pilot study, some interesting behaviour patterns were found from the design students while they were sketching. From their point of view, these ‘unnecessary moves’ were actually of great value for them. Therefore, these moves were summarized and described as ‘sketching habits’.

This section presents the results of the identified sketching habits in design (Table 4.18) derived from the data in the cluster of ‘sketching habits’ (Table 4.2–4.6). In total, eight types of sketching habits were identified. The top three identified ‘sketching habits’ are the ‘use of visual stimuli’, ‘listen to music while sketching’ and the ‘use of warming-up sketch’. The rest of the five habits were only counted once.

Table 4.18 Identified sketching habits

<table>
<thead>
<tr>
<th>Summary of findings</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use visual stimuli (i.e. images and videos) as inspiration</td>
<td>3</td>
</tr>
<tr>
<td>Listen to music or even TV play while sketching</td>
<td>2</td>
</tr>
<tr>
<td>Use warming-up sketch (e.g. lines, ellipse and doodling) before the design process</td>
<td>2</td>
</tr>
<tr>
<td>Heavy use of thinking tools and annotations</td>
<td>1</td>
</tr>
<tr>
<td>Search and copy the good sketching examples</td>
<td>1</td>
</tr>
<tr>
<td>Draw something randomly when getting stuck with the idea generation</td>
<td>1</td>
</tr>
<tr>
<td>Frequently change the sketching subjects during the design process</td>
<td>1</td>
</tr>
<tr>
<td>Like to sketch in the night</td>
<td>1</td>
</tr>
</tbody>
</table>

4.3.11. The interplay between sketching and design ideation process

When piecing together all the data collected from the think-aloud experiment and the follow-up interview relating to ‘Supporting Roles’, ‘Influences’ and ‘Design Process’ (Table 4.2–4.6), the interplay between sketching and ideation process of product design becomes clear. This section presents the analysis and findings on how sketching was used to support the design ideation process in the assigned design task. It starts with the analysis of the basic unit of design ideation entitled ‘Ideation Segment’; then presents a descriptive model to illustrate the sketching supported creative design process.

**Ideation Segment of design sketching**
Sketching is a complex process that involves various types of activities, i.e. draw the object, draw context, add shading, emphasize, write the textual description, move and look (Sun, Xiang, Chai, et al., 2014). These types of sketching activities are emerged in different stages of the design process and can “have disparate effects on the design outcomes” (Sun, Xiang, Chai, et al., 2014). A clear understanding of the roles of design sketching requires investigating how design concepts emerge during the sketching process and were developed into the design outcomes. Therefore, an ‘Ideation Segment’ structure was proposed by the author to describe the design sketching process.

The Ideation Segment can be viewed as a loop of the thinking process enabling new idea generation, development and expression for possible design solutions (Suwa, Gero and Purcell, 1998; Howard, Culley and Dekoninck, 2008), which involves idea generation & development, idea expression, and idea perception and interpretation. Figure 4-20 illustrates the basic structure of an Ideation Segment. Designers continually generate design ideas based on inspiring design inputs, including related memory, domain/context knowledge, various types of references and stimuli (see Section 4.3.8). Every Ideation Segment starts from the generation of an idea (Sun, Xiang, Chai, et al., 2014), and creates a Mental Image of the idea in his/her mind. The designer uses his/her sketching skills to transform the mental image into a sketch as a physical representation. The sketching skills of a designer can be measured by how close the sketch is to the mental image (Shah et al., 2001). It should be noted that ‘sketching ability’ also plays an important role at this stage. Previous studies (Goldschmidt, 1991; Jami J. Shah1, Noe Vargas-Hernandez, Joshua D. Summers, 2001) have reported designers to benefit to different degrees from the use of sketching due to their abilities to use it. According to Larkin and Simon (1987), the ability to use sketching in an effective way “comes with practice and experience”. After the designer received the visual feedback from his/her sketches, the ‘talk-back’ begins and the designer enters a dialogue with his/her own sketches (Goldschmidt, 2003). As the dialogue proceeds, sketching continues until a new idea or a revised idea emerges.

![Figure 4-21. The structure of Ideation Segment](image)

### A descriptive model of the creative design sketching process
Designers use sketching to explore multiple design paths for possible solutions during the design process. The understanding of the design problem and its solutions emerge and improve through the sketching process (Cross, 2006). This process can be described as an ‘ideation tree’ with the design paths represented by branches (Jin and Chusilp, 2006; Sun, Xiang, Chai, et al., 2014). This ideation tree grows with new ideas emerging as branch points (i.e. lateral transformation) and ideas finally evolving to alternative design solutions (i.e. vertical transformation).

This Ideation Segment tree can be constructed from the think-aloud reports and design sketching outcomes. A typical design sketching process to solve the assigned design task (Student C) is illustrated in Figure 4-21. In this specific example, the participant was asked to think aloud while she was sketching and working on the assigned design task. She designed a digital pet handset for children to play with and the whole process lasted for 47 minutes. In total, six Ideation Segments were identified according to the participant’s think-aloud report and sketches.
Figure 4-21. Sketching and ideation process of Student C
At the beginning of the process, the participant used Pinterest to search for visual references and she was inspired by an MP3 design sketch resulting in Ideation Segment 1 (IS1) and IS1-1 (Figure 4-22). Then, she was inspired by a cell phone design and generated the IS2 and IS2-1 (Figure 4-23). She decided to change the temperament of the design by giving it a lovely look, which might make the design more appealing to children. She stopped the sketching and watched a video about an owl-shaped camera design. This inspired her and resulted in the IS3, IS4 and IS6 (Figure 4-24, 4-25 & 4-26). However, she seemed not very clear about the concept, the design of IS3, IS3-1 and IS3-2 were quite different from each other and she even stopped drawing the IS3-2 in the middle of its sketching process. The participant then reviewed the previous sketches and started sketching again giving a portable feature to her design (IS5-1, Figure 4-26). The next Ideation Segments (IS6) also related to owl-shaped camera design which imitated the shape of the beak. She then combined the portable design of IS5-1 with IS6 which resulting in the IS6-1 (Figure 4-26). Finally, she reviewed all the previous sketches again evaluating the ideas and made her final decision. As shown in Figure 4-27, an explanatory sketch (IS6-3) was generated to express the final design concept, which was developed based on the design of IS6, IS6-1 and IS6-2.

Figure 4-22. Sketches of IS1 and IS1-1
Figure 4-23. Sketches of IS2 and IS2-1

Figure 4-24. Sketches of IS3, IS3-1 and IS3-2
Figure 4-25. Sketches of IS4

Figure 4-26. Sketches of IS5, IS5-1, IS6, IS6-1 and IS6-2
Figure 4-27. Sketches of IS6-3

Compared with the mass sketches on paper, the Ideation Segment structure provides an easy way to understand the design sketching and ideation process. According to the findings from the design experiment and sketching outcomes, the author proposed a descriptive model of the design sketching process which is illustrated in Figure 4-28. Overall, this Ideation Segment model provides a comprehensive description of the design sketching process. It displays how design ideas emerge and evolve to the final design outcomes in a concise and informative way. It also explained how design ideas are expressed and perceived by designers, which is crucial for supporting design creativity. This model incorporates the findings presented in the former sections (i.e. Section 4.3.6 – 4.3.8), and highlights the importance of various types of ‘Influences’ (e.g. context and domain knowledge, reference & stimuli, sketching abilities & skills, and supporting tools) and illustrates their applied stages during the design sketching process. Therefore, this model was used as the framework for guiding future studies. The development of the practical supporting tools for sketching would also take it as an important reference.
4.4. Discussion

In this section, the objectives of the pilot study (refer to Section 4.1) are reviewed and the methods adopted are discussed in the following paragraphs.

4.4.1. Review of objectives of the study

*The understanding of sketching in today’s design context* is far from sufficient, especially in the product design field. As mentioned, most of the studies on visual thinking and sketching were conducted by experts from three fields, namely cognitive psychology, architectural and engineering design. For example, the types of sketches used in current product design practice were not clear before the study, among which the non-working sketches were not incorporated in the existing sketching taxonomies. Therefore, a new sketching taxonomy was developed which contains 15 types of sketches identified in the study, including four types of non-working sketches (Section 4.3.9). The students participating in the experiments reported novice sketchers like them, in general, were unaware of the roles of sketching in product design, especially those relating to design ideation. The Ideation Segment model was proposed to address this problem (Section 4.3.10). In addition, there were few tools found to be available for designers to support their sketching process.

*Important issues surrounding design sketching*, according to the recurrence in the conducted experiment and follow-up interview, include:

- Understanding the roles of sketching in product design (Section 4.3.7)
• Utilizing visual reference/stimuli to support product design sketching process (Section 4.3.8)

• Identifying the appropriate contents of sketching supporting tools (Section 4.3.8)

• Identifying the types of sketches useful in today’s product design context (Section 4.3.8 & 4.3.9)

• Developing supporting tools to enhance the design ideation process (Section 4.3.8 & 4.3.10)

In summary, there are two broad issues, i.e. understanding the roles (especially those relating to design ideation) and developing supporting tools (including augmented memory, external stimuli, guidance on sketching skills and classification system of product design sketches)

**Hypotheses testing**

According to the findings from the pilot study, design students, in general, lacked the understanding of sketching in the product design field (refer to the 1st paragraph of the section). This supports Hypothesis 1: There is a need to get a better understanding of the roles of sketching in the product design field.

Section 4.3.6 presents the findings of basic awareness of product design sketching. Four out of five participants believed that the use of sketching can strongly influence their idea generation process, and three participants thought sketching is an effective way to make quick records of the fleeting ideas which are essential for facilitating the design ideation process (Section 4.3.6). These were also supported by the results of identified functions (i.e. ‘supporting idea generation’ and ‘recording the fleeting design ideas’) of design sketching (refer to Section 4.3.7). These findings highlighted the importance of sketching in supporting design ideation. Although the participants expressed their interests in this topic, few resources are available for them to use due to the lack of ‘translation’ of research on how sketching supports design ideation from academic works to applied teaching materials. These findings partially support Hypothesis 3: Understanding the cognitive interplay between sketching and design ideation process may be of use to both design academics and practitioners. In addition, the author proposed an Ideation Segment model to describe how design ideas emerge and evolve to the final design outcomes. It is expected to be a useful framework providing guidance for both design researcher and educators to use.

According to the results presented in Section 4.3.8, visual stimuli were mentioned 21 times by the participants as a support for design sketching. Specifically, the pictorial and video stimuli were most welcomed by the participants mentioned nine times and four times respectively, while textual stimuli were only mentioned twice by the participants. Although the ‘ability/experience to use sketching’ was reported to be effective influences in previous studies (Section 2.6), they were only mentioned twice (combined) by the participants. Instead ‘sketching skills’ was mentioned four times
(the highest reoccurrence) as an important influence for design sketching. This supports Hypothesis 4: External stimuli and sketching instruction can be helpful in supporting the design sketching process.

In total, 14 comments selected from participants’ reports and interviews were relevant to the presentation and format of the supporting tools. All of the five participants thought image search platforms (e.g. Behance and Pinterest) were most effective as the supporting tool for design sketching. Three participants thought thinking aids and their personal sketch notebook were useful for them and two participants selected to use searching engines (e.g. Google and Baidu) for relevant information. However, the rest of the types of supporting tools were only mentioned once by the participants. To summarise, supporting tools providing visual references and facilitating the design thinking process was perceived to be most useful while other types of supporting tools were not. These findings partially support Hypothesis 5: Effective support of design sketching is critically dependent on the presentation of supporting materials.

The pilot study involved five design students with a similar level of sketching experience in a think-aloud experiment, and their reports and comments on design sketching were only a reflection of the perceptions of design sketching. Therefore there is a need for further studies which could involve students from different backgrounds but related to product design, as well as explore perceptions on design sketching from design professionals. Overall, the pilot study met the research objectives. The discussion about the methods used for data collection and analysis is presented in the following section.

4.4.2. Critique of the research methodology

Methodological triangulation was implemented in the pilot study, and multiple sources of data were adopted to add the validity of the research findings (Flick, 2004; Yin, 2017). The think-aloud protocols and follow-up interviews were employed as the main data collection method. Few studies in the design literature relied on think-aloud recordings as their only source of data collection. The assumption behind the think-aloud method is that examined subjects could provide an accurate description and explanation about their actions and thoughts. However, it is impossible to be absolutely certain about the accuracy of the data due to the nature of the self-report method. Various factors may have an impact on the use of the method, including the cognitive load, the added strain on users, and the interruption caused by the observer during the test. As Ericsson and Simon (1980) pointed out: “think-aloud data from working memory will always be incomplete and exclude a number of thought processes which are not held in working memory long enough to be expressed verbally.” In response to these problems, the author adopted a follow-up interview method to illuminate and expand on think-aloud results. The use of the follow-up interview method aimed to add depth of information about the participants’ thinking process, but interviews can be biased by leading questions, and also "difficult for the
participants to retrieve from long-term memory”. Therefore, alternative methods which do not rely on ‘self-reporting’ were involved in the study, namely observations of the sketching process and analysis of sketching outcomes.

A ‘coding and clustering’ method was adopted to analyse the data gathered during the pilot study. The main points of findings were summarised and presented according to each involved design students in Table 4.2-4.6, and the summary of findings against pre-defined five topics was shown in Table 4.7-4.16. The tabulation of the findings was to minimise the complexity of the presentation and to facilitate the comparison. The frequency of occurrence listed in Table 4.7-4.16 turned qualitative data into quantitative data. The interpretations mainly focused on the high frequency of occurrence. The validity of the findings with this method will be further confirmed by the following studies (surveys on design students and professionals), which are presented and discussed in detail way in Chapter 5 and Chapter 6.

4.5. Conclusions

The pilot study with the five design students provided a picture of the use of sketching in product design. Data gathered from the study supported four of the research hypotheses (i.e. hypothesis 1, 3, 4 and 5). The pilot study revealed the perceptions of design students on design sketching and identified the major roles of sketching in supporting the design process, especially those relating to design ideation. It also helped to explore a number of important issues about design sketching, including remarkable influences of design sketching (e.g. pictorial material was the dominant source of inspiration), the taxonomy of product design sketches (identified the existence of non-working sketches), and the structure of design ideation & sketching process. General directions for future studies were identified, namely understanding the roles of product design sketching in today’s design context and developing practical supporting tools to enhance the roles. The pilot study also suggested that further studies should involve design sketchers with different levels of experience, including design students and design professionals.
Chapter Five: Understanding the Supporting Roles of Sketching for Design Students

5.1. Introduction

This chapter aims to further investigate the perceptions of industrial design and engineering design students with respect to roles of sketching and its expertise in design, and collect more information about their preference in regard to sketching. A retrospective interview method was adopted for the pilot study. According to Seale (1999), from the perspective of methodological triangulation, it would add the validity of a research if another method is used for further data collection. As a common research method, the survey could provide ‘a straightforward approach to the study of attitudes, values, beliefs and motives’ (Robson, 2011). When compared with the interview method, it is easier for questionnaire research to collect and analyze the data, and the subjects involved are controlled to give specific answers rather than general information. Thus, a questionnaire method was adopted in the descriptive studies, which were expected to give us more specific information about the preference and perceptions of design sketching among design students and professionals. In addition, studies conducted with a similar purpose in other design fields (graphic design, automotive design and architectural design) also adopted the survey methods (interview and postal questionnaire). It seems that it is appropriate to adopt the questionnaire method at this stage as an effective supplement to the pilot study.

5.2. Setting-up of the survey

According to the results of the pilot study (see Section 4.3), the effective use of sketching in design may be influenced by a number of factors, e.g. sketching habits, external stimuli and sketching expertise. These findings highlighted the need to explore the perceptions of design students, and to identify the unique roles of industrial/engineering design sketches by comparing the survey results from the graphic design field. According to the literature review (Section 2.4), surveys that shared a similar research aim (i.e. to understand designers’ perceptions of design sketching and sketching expertise) were only found being carried out in graphic design (Schenk, 1989) and automotive design (Yusoff, 2007). Automotive design is often considered as a sub-discipline of industrial design. No similar survey-based study was identified in architectural design or any other relevant design fields.
Therefore, comparisons were made between the author’s findings from the industrial & engineering design students and the findings from the graphic design students. The perceptions, especially those on the unknown roles of sketches (e.g. the non-working sketch), would be helpful in directing the development of means of the practical supporting tool for sketching in design. Therefore, the objectives of the study described in this chapter were:

- To identify the perceived roles of sketching for design students
- To identify the perceived roles of sketching expertise for design students
- To compare the perceptions between industrial design students and engineering design students
- To compare the perceptions of industrial/engineering design students with those of the graphic design students
- To collect further data to test and verify the research hypotheses

Compared with the interview method, the questionnaire method is an effective way to reach a large number of subjects. Considering the cost of time and money, an online questionnaire was adopted as an efficient way to gather a large amount of data. The questionnaire was distributed online through two platforms (i.e. the Smart Survey for students from the UK and the Tencent Survey for students from China) and invitations were sent to participants via e-mail.

### 5.2.1. Questionnaire design

Questionnaire design is perhaps the most important part of the survey process. However, designing the questionnaire can be quite challenging requiring control of the overall framework and attention to many details. In addition, it was also important that the data gathered from the survey enabled comparison with results from the graphic design. Therefore, the design of the questionnaire adopted a multistage design process. The initial survey questionnaire was designed mainly based on the instructions from Handbook of Survey Research (Krosnick and Presser, 2010) and also with reference to the existing questionnaires from several PhD projects (Schenk, 1989; Yusoff, 2007; Gharib, 2013) conducted in different design fields, e.g. graphic design, architectural design and automotive design. The draft of the questionnaire was sent to three design research experts, two of them from the Dyson School of Design Engineering at Imperial College of London and the other from the School of Design and Innovation at Zhejiang Normal University. The suggestions from the reviewers, for example, targeted versions of questionnaires that should be developed for different participants (i.e. design students and professionals) were followed in this survey and the other survey presented in the next chapter. Then, the revised version of the questionnaire was sent to five expert level design sketchers and three colleagues for a second round review. According to the feedback from the sketchers
and colleagues, the questionnaire was revised for the second time.

The final version of the questionnaire was composed of five main sections which are listed as follows:

Section 1: general information about the participants, e.g. the education background of the participants;

Section 2: general questions about sketching, e.g. students’ preference regarding sketching tools;

Section 3: perceptions of roles of sketching in design, e.g. the role of talking sketch;

Section 4: perceptions of sketchers’ expertise in design, e.g. the role of perspective drawing skill;

Section 5: other information of interest, e.g. the willingness of the participants to give further comments and suggestions.

A 1-7 Likert-type scale was employed to scale the responses for the questions in Section 3 and 4, i.e. those questions about the perceptions. When compared with the 1-4 point scale or 1-5 point scale, the 1-7 point scale has advantages in minimizing bias (Dong, 2004). Participants were asked to select from 1 to 7 according to their perceptions on the importance of each sub-options. Here ‘1’ represented the most negative response (e.g. least important) and ‘7’ represented the most positive response (e.g. most important). For example, regarding the statement ‘sketching plays a role in promoting idea generation and exploration’, if the participants think ‘promoting idea generation and exploration is the least important role of sketching in design’, he or she should mark ‘1’; but if on the contrary, they think ‘promoting idea generation and exploration is the most important role of sketching in design’, they should mark ‘7’.

In addition, participants were allowed to fill in additional information after each corresponding section (i.e. Question section 2-4). At the end of the questionnaire, additional space was provided to participants to give further comments and suggestions for our study. A copy of the final version of the questionnaire is given in Appendix B.

5.2.2. Survey procedure

The questionnaire is an effective method of gathering data from a large number of respondents. However, it can be challenging to get a satisfactory response rate and may result in incomplete answers. In our case, the questionnaires were distributed online, which requires a relatively short period of time to receive the response and only needs repeat mailing and reminder to encourage the responses (Robson, 2011). Thus, a three-step survey procedure was employed:

1. Initial contact: Two different strategies were adopted at this stage. First, participants were contacted by email asking if they would be willing to take part in
our survey. This method may lead to a high response rate while it was laborious and time-consuming. Thus, a second strategy was employed, the questionnaires were also sent via email to the course tutors of a number of universities (e.g. Zhejiang Normal University and Tongji University) with a request to distribute the questionnaires among their students.

2. Distribution: Following the initial contact, invitations were sent to individuals (design students and design course tutors) in the UK and China via emails, together with the questionnaire and a covering letter to explain the purpose of the study and the structure of the questionnaire.

3. Reminder to the non-respondents and incomplete respondents: The respondents who completed the questionnaire were acknowledged via email or social media. On the contrary, the respondents who did not complete the questionnaire were contacted again as a reminder. An email attached with the questionnaire and covering letter was sent to them again two weeks after the initial distribution.

5.2.3. Method of analysis

A two-stage of analytical strategy was employed, namely exploratory data analysis (EDA) and formal data analysis (FDA). Exploratory data analysis started in the first round of questionnaire distribution. Feedback was received from 16 respondents at the Royal College of Art and Imperial College of London, and then ideas for interpretation and analysis plans emerged in the quick review and analysis process of the data. After the EDA, the other round of the survey was carried out and the data were formally analysed using descriptive statistics. According to the inspection of data distribution in EDA, arithmetic means and standard deviations, rather than mode (the data value that occurs most often) or median (the data value that separates the higher half from the lower half of a set of data), were selected to describe the data in the subsequent stage of deriving the main findings. The mode does not apply to our case because there may be more than one mode for some questions and the median also has its limitations because it is a less representative average which only takes the middle one or two answers into account while the others are not.

Coding scheme

It was important to identify the roles of sketching and sketching expertise in design through the survey. More importantly, these identified roles should be classified into different types so that high-level strategies could be developed accordingly. Therefore a coding scheme was generated for classifying types of roles of sketching and sketching expertise. The perceived functions of working sketches and non-working sketches were combined as ‘roles’ and then divided into two groups (i.e. ‘creative roles’ and ‘general roles’) which are listed as below:

- ‘creative roles’ (roles that relate to the design ideation process, e.g. promoting design communication with other designers for creative design collaboration)
• ‘general roles’ (roles that relate to other design activities rather than idea generation and development, e.g. sketching as a practice to improve their sketching techniques).

The sketching expertise was classified into two groups, which are listed as follows:

• ‘sketching abilities’ (expertise that relates to cognitive and intellectual abilities and the awareness of appropriate use of sketching in the design process, e.g. ability to sketch from memory)

• ‘sketching skills’ (expertise that relates to the practical drawing techniques, e.g. drawing skill in using drop shadow).

In order to verify the reliability of the proposed method, the subjectivity of the grouping was tested. Two experienced design researchers were invited to classify the roles of sketching and sketching expertise independently. The results showed that the consensus rate for grouping the roles of sketching was 93% and for grouping the roles of sketching expertise was 90%.

**Multi-comparisons**

Comparisons were made between the following groups:

• Novice student sketchers and expert student sketchers (criteria for the classification please refer to Section 5.3.1).

• Design students from the fields of industrial design, engineering design and graphic design.

**5.3. Results and findings**

Most of the data given and analysed in the following sections were collected from the online questionnaire sent via emails to industrial and engineering design students in the UK and China. The rest of the data were selected for further comparison from the PhD projects with a similar topic in the related fields, i.e. graphic design (refer to Section 5.1). Therefore, the findings are presented according to the order that the questions were set out (see Appendix B).

**5.3.1. Profile of respondents**

183 students were invited to participate in the survey to complete an online questionnaire. 88 responses (48.1% of the total sample) were received in total, among which 79 (43.2%) questionnaires were complete.

Among the 79 completed questionnaires, 48 were from industrial design students and 31 were from engineering design students. 12 of the respondents were
undergraduate students and the rest 67 respondents were postgraduate students. There were 28 male respondents and 51 female respondents involved in this study. 29 of the respondents were from the UK while the rest of the 50 respondents were from China. The participants range in age from 19 to 44 years old and the breakdown is shown in Table 5.1.

Table 5.1 Profile of respondents – age group of the design students

<table>
<thead>
<tr>
<th>Age Group</th>
<th>≤20</th>
<th>21-25</th>
<th>26-30</th>
<th>31-35</th>
<th>36-40</th>
<th>≥41</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of industrial design students</td>
<td>0</td>
<td>17</td>
<td>26</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>48</td>
</tr>
<tr>
<td>No. of engineering design students</td>
<td>2</td>
<td>17</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>34</td>
<td>34</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>79</td>
</tr>
</tbody>
</table>

In the category of sketching experience, the levels of sketching experience were classified into ‘Very experienced’, ‘Experienced’, ‘Less experienced’ and ‘Novice’. Most of the students were found to be ‘Experienced’ and ‘Less experienced’ with a total number of 39 (49.4%) and 28 (35.4%) respectively. Ten (12.7%) students were found to be ‘Very experienced’ while the rest two (2.5%) students were novice design sketchers. There was only one undergraduate student who was found to be at an ‘Experienced’ level and the other 11 of them were found at the ‘Less experienced’ level. As to the postgraduate students group, ten of them were found to be ‘Very experienced’ sketchers, 38 were ‘Experienced’ sketchers and 19 were ‘Less experienced’ sketchers (see Table 5.2).

Table 5.2 Sketching experience of the design students

<table>
<thead>
<tr>
<th>Sketching Experience</th>
<th>Very experienced</th>
<th>Experienced</th>
<th>Less experienced</th>
<th>Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of industrial design students</td>
<td>7 (14.6%)</td>
<td>29 (60.4%)</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>No. of engineering design students</td>
<td>3 (9.7%)</td>
<td>10 (32.3%)</td>
<td>16 (51.6%)</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>10 (12.7%)</td>
<td>39 (49.3%)</td>
<td>28 (35.5%)</td>
<td>2</td>
</tr>
</tbody>
</table>

These students would be grouped according to their sketching experience to facilitate the subsequent comparison and analysis. The students who were found to be ‘Very experienced’ or ‘Experienced’ in sketching would be combined as ‘expert students’, while the students who were found to be ‘Less experienced’ or ‘Novice’ in sketching would be named as ‘novice students’ in the subsequent analysis.
5.3.2. Perceived importance of sketching and sketching ability to industrial design students and engineering design students

The responses given by the design students when asked to rate the importance of sketching, including the breakdown according to the background of students, is shown in Table 5.3. Among the 79 respondents, 34 (43.0%) of them thought sketching was an essential tool in design and 45 (57%) of them thought sketching was useful. In addition, none of the respondents thought that sketching was irrelevant or detrimental.

Table 5.3 Rating of the importance of sketching to design students

<table>
<thead>
<tr>
<th></th>
<th>Essential</th>
<th>Useful</th>
<th>irrelevant</th>
<th>Detrimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of industrial design students</td>
<td>20 (41.7%)</td>
<td>28</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No. of engineering design students</td>
<td>14 (45.2%)</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>34 (43.0%)</td>
<td>45</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

When asked about the importance of expertise in design sketching, 24 of the respondents considered it was essential to develop the sketching expertise for industrial and engineering designers, whereas 54 felt it would be useful. There was only one respondent who thought that sketching expertise is irrelevant. The data is set out in Table 5.4.

Table 5.4 Rating of the importance of sketching expertise to design students

<table>
<thead>
<tr>
<th></th>
<th>Essential</th>
<th>Useful</th>
<th>irrelevant</th>
<th>Detrimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of industrial design students</td>
<td>13 (27.1%)</td>
<td>35</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No. of engineering design students</td>
<td>11 (35.5%)</td>
<td>19     (61.3%)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>24 (30.4%)</td>
<td>54     (68.4%)</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

From these results, it could be concluded that almost all of the respondents thought that both sketching and sketching expertise was important in design, and only one respondent thought that sketching expertise was irrelevant. In addition, a higher proportion of engineering design students thought that sketching and sketching expertise was essential in design than the industrial design students did (Figure 5-1). It seemed that sketching and sketching expertise were thought to be more important to engineering design students than industrial design students. Other conclusions could not be drawn.
5.3.3. The preference of design students for sketching

This section includes three questions to investigate students’ preference regarding sketching tools, types of references and methods for learning sketching skills. They were told more than one answers could be selected for the questions in this section.

For the tools or the medium that design students prefer to use in sketching, 38 (48.1%) respondents prefer to use pencil and paper, 22 (27.8%) prefer to use pen and paper and 8 (10.1%) chose to use colours and paper. In total 68 (86.1%) of the respondents showed their preference for paper-based freehand sketching while the rest 11 (13.9%) of respondents were used to visualize their ideas with CAD systems (see Table 5.5). It seems that design students have a clear preference for paper-based freehand sketching rather than CAD systems supported sketching.

Table 5.5 Design students’ preference regarding sketching tools

<table>
<thead>
<tr>
<th></th>
<th>Pencil and paper</th>
<th>Pen and paper</th>
<th>Colours and paper</th>
<th>CAD systems (e.g. Photoshop,)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of respondents</td>
<td>38 (48.1%)</td>
<td>22 (27.8%)</td>
<td>8 (10.1%)</td>
<td>11</td>
</tr>
</tbody>
</table>

Respondents were asked to select their preferred sources of references, i.e. internet, memory, daily life, natural environment, books, imagination and existing designs. Only ‘reference from the internet’ was selected in a high proportion, with 60 respondents reaching 75.9%, while the rest of the options were selected at a relatively low percentage ranging from 25% to around 50% (see Table 5.6). Note that one of the respondents suggested that he used to collect images to form a personal database as a source of reference.
Table 5.6 Design students’ preference regarding types of references

<table>
<thead>
<tr>
<th>Sources of references</th>
<th>No. of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference from internet</td>
<td>60 (75.9%)</td>
</tr>
<tr>
<td>Reference from memory</td>
<td>29 (36.7%)</td>
</tr>
<tr>
<td>Reference from observation in daily life</td>
<td>31 (39.2%)</td>
</tr>
<tr>
<td>Reference from the natural environment</td>
<td>25 (31.6%)</td>
</tr>
<tr>
<td>Reference from books/magazines</td>
<td>38 (48.1%)</td>
</tr>
<tr>
<td>Reference from imagination</td>
<td>28 (35.4%)</td>
</tr>
<tr>
<td>Reference from existing designs</td>
<td>38 (48.1%)</td>
</tr>
<tr>
<td>Others</td>
<td>1 (1.2%)</td>
</tr>
</tbody>
</table>

Respondents were asked to choose the preferred ways to learn sketching from seven fixed options. The results are summarised in Table 5.7, based on the feedback from 79 respondents, 72 (91.1%) of them thought the practice was an important way to improve their sketching expertise. Besides, it seems that students do not have specific preferences for the ways (i.e. books, website, videotape, course/training and other people) to learn sketching. No other method of learning was provided by the respondents. The results might suggest that alternative learning formats should be provided.

Table 5.7 Design students’ preference regarding the ways to learn sketching

<table>
<thead>
<tr>
<th>The way to develop one’s sketching ability</th>
<th>No. of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>By practice</td>
<td>72 (91.1%)</td>
</tr>
<tr>
<td>By learning from books</td>
<td>27 (34.2%)</td>
</tr>
<tr>
<td>By learning from the website</td>
<td>24 (30.4%)</td>
</tr>
<tr>
<td>By learning from videotape</td>
<td>19 (24.1%)</td>
</tr>
<tr>
<td>By learning from course/training</td>
<td>26 (32.9%)</td>
</tr>
<tr>
<td>By learning from tutors/friends/colleagues</td>
<td>30 (38.0%)</td>
</tr>
<tr>
<td>Others</td>
<td>0</td>
</tr>
</tbody>
</table>

5.3.4. The perception of sketching habits for design students

The identified sketching habits have been segmented into seven categories, together with the respondents’ preferences regarding the sketching habits are summarised in Table 5.8. The top two preferences were ‘listening to the music’ and ‘searching for visual reference’. Specifically, 51 out of 79 respondents (64.6%) suggested that they
would like to listen to music while they were sketching and 52 out of 79 respondents (65.8%) thought visual reference could be helpful while sketching.

Only 7 (8.9%) respondents out of 79 indicated that they would like to eat something while they are sketching; whilst 20 respondents (25.3%) were found that they had some habitual actions (e.g. pen spinning) and 34 respondents (43.0%) liked to drawing something irrelevant to the design object in their design sketching process. Four respondents suggested that they have other sketching habits and two of them further specified, i.e. straightening the paper and cleaning up the worktable before sketching; using clay to help to understand the shape.

<table>
<thead>
<tr>
<th>Personal sketching habits</th>
<th>No. of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Listening to music while sketching</td>
<td>51 (64.6%)</td>
</tr>
<tr>
<td>Eating snacks while sketching</td>
<td>7 (8.9%)</td>
</tr>
<tr>
<td>Searching for visual reference</td>
<td>52 (65.8%)</td>
</tr>
<tr>
<td>Doing some form of habitual actions (e.g. pen spinning, crack knuckles ... etc)</td>
<td>20 (25.3%)</td>
</tr>
<tr>
<td>Drawing something irrelevant (e.g. line practice, doodle, cartoon figures ... etc)</td>
<td>34 (43.0%)</td>
</tr>
<tr>
<td>Others</td>
<td>4 (0.05%)</td>
</tr>
</tbody>
</table>

Table 5.8 Design students’ preference regarding sketching habits

Table 5.9 presents the perceived roles of sketching habits. 32 (40.5%) of the respondents thought these sketching habits may help them to relax; a higher proportion, 63 (79.7%) of the respondents chose ‘helping to inspire new ideas’; 30 (38.0%) of the respondents chose ‘helping them to focus’; 33 (41.8%) of the respondents chose ‘helping them to quickly enter the drawing state’ and 39 (49.4%) of the respondents chose ‘helping them to feel comfortable and confident with the task ahead’. However, there were still 14 (17.7%) respondents who answered ‘they do not know why they like to keep these habits’. In addition, 6 (7.6%) respondents suggested that sketching habits may serve other purposes in the sketching process, i.e. ‘helping them to enjoy the sketching processes and ‘helping them to know the design context’. Their comments may provide new insights to help us better understand the phenomenon.
### Table 5.9 Perceived roles of sketching habits

<table>
<thead>
<tr>
<th>Perceived roles of sketching habits in design</th>
<th>No. of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helping to calm down and relax</td>
<td>32 (40.5%)</td>
</tr>
<tr>
<td>Helping to focus and concentrate on the task</td>
<td>30 (38.0%)</td>
</tr>
<tr>
<td>Helping to inspire new ideas</td>
<td>63 (79.7%)</td>
</tr>
<tr>
<td>Helping to warm up and quickly enter the drawing state</td>
<td>33 (41.8%)</td>
</tr>
<tr>
<td>Helping to feel comfortable and confident with the task ahead</td>
<td>39 (49.4%)</td>
</tr>
<tr>
<td>Don’t know, simply like to do it</td>
<td>14 (17.7%)</td>
</tr>
<tr>
<td>Others</td>
<td>6 (7.6%)</td>
</tr>
</tbody>
</table>

#### 5.3.5. Perceived roles of sketching for industrial design students and engineering design students

In the questionnaire, two sets of questions were designed to explore the roles of design sketching, i.e. the roles of working sketches and the roles of non-working sketches. In total, 79 students from industrial design and engineering design background were involved. Their perceptions were computed as mean values on the 1-7 Likert-type scale. The results were combined and divided into two groups as shown in Table 5.10 (‘creative roles’) and Table 5.11 (‘general roles’). Standard deviations (SD) are also presented. Note that top table values are shaded to facilitate the discussion.
### Table 5.10 Students’ perceptions of ‘creative roles’ of design sketching

<table>
<thead>
<tr>
<th>Perception roles of design sketching</th>
<th>Industrial design students</th>
<th>Engineering design students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Expanding designer’s thoughts using mind maps, notes and annotations</td>
<td>4.8</td>
<td>2.1</td>
</tr>
<tr>
<td>Recalling design elements from previous experience</td>
<td>4.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Promoting idea generation and exploration</td>
<td>5.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Facilitating idea evaluation and selection</td>
<td>4.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Investigating the aesthetic details such as appearance, texture and scale</td>
<td>4.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Exploring the technical details such as function, structure and manufacturing</td>
<td>4.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Promoting design communication with other designers for design collaboration</td>
<td>4.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Sketching as a warm-up exercise at the initial design stage to let designers quickly enter the sketching state</td>
<td>4.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Sketching for fun and enabling designers to play with sketches and ideas</td>
<td>4.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Keeping sketches as records for future reference (e.g. sketch notebooks, sketch diaries ….etc)</td>
<td>4.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Table 5.11 Students’ perceptions of ‘general roles’ of design sketching

<table>
<thead>
<tr>
<th>Perception roles of design sketching</th>
<th>Industrial design students</th>
<th>Engineering design students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Defining and clarifying the design task</td>
<td>4.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Promoting design communication with engineers regarding technical points</td>
<td>4.4</td>
<td>1.9</td>
</tr>
<tr>
<td>Promoting design communication with clients regarding product appearance, function and scenario</td>
<td>4.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Sketching as practice to improve their sketching techniques</td>
<td>4.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Sketching for emotional and aesthetic expression</td>
<td>4.2</td>
<td>1.7</td>
</tr>
</tbody>
</table>

It seemed that industrial design students and engineering design students agreed on three of the most significant roles of sketching, i.e. ‘promoting idea generation and exploration’ (score: 5.0 for industrial design students and 4.9 for engineering design students), ‘investigating the aesthetic details such as appearance, texture and scale’ (score: 4.6 for industrial design students and 5.1 for engineering design students) and ‘promoting design communication with other designers for design collaboration’ (score: 4.9 for industrial design students and 5.1 for engineering design students). The other important roles perceived by industrial design students were ‘expanding designer’s thoughts using mind maps, notes and annotations’ (score: 4.8), while for engineering design students it was ‘promoting design communication with clients regarding product appearance, function and scenario’ (score: 5.0). The results are presented and the most important roles are shaded in Table 5.10 and Table 5.11. The respondents were invited to identify additional roles and only one answer was added, i.e. ‘forming empathy in multidisciplinary team’. In addition, the identified roles of non-working sketches were also involved in this survey and the results were presented (Table 5.12) as follows:
Table 5.12 Students’ perceived roles of ‘non-working sketching’ in design

<table>
<thead>
<tr>
<th>Perception roles of non-working sketching</th>
<th>Industrial design students</th>
<th>Engineering design students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Sketching as practice to improve their sketching techniques</td>
<td>4.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Sketching as a warm-up exercise at the initial design stage to let designers quickly enter the sketching state</td>
<td>4.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Sketching for fun and enabling designers to play with sketches and ideas</td>
<td>4.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Sketching for emotional and aesthetic expression</td>
<td>4.2</td>
<td>1.7</td>
</tr>
<tr>
<td>Keeping sketches as records for future reference (e.g. sketch notebooks, sketch diaries ....etc)</td>
<td>4.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>

5.3.6. Perceived roles of sketching expertise for industrial design students and engineering design students

The mean values and standard deviations of the responses to the roles of sketching expertise are presented in Table 5.13 (‘sketching abilities’) and Table 5.14 (‘sketching skills’)

102
Table 5.13 *Students’ perceptions of roles of sketching abilities*

<table>
<thead>
<tr>
<th>Perception roles of sketching ability</th>
<th>Industrial design students</th>
<th>Engineering design students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Ability to sketch from memory</td>
<td>4.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Ability to sketch from reference</td>
<td>4.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Ability to sketch from imagery</td>
<td>4.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Ability to sketch to visualise ideas</td>
<td>5.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Ability to sketch to organise ideas</td>
<td>5.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Ability to sketch to explore and evaluate ideas</td>
<td>4.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Ability to sketch for design analysis</td>
<td>4.6</td>
<td>1.5</td>
</tr>
<tr>
<td>Ability to use sketches to communicate design thoughts to others</td>
<td>5.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Ability to use sketches to instruct others</td>
<td>4.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Ability to master various kinds of technical drawing techniques</td>
<td>3.8</td>
<td>1.7</td>
</tr>
<tr>
<td>Ability to master various kinds of artistic drawing techniques</td>
<td>3.8</td>
<td>1.7</td>
</tr>
<tr>
<td>Ability to sketch with proper style</td>
<td>4.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Ability to access and understand the quality of a sketch</td>
<td>4.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Ability to enjoy the process of sketching</td>
<td>4.4</td>
<td>1.9</td>
</tr>
<tr>
<td>Perception roles of sketching skill</td>
<td>Industrial design students</td>
<td>Engineering design students</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-----------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Skill in drawing contour lines</td>
<td>4.7</td>
<td>1.9</td>
</tr>
<tr>
<td>Skill in line quality control</td>
<td>4.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Skill in using shading</td>
<td>4.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Skill in using drop shadow</td>
<td>3.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Skill in using of colour/tone</td>
<td>4.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Skill in using 2D drawing</td>
<td>4.4</td>
<td>1.9</td>
</tr>
<tr>
<td>Skill in using perspective drawing</td>
<td>5.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Skill in using primitive objects</td>
<td>4.5</td>
<td>1.9</td>
</tr>
<tr>
<td>(e.g. box, cylinder ...) to simplify your drawing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skill in using assistant lines</td>
<td>4.4</td>
<td>1.8</td>
</tr>
<tr>
<td>while sketching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skill in drawing human figures</td>
<td>4.3</td>
<td>1.8</td>
</tr>
<tr>
<td>and scenario</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skill in quick sketch</td>
<td>4.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Skill in arranging the layout</td>
<td>4.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Skill in handling a range of media</td>
<td>4.5</td>
<td>1.9</td>
</tr>
</tbody>
</table>

The top four roles of sketching abilities perceived by industrial design students and engineering design students were the same, i.e. ‘ability to sketch to visualise ideas’ (score: 5.2 for industrial design students, 5.1 for novice students), ‘ability to sketch to organise ideas’ (score: 5.0 for industrial design students, 5.0 for novice students), ‘ability to sketch to explore and evaluate ideas’ (score: 4.8 for industrial design students, 5.0 for novice students) and ‘ability to use sketches to communicate design thoughts to others’ (score: 5.0 for industrial design students, 5.0 for novice students), as shaded in Table 5.13. The other important role of sketching ability for expert student was ‘ability to sketch from imagery’ (score: 4.8), while for novice students was ‘ability to sketch for design analysis’ (score: 5.1).
The main roles of sketching skills (Table 5.14) perceived by industrial design students were 'skill in line quality control' (score: 4.8), 'skill in using perspective drawing' (score: 5.0) and 'skill in quick sketching' (score: 4.9), while for engineering design students were 'skill in drawing contour lines' (score: 5.0), 'skill in using perspective drawing' (score: 5.2) and 'skill in using primitive objects (e.g. box, cylinder ....etc) to simplify your drawing' (score: 5.0).

In addition to the 27 sketching abilities/skills listed in the questionnaire, the respondents added two more sketching abilities, i.e. ‘ability to sketch from observation’ and ‘ability to use the sketch for recording ideas and related design information’; and one sketching skill, i.e. ‘skill in using of annotation’.

5.3.7. Comparison of perceptions of expert and novice design students

As shown in Table 5.2, among the 79 students that responded, 36 were expert level industrial design students, 12 were novice level industrial design students, 13 were expert-level engineering design students and 18 were novice level engineering design students. The mean values of each role of sketching and sketching expertise for each of these four groups of students, i.e. 1) expert industrial design students, 2) novice industrial design students, 3) expert engineering design students, 4) novice engineering design students, were calculated and compared. According to the comparison, it was found that differences were prevalent while similarities were rare. Thus the analysis in this section chose to focus on differences. Those differences in mean values of 1 or more are selected and illustrated in Figure 5-2 to Figure 5-7. Note that this is only an approach to describe the data and not a result of statistical tests. The sample size of some subgroups was relatively small (i.e. 12 novice industrial design students, 13 expert engineering design students) and the numbers of respondents from the expert industrial design students group (36 respondents) and novice industrial design students group (12 respondents) were uneven. Therefore, it is not appropriate to apply any statistic test for reliable results.

Comparison of the perceived roles of design sketching

As shown in Figure 5-2, the expert industrial design students perceived two roles as more significant than novice industrial design students, namely, ‘expanding designer’s thoughts using mind maps, notes and annotations’ and ‘investigating the aesthetic details such as appearance, texture and scale’.
Figure 5-2. **Comparison of perceived roles of sketching for expert and novice industrial design students**

Figure 5-3 illustrates that three roles of sketching are thought to be more important for expert engineering design students than novice engineering design students, namely, ‘promoting idea generation and exploration’, ‘recalling design elements from previous experience’ and ‘investigating the aesthetic details such as appearance, texture and scale’.

Figure 5-3. **Comparison of perceived roles of sketching for expert and novice engineering design students**

As shown in Figure 5-2 and Figure 5-3, the expert design students perceived four roles of sketching as more significant than novice design students, namely, ‘expanding designer’s thoughts using mind maps, notes and annotations’, ‘promoting
idea generation and exploration’, ‘recalling design elements from previous experience’ and ‘investigating the aesthetic details such as appearance, texture and scale’. All of these four roles of sketching belong to the ‘creative roles’ category, which may indicate that expert design students tend to place more emphasis on the creative roles of sketching than novice design students, while they have similar perceptions of the general roles. Other conclusions could not be drawn.

**Comparison of the perceived roles of design sketching ability and skill**

The expert industrial design students perceived two sketching abilities (i.e. ‘ability to sketch from reference’ and ‘ability to master various kinds of technical drawing techniques’) and three sketching skills (i.e. ‘skill in using 2D drawing’, ‘skill in drawing human figures and scenario’ and ‘skill in quick sketch’) as more significant than novice industrial design students (Figure 5-4 and Figure 5-5).

![Comparison of perceived roles of sketching ability for expert and novice industrial design students](image)

Figure 5-4. Comparison of perceived roles of sketching ability for expert and novice industrial design students
It seemed that the sketching ability ‘to sketch for design analysis’ and ‘to enjoy the process of sketching’ was more significant to expert engineering design students than novice ones (Figure 5-6). As to sketching skills, there was only one remarkable difference between the two groups of students, namely, ‘skill in quick sketch’ (Figure 5-7). Other conclusions could not be drawn.
5.3.8. Comparison between industrial design students, engineering design students and graphic design students

This section compares the findings between the students from backgrounds of industrial design, engineering design and graphic design. As a complementary study to the survey of industrial design students and engineering design students, the survey of graphic design was involved to present comparative data on the roles of sketching and sketching expertise. The data were selected from a PhD project with a similar topic in the graphic design field conducted by Schenk (1989).

Comparison between industrial design students and engineering design students

The mean values of the industrial design students’ and engineering design students’ responses to the roles of sketching are compared and illustrated in Figure 5-2. It was found that engineering design students tended to assign a slightly higher level of significance than industrial design students to most of the roles of sketching. There were only two exceptions, namely ‘expanding designer’s thoughts using mind maps, notes and annotations’ and ‘promoting idea generation and exploration’, which were among the top four roles of sketching for industrial design students. The average rating score regarding the perceived roles of sketching was 4.4 for industrial design students and 4.7 for engineering design students.
Figure 5-8. *Comparison of perceived importance of sketching: expert design students and novice design students*

To identify whether there are statistically significant differences between the means, statistical analysis was conducted by using SPSS statistics software and the significance levels of the statistical tests are set as 5% (α=0.05) as a convention. The T-test was conducted to analyse the statistically significant differences of the perceived roles of sketching between industrial design students and engineering design students, as the data of all the roles' scores were normally distributed. The role ‘exploring the technical details such as function, structure and manufacturing’ yields a P value of 0.06 and no significant results were identified. In addition, according to the comparison illustrated in Figure 5-1 (overall perception) and Figure 5-8 (the perceived breakdown of roles), it seemed that engineering design students attached more
importance to sketching when compared with industrial design students. Other conclusions could not be drawn.

The perceptions of industrial design students regarding some of the sketching abilities or skills differed from those of engineering design students. Therefore this section of comparison focused on differences. Remarkable differences (defined as more than 0.5 points on the difference of mean value) between the two groups were illustrated in Figure 5-9.

Table 5.15: Comparison of perceived importance of sketching expertise: expert design students and novice design students

| Ability to master various kinds of artistic drawing techniques | 4.3 | 3.8 |
| Ability to sketch for design analysis | 5.1 | 4.6 |
| Ability to sketch from imagery | 4.8 | 3.7 |
| Ability to sketch from reference | 4.8 | 4.3 |
| Ability to sketch from memory | 4.9 | 4.0 |
| Skill in using primitive objects (e.g. box, cylinder ...etc) to simplify your drawing | 5.0 | 4.5 |
| Skill in using of drop shadow | 4.5 | 3.7 |
| Skill in line quality control | 4.8 | 3.8 |

Figure 5-9. Comparison of perceived importance of sketching expertise: expert design students and novice design students

The T-test was applied to the two groups and four statistical significant results were identified, namely, ‘ability to sketch from memory’, ‘ability to sketch from imagery’, ‘skill in line quality control’ and ‘skill in using of drop shadow’ (Table 5.15). It seemed that the preferences on internal references between the two groups of students were different, i.e. industrial design students were more likely to sketch from their mental imagery, while engineering design students might rely more on their memory during the sketching process. In addition, the sketching skills such as ‘skill in line quality control’ and ‘skill in using of drop shadow’ were believed to be more relevant to students from the industrial design background.
### Table 5.15 Comparison between industrial design students and engineering design students' perceptions of roles of sketching expertise - significant results from the T-test

<table>
<thead>
<tr>
<th>Roles of sketching ability/skill</th>
<th>Probability (P)</th>
<th>Means of industrial design students</th>
<th>Means of engineering design students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to sketch from memory</td>
<td>P=0.021</td>
<td>4.0</td>
<td>4.9</td>
</tr>
<tr>
<td>Ability to sketch from imagery</td>
<td>P=0.018</td>
<td>4.8</td>
<td>3.7</td>
</tr>
<tr>
<td>Skill in line quality control</td>
<td>P=0.026</td>
<td>4.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Skill in using drop shadow</td>
<td>P=0.050</td>
<td>3.7</td>
<td>3.0</td>
</tr>
</tbody>
</table>

### Comparison with graphic design students

As mentioned, Schenk (1989) conducted a survey on design sketching with graphic design students. Some of the results were presented in the form of percentages in this survey, which means a comparison can be easily made with results from the survey of industrial design students and engineering design students. The perceptions of roles of sketching and sketching expertise were rated on the 1-7 Likert-type scale, therefore the data collected from the questions in section 3 and section 4 of our questionnaire need to be converted into percentages so that to facilitate the comparison. The conversion method employed can be described as follows: the rating scores that equal to or greater than 4 were regarded as ‘significant’. All of the significant scores were counted and then converted to percentages. For example, if 23 out of 48 industrial design students rated 4 or more to a certain question, then the percentage regarding this question would be 23 out of 48, i.e. 47.9%.

The responses given by the three groups of design students when asked to rate the importance of sketching in the design are presented in Table 5.16. According to the results, almost all of the respondents thought that sketching was useful or essential for them. A much higher percentage of graphic design students thought sketching was essential for them than the other two groups of design students did.

### Table 5.16 Rating of the importance of sketching to design students

<table>
<thead>
<tr>
<th></th>
<th>Essential</th>
<th>Useful</th>
<th>irrelevant</th>
<th>Detrimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of industrial design students</td>
<td>27.1%</td>
<td>72.9%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No. of engineering design students</td>
<td>35.5%</td>
<td>61.3%</td>
<td>3.2%</td>
<td>-</td>
</tr>
<tr>
<td>No. of graphic design students</td>
<td>78%</td>
<td>22%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Graphic design students stressed the significance of sketching for both the development and the communication of ideas. Schenk (1989) further explained that “drawing was described as being a basic skill in terms of the design practice of graphic designers, for example, the ability to sketch enables the designer to visualise with clarity, draft out designs successfully, and gives the individual freedom of expression and the opportunity to take on a broad approach”. Data collected from the industrial design students and engineering design students showed similar results. Identified key roles include ‘promoting idea generation and exploration’ (5.0 for industrial design students and 4.9 for engineering design students), ‘investigating the aesthetic details such as appearance, texture and scale’ (4.6 for industrial design students and 5.1 for engineering design students) and ‘promoting design communication with other designers for design collaboration’ (4.9 for industrial design students and 5.1 for engineering design students). These results implied that, from the point of view of design students (industrial design, engineering design and graphic design), sketching was useful for them and played key roles in supporting design ideation and communication process. However, the graphic design students were asked only to score the general role of sketching and no statistical data could be provided for the subdivided functions. Therefore, it was impossible to compare the relevant conclusions from the industrial design and engineering design groups quantitatively.

The comparison of the importance of sketching abilities between graphic design students and industrial/engineering design students are presented in Table 5.17. Since the formulation of questions was different for the two surveys, similar questions were combined to generate comparative categories. For example, the ‘using drawing well in analysis’ in the survey of graphic design students and the ‘ability to sketch for design analysis’ in the survey of industrial/engineering design students were combined into one category ‘ability to sketch for design analysis’ for the comparison.

As presented in Table 5.17, a higher percentage of industrial and engineering design students tend to see ‘ability to sketch for design analysis’ as an important sketching ability compared with graphic design students. A much lower percentage of industrial design and engineering design students regard ‘ability to sketch to visualise ideas’ and ‘ability to sketch for design communication’ as an important sketching ability compared with graphic design students. It should be noted that all of the involved 14 respondents (100%) from the graphic design group provided the ‘Yes’ response when asked whether it was important to develop the above two sketching abilities. A high proportion of graphic design students thought ‘ability to sketch from imagery’ was a significant sketching ability for them, which was followed by industrial design students, and then engineering design students.
Table 5.17 Comparison of perceptions of roles of sketching ability between industrial/engineering design students and graphic design students

<table>
<thead>
<tr>
<th>Sketching abilities</th>
<th>Industrial design students</th>
<th>Engineering design students</th>
<th>Graphic design students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to sketch for design analysis</td>
<td>70.8%</td>
<td>77.4%</td>
<td>57%</td>
</tr>
<tr>
<td>Ability to sketch to visualise ideas</td>
<td>77.1%</td>
<td>74.2%</td>
<td>100%</td>
</tr>
<tr>
<td>Ability to sketch from imagery</td>
<td>70.8%</td>
<td>51.6%</td>
<td>93%</td>
</tr>
<tr>
<td>Ability to sketch for design communication</td>
<td>75.0%</td>
<td>74.2%</td>
<td>100%</td>
</tr>
</tbody>
</table>

The survey of graphic design students also identified several major sketching skills for designers, and they were compared with the findings from the industrial design and engineering design students. As presented in Table 5.18, perceptions of industrial and engineering design students regarding ‘skill in using 2D drawing’ were similar to those of graphic design students. A much higher percentage of industrial design and engineering design students perceived ‘skill in using 3D drawing’ as significant compared with graphic design students. A high proportion of graphic design students thought ‘skill in handling a range of media’ was significant sketching skill for them, which was followed by industrial design students and then engineering design students.

Table 5.18 Comparison of perceptions of roles of sketching skills between industrial/engineering design students and graphic design students

<table>
<thead>
<tr>
<th>Sketching skills</th>
<th>Industrial design students</th>
<th>Engineering design students</th>
<th>Graphic design students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skill in using 2D drawing</td>
<td>64.6%</td>
<td>67.7%</td>
<td>71%</td>
</tr>
<tr>
<td>Skill in using 3D drawing</td>
<td>75.0%</td>
<td>77.4%</td>
<td>57%</td>
</tr>
<tr>
<td>Skill in handling a range of media</td>
<td>70.8%</td>
<td>67.7%</td>
<td>89%</td>
</tr>
</tbody>
</table>
Other sketching abilities identified in the graphic design field included ‘theoretical appreciation of appropriate use of drawing in cultural or historical context’, ‘dexterity and manual control’, ‘using drawing well in observation’ and ‘sensitivity to the 3D spatial organisation’. As to sketching skills, it also involved ‘calligraphic skills’, ‘skill in handling specialist graphics materials’, ‘skill in tracing’, ‘skill in handling drawing instruments’ and ‘skill in airbrush techniques’. Some of them may also be of use in industrial and engineering design fields, e.g. ‘dexterity and manual control’, which would be involved in the subsequent studies.

5.4. Summary and discussion

In this section, the objectives of the survey (refer to Section 5.2) are reviewed. The appropriateness and limitations of the research method are discussed. Findings from the survey and the interpretation of the data are summarised.

5.4.1. Review of objectives of the study

Roles of sketching and sketching expertise for industrial design students and engineering design students

It was found that industrial design students’ perceptions of the roles of sketching were similar to those of engineering design students’, the former assigned slightly lower scores than the latter to most of the roles of sketching. The average rating score regarding the perceived roles of sketching was 4.4 for industrial design students and 4.7 for engineering design students. Both were higher than the average score of importance (i.e. score 4), which implied that respondents, in general, welcomed the use of sketching in design. The two groups of students agreed on the three most significant roles of sketching, i.e. ‘promoting idea generation and exploration’, ‘investigating the aesthetic details such as appearance, texture and scale’ and ‘promoting design communication with other designers for design collaboration’, which all belong to the ‘creative roles’ category (Table 5.10). In addition, it was found that both the industrial design students and engineering design students perceived non-working sketches play important roles (Table 5.13) in the design process, the average rating score was 4.3 (industrial design students) and 4.6 (engineering design students) respectively, while 4.0 was defined as significant in our study.

The study implied that sketching for design ideation formed the major roles of design sketching and were the most significant among the identified roles, followed by supporting design communication. The main roles of sketching for supporting design communication were similar for industrial design students and engineering design students. The implications of these were that means of support should focus on facilitating the ‘sketching-ideation’ process and that common means could be provided to both the industrial design students and engineering design students to
overcome barriers of design communication. However, it should be noted that different strategies should be applied according to the different needs of industrial design students and engineering design students. Industrial design students tended to see sketching as an important ideation tool at the early design stage to facilitate their visual thinking process, mainly for expanding and visualising their design thoughts, while engineering design students stressed the importance of sketching for design analysis and idea evaluation. In addition, since the perception of internal reference of industrial design students are significantly different from the engineering design students, external visual stimuli could be provided as a means of support for both of the two groups of students.

The study also suggested that sketching skills regarding shaping skills (e.g. skill in drawing contour lines and skill in using perspective drawing) were the most significant, followed by skills for using sketching tools/media (e.g. markers, needle pen, colour pencils and digital tools), rendering skills (e.g. skill in using of colour/tone) and then other supplementary skills (e.g. skill in drawing human figures and scenario). These findings indicate that rendering skills are not as important as they used to be. In traditional design sketching education, rendering skills were commonly regarded as the most significant sketching skills and the content of teaching rendering skills often occupied a large part of a sketching book (e.g. Shimizu, 1990, 2002; Liu, 2005; Pavel, 2005; Eissen and Steur, 2007; Luo, 2015). This was mainly because the rendering sketch (also known as presentation sketch) played a unique and crucial role in facilitating design presentation to the clients (see Figure 2-1). As Cross (2006) pointed out that: “...before the high-performance 3D modelling software is applied in the field, design outcomes are normally presented in the form of rendering sketches to communicate with other involved parties, which is particularly useful for decision making by non-designer (e.g. the clients)”. However, the development of CAD software has replaced the application of some types of rendering sketches which need to contain a high level of realism to fully define the appearance of products (Tovey, 1989; Chang et al., 2016) These types of sketches were extremely important in the past for selling design ideas and facilitating decision making, but they are now largely replaced by CAD photorealistic renderings. As Henry (2012) suggests that, “product design concepts are increasingly rendered in the computer for the reasons of speed, accuracy and flexibility”. Therefore the related rendering skills were not as important as they used to be and fade away together with some types of presentation sketches.

Perceptions between industrial design students and engineering design students

The top four roles of sketching abilities perceived by industrial design students and engineering design students were the same, i.e. ‘ability to sketch to visualise ideas’ ‘ability to sketch to organise ideas’, ‘ability to sketch to explore and evaluate ideas’ and ‘ability to use sketches to communicate design thoughts to others’ (Table 5.13). The top three sketching skills for industrial design students were ‘skill in line quality
control’, ‘skill in using perspective drawing’ and ‘skill in quick sketching’. The most important sketching skills for engineering design students were ‘skill in drawing contour lines’, ‘skill in using perspective drawing’ and ‘skill in using primitive objects (e.g. box, cylinder ….etc) to simplify your drawing’ (Table 5.14). The average rating score of industrial design students’ perception of sketching ability and sketching skill were 4.5 and 4.5, while that of engineering design students were 4.8 and 4.7. Both were above the average effectiveness (i.e. score 4), which implied that respondents in general thought sketching expertise was important for them. As Lawson (2006) points out that design is a highly “complex and sophisticated” work, which requires designers to “use their utmost ability of thinking and sketching skill to propose a design solution”. The implication of these findings is that practical supporting tool (including tools and methods) for design sketching should be made available to design students mainly focusing on improving their sketching expertise. The major perception of the roles of design sketching differed from industrial design students to engineering design students, and it seemed that engineering design students tend to attach more importance to sketching expertise when compared with industrial design students. The average rating score of industrial design students' perception of the roles of design sketching was 4.4, while that of engineering design students was 4.7. In addition, the average score of engineering design students was slightly higher than industrial design students, which might suggest that engineering design students perceived sketching as more significant than industrial design students.

No statistically significant differences in perceptions of the roles of sketching were found between industrial design students and engineering design students, while four significant results were identified when comparing the perceptions of sketching expertise between the two groups. A number of remarkable differences were found in the perceptions of sketching and sketching expertise between expert and novice design students. The implications of these were that the development of teaching material should have its focuses based upon the similarities between industrial design students and engineering design students, and also to be inclusive by balancing the identified differences between them (Pei, 2009).

**Perceptions of industrial/engineering design students compared with those of the graphic design students**

The results from the cross-disciplinary comparison showed that the 'ability to sketch for design analysis' was perceived by a larger percentage of industrial/engineering design students as major sketching ability when compared with graphic design students. ‘Ability to sketch from imagery’ was perceived to be less important by engineering design students compared with industrial design students and graphic design students. This may be because the design focus of engineering design students is different from industrial design students and graphic design students. Engineering design students use sketching to facilitate their design analysis and exploration for technical details, e.g. function, structure and manufacturing (Schütze, Sachse and Römer, 2003), while industrial/graphic design students rely much on
sketching for visual thinking and aesthetic reasons, e.g. appearance, layout and appropriate style (H. Chen, You and Lee, 2003; Stones and Cassidy, 2010).

More industrial/engineering design students tend to regard ‘skill in using 3D drawing’ as an effective sketching skill for the design process compared with graphic design students. This may be due to the differences in the design objects between industrial/engineering design and graphic design. The comparisons between the perceptions of students from industrial design, engineering design and graphic design were restricted by the available data and thus other conclusions could be drawn.

**Hypothesis testing**

The differences in perceptions of major sketching expertise between industrial design students and engineering design students partially supported **Hypothesis 2: The perception of design sketching may be different for designers with different expertise**. In addition, the comparison between expert design students and novice design students suggested that the perceived roles of sketching and sketching expertise might differ for students with different levels of experience. It should be noted that the sample size did not accommodate an appropriate statistical test on this.

The top three perceived roles of sketching in design, i.e. ‘promoting idea generation and exploration’, ‘investigating the aesthetic details such as appearance, texture and scale’ and ‘promoting design communication with other designers for design collaboration’ all belong to the ‘creative roles’ category. For both industrial design students and engineering design students, the most significant sketching ability was ‘ability to sketch to visualise ideas’. These results suggest the ‘cognitive benefits’ that design students can expect from the use of sketching in design, i.e. supporting design exploration of possible ideas and aesthetic details, and facilitating design expression and communication. There is a large body of design literature (e.g. Goldschmidt, 1991; Goel, 1995; Suwa, Gero and Purcell, 1998; Stubbs, 2006; Tversky and Suwa, 2009; Schön, 2017) focusing on the cognitive actions of ‘generation’ and ‘interpretation’ in sketching. This research confirms the importance of the study on the ‘generation’ effect and highlights the needs for understanding the ‘production’ part of the cyclic sketching process. These findings partially support **Hypothesis 3: Understanding the cognitive interplay between sketching and design ideation process may be of use to both design academics and practitioners**.

The engineering design students rated a relatively high score of 4.8 to the sketching ability that ‘sketch from reference’ and the industrial design students rated it 4.3 (4.0 was defined as significant). 65.8% of involved design students regarded ‘searching for visual reference’ as an effective sketching habit to facilitate their design process. The breakdown of their preferences for types of references is presented in Table 5.6. A high percentage of respondents (i.e. 78.5%) showed their interests in receiving different types of sketching instruction (e.g. learning from books, website, videotape and course training). The data support **Hypothesis 4: External stimuli and sketching instruction can be helpful in supporting the design sketching process**.

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5.4.2. Critique of the research methodology

An online survey was employed and turned out as an appropriate method for this study. It proved to be effective as the required data were successfully collected. However, it is believed that self-administered surveys often have some limitations (Robson, 2011), for example:

- The response rate is often too low
- Questionnaires may result in incomplete answers
- The survey questions may not be perceived correctly because of the potential ambiguity and misunderstanding of the questions
- Conclusions could not be drawn based on data from subsamples that were too small

Bearing these problems in mind, a number of strategies were employed to minimise the disadvantages. Two different strategies were adopted for pre-contacting the potential participants, i.e. directly sending emails to target students or sending emails to the course tutors of target universities (e.g. Zhejiang Normal University) with a request to distribute the questionnaires among their students. In addition, the respondents who did not respond or complete the questionnaire were contacted again as a reminder so that to increase the response rate. The final response rate was 48.1% (useful response rate was 43.2%), which was higher than the general response rate, i.e. 32.6% for online surveys (Watt et al., 2002). The majority of the respondents completed the questionnaire well. In total, 79 of the completed questionnaires were identified as useful.

The method of multi-comparisons was adopted to facilitate data analysis. Remarkable differences were found when comparisons were made between expert level industrial design students and novice level industrial design students and between expert-level engineering design students and novice level engineering design students. However, after two rounds of grouping, the number of subsamples in some subgroups was too small, i.e. 12 students involved in the novice industrial design students group and 13 students involved in the expert engineering design students group. The data gathered from such a small sample would have a large margin of sampling error. It is not appropriate to apply any statistic test for reliable results. Therefore, remarkable results were only described in Section 5.6.7 while no significant conclusions could be drawn.

Attitudes and perceptions can change quickly, especially in the design fields due to the fast-changing design context and development of CAD technology. Therefore, the study was carried out to gain insights and understanding of design sketching, rather than looking for accurate analysis of current perceptions. Although it can be difficult to interpret some of the results which were not significant, the data collected have provided insights into the approaches for supporting design sketching and also helped with the hypotheses testing.
5.5. Conclusions

This survey explored the industrial design students’ and engineering design students’ perceptions of sketching and sketching ability for design. It was found that industrial design students’ perceptions of sketching were similar to those of engineering design students, while industrial design students’ perceptions of major sketching abilities differed from those of engineering design students. Both the industrial design students and engineering design students perceived sketching as an important ideation tool. However, industrial design students were more likely to perceive that sketching was important for idea generation and communication, while engineering design students tend to use sketching as an effective tool for design analysis. These findings suggested that sketching for design ideation formed the major roles of design sketching and were the most significant. Therefore, the means of support should focus on facilitating the ‘sketching-ideation’ process first. Support should also be provided to facilitate design communication. In addition, the perceived differences between industrial design students and engineering design students should also be taken into consideration while the development of sketching supporting tools.

‘Ability to sketch from imagery’ was less effective sketching ability for engineering design students when compared with graphic design students, instead, the ‘ability to sketch for design analysis’ seemed to play a significant role in the industrial/engineering design process. In addition, it seemed that the perceptions of expert-level design students regarding design sketching differed from those of novice level design students. This finding supported some of the previous studies (e.g. Verstijnen et al., 1998; Casakin and Goldschmidt, 1999; Kavakli and Gero, 2001) conducted in the field, which can be a hypothesis for future research.

Data collected from this study support (or are at least consistent with) three research hypotheses, namely:

Hypothesis 2: The perception of design sketching may be different for designers with different expertise.

Hypothesis 3: Understanding the cognitive interplay between sketching and design ideation process may be of use to both design researchers and practitioners and educators.

Hypothesis 4: External stimuli and sketching instruction can be helpful in supporting the design sketching process.

It should be noted that Hypothesis 2 is only valid for major sketching expertise and Hypothesis 3 confirmed the importance of the study on two elements (i.e. idea generation and idea expression) in the Ideation Segment model.
Chapter Six: Understanding the Supporting Roles of Sketching for Design Professionals

6.1. Introduction

This chapter presents the results and findings from a survey of perceptions of sketching in design among design professionals. Design professionals in this project refer to professional designers or academics from industrial or engineering design backgrounds. The perceptions of the professionals surveyed are compared with perceptions of design students. As discussed in Section 5.1, the survey method was employed for this study. Both quantitative methods (e.g. statistical tests) and qualitative methods (e.g. coding and clustering) were adopted to facilitate the data analysis.

6.2. Setting-up of the survey

As a complementary study to the survey of industrial design students and engineering design students (Chapter 5), this study was carried out with a similar objective: exploring perceptions of sketching in design. Specifically, the survey among design students identified that expert students and novice students tended to interpret sketching differently (refer to Section 5.3.7), which suggested that experience may play a key role in affecting the students' perceptions of design sketching. Therefore this phenomenon was investigated further by involving design professionals (i.e. professional designers and design researchers/educators) and comparing the results with those from design students. In addition, the findings from the survey of industrial design students and engineering design students suggested that a practical supporting tool should be developed for design sketching. However, it did not elicit detailed requirements for the content and format of the supporting tool (refer to Section 3.2.2). Thus the objectives of this study were:

- To identify the perceived roles of sketching for design professionals
- To identify the perceived roles of sketching expertise for design professionals
- To capture requirements on developing a practical supporting tool for design sketching
- To collect data to further test and verify the research hypotheses
6.2.1. Questionnaire design

Since this study was carried out with new research objectives and involved different targeted participants (i.e. professional designers and design academicians), the content and format of the questionnaire had to be redesigned accordingly.

The redesign of the questionnaire (professional category) followed the instructions from the ‘Total Design Method’ (Dillman, Smyth and Christian, 2014) which is a widely adopted methodology for planning online surveys. This study planned to involve professional designers, so the visual design (e.g. the layout) of the questionnaire also needed to be improved. Therefore good practices on questionnaire design (Robson, 2011; Dillman, Smyth and Christian, 2014) were referenced.

The content of the questionnaire was mainly based on the questionnaire of students category and also with reference to the existing questionnaires from several PhD projects (Schenk, 1989; Yusoff, 2007; Gharib, 2013). Changes were made when related to the new research objectives, e.g. question about the content requirement regarding supporting tools for design sketching was added. In addition, findings from the previous survey were also added to the redesigned questionnaire, for example, the new sketching expertise identified, i.e. ‘ability to sketch from observation’, ‘ability to use sketching for recording’ and ‘skill in using of annotation’.

The draft of the questionnaire was pilot-tested before its distribution. Six design experts (i.e. professional designers and design academicians) from both industry and academia were involved. Their feedback was used to improve the quality of the questionnaire. The questions of the final version of the questionnaire were divided into six sections, which can be described as follows:

Section 1: general information about the participants, e.g. the education background of the participants;

Section 2: general questions about sketching, e.g. participants' sketching experience and sketching habits;

Section 3: perceptions of roles of sketching in design, e.g. the role of talking sketch;

Section 4: perceptions of roles of sketching abilities and sketching skills in design, e.g. the role of perspective drawing skill;

Section 5: requirements of content and format regarding supporting tools for design sketching;

Section 6: other information of interest, e.g. the willingness of the participants to give further comments and suggestions.

This study adopted a similar method used in the survey of design students. The 1-7 Likert-type scale was employed to scale the responses for the questions in Section 3 and Section 4. However, a small change was made to the blank space designed for participants to add comments. Specifically, the questionnaire was designed to lead
the participants to make comments before they started to rate the fixed alternatives. There were two reasons for these changes:

1. to encourage participants to give more comments
2. to minimise bias caused by the fixed alternatives

A sample of redesigned question is presented as below (Figure 6-1):

5. Second 3 (The importance of design sketching)

What do you think would be the important roles of sketching for supporting design process?
Please write down the first couple you immediately think of.

Please rate how significant you consider the following roles of sketches to designers/design process. (1: least effective —— 7: most effective) *

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defining and clarifying the design task</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expanding designer’s thoughts using mind maps, notes and annotations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6-1 Sample question (screenshot of the online questionnaire)

According to feedback from the survey of design students, a few additional sketching expertise, e.g. ‘ability to sketch from observation’, were added to the redesigned questionnaire for design professionals. A copy of the final version of the questionnaire is given in Appendix C.

6.2.2. Survey procedure

The survey was distributed following two steps:

1. Distribution: Invitations were sent to individuals in the UK and China via emails and social media (e.g. WhatsApp, Facebook, Tencent QQ and WeChat), together with a link to our online questionnaire and a covering letter (explaining the purpose of the study and the structure of the questionnaire).

2. Reminder to the non-respondents and incomplete respondents: The respondents who completed the questionnaire were acknowledged via email or social media. On the contrary, the respondents who didn’t complete the questionnaire were contacted again as a reminder. An email attached with the questionnaire and covering letter was sent to them again a couple of days after the initial distribution.
6.2.3. Method of analysis

Both qualitative and quantitative methods were employed to facilitate data analysis. The method used for qualitative analysis was similar to that used in the pilot study (Section 4.2.3), i.e. ‘coding and clustering’ and counting recurrence of comments; the same analysis method used in the previous survey (Section 5.2.3) was adopted for quantitative data analysis, i.e. descriptive statistics and inferential statistics. Comments gathered from each section (spontaneous comments) and the end of the questionnaire (general comments) was clustered, grouped and then discussed under each topic (e.g. ‘the roles of sketching in design’ or ‘the preference of design professionals for sketching supporting tools’). In addition, example quotations of typical comments were also presented to facilitate the analysis and discussion.

6.3. Results and findings

6.3.1. Profile of respondents

161 design professionals were invited to participate in the survey to complete an online questionnaire. 66 responses (41.0% of the total sample) were received in total, among which 51 (31.7%) questionnaires were completed while 15 (9.30%) were incomplete.

The profiles of the respondents are presented in Table 6.1 to Table 6.5

Table 6.1 Profile of respondents - workgroup of the design professionals

<table>
<thead>
<tr>
<th>Category of work</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designers</td>
<td>29</td>
</tr>
<tr>
<td>Design academics</td>
<td>22</td>
</tr>
<tr>
<td>Total</td>
<td>51</td>
</tr>
</tbody>
</table>

Table 6.2 Profile of respondents - age group of the design professionals

<table>
<thead>
<tr>
<th></th>
<th>&lt;20</th>
<th>20-25</th>
<th>26-30</th>
<th>31-35</th>
<th>36-40</th>
<th>&gt;40</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of designers</td>
<td>0</td>
<td>1</td>
<td>22</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td>No. of design academics</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>12</td>
<td>0</td>
<td>22</td>
</tr>
</tbody>
</table>
Table 6.3 Profile of respondents - gender group of the design professionals

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of designers</td>
<td>5</td>
<td>24</td>
<td>29</td>
</tr>
<tr>
<td>No. of design academics</td>
<td>12</td>
<td>10</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 6.4 Profile of respondents - years of working of the design professionals

<table>
<thead>
<tr>
<th></th>
<th>&lt;3</th>
<th>3-5</th>
<th>6-10</th>
<th>11-15</th>
<th>16-20</th>
<th>&gt;20</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of designers</td>
<td>8</td>
<td>17</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td>No. of design academics</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>0</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 6.5 Profile of respondents - education background of the design professionals

<table>
<thead>
<tr>
<th></th>
<th>Undergraduate</th>
<th>Postgraduate</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of designers</td>
<td>6</td>
<td>23</td>
<td>29</td>
</tr>
<tr>
<td>No. of design academics</td>
<td>1</td>
<td>21</td>
<td>22</td>
</tr>
</tbody>
</table>

6.3.2. Perceived importance of sketching and sketching expertise to design professionals

The responses were given by the design professionals when asked to rate the importance of sketching, including the breakdown according to their occupational background (i.e. professional designer and design academics), as shown in Table 6.6. Among the 51 respondents, 18 (35.3%) of them thought sketching was an essential tool in design and 32(62.7%) of them thought sketching was useful. There was only one respondent who thought that the sketching was irrelevant. In addition, none of the respondents thought that sketching was detrimental.
Table 6.6 Rating of the importance of sketching to design professionals

<table>
<thead>
<tr>
<th></th>
<th>Essential</th>
<th>Useful</th>
<th>irrelevant</th>
<th>Detrimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of designers</td>
<td>11 (37.9%)</td>
<td>18</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No. of design academics</td>
<td>7 (31.8%)</td>
<td>14 (63.6%)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>18 (35.3%)</td>
<td>32 (62.7%)</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

When asked about the importance of expertise in design sketching, 18 (35.3%) of the respondents considered it was essential to develop the sketching expertise for industrial and engineering designers, whereas 32 (62.7%) felt it would be useful. There was only one respondent who thought that the sketching expertise was irrelevant. And none of the respondents thought that the sketching expertise was detrimental. The data is set out in Table 6.7.

Table 6.7 Rating of the importance of sketching expertise to design professionals

<table>
<thead>
<tr>
<th></th>
<th>Essential</th>
<th>Useful</th>
<th>irrelevant</th>
<th>Detrimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of designers</td>
<td>10 (34.5%)</td>
<td>19</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No. of design academics</td>
<td>8 (36.4%)</td>
<td>13 (59.1%)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>18 (35.3%)</td>
<td>32 (62.7%)</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

According to the results, it was found that almost all of the respondents thought that both sketching and sketching expertise was important (i.e. essential and useful) in design. There was only one respondent selected irrelevant for each question. No remarkable difference could be found when comparing the perceived importance of sketching and sketching expertise between professional designers and design academics. Other conclusions could not be drawn.

6.3.3. The preference of design professionals for sketching tools and reference sources

This section includes two questions to investigate the preference of design professionals regarding sketching tools and types of references. They were told more than one answers could be selected for the questions in this section.

For the tools or the medium that design professionals prefer to use in sketching, 18 (35.3%) respondents prefer to use pencil and paper, 20 (39.2%) prefer to use pen and paper, and 4 (7.8%) chose to use colours and paper. In total 42 (82.4%) of the
respondents showed their preference for paper-based freehand sketching while the rest 11 (13.9%) of respondents prefer to visualize their ideas with CAD systems (see Table 6.8). It seems that design professionals have a clear preference for paper-based freehand sketching rather than CAD systems supported sketching.

Table 6.8 Design professionals' preference regarding sketching tools

<table>
<thead>
<tr>
<th>Sketching tools</th>
<th>No. of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pencil and paper</td>
<td>18 (35.3%)</td>
</tr>
<tr>
<td>Pen and paper</td>
<td>20 (39.2%)</td>
</tr>
<tr>
<td>Colours and paper</td>
<td>4 (7.8%)</td>
</tr>
<tr>
<td>CAD systems (e.g. Photoshop,)</td>
<td>9</td>
</tr>
</tbody>
</table>

Respondents were asked to select their preferred sources of references, i.e. internet, memory, daily life, natural environment, books, imagination and existing designs. According to the results, ‘reference from the internet’ was selected in a high proportion, with 44 respondents reaching 86.3%, which was followed by ‘reference from books/magazines’ with 31 (60.8%) respondents, ‘reference from observation in daily life’ with 27 (52.9%) respondents and ‘reference from existing designs’ with 26 (51.0%) respondents. The rest of the options were selected at a relatively low percentage of less than 50% (see Table 6.9).

Table 6.9 Design professionals' preference regarding types of references

<table>
<thead>
<tr>
<th>Sources of references</th>
<th>No. of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference from internet</td>
<td>44 (86.3%)</td>
</tr>
<tr>
<td>Reference from memory</td>
<td>16 (31.4%)</td>
</tr>
<tr>
<td>Reference from observation in daily life</td>
<td>27 (52.9%)</td>
</tr>
<tr>
<td>Reference from the natural environment</td>
<td>18 (35.3%)</td>
</tr>
<tr>
<td>Reference from books/magazines</td>
<td>31 (60.8%)</td>
</tr>
<tr>
<td>Reference from imagination</td>
<td>18 (35.3%)</td>
</tr>
<tr>
<td>Reference from existing designs</td>
<td>26 (51.0%)</td>
</tr>
<tr>
<td>Others</td>
<td>1 (2.0%)</td>
</tr>
</tbody>
</table>
6.3.4. The perception of sketching habits for design professionals

The respondents' preferences regarding sketching habits and their perceived roles in the design are summarised in Table 6.11 and Table 6.12. The top three preferences for sketching habits were 'listening to the music', 'searching for visual reference' and 'drawing something irrelevant'. Specifically, 29 (56.9%) respondents suggested that they would like to listen to music while they were sketching, 33 (64.7%) respondents thought visual reference could be helpful while sketching and 28 (54.9%) respondents liked to draw something irrelevant to the design object in their design sketching process.

There were only 6 (11.8%) respondents who showed their interests in eating something while they are sketching; whilst 19 (37.3%) were found that they had some habitual actions (e.g. pen spinning). There were also three respondents who suggested that they have other sketching habits and two of them further specified, i.e. sketching at night; drinking wine while sketching.

Table 6.10 Design professionals' preference regarding sketching habits

<table>
<thead>
<tr>
<th>Personal sketching habits</th>
<th>No. of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Listening to music while sketching</td>
<td>29 (56.9%)</td>
</tr>
<tr>
<td>Eating snacks while sketching</td>
<td>6 (11.8%)</td>
</tr>
<tr>
<td>Searching for visual reference</td>
<td>33 (64.7%)</td>
</tr>
<tr>
<td>Doing some form of habitual actions (e.g. pen spinning, crack knuckles ... etc)</td>
<td>19 (37.3%)</td>
</tr>
<tr>
<td>Drawing something irrelevant (e.g. line practice, doodle, cartoon figures ... etc)</td>
<td>28 (54.9%)</td>
</tr>
<tr>
<td>Others</td>
<td>3 (5.9 %)</td>
</tr>
</tbody>
</table>

According to the results showed in Table 6.12, 20 (39.2%) of the respondents thought these sketching habits may help them to relax; a higher proportion, 23 (45.1%) of the respondents chose 'helping them to focus'; 41 (80.4%) of the respondents chose 'helping to inspire new ideas'; 31 (60.8%) of the respondents chose 'helping them to quickly enter the drawing state' and 28 (54.9%) of the respondents chose 'helping them to feel comfortable and confident with the task ahead'. However, there were still 9 (17.6%) respondents who answered 'they do not know why they like to keep these habits'. In addition, 2 (3.9%) respondents suggested that sketching habits may serve other purposes in the sketching process, but none of them further explained the question.
Table 6.11 *Perceived roles of sketching habits*

<table>
<thead>
<tr>
<th>Perceived roles of sketching habits in design</th>
<th>No. of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helping to calm down and relax</td>
<td>20 (39.2%)</td>
</tr>
<tr>
<td>Helping to focus and concentrate on the task</td>
<td>23 (45.1%)</td>
</tr>
<tr>
<td>Helping to inspire new ideas</td>
<td>41 (80.4%)</td>
</tr>
<tr>
<td>Helping to warm up and quickly enter the drawing state</td>
<td>31 (60.8%)</td>
</tr>
<tr>
<td>Helping to feel comfortable and confident with the task ahead</td>
<td>28 (54.9%)</td>
</tr>
<tr>
<td>Do not know, simply like to do it</td>
<td>9 (17.6%)</td>
</tr>
<tr>
<td>Others</td>
<td>2 (3.9%)</td>
</tr>
</tbody>
</table>

6.3.5. *Perceived roles of sketching for design professionals*

In the survey questionnaire for design professionals, two sets of questions were designed to explore their perceived roles of sketching in design, i.e. the roles of ‘working sketches’ and the roles of ‘non-working sketches’. The results are presented according to the sequence of the answers, i.e. 1) spontaneous comments; 2) ratings of the fixed alternatives; 3) general comments. A brief summary is also provided afterwards. Table 6.12 presented the summarised comments on the roles of working sketches; whilst the ratings on the roles of working sketches are presented in Table 6.13. High values are marked in grey.
### Table 6.12 Comments on the roles of ‘working sketches’

<table>
<thead>
<tr>
<th>Roles of ‘working sketches’</th>
<th>No. of mentions</th>
<th>Example of comments (quotation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarifying the design tasks</td>
<td>2</td>
<td>“Helping to understand the design problems”</td>
</tr>
<tr>
<td>Exploring design ideas</td>
<td>9</td>
<td>“Sketching stimulates the imagination, it is the development of an idea itself”</td>
</tr>
<tr>
<td>Recording design ideas</td>
<td>5</td>
<td>“Sketching book is my inspiration for design”</td>
</tr>
<tr>
<td>Developing design ideas</td>
<td>7</td>
<td>“The process of creating a design or illustration at later stages involves refinement”</td>
</tr>
<tr>
<td>Facilitating design analysis</td>
<td>3</td>
<td>“Sketching is an essential design analysis tool. It makes the step-by-step analysis process visible and organised”</td>
</tr>
<tr>
<td>Exploring appearance details, e.g. shape, texture, finish and colour of the product</td>
<td>6</td>
<td>“Exploring forms in the space”</td>
</tr>
<tr>
<td>Facilitating design evaluation and decision making</td>
<td>2</td>
<td>“Sketching is the best way to facilitate iterative evaluation-to see if the ideas are worth exploring further”</td>
</tr>
<tr>
<td>Communication with other designers</td>
<td>10</td>
<td>“Great for collaborating with other designers”</td>
</tr>
<tr>
<td>Communication with technician</td>
<td>3</td>
<td>“Communicating ideas with engineers”</td>
</tr>
<tr>
<td>Communication with clients</td>
<td>5</td>
<td>“Drawing to tell a visual story to clients”</td>
</tr>
<tr>
<td>Other</td>
<td>1 (for each)</td>
<td>“for each)o tell to separate concepts from details”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Sketching helps to communicate with users”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“The sensory experience of sketching engages creative thinking and exploration, including unexpected happy accidents.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Having fun at work”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Helping evaluate the feasibility of features”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Sketching is a timesaver”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Sketching is a good option for me to be an idea and problem-solving thinker”</td>
</tr>
</tbody>
</table>
Table 6.13 Design professionals’ perceived roles of ‘working sketching’ in design

<table>
<thead>
<tr>
<th>Perception roles of working sketching</th>
<th>Design Professionals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Defining and clarifying the design task</td>
<td>4.4</td>
</tr>
<tr>
<td>Expanding designer's thoughts using mind maps, notes and annotations</td>
<td>4.9</td>
</tr>
<tr>
<td>Recalling design elements from previous experience</td>
<td>5.0</td>
</tr>
<tr>
<td>Promoting idea generation and exploration</td>
<td>4.8</td>
</tr>
<tr>
<td>Facilitating idea evaluation and selection</td>
<td>4.6</td>
</tr>
<tr>
<td>Investigating the aesthetic details such as appearance, texture and scale</td>
<td>4.5</td>
</tr>
<tr>
<td>Exploring the technical details such as function, structure and manufacturing</td>
<td>4.4</td>
</tr>
<tr>
<td>Promoting design communication with other designers for design collaboration</td>
<td>5.1</td>
</tr>
<tr>
<td>Promoting design communication with engineers regarding technical points</td>
<td>4.7</td>
</tr>
<tr>
<td>Promoting design communication with clients regarding product appearance, function and scenario</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Spontaneous comments on the roles of ‘working sketches’: the most frequently cited role was ‘communication with other designers’. The second and third major roles of working sketches were also relevant to design ideation, i.e. ‘exploring design ideas’ and ‘developing design ideas’. The fourth major role of the working sketch was ‘exploring appearance details’.

Ratings on the roles of ‘working sketches’: the highest rating score was assigned to ‘promoting design communication with other designers for design collaboration’, and the second-highest to ‘recalling design elements from previous experience’. The third and the fourth-highest scores assigned to ‘expanding designer’s thoughts using mind maps, notes and annotations’ and ‘promoting idea generation and exploration’, both of
which are relevant to the idea generation process.

General comments: four general comments were relevant to the roles of ‘working sketches’, namely:

- Work together with other ideation tools: “sketching is very useful for brainstorming ideas and collaborating with team members.”

- Workflow: “a crossover workflow of using sketching and 3D development software could offer a much richer, faster and practical approach, which often leads to better solutions.”

- Designer’s willingness: “Almost all of the designers will use sketching in the design process to some degree”.

- Client relation: “Sketching is the best way to communicate ideas with the client, its immediacy and personal touch will never be matched by a print-out which is good for client relations.”

Both high frequencies of mentions and high rating scores are indicators of importance. Although the major comments on and ratings of the roles of ‘working sketches’ are ranked in a slightly different order, the results suggest that ‘idea exploration/generation’ and ‘design commutation with other designers/technician’ are the most important roles of ‘working sketches’ in design.

One designer’s comments indicated that sketching is also important for idea development:

“I think the value of sketching as a tool for conceptual design is not limited to a specific phase in the design process. In my experience as a designer, I use both low and high fidelity sketches throughout the whole process and find myself developing concepts at every stage of the design. The only difference is the level of abstraction of the subject that will often shift from scenario-based sketches to more concrete sketches of objects and interfaces to an exploration of design and engineering details. I think it is important to recognize this fact and emphasize the value of sketching at all stages of the design process.”

The comments and ratings on the roles of ‘non-working sketches’ in the design are summarized and presented in Table 6.14 and Table 6.15 respectively.
Table 6.14 Comments on the roles of ‘non-working sketches’

<table>
<thead>
<tr>
<th>Roles of ‘non-working sketches’</th>
<th>No. of mentions</th>
<th>Example of comments (quotation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sketching to practice drawing skills</td>
<td>7</td>
<td>“Sketching skills are important for designers, however, it requires a lot of time to practice”</td>
</tr>
<tr>
<td>Sketching as visual notes</td>
<td>12</td>
<td>“Designers can sketch at anywhere to record their impressions, ideas, or good designs”</td>
</tr>
<tr>
<td>Sketching for fun</td>
<td>8</td>
<td>“Rest and relaxation is one of the main advantages of sketching, as a hobby”</td>
</tr>
<tr>
<td>Other</td>
<td>1 (for each)</td>
<td>“Helping developing one’s abilities, e.g. focus and pay attention, hand-eye coordination”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Sketching can build your self-esteem and confidence through your sketches as you become better and better”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Sketching is a good way to facilitate thinking”</td>
</tr>
</tbody>
</table>

Table 6.15 Design professionals’ perceived roles of ‘non-working sketching’ in design

<table>
<thead>
<tr>
<th>Perception roles of Non-working sketching</th>
<th>Design Professionals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Sketching as a practice to improve their sketching techniques</td>
<td>3.8</td>
</tr>
<tr>
<td>Sketching as a warm-up exercise at the initial design stage to let designers quickly enter the sketching state</td>
<td>4.2</td>
</tr>
<tr>
<td>Sketching for fun and enabling designers to play with sketches and ideas</td>
<td>4.5</td>
</tr>
<tr>
<td>Sketching for emotional and aesthetic expression</td>
<td>4.3</td>
</tr>
<tr>
<td>Keeping sketches as records for future reference (e.g. sketch notebooks, sketch diaries ....etc)</td>
<td>4.7</td>
</tr>
</tbody>
</table>
Spontaneous comments on the roles of non-working sketches: ‘sketching as visual notes’ was the most frequently cited role of non-working sketches. Eight comments were found to be relevant to the role of ‘sketching for fun’ and seven comments were found to be relevant to the role ‘sketching to practice drawing skills’.

Ratings on the roles of non-working sketches: the top two rating score was assigned to ‘keeping sketches as records for future reference’ and ‘sketching for fun and enabling designers to play with sketches and ideas’.

General comments: two general comments were relevant to the roles of non-working sketches, namely:

- Visual thinking tool: “Sketching gives you a unique space which can help you think differently.”
- Sketching practice: “Getting comfortable with sketching in the design process requires practice and repetition, which makes all the difference”.

It was found that the key results were similar when compared the comments on and ratings of the roles of non-working sketches in design. In addition, these results were consistent with the findings from the previous pilot study (see Chapter 4).

It is interesting to find that ‘sketching as a hobby’ was cited by nearly one-third of the respondents (Table 6.14) as an important role of non-working sketches. Similar comments were also found from Table 6.12, i.e. ‘having fun at work’. These results may suggest that many designers love sketching and can have fun with it both at work and in leisure situations.

6.3.6. Perceived roles of sketching abilities and skills for design professionals

The respondent’s comments on and ratings of the roles of sketching abilities and skills are summarised in Table 6.16, Table 6.17 (sketching abilities, e.g. ‘ability to use sketches to communicate design thoughts to others’) and Table 6.18 (sketching skills, e.g. ‘line drawing skills’).
Table 6.16 Comments on the roles of sketching expertise

<table>
<thead>
<tr>
<th>Types of sketching abilities or skills</th>
<th>No. of mentions</th>
<th>Example of comments (quotation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to use sketching for design collaboration</td>
<td>18</td>
<td>“Good sketching is an invitation for discussion”</td>
</tr>
<tr>
<td>Ability to use sketching for design ideation</td>
<td>11</td>
<td>“Sketching is an amazing skill which lets you work through ideas on paper in the most fun and effective way”</td>
</tr>
<tr>
<td>Quick drawing skills</td>
<td>9</td>
<td>“Freehand sketching is often the quickest way to get thoughts noted down”</td>
</tr>
<tr>
<td>Structure sketch skills (e.g. line drawing and perspective drawing)</td>
<td>7</td>
<td>“If your lines are fluent, your ideas will flow as well”</td>
</tr>
<tr>
<td>Rendering skills</td>
<td>5</td>
<td>“Rendering has been an essential part of design commutation from the very beginning of industrial design”</td>
</tr>
<tr>
<td>Other</td>
<td>1 (for each)</td>
<td>“Sometimes, sketching is also about personal expression, your style can help you to better sell your idea”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Good sketching skills gives me confidence, greater confidence often leads to better design results”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Sketching is about exploring and express ideas, rather than making perfect drawings”</td>
</tr>
</tbody>
</table>
Table 6.17 *Design professionals’ perceptions of roles of sketching abilities*

<table>
<thead>
<tr>
<th>Perception roles of sketching ability</th>
<th>Design Professionals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Ability to sketch from memory</td>
<td>4.9</td>
</tr>
<tr>
<td>Ability to sketch from reference</td>
<td>3.9</td>
</tr>
<tr>
<td>Ability to sketch from observation</td>
<td>4.2</td>
</tr>
<tr>
<td>Ability to sketch to visualise ideas</td>
<td>4.7</td>
</tr>
<tr>
<td>Ability to sketch to organise ideas</td>
<td>4.9</td>
</tr>
<tr>
<td>Ability to sketch to explore and evaluate ideas</td>
<td>4.7</td>
</tr>
<tr>
<td>Ability to sketch for design analysis</td>
<td>4.8</td>
</tr>
<tr>
<td>Ability to use sketches to communicate design thoughts to others</td>
<td>4.9</td>
</tr>
<tr>
<td>Ability to use sketches to instruct others</td>
<td>4.6</td>
</tr>
<tr>
<td>Ability to master various kinds of technical drawing techniques</td>
<td>4.5</td>
</tr>
<tr>
<td>Ability to master various kinds of artistic drawing techniques</td>
<td>4.2</td>
</tr>
<tr>
<td>Ability to sketch with proper style</td>
<td>4.1</td>
</tr>
<tr>
<td>Ability to access and understand the quality of a sketch</td>
<td>4.5</td>
</tr>
<tr>
<td>Ability to enjoy the process of sketching</td>
<td>4.4</td>
</tr>
<tr>
<td>Ability to use sketching for recording</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Spontaneous comments on the roles of sketching abilities: the most frequently cited type of sketching ability was ‘*using sketching for design collaboration*’, followed by ‘*using sketching for design ideation*’.

Ratings on the roles of ‘*sketching abilities*’: the highest rating score (4.9) was assigned to three types of sketching abilities, namely ‘*ability to sketch from memory*’,
‘ability to sketch to organise ideas’ and ‘ability to use sketches to communicate design thoughts to others’.

General comments: no general comments were received relevant to the roles of ‘sketching ability’.

In general, the comparison between comments on and ratings of the roles of sketching abilities in design suggested similar key results, i.e. supporting design ideation (organizing ideas) and supporting design communication.

Table 6.18 Design professionals’ perceptions of roles of sketching skills

<table>
<thead>
<tr>
<th>Perception roles of sketching skill</th>
<th>Design Professionals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Skill in drawing contour lines</td>
<td>4.8</td>
</tr>
<tr>
<td>Skill in line quality control</td>
<td>4.6</td>
</tr>
<tr>
<td>Skill in using shading</td>
<td>4.1</td>
</tr>
<tr>
<td>Skill in using the drop shadow</td>
<td>4.0</td>
</tr>
<tr>
<td>Skill in using colour/tone</td>
<td>4.1</td>
</tr>
<tr>
<td>Skill in using 2D drawing</td>
<td>4.5</td>
</tr>
<tr>
<td>Skill in using perspective drawing</td>
<td>4.8</td>
</tr>
<tr>
<td>Skill in using primitive objects (e.g. box, cylinder ....etc) to simplify your drawing</td>
<td>4.4</td>
</tr>
<tr>
<td>Skill in using assistant lines while sketching</td>
<td>4.2</td>
</tr>
<tr>
<td>Skill in drawing human figures and scenario</td>
<td>4.3</td>
</tr>
<tr>
<td>Skill in the quick sketch</td>
<td>4.6</td>
</tr>
<tr>
<td>Skill in arranging the layout</td>
<td>4.4</td>
</tr>
<tr>
<td>Skill in handling a range of media</td>
<td>4.0</td>
</tr>
<tr>
<td>Skill in using annotation</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Spontaneous comments on the roles of ‘sketching skills’: the most frequently cited type of sketching skill was ‘quick drawing skills’, followed by ‘line drawing skills’, and ‘rendering skills’.

Ratings on the roles of ‘sketching skills’: the highest rating score (4.8) was assigned to two types of sketching skills, namely ‘skill in drawing contour lines’ and ‘skill in using perspective drawing’. The second-highest rating score (4.6) was also assigned to two types of sketching skills, i.e. ‘skill in line quality control’ and ‘skill in quick sketch’.

General comments: two general comments were received relevant to the roles of ‘sketching skills’, namely:

- Visual thinking tool: “Sketching gives you a unique space which can help you think differently”

- Developing sketching related skills: “As a designer, you must be equipped with those extra skills that can be used in your design work. You may discover these skills (e.g. artistic expression and creating storyboards) while you are practising your sketching skills.”

Both of the comments on and ratings of the roles of sketching skills in design highlighted the importance of ‘line quality control’ and ‘quick sketching’. As one participant's comment indicates that ‘quick sketching skill’ is important, this is relevant to both design ideation and communication:

“Freehand sketching is often the quickest and most efficient way to record my thoughts and to explore design ideas. In the country, working on a computer can be very slow, I may even forget my new ideas by the time I've finished my last one. Freehand sketching also allows us to share our ideas and talk it through at a purer, more conceptual level with clients so that we can communicate our design and get instant feedback.”

In addition, Table 6.18 suggests ‘skill in drawing contour lines’ and ‘skill in using perspective drawing’ were also considered as important sketching skills. Both of these two skills are related to the depiction of forms, which are difficult skills to master and also important for form design. Except for the 29 sketching expertise listed in the questionnaire, the respondents added one more sketching skill (i.e. skill in using proper drawing sequence), whilst no sketching ability was added. Spontaneous comments were given in a relatively general way, thus no further conclusion can be drawn from the comparison. In general, the results were consistent with the findings from the pilot study.

6.3.7. Preferences regarding the content and format of a supporting tool for design sketching

The preferences of respondents regarding the content for supporting design sketching and its format are summarised in Table 6.19 and Table 6.20. The top four preferences
for the content included:

- External stimuli
- Instruction on drawing skills
- Examples of design sketches
- Design sketching case studies

Specifically, ‘instruction on drawing skills’ was selected as the most important content for supporting material, 34 out of 51 respondents (66.7%) were interested in learning sketching skills. In term of visual stimuli, 28 out of 51 respondents (54.9%) were interested in ‘pictorial stimuli’; whilst 16 out of 51 respondents (31.4%) were interested in ‘textual stimuli’; and 13 out of 51 respondents (25.5%) selected both types of visual stimuli. In term of examples, 27 out of 51 respondents (52.9%) were interested in receiving ‘sketching samples’ as references or learning materials; whilst 31 out of 51 respondents (60.8%) were interested in ‘sketching case studies’ to see the use of sketching in the design projects, and 16 out of 51 (31.4%) selected both types of examples.

Other content of interest mentioned by the respondents included (each was mentioned once):

- ‘methods for keeping a sketching dairy’
- ‘brief introduction of design sketching history’
Table 6.19 Design professionals' preferences regarding the content of a practical supporting tool for design sketching

<table>
<thead>
<tr>
<th>Content of the supporting tool for design sketching</th>
<th>No. of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to sketching</td>
<td>10 out of 51 (19.6%)</td>
</tr>
<tr>
<td>The basic theory of sketching (e.g. the psychology of sketching)</td>
<td>18 out of 51 (35.3%)</td>
</tr>
<tr>
<td>Sketching taxonomy</td>
<td>13 out of 51 (25.5%)</td>
</tr>
<tr>
<td>Pictorial stimuli</td>
<td>28 out of 51 (54.9%)</td>
</tr>
<tr>
<td>Textual stimuli</td>
<td>16 out of 51 (31.4%)</td>
</tr>
<tr>
<td>Instruction on sketching tools/media</td>
<td>17 out of 51 (33.3%)</td>
</tr>
<tr>
<td>Introduction to sketching abilities</td>
<td>23 out of 51 (45.1%)</td>
</tr>
<tr>
<td>Instruction on drawing skills</td>
<td>34 out of 51 (66.7%)</td>
</tr>
<tr>
<td>Instruction on practise methods (e.g. sketching abilities/skills)</td>
<td>24 out of 51 (47.1%)</td>
</tr>
<tr>
<td>Basic principles of design sketching</td>
<td>15 out of 51 (29.4%)</td>
</tr>
<tr>
<td>Instruction on developing sketching habits</td>
<td>11 out of 51 (21.6%)</td>
</tr>
<tr>
<td>Examples of design sketches</td>
<td>27 out of 51 (52.9%)</td>
</tr>
<tr>
<td>Design sketching case studies</td>
<td>31 out of 51 (60.8%)</td>
</tr>
<tr>
<td>Useful information (e.g. useful links, reading list)</td>
<td>9 out of 51 (17.6%)</td>
</tr>
</tbody>
</table>

Respondents were also asked to choose their preferred formats for supporting materials from six fixed options. The results are summarised in Table 6.20, based on the feedback from 51 respondents, 32 (62.7%) of them thought a booklet was still the best way to improve the awareness of sketching so that to support their sketching activity. 23 out of 51 respondents (45.1%) thought that a website and a CAD tool were important ways to support design sketching. 20 out of 51 respondents (39.2%) believed that a textbook would be helpful for learning and improving sketching. The results again suggest that alternative learning formats should be provided. The top four preferences for the format of a practical supporting tool included:
• A booklet
• A website
• A CAD tool
• A textbook

Other preferred formats of content mentioned by the respondents included (each was mentioned once):

• A set of card-based tool
• A workbook with sketching sample for tracing

Table 6.20 *Design professionals' preference regarding the format of a practical supporting tool for design sketching*

<table>
<thead>
<tr>
<th>Format of the supporting tool for design sketching</th>
<th>No. of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>A textbook</td>
<td>20 out of 51 (39.2%)</td>
</tr>
<tr>
<td>A booklet</td>
<td>32 out of 51 (62.7%)</td>
</tr>
<tr>
<td>A course/training</td>
<td>12 out of 51 (23.5%)</td>
</tr>
<tr>
<td>A website</td>
<td>23 out of 51 (45.1%)</td>
</tr>
<tr>
<td>A videotape/CD-Rom</td>
<td>9 out of 51 (17.6%)</td>
</tr>
<tr>
<td>A CAD tool</td>
<td>23 out of 51 (45.1%)</td>
</tr>
</tbody>
</table>

General comments relevant to the preference of a practical supporting tool for design sketching included:

• Difficulty in finding publications: *‘there were very few references available for professional designers to seek help.’*

• Design education: *‘gear the sketching teaching along with the practical design projects.’*

• Design cases: designers’ awareness of the benefit of freehand sketching is probably best achieved by demonstrating the communicative effect rather than cognitive benefits.
6.3.8. Comparison between professional designers and design academics

This section compares the findings between professional designers and design academics. As shown in Table 6.1, among the 51 design professionals that responded, 29 were professional designers (e.g. industrial designers or engineering designers), 22 were design academics (design researchers or design educators).

The mean values of the professional designers’ and design academics’ responses to the roles of sketching are compared and illustrated in Figure 6-2. It was found that design academics, in general, tended to assign a slightly higher level of significance than professional designers to most of the roles of sketching. The average rating score regarding the perceived roles of sketching was 4.5 for professional designers and 4.6 for design academics. There were only three exceptions, namely ‘sketching for fun and enabling designers to play with sketches and ideas’ (score: 4.7 for professional designers and 4.3 for design academics), ‘keeping sketches as records for future reference, e.g. sketch notebooks, sketch diaries ….etc’ (score: 4.8 for professional designers and 4.5 for design academics) and ‘sketching for the emotional and aesthetic expression’ (score: 4.6 for professional designers and 4.0 for design academics), which were all belong to the non-working sketches category. The average rating score regarding the perceived roles of non-working sketching was 4.5 for professional designers and 4.3 for design academics. These imply that professional designers attached more importance to non-working sketches when compared with design academics.

To identify whether there are statistically significant differences between the means, statistical analysis was conducted by using SPSS statistics software and the significance levels of the statistical tests are set as 5% (α=0.05) as a convention. The T-test was conducted to analyse the statistically significant differences of the perceived roles of sketching between professional designers and design academics, as the data of all the roles’ scores were normally distributed. No significant results were identified.
The mean values of the professional designer’s and design academics’ responses to the roles of sketching abilities and sketching skills are compared and illustrated in Figure 6-3 and Figure 6-4 respectively. It was found that the average scores regarding the roles of sketching abilities of the professional designer were slightly higher than design academics. The average rating score regarding the perceived roles of sketching abilities was 4.7 for professional designers and 4.4 for design academics. Both of the professional designer and design academics agreed on the five most important roles of sketching abilities, i.e. ‘ability to sketch to visualise ideas’, ‘ability to
sketch to organise ideas’, ‘ability to sketch to explore and evaluate ideas’, ‘ability to sketch for design analysis’ and ‘ability to use sketches to communicate design thoughts to others’. Also, two remarkable differences were identified, namely ‘ability to sketch from observation’ and ‘ability to use sketches to instruct others’.

It was also found that professional designers’ perceptions of sketching skills were similar to those of design academics’. The average rating score regarding the perceived roles of sketching skills was 4.3 for professional designers and 4.4 for design academics. The major sketching skills identified were similar for professional designer and design academics, for example ‘skill in drawing contour lines’, ‘skill in line quality control’, ‘skill in using perspective drawing’ and ‘skill in quick sketch’. The T-test was applied to the two groups, but no statistically significant results were identified.

<table>
<thead>
<tr>
<th></th>
<th>Design academicians</th>
<th>Professional designers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to enjoy the process of sketching</td>
<td>4.1</td>
<td>4.6</td>
</tr>
<tr>
<td>Ability to access and understand the quality of a sketch</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Ability to sketch with proper style</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Ability to master various kinds of artistic drawing techniques</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Ability to master various kinds of technical drawing techniques</td>
<td>4.1</td>
<td>4.3</td>
</tr>
<tr>
<td>Ability to use sketches to instruct others</td>
<td>4.4</td>
<td>4.8</td>
</tr>
<tr>
<td>Ability to use sketches to communicate design thoughts to others</td>
<td>4.7</td>
<td>5</td>
</tr>
<tr>
<td>Ability to sketch for design analysis</td>
<td>4.7</td>
<td>4.9</td>
</tr>
<tr>
<td>Ability to sketch to explore and evaluate ideas</td>
<td>4.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Ability to sketch to organise ideas</td>
<td>4.8</td>
<td>4.9</td>
</tr>
<tr>
<td>Ability to sketch to visualise ideas</td>
<td>4.5</td>
<td>4.9</td>
</tr>
<tr>
<td>Ability to sketch from imagery</td>
<td>4.2</td>
<td>4.9</td>
</tr>
<tr>
<td>Ability to sketch from reference</td>
<td>4.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Ability to sketch from memory</td>
<td>4.1</td>
<td>4.4</td>
</tr>
</tbody>
</table>
6.3.9. Comparison between design students and design professionals

In Chapter 5, the comparison between expert design students and novice design students suggested that the perceived roles of sketching and sketching expertise might differ for students with different levels of experience. However, the sample size did not accommodate an appropriate statistical test and no significant conclusion can be drawn. Therefore, this survey of design professionals was designed to collect comparative data on the roles of sketching and sketching expertise in design. As a complementary study to the survey of design students, the data were compared to
those collected from the previous survey (Chapter 5). There were 51 design professionals involved in this survey (refer to Table 6.1) and 79 design students involved in the previous survey (refer to Table 5.1).

The mean values of the responses from design professionals and design students to the roles of sketching are presented in Figure 6-5.

![Comparison of perceived importance of sketching: design professionals and design students](image-url)
The most significant roles of working sketches to designing professionals were ‘expanding designer’s thoughts using mind maps, notes and annotations’ (score: 4.9), ‘recalling design elements from previous experience’ (score: 5.0) and ‘promoting design communication with other designers for design collaboration’ (score: 5.1), while for design students they were ‘promoting idea generation and exploration’ (score: 5.0), ‘investigating the aesthetic details such as appearance, texture and scale’ (score: 4.8) and ‘promoting design communication with other designers for design collaboration’ (score: 5.0). All of these roles belong to the ‘creative roles’ category.

The rating of the top two ‘non-working sketches’ were similar for design professionals and design students, i.e. ‘sketching for fun and enabling designers to play with sketches and ideas’ (score: 4.5 for design professionals, 4.5 for design students) and ‘keeping sketches as records for future reference’ (score: 4.7 for design professionals, 4.5 for design students). Main findings relating to the roles of sketching are summarised in Table 6.21.

Table 6.21 Comparison: main roles of sketching perceived by design professionals and design students

<table>
<thead>
<tr>
<th>Main roles of sketching in design</th>
<th>Design professionals (refer to Section 6.3.2)</th>
<th>Design students (refer to Section 5.3.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Working sketches</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expanding designer’s thoughts using mind maps, notes and annotations (score: 4.9)</td>
<td>Promoting idea generation and exploration (score: 5.0)</td>
<td></td>
</tr>
<tr>
<td>Recalling design elements from previous experience (score: 5.0)</td>
<td>Investigating the aesthetic details such as appearance, texture and scale (score: 4.8)</td>
<td></td>
</tr>
<tr>
<td>Promoting design communication with other designers for design collaboration (score: 5.1)</td>
<td>Promoting design communication with other designers for design collaboration (score: 5.0)</td>
<td></td>
</tr>
<tr>
<td><strong>Non-working sketches</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sketching for fun and enabling designers to play with sketches and ideas (score: 4.5)</td>
<td>Sketching for fun and enabling designers to play with sketches and ideas (score: 4.5)</td>
<td></td>
</tr>
<tr>
<td>Keeping sketches as records for future reference (score: 4.7)</td>
<td>Keeping sketches as records for future reference (score: 4.5)</td>
<td></td>
</tr>
</tbody>
</table>
It was found that design professionals tended to assign a slightly higher level of significance than design students to the roles of sketching. The average rating score regarding the perceived roles of sketching was 4.7 for design professionals and 4.5 for design students. The T-test was employed to access whether the perceived roles of sketching were significantly different between design professionals and design students. Two significant results (i.e. P<5%) were identified (Table 6.22).

The mean values of the responses to the roles of sketching abilities and sketching skills are compared and presented in Figure 6-6 and Figure 6-7.

![Comparison of perceived importance of sketching abilities: design professionals and design students](image-url)
Figure 6-7 Comparison of perceived importance of sketching skills: design professionals and design students

The most important sketching ability to design professionals was ‘ability to sketch from memory’ (score: 4.9), while for design students were ‘ability to sketch to visualise ideas’ (score: 5.1). The other two main sketching abilities were the same, i.e. ‘ability to sketch to organise ideas’ (score: 4.9 for design professionals, 5.0 for design students) and ‘ability to use sketches to communicate design thoughts to others’ (score: 4.9 for design professionals, 5.0 for design students).

The main sketching skills were similar for design professionals and design students, for example ‘skill in drawing contour lines’ (score: 4.8 for design professionals, 4.8 for design students), ‘skill in line quality control’ (score: 4.6 for design professionals, 4.8 for design students), ‘skill in using perspective drawing’ (score: 4.8 for design professionals, 5.1 for design students) and ‘skill in quick sketch’ (score: 4.6 for design professionals, 4.8 for design students).
The average rating score regarding the perceived roles of sketching abilities was the same for design professionals and design students (i.e. scored 4.6), while the average rating scores of sketching skills were 4.4 for design professionals and 4.6 for design students. Both of the two groups scored higher than the average significance (i.e. score 4), which suggested that the respondents, in general, perceived sketching abilities and sketching skills are important in design. It seemed that sketching skills were perceived as more important to design students than design professionals. Other conclusions could not be drawn. Main findings relating to the roles of sketching are summarised in Table 6.22.

Table 6.22 Comparison: main roles of sketching expertise perceived by design professionals and design students

<table>
<thead>
<tr>
<th>Main roles of sketching expertise in design</th>
<th>Design professionals</th>
<th>Design students</th>
</tr>
</thead>
<tbody>
<tr>
<td>(refer to Section 6.3.3)</td>
<td>(refer to Section 5.3.3)</td>
<td></td>
</tr>
<tr>
<td><strong>Sketching abilities</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to sketch from memory (score: 4.9)</td>
<td>Ability to sketch to visualise ideas (score: 5.1)</td>
<td></td>
</tr>
<tr>
<td>Ability to sketch to organise ideas (score: 4.9)</td>
<td>Ability to sketch to organise ideas (score: 5.0)</td>
<td></td>
</tr>
<tr>
<td>Ability to use sketches to communicate design thoughts to others (score: 4.9)</td>
<td>Ability to use sketches to communicate design thoughts to others (score: 5.0)</td>
<td></td>
</tr>
<tr>
<td><strong>Sketching skills</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skill in drawing contour lines (score: 4.8)</td>
<td>Skill in drawing contour lines (score: 4.8)</td>
<td></td>
</tr>
<tr>
<td>Skill in line quality control (score: 4.6)</td>
<td>Skill in line quality control (score: 4.8)</td>
<td></td>
</tr>
<tr>
<td>Skill in using perspective drawing (score: 4.8)</td>
<td>Skill in using perspective drawing (score: 5.1)</td>
<td></td>
</tr>
<tr>
<td>Skill in the quick sketch (score: 4.6)</td>
<td>Skill in the quick sketch (score: 4.8)</td>
<td></td>
</tr>
</tbody>
</table>

The T-test was employed to facilitate the analysis and statistically significant results are summarised in Table 6.23. The perceptions of design professionals to the following issues are different from the perceptions of design students:

- ‘Recalling design elements from previous experience’ (as a ‘creative role’)
- ‘Sketching as a practice to improve their sketching techniques’ (as a ‘general role’)
- ‘Ability to sketch from memory’ (as a ‘sketching ability’)
- ‘Ability to sketch from reference’ (as a ‘sketching ability’).
**significant results from the T-test**

<table>
<thead>
<tr>
<th>Role</th>
<th>Probability (P)</th>
<th>Means of design professionals (51 in total)</th>
<th>Means of design students (79 in total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Creative role'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recalling design elements from previous experience</td>
<td>0.045</td>
<td>5.0</td>
<td>4.4</td>
</tr>
<tr>
<td>'General role'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sketching as a practice to improve their sketching techniques</td>
<td>0.039</td>
<td>3.8</td>
<td>4.4</td>
</tr>
<tr>
<td>'Sketching ability'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to sketch from memory</td>
<td>0.029</td>
<td>4.9</td>
<td>4.3</td>
</tr>
<tr>
<td>Ability to sketch from external reference</td>
<td>0.023</td>
<td>3.9</td>
<td>4.5</td>
</tr>
</tbody>
</table>

The role ‘recalling design elements from previous experience’ seems more relevant to experienced design professionals (Score: 5.0) than inexperienced design students (score: 4.4). This is probably because design professionals have more design experience and design materials accumulation, so they can benefit more from ‘previous experience’ with the help of sketching. Besides, design professionals rated higher regarding the role of recording sketch (Keeping sketches as records for future reference, e.g. sketch notebooks, sketch diaries …etc) than design students (score: 4.7 for design professionals and 4.5 for design students). This also supports our statement.

The role of ‘sketching as a practice to improve their sketching techniques’ seems more important for design students (Score: 4.4) than for design professionals (score: 3.8). This does not mean that sketching skills are not important for design professionals. On the contrary, this may be because design professionals, in general, are more skilled in sketching than design students through years of practice and daily work, so they are less likely to pay much attention to practising sketching skills at this stage.

Design students, in general, rated higher regarding the sketching ability ‘to sketch from external reference’ (Score: 4.3) than design professionals (score: 4.9). The sketching ability ‘to sketch from memory’ seems a much more appropriate means of support for design professionals (Score: 3.9) than design students (score: 4.5). These suggest that the provision of ‘external reference’ could be useful to design students, while the provision of ‘memory aids’ could be helpful to design professionals.
6.4. Summary and discussion

In this section, the objectives of the survey (refer to Section 6.2) are reviewed. The appropriateness and limitations of the research methods are discussed. Findings from all three descriptive studies, described in Chapter 4, Chapter 5 and Chapter 6, are summarised and compared.

6.4.1. Review of objectives of the study

This survey had four research objectives (Section 6.2), which are discussed as follows:

**Roles of sketching for design professionals**

For design professionals, the frequently cited and highly rated roles of ‘working sketches’ were related to design ideation (‘promoting idea generation and exploration’) and design communication (i.e. ‘promoting design communication with other designers for design collaboration’). The most significant roles of ‘non-working sketches’ were ‘sketching for fun and enabling designers to play with sketches and ideas’ and ‘sketching as visual records for future reference’.

In general, design academics were found to tend to assign a slightly higher level of significance than professional designers to most of the roles of sketching. There were only three exceptions, i.e. ‘sketching for fun and enabling designers to play with sketches and ideas’, ‘keeping sketches as records for future reference, e.g. sketch notebooks, sketch diaries …etc’ and ‘sketching for emotional and aesthetic expression’ (Figure 6-2), which were all belong to the ‘non-working sketches’ category. The average rating score regarding the perceived roles of ‘non-working sketches’ was 4.5 for professional designers and 4.2 for design academics. These imply that design academics attached less importance to ‘non-working sketches’ when compared with professional designers. However, no statistically significant differences were found between professional designers and design academics. This finding could help to explain why little attention has been paid by design researchers to explore the roles of ‘non-working sketches’ in design.

The comparison was also made between design students and design professionals, who were agreed on three of the major roles of sketching in design, i.e. ‘promoting idea generation and exploration’, ‘promoting design communication with other designers for design collaboration’ and ‘expanding designer’s thoughts using mind maps, notes and annotations’. Two significant differences in perception of roles of sketching in design were also identified between design students and design professionals, i.e. ‘recalling design elements from previous experience’ and ‘sketching as a practice to improve their sketching techniques’.

**Roles of sketching expertise for design professionals**

Major roles of sketching ability for design professionals were ‘ability to sketch from
memory’, ‘ability to sketch to organise ideas’ and ‘ability to use sketches to communicate design thoughts to others’. The most important roles of sketching skill for them were i.e. ‘skill in line drawing’ and ‘skill in quick sketch’.

The average scores regarding the roles of sketching abilities of professional designer (Score: 4.7) were higher than design academics (score: 4.4). Both of the professional designer and design academics agreed on the five most important roles of sketching abilities, i.e. ‘ability to sketch to visualise ideas’, ‘ability to sketch to organise ideas’, ‘ability to sketch to explore and evaluate ideas’, ‘ability to sketch for design analysis’ and ‘ability to use sketches to communicate design thoughts to others’. In addition, two remarkable differences (defined as more than 0.5 points on the difference of mean value) were identified, namely ‘ability to sketch from observation’ and ‘ability to enjoy the process of sketching’. As to design sketching skills, professional designers' perceptions were similar to those of design academics’. The average rating score regarding the perceived roles of sketching skills was 4.3 for professional designers and 4.4 for design academics. Professional designer and design academics agreed on the top four roles of sketching skills, i.e. ‘skill in drawing contour lines’, ‘skill in line quality control’, ‘skill in using perspective drawing’ and ‘skill in quick sketch’. No statistically significant differences in perceptions of the roles of sketching expertise were found between professional designer and design academics.

The comparison between design professionals and design students showed that the ‘ability to sketch from memory’ was perceived as more important for design professionals, while the ‘ability to sketch from external reference’ was more relevant to design students. In addition, design professionals also rated a higher score for ‘keeping sketches as records for future use’ than design students (refer to Figure 6-2). These results suggested that design professionals tend to rely on their long-term accumulation of experience, knowledge, design materials etc during the sketching process, while design students need to intensively search for external references to support this process. This may be because the lack of accumulation for design students drives them to look for external references as supports, or may like some researchers have pointed out, it is because design professionals are more skilled at interpreting and manipulating design information thus they are less likely to rely much on external references.

Requirements on the content and format of a supporting tool for design sketching

According to the responses to preferences of a practical supporting tool, contents such as external stimuli, instruction on drawing skills, examples of design sketches and design sketching case studies, were liked by respondents. When it comes to the format of a practical supporting tool, booklets, textbooks, CAD tools and websites were preferred. It was found that the preferences regarding the practical supporting tool of design academics differed from the preferences of professional designers. Design academics were more in favour of ‘instruction on drawing skills or training methods’, ‘the sketching taxonomy’ and ‘examples of design sketches’, and they tend
to regard sketching as a set of ‘learned skills’ in the design education. Professional designers were more interested in receiving ‘design sketching case studies’ and ‘instruction on sketching tools/media’, this might be because designers shared different perspectives with design academics, who were more likely to concerned with the effective use of sketching in the design practices, e.g. if there are any emerging sketching tools/media they could use to support their design work.

**Hypothesis testing**

As a complementary study to the comparison between expert and novice design students (Chapter 5), a further comparison was made between professional designer and design students. The results, in general, were consistent with the findings from the previous study and significant differences were identified. The findings were summarized in Table 6.21 and Table 6.22 which support Hypothesis 2: The perception of design sketching may be different for designers with different expertise. In addition, a comparison was also made between professional designers and design academics regarding the perceptions of design sketching. The results imply that professional designers attached more importance to non-working sketches than design academics. This finding also partially supported Hypothesis 2.

The major comments on and ratings of the roles of design sketching, i.e. ‘expanding designer’s thoughts using mind maps, notes and annotations’, ‘recalling design elements from previous experience’ and ‘promoting idea generation and exploration’. The highest rating score (4.9) of ‘sketching abilities’ was assigned to three types of sketching abilities, namely ‘ability to sketch from memory’, ‘ability to sketch to organise ideas’ and ‘ability to use sketches to communicate design thoughts to others’, among which the latter two were further supported by the spontaneous comments. In terms of sketching habits, the top favourites were ‘searching for visual reference’ (33/64.7% respondents), ‘listening to the music’ (29/56.9% respondents) and ‘drawing something irrelevant’ (28/54.9% respondents). These results confirmed the importance of sketching in supporting design ideation, especially for shaping the problem/solution spaces to facilitate the idea exploration process. A number of internal references (e.g. previous experience) and external stimuli (e.g. visual references including one’s sketches and music) were identified. These are in line with findings that external stimuli have an impact on constructing the problem space for searching for design solutions (Goldschmidt, Ben Zeev and Levi, 1996; Goldschmidt and Smolkov, 2006). For example, Goldschmidt and Smolkov (2006) suggest that “for short design problems and a modest amount of design experience, external stimuli can expand or shrink the problem space in which the designers search for solutions and primarily for original solutions which are supported by our findings”. These findings support Hypothesis 3: Understanding the cognitive interplay between sketching and design ideation process may be of use to both design academics and practitioners.

The top two preferences for the content of a practical supporting tool, i.e. 34 out of 51 respondents (66.7%) were interested in ‘instruction on drawing skills’ and 31 out of 51
respondents (60.8%) selected ‘pictorial/textual stimuli’. In addition, when asked about sketching habits, 33 out of 51 respondents (64.7%) chose that they have the habit of ‘searching for visual reference’ during the design and sketching process. Both the findings support Hypothesis 4: External stimuli and sketching instruction can be helpful in supporting the design sketching process.

Comments from respondents, such as designers’ awareness of the benefit of freehand sketching are probably best achieved by demonstrating the communicative effect rather than cognitive benefits and preferences for content and format of a practical supporting tool (Section 6.3.7) support Hypothesis 5: Effective support of design sketching is critically dependent on the presentation of supporting materials.

6.4.2. Critique of the research methodology

The response rate of this survey was 40.2%, while the useful response rate was 35.6%, which was slightly higher than the general response rate, i.e. 32.6% for online surveys (Watt et al., 2002). However, this response rate is lower than the previous survey (the useful response rate was 43.2%). Similar strategies for questionnaire distribution were adopted, including pre-contacting the potential participants (i.e. sending emails to target designers/researchers) and contacting those respondents who did not respond or complete the questionnaire as a reminder so that to increase the response rate. The only difference was that part of the survey questionnaires of the design students group was distributed by their course tutors or supervisors. This might be the reason for the decline in the response rate of the design professionals group. In addition, Sims (2003) conducted a survey of design professionals that also revealed a number of reasons for non-participation, e.g. ‘not interested’, ‘not relevant’, ‘lack of time’ and ‘concerns about confidentiality’.

The survey of design professionals received 167 comments in total, among which 23 were general comments and the rest 144 were spontaneous comments. Specifically, 58 spontaneous comments were on the roles of working sketches, 30 on the roles of non-working sketches, 52 on the roles of ‘sketching expertise’ (i.e. sketching abilities and sketching skills), two on ‘content of a practical supporting tool for design sketching’ and two on ‘format of a practical supporting tool for design sketching’. The response rate of comments (i.e. spontaneous comments and general comments) strongly increased when compared with the survey of design students (Chapter 5), from which only a couple of comments were gained. This increase in response rate may be because of the new design of the questionnaire. For example, the order of comments and questions was redesigned, i.e. comments were arranged before the fixed options. It may also be because the respondents in this survey were more articulate than those in the previous survey. However, the comments were tended to be given in a more general way by the respondents when compared with those in the previous survey. This may be because the respondents (design professionals) lost the chance to see the fixed options (the breakdown of the roles of sketching and
sketching expertise) before they gave the comments.

The increased comments from design professionals also added internal validity to this survey. Data triangulation (Flick, 2004) was reflected by the use of three data sources to develop a comprehensive understanding of each role of sketching or sketching ability/skill, i.e. 1) the spontaneous comments, 2) the selections or ratings for fixed alternatives and 3) the general comments at the end of the survey. In general, frequently mentioned roles were also rated highly, the three sets of data lead to similar results. Triangulation also gave us more perspectives on what is being investigated. The multi-source of data increased the chances of gaining new insights, as one of the respondents commented:

“Sketching is the best way to communicate ideas with the client, its immediacy and personal touch will never be matched by a print-out which is good for client relations.”

The role that sketching could add ‘personal touch’ which is good for client relation was not mentioned in the questionnaire but pointed out by this participant in his comments.

Triangulation was adopted as a validation strategy through the three descriptive studies presented in Chapter 4, 5 and 6. Mixed research methods (i.e. think-aloud experiment and follow-up interview were adopted in the pilot study, a questionnaire survey was adopted in two surveys) and multiple sources of data were used to explore the roles of sketching and sketching expertise in design. Every single method had its inherent limitations, thus this mixed methods can help to add breadth and depth to our study (Bryman, Teevan and Bell, 2009). In the two surveys of design students and design professionals, the focus of the analysis was on the relative differences between groups rather than on absolute measurements of individual characteristics. These comparisons were fruitful, a number of common findings emerged which led to confident conclusions.

6.5. Conclusions

This section presents the conclusions drawn from the three descriptive studies, i.e. the pilot study and two surveys, which formed a basis for the prescriptive study (Chapter 7).

The objective of the descriptive studies was to identify and understand the roles of sketching in product design (Table 3.3). It was found that the perceived roles of sketching in design were different between design students and professionals. This might be due to their different levels of experience, which could play a key role in affecting their perceptions of design sketching. In contrast, design students and professionals shared similar requirements for the contents of practical supporting tools. Based on these findings, a set of common supports (focusing on common requirements) were developed for designers to support their design sketching process.
According to the findings that emerged from the pilot study, design students, in general, lacked the understanding of sketching in the product design field (refer to Section 4.4.1). The study with design students and professionals also indicated that sketching for supporting design ideation formed the major roles of design sketching and were the most significant, followed by sketching for supporting design communication. In addition, the survey with professional designers and design academics highlighted the importance of sketching expertise in design, and they tended to agree on the top roles of sketching expertise. These findings provide a useful basis for the development of common supports. The implication of these findings was that the supports for design sketching should focus on grabbing the attention of design students/professionals, enhancing understanding of sketching, providing external reference (i.e. stimuli and information) and providing instruction on sketching ability & skill.

Specific conclusions from the survey with design professionals were:

- Design professionals’ perception of design sketching implied that understanding the roles of sketching in supporting design ideation was a key issue in the field as the most frequently cited and highest rated roles of sketching were all related to design ideation, i.e. ‘promoting idea generation and exploration’ from ‘working sketches’ category, and ‘sketching for fun and enabling designers to play with sketches and ideas’ and ‘sketching as visual records for future reference’ from ‘non-working sketches’ category.

- Top preferences for the contents of practical supporting tools were external stimuli, instruction on drawing skills, examples of design sketches and design sketching case studies.

- Top preferences for the formats of practical supporting tools were booklets, textbooks, CAD tools and web-based tools.

- Comparison between design academics and professional designers showed that they tended to share a similar view on the roles of sketching and sketching ability & skill in design, but have different preferences for supporting tools. Specifically, design academics were more in favour of ‘instruction on drawing skills or training methods’, ‘the sketching taxonomy’ and ‘examples of design sketches’, while professional designers were more interested in receiving ‘design sketching case studies’ and ‘instruction on sketching tools/media’.

These findings specified requirements for the prescriptive studies will be described in the next chapter.
Chapter Seven: Supporting Design Sketching: Development and Evaluation of a Supporting tool

7.1. Introduction

This chapter presents the requirements list for a practical supporting tool and describes the development and evaluation of the supporting tool. Requirements for supporting design sketching were captured through three descriptive studies (Chapters 4, 5, 6). The development of the toolkit was based upon the findings from the descriptive studies. The feedback on and experiment data from the evaluation of the toolkit were also presented, which has been used to further verify the research hypotheses.

7.2. Requirements list of a supporting tool for design sketching

The pilot study (reported in Chapter 4) was carried out aiming to enhance the understanding of the roles of sketching in design. Through the research, a number of important issues related to design sketching were identified. These included (Section 4.4.1):

- understanding the functions of types of sketches used in the design process
- identifying the types of sketches using in today’s design contest
- understanding non-working sketches
- investigating perceived roles of sketching ability in design
- providing information to support design sketching practice
- exploring the interplay between sketching and design cognition
- identifying the preference (e.g. types of sketches used, sketching habits and sketching tool/media) of design students regarding design sketching

To further investigate and identify the issues found in the pilot study, two surveys were conducted followed by the pilot study, presented in Chapter 5 and Chapter 6 respectively. Relevant findings included:

- both design students and professionals have a clear preference for paper-based freehand sketching rather than CAD systems supported sketching (Section 5.3.3
and Section 6.3.3); the internet was selected as the most favoured source for references (Section 5.3.3 and Section 6.3.3)

- sketching for design ideation formed the majority of roles of design sketching in today’s design context and was the most significant among the identified roles (Section 5.3.5 and Section 6.3.5)

- the perceptions of the roles of sketching and sketching abilities differed for novice design students, expert design students and design professionals (Section 5.3.7 and Section 6.3.9), which suggested that experience may have an influence on the designers’ perceptions of design sketching

- design professionals tend to rely on their long-term accumulation of experience, knowledge and design materials during the sketching process, while design students need to intensively search for external references to support this process (Section 6.4.1)

- searching for visual reference was among the most welcomed sketching habits for designers (Table 5.8 and Table 6.10)

The implications of these findings for the prescriptive study were made explicit. The development of a practical supporting tool for design sketching focused on four main requirements, i.e. grabbing attention, enhancing understanding, providing external stimuli and providing instruction & information (Section 6.5).

The key elements for supporting the design sketching process, together with detailed findings from the three descriptive studies, were adopted to capture requirements for a practical supporting tool. Subsequently, the requirements were summarised and a requirements list was generated (Table 7.1).

The development of the PD- Sketching Toolkit followed a three-step process:

Step one: identifying requirements for the development of toolkit;

Step two: development of a concise guide, i.e. the PD- Sketching Primer (Appendix D) for design sketching;

Step three: development of a prototype toolkit, i.e. the PD- Sketching Toolkit for design sketching.

The details of each step of the development process were described in the following sections.
<table>
<thead>
<tr>
<th>Requirements</th>
<th>Sub-requirements</th>
<th>Demands (D) or Wishes (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grabbing attention</td>
<td>• Get the attention of design students and professionals</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>• Get the attention of design educators</td>
<td>D</td>
</tr>
<tr>
<td>Enhancing understanding</td>
<td>• Introduction to product design</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>• Introduction to the product design process</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>• Introduction to product design sketching</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>• Introduction to design ideation</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td>• Introduction to design commutation</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>• Introduction to sketching classification</td>
<td>D</td>
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<td>• Introduction to functions of sketching in design</td>
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<td></td>
<td>• Introduction to the interplay between sketching and design creativity</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td>• Introduction to key design information</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td>• Introduction to key technical information</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td>• (Sketches) relevance to the design stages</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>• (Sketches) relevance to the design/technical information</td>
<td>D</td>
</tr>
<tr>
<td>Providing external stimuli</td>
<td>• Pictorial stimuli</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>• Textual stimuli</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>• Combined stimuli</td>
<td>W</td>
</tr>
<tr>
<td>Providing instruction &amp; information</td>
<td>• Overview of design sketching</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>• Sketching tools and media</td>
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<td>• Sketching skills</td>
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<td>• Sketching training methods</td>
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<td>• Presentation skills</td>
<td>D</td>
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<tr>
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<td>• Product design sketching case studies</td>
<td>D</td>
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<td></td>
<td>• Product design sketching examples</td>
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<td>• Tools and recourses available</td>
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<td></td>
<td>• Report on popular trends</td>
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<td>• References</td>
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7.3. Development of the *PD-Sketching Primer*

This section describes the development of the *PD-Sketching Primer*, which was developed by the author based on the requirements summarised in Table 7.1. It was developed to solve the four problems (i.e. grabbing attention, enhancing understanding, improving sketching ability and providing useful information) together and combine them into one concise guide. Information gathered was used to raise awareness and get the attention of design practitioners and academicians. The primer went through four versions as a result of the iterative development and testing procedure. Then, the primer was sent to design schools and training institutions for evaluation. The following two sections describe the content and format of the concise guiding tool called the *PD-Sketching Primer* (Appendix D).

7.3.1. Considerations on the content

Table 7.1 presents the summarised requirements from previous studies, which specified the contents to be included in the *PD-Sketching Primer*. These requirements were restructured and then integrated so that the contents would make sense to the target audience (i.e. design students, professional designers and design educators). This process is described in the next paragraph.

An introduction of product design sketching and related knowledge points was key to the effective use of the tool. The primer was developed for grabbing attention and spreading basic knowledge of sketching. Therefore, an ‘Introduction’ section was used as the opening chapter. The primer was also designed for both design practitioners (e.g. design students and professionals) and design educators, so it was crucial to include practice-oriented information and theory-oriented information. Therefore, two main sections were included in the primer, i.e. ‘understanding sketching’ and ‘sketching skills’. After these requirements were addressed, a common preference, i.e. case study with good examples of sketching was included in the primer. According to the feedback from previous studies, a list of available resources was also thought to be very useful for sketching and thus was also included in the tool. The primer was designed with five sections as described above, namely ‘Introduction’, ‘Understanding Sketching’, ‘Sketching Skills’, ‘Case Studies & Examples’ and ‘Resources’. Table 7.2 presents the detailed structure of the primer and the relationships with the requirements list. It should be noted that no detailed information such as training methods for improving line drawing skills was included in the *PD-Sketching Primer*, as the aim was to keep the primer informative but concise.
<table>
<thead>
<tr>
<th>Requirements</th>
<th>Contents</th>
<th>I</th>
<th>US</th>
<th>SS</th>
<th>CS&amp;E</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Get the attention of design practitioners</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Get the attention of design educators</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to product design</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to the product design process</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to design sketching</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to design ideation</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to design commutation</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to sketching classification</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to functions of sketching</td>
<td></td>
<td>✓</td>
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<td></td>
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<td></td>
</tr>
<tr>
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<td></td>
<td>✓</td>
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<td></td>
</tr>
<tr>
<td>Introduction to the interplay between sketching and design creativity</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Introduction to key design information</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Introduction to key technical information</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Sketches) relevance to the design stages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Sketches) relevance to the design/technical information</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overview of design sketching</td>
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<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sketching tools and media</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sketching skills</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sketching training methods</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presentation skills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product design sketching case studies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Product design sketching examples</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supporting tools and recourses available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Report of the popular trends</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

**Coding of the content:** I: Introduction; US: Understanding Sketching; SS: Sketching Skills; CS&E: Case Studies & Examples; R: Resources
7.3.2. Considerations on the format

Previous studies suggest that an appropriate format is crucial to the success of tool development for designers (Lofthouse, 2001; 2006). According to the results of previous interviews and questionnaires studies, designers favoured the booklets the most as the format for receiving design information (Section 6.3.7). Moreover, it was found that designers preferred design information to be presented in a physical format, even if the bulk of it was available on the Internet. This is supported by the results of previous researches in the design field (Dong, 2004; Clarkson et al., 2007). Therefore, a portable booklet was selected as the format for the PD-Sketching Primer. It is A4 size and adhesive binding booklet. A photograph of the physical booklet is presented in Figure 7-9.

An example of the graphic design of the booklet is presented in Figure 7-1. The first page provides the readers with an index of booklet and pages are numbered thereafter to locate the information. Each page of the booklet contains a grey box, which provides relevant information as a reference. Both texts and images are provided when appropriate and the balance between the textual and pictorial information was carefully designed. Important information was deliberately presented in different formats, for example, the table on page 12 of the primer and the text highlighted in red on page 7 of the primer (Appendix D). The final version of the PD-Sketching Primer is in Appendix D.
PD-Sketching

**Index**

**INTRODUCTION**
1. Sketching for design
2. Design thinking
3. Examples (design analysis)
4. Examples (design ideation)
5. Design commutation
6. Examples (for designer)
7. Examples (for engineer)
8. Examples (for customer)

**UNDERSTANDING SKETCHING**
9. Defining sketching
10. The design process
11. Types of sketches
12. General roles of sketching
13. The psychology of sketching

**SKETCHING SKILLS**
14. Tools
15. Lines
16. Perspective
17. Form
18. Material
19. Shading & Colour
20. Cast shadows

**CASE STUDIES & EXAMPLES**
21. Analysis
22. Appreciation

**RESOURCES**
23. Supporting Tools
24. Books
25. Web sites

This booklet contains information that we think is crucial for learning design sketching. It provides resources in a concise way, which enables both novice and experienced designers who have an interest in design sketching to grasp the essence quickly.

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Figure 7-1 Cover and content page of the booklet
Freehand sketching has traditionally been considered an essential part of the design process. Designers are generally taught to think with their sketches in order to externalise concepts, communicate ideas and solve complex problems.

**Thinking sketches** are a group of sketches that designers use to support their individual thinking processes, i.e. focusing and guiding nonverbal thinking.

**Talking sketches** are used for facilitating design communication. They encourage discussion and build a common understanding of the design idea among the parties involved.

**Non-working sketches** can be defined as a group of sketches that are produced by designers outside the design process in their spare time.

---

**Examples: design ideation**

These sketches are produced for supporting design ideation process.

---

1. Exploring auto-body design (by Prathyush Devadas)
2. Exploring form design (by David Sosnovsky)
3. Exploring handle design (by Adityaraj Dev)
4. Exploring colour scheme (by Yanming Ge)
5. Exploring accessories (by Jeemin Han)
6. Exploring details (by Adityaraj Dev)
7. Exploring material of watchband (by Victor Xu)

---

Figure 7-2. *Extracts of the booklet, section 1 (Introduction)*
Figure 7-3. Extracts of the booklet, section 2 (Understanding Sketching)
**PD-Sketching**

**Perspective**

**One-point perspective**
1. Begin one-point perspective by drawing a horizon line.
2. Place a vanishing point on the horizon line.
3. Draw a box to represent the building that you want to draw in perspective.
4. Draw lines from all four corners back to the vanishing point.
5. Draw a smaller box that touches each of the lines that you drew in the previous step.
6. Erase the lines that you no longer need to reveal a 3D form.

**Two-Point Perspective**
1. Define the horizon line and the vanishing points.
2. Draw the corner of the object in between the vanishing points.
3. Draw lines from each end of the corner to each of the vanishing points.
4. Draw parallel, vertical lines to indicate where the object ends.
5. Erase the lines you no longer need to reveal your 3D form.

**Basic Perspective Rules:**
- All lines running away from you, above your eye level, will run down towards your eye level.
- All lines running away from you, below your eye level, will run up towards your eye level.
- Horizontals and verticals will remain unchanged.

---

**PD-Sketching**

**Cast shadows**

Examples of good sketches

**Light Source** (sunlight)

**Projected Direction**

**Area between edge of cuboid base and where lines cross**

---

Figure 7-4. *Extracts of the booklet, section 3 (Sketching Skills)*
PD-Sketching

Analysis

Skeching process of backpack design (by Tus Nguyen)

From top left to bottom right:
1. Idea generation
2. Idea development and selection
3. Idea development and detail design
4. Material design
5. Usage, colour and scenario 1
6. Usage, colour and scenario 2
7. Prototype

PD-Sketching

Appreciation

Examples of good sketches

Useful search platforms:
1. Pinterest
   [Link: https://www.pinterest.co.uk/]
2. Behance
   [Link: https://www.behance.net/]
3. Dribbble
   [Link: https://dribbble.com/]
4. Google image
   [Link: https://www.google.co.uk/imghp?hl=en&tab=ui&authuser=0&q=sketches]

Figure 7-5. Extracts of the booklet, section 4 (Case Studies & Examples)
Books

Sketching: The Basics
(Learn to use and master the different techniques and also how to apply sketches in the design process)

Creative Sketching in Product Design
(This book includes perspective theory, basic sketching skill in the light and shadow, sketching tools and material effect of product, and presenting over 50 outstanding sketches design from all around the world)

Drawing for Product Designers
(This book includes freehand sketching, digital rendering, information graphics, and presentation skills)

Sketching-Drawing Techniques for Product Designers
(This book explains the basic sketching techniques and provides step-by-step example drawings, which is suitable for students/professionals to become better sketchers.)

PD-Sketching

Web-sites

Drawing Gym-Teaching Engineers to Draw
https://www.uel.ac.uk/drawing-gym/about/

Drawing At Work
http://www.drawingatwork.co.uk/index.php

Introduction to Design Sketching
https://www.udemy.com/course/introduction-to-design-sketching/

Design Sketching Class
https://www.instructables.com/class/Design-Sketching-Class/

Online sketch training for all!
https://www.designsketchingcourses.com/

Design Sketching
https://vimeo.com/designsketching

Figure 7-6. Extracts of the booklet, section 5 (Resources)
7.4. Evaluation of the PD-Sketching Primer

The PD-Sketching Primer was developed according to the requirements gathered from previous studies, which primarily focused on grabbing designers’ attention on design sketching and spreading basic knowledge with the targeted audience. This section presents the results of the preliminary evaluation and formal evaluation.

7.4.1. Preliminary evaluation

The preliminary evaluation was carried out aiming to verify whether the PD-Sketching Primer contained the appropriate information and was presented in an appropriate format.

Participants and evaluation procedure

In total, 130 respondents (79 design students and 51 design professionals) participated in the two surveys described in Chapter 5 and Chapter 6, among which 56 of them expressed their willingness to be further involved in the research. A questionnaire survey method was adopted for the preliminary evaluation. Therefore, 56 copies of the PD-Sketching Primer were sent to these participants, together with a two-page evaluation questionnaire (Appendix F). The evaluation was structured in four sections, namely:

- Evaluation of the contents, i.e. the content of the booklet, quality of the content and quality of the reference (on a 1 - 5 point scale, 1 - poor, 2 - adequate, 3 - good, 4 - very good, 5 - excellent)
- Evaluation of the format, i.e. layout of the booklet and visual quality and clarity (on the same 1 - 5 point scale)
- Overall impression of the booklet (on the same 1 - 5 point scale)
- Suggestions for improvement

Results

In total, 24 design students and professionals returned the feedback in time. The results of the evaluation of the contents are presented in Table 7.3. The average score of content was 4.1 (between ‘very good’ and ‘excellent’), the average score of quality of the content was 3.6 (between ‘good’ and ‘very good’), and the average score of quality of the reference was 3.7 (between ‘good’ and ‘very good’).

The average score of the layout of the booklet was 3.7 (between ‘good’ and ‘very good’) and the average score of visual quality and clarity was 3.8 (between ‘good’ and ‘very good’).

The average scores regarding the overall impression of the booklet were 3.7 (between ‘good’ and ‘very good’) with 3.1 the lowest score and 3.9 the highest.
Table 7.3 Rating scores of evaluation of the PD-Sketching Primer

<table>
<thead>
<tr>
<th>Individual attributes</th>
<th>Average rating score</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content of the booklet</td>
<td>4.1</td>
<td>0.76</td>
</tr>
<tr>
<td>Quality of the content</td>
<td>3.6</td>
<td>0.82</td>
</tr>
<tr>
<td>Quality of the reference</td>
<td>3.7</td>
<td>0.78</td>
</tr>
<tr>
<td>The layout of the booklet</td>
<td>3.7</td>
<td>0.94</td>
</tr>
<tr>
<td>Visual quality and clarity</td>
<td>3.8</td>
<td>0.89</td>
</tr>
<tr>
<td>Overall (content and format)</td>
<td>3.7</td>
<td>0.77</td>
</tr>
</tbody>
</table>

The respondents were asked about the next step they would take after they had read the PD-Sketching Primer. An eight-fold multiple-choice question was used to explore their reaction to the booklet. The results are presented in Table 7.4. The majority of respondents would like to ‘keep the booklet as a reference’, ‘get more information about design sketching’ and ‘be more aware of design sketching’.

Table 7.4 ‘Reaction’ to the PD-Sketching Primer

<table>
<thead>
<tr>
<th>‘Reactions’</th>
<th>Frequency of mentions (percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be more aware of design sketching</td>
<td>19 (79.2%)</td>
</tr>
<tr>
<td>Keep the booklet as a reference</td>
<td>21 (87.5%)</td>
</tr>
<tr>
<td>Circulate the booklet among colleague</td>
<td>11 (45.8%)</td>
</tr>
<tr>
<td>Check references to get more information</td>
<td>16 (66.7%)</td>
</tr>
<tr>
<td>Hope to get an extended version of the primer</td>
<td>9 (37.5%)</td>
</tr>
<tr>
<td>Do nothing</td>
<td>0</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>1 (4.2%)</td>
</tr>
</tbody>
</table>

Suggestions regarding the content of the PD-Sketching Primer included:

- “more case studies and examples of the use of sketching in product design practice should be included in the booklet”
- “the psychology part is interesting, but it seems this topic is too big and complex for a booklet like a primer. Maybe, it is better to only focus on the ideation topic”
- more information about “the non-working sketches”
- “it is interesting to see the research into the sketching habits, but more detailed information could be included, e.g. why and how listening to music may change the sketching behaviour?”
Suggestions regarding the format of the PD-Sketching Primer included “bigger pages”, “better contrast”, and “bigger pictures”. The PD-Sketching Primer was acknowledged as “a useful and concise guide for design sketching” and “easy to use and understand”. According to the results of the preliminary evaluation, it was found that the feedback on the PD-Sketching Primer booklet was positive. The results suggested that the knowledge contained in the booklet and its format were appropriate.

7.4.2. Formal evaluation

Six months after the first introduction of the PD-Sketching Primer to the educational world, a formal evaluation was carried out. The aim of the evaluation was two-fold: to assess the impact of the PD-Sketching Primer had made on design education, and to identify whether it had fulfilled its aim in grabbing attention and spreading basic knowledge of sketching.

Participants and procedure

Participants of the formal evaluation of the PD-Sketching Primer were selected from those who had previously received the booklet and returned feedback to the preliminary evaluation. In total, 24 participants who involved in the preliminary evaluation and were willing to help with the research project (refer to Appendix F) were contacted through email. In order to encourage responses, a two-step procedure was adopted. In the email, a brief introduction of the previous research work was given as a reminder of the ongoing research. In addition, a refined version of PD-Sketching Primer in a format of PDF file and an evaluation form contained the evaluation questions were attached with the email. The participants were asked to send their feedback via email and were informed they would be contacted again if their feedback were not received in two weeks time. The participants who sent feedback were acknowledged via email, while the non-respondents were sent another email to invite them again to join the evaluation two weeks after the initial distribution.

Framework of evaluation

The Kirkpatrick Model is one of the best-known models for analyzing and evaluating new tools, methods, and training and educational programs in education and industry (Dong, 2004; La Duke, 2017). This model also worked as a framework providing an assist in determining what data (e.g. reaction, learning, behaviour and results) should be collected. It could be applied to any style of tools, methods or training programs to determine the effectiveness of use based on four levels of evaluation criteria, i.e. reaction, learning, behaviour and results. These four levels of evaluation criteria are briefly introduced in Table 7.5 and each followed an example of a question for participants.
Table 7.5 Kirkpatrick Model of evaluation

<table>
<thead>
<tr>
<th>Level of evaluation</th>
<th>Description</th>
<th>Sample questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.Reaction</td>
<td>Reaction evaluation is how the participants felt and their personal reactions to the training/learning</td>
<td>“Were the participants pleased with the tool?”</td>
</tr>
<tr>
<td>2.Learning</td>
<td>Learning evaluation is the measurement of the improvement in knowledge or intellectual capability from before to after the learning experience</td>
<td>“What did the participants learn from the tool and how easy was the tool to use?”</td>
</tr>
<tr>
<td>3.Behaviour</td>
<td>Behaviour evaluation is the extent to which the trainees applied the learning and changed their behaviour</td>
<td>“Was there a noticeable and measurable change in the performance of the participants based on what was learnt?”</td>
</tr>
<tr>
<td>4.Results</td>
<td>Results evaluation is the effect on the team resulting from the improved performance of the trainee</td>
<td>“Did the change in behaviour positively affect the organisation?”</td>
</tr>
</tbody>
</table>

It is desirable to measure the new tool from level 1 to level 4 when applying the Kirkpatrick Model, but this is usually not possible in a practical application. According to the literature, only less than 10% of the evaluation work using the Kirkpatrick Model conducted Level 4 evaluation (Ping et al., 2003; Wittenborn, 2008). In addition, level 4 was considered as not applicable to this study as it was not relevant to the educational context that the booklet was applied. Therefore, level 1, level 2 and parts of level 3 where possible were implemented in this study.

In addition to these three levels of evaluation criteria, validation was also taken into consideration as another important level of evaluation. The validation question was: “did the PD-Sketching Primer raise the participants’ awareness of design sketching?”

Table 7.6 presents all of the evaluation questions sent to the participants. These presupposed questions were used as the framework of the evaluation. A blank space was also provided after each question to invite comments on the evaluation questions or other issues related to the booklet.
Table 7.6 Evaluation questions

<table>
<thead>
<tr>
<th>Q 1: Do you like the PD-Sketching Primer?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q 2: What did you learn from the PD-Sketching Primer?</td>
</tr>
<tr>
<td>Q 3: Will you change your behaviour based upon what was learnt from the PD-Sketching Primer?</td>
</tr>
<tr>
<td>Q 4: Did the PD-Sketching Primer help to raise your awareness of design sketching?</td>
</tr>
</tbody>
</table>

**Results**

24 emails were sent out to invite participation in the formal evaluation of *PD-Sketching Primer*. 16 responses (66.7% of the total sample) on the evaluation questions were received in total after two rounds of distribution, among which 13 (54.2%) questionnaires were completed. An ID code was assigned to each respondent, which was used to identify their quotations. The respondents were coded in the form of XY0, i.e. two letters and one number. The first letter stands for their experience of design sketching (i.e. V: Very experienced; E: Experienced; L: Less experienced; N: Novice), the second letter stands for the occupation information of the respondents (i.e. S: Design students; D: Professional designers; A: Design academicians), and the number was assigned consecutively for differentiation. The results of the evaluation are summarised in Table 7.7 and described in the following paragraphs according to the Kirkpatrick Model.

The first question (Q1 in Table 7.7) accessed the reaction of the respondents to the *PD-Sketching Primer*. The feedback on this question was positive and 12 out of 13 respondents liked the *PD-Sketching Primer*. The comments related to this question suggested that the participants liked the booklet. Examples including:

“This is a very good booklet---certainly helps to expand our knowledge of design sketching---keeping us up-to-date and making sure that we use sketching in the right way” (ES-2)

“Thanks for sending me this great piece of work!” (ES-7)

Participants also expressed their appreciation through the emails. Ten participants said they would like to keep the primer as a reference. Five participants asked whether they could circulate the booklet among their colleagues and would like to disseminate the *PD-Sketching Primer* when it was finally published. There were another four participants. In addition, data collected from the preliminary evaluation also supports the finding, i.e. respondents found the *PD-Sketching Primer* informative and useful, and 87.5% of them would like to keep the booklet (Table 7.4)

The learning level of the evaluation was addressed by Question 2: What did you learn from the *PD-Sketching Primer*? This question received feedback from 11 respondents, among which 10 was positive, one was negative, and two participants did not make comments on this question (Q2 in Table 7.7). It seemed that different respondents learned different things from the booklet. Their comments are summarised and
presented in Table 7.7. This is understandable as the participants involved had different experience and different interests.

The positive example of comment is as follows:

‘I think the main thing we’ve learnt is from the taxonomy. It is quite useful for learning and teaching design sketching.’ (EA-4)

‘This booklet is informative … I think I would like to change my sketching behaviour, for example, I will try to use ‘warming-up sketch’ before my sketching process in the future.’ (ED-11)

The neutral example of comment is as follows:

“…I still have to say that I may need more detailed information to justify certain things…But I think it is inspiring and provides a good start.” (ES-13)

Question 3 (‘will you change your behaviour based upon what was learnt from the PD-Sketching Primer?’) was used for behaviour level of evaluation. The feedback on this question was not clear-cut, but the majority of the comments were positive. In total, 13 responses were received, among which 8 were positive, two were negative, and three did not give their answers. Related comments were also presented in Table 7.7.

The positive example of comment is as follows:

‘This booklet is informative and contained some knowledge that I do not know before, especially the knowledge about non-working sketches… I will try to use ‘warming-up sketch’ before my sketching process in the future.’ (ED-11)

The negative feedback is as follows:

‘I cannot point out a change in my sketching behaviour, but I’m interested in the information contained in the booklet and welcome to receive new versions of it.’ (VA-9)

Several respondents commented that they would not change their behaviour. According to their feedback, the reason was the same, as respondent VD-6 said probably because he was already familiar with the information contained in the booklet.

Question 4 was designed to validate the PD-Sketching Primer, i.e. ‘Did the PD-Sketching Primer help raising your awareness of design sketching?’ Altogether 13 responses were received, nine respondents gave positive feedback that they thought the primer was useful in raising their awareness of design sketching, while three was negative and one did not answer (Q4 in Table 7.7).

The positive example of comment is as follows:

“It (the booklet) certainly did raise an awareness… it gave you an extra framework to study design sketching.” (ES-1)

‘It has raised my awareness of the impact the stimuli on design sketching and ideation.’ (NS-8)
<table>
<thead>
<tr>
<th>ID</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Examples of Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES-1</td>
<td>√</td>
<td>√</td>
<td>×</td>
<td>√</td>
<td>“It (the booklet) certainly did raise an awareness…it gave you an extra framework to study design sketching”</td>
</tr>
<tr>
<td>ES-2</td>
<td>√</td>
<td>-</td>
<td>√</td>
<td>√</td>
<td>“This is a very good booklet…certainly helps to expand our knowledge of design sketching…keeping us up-to-date and making sure that we use sketching in the right way”</td>
</tr>
<tr>
<td>VD-3</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>×</td>
<td>-</td>
</tr>
<tr>
<td>EA-4</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>×</td>
<td>“I think the main thing we’ve learnt is taxonomy. It is quite useful for learning and teaching design sketching”</td>
</tr>
<tr>
<td>LS-5</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>“This booklet is informative and contained some knowledge that I do not know before, especially the knowledge about non-working sketches. I think I would like to change my sketching behaviour, for example, I will try to use ‘warming-up sketch’ before my sketching process in the future.”</td>
</tr>
<tr>
<td>VD-6</td>
<td>-</td>
<td>√</td>
<td>×</td>
<td>√</td>
<td>“I think I’m quite familiar with the information, it can be quite useful for me years ago”</td>
</tr>
<tr>
<td>ES-7</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>-</td>
<td>“Thanks for sending me this great piece of work!”</td>
</tr>
<tr>
<td>NS-8</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>“It has raised my awareness of the impact the stimuli on design sketching and ideation”</td>
</tr>
<tr>
<td>VA-9</td>
<td>√</td>
<td>×</td>
<td>×</td>
<td>√</td>
<td>“I cannot point out a change in my sketching behaviour, but I’m interested in the information contained in the booklet and welcome to receive new versions of it.”</td>
</tr>
<tr>
<td>LS-10</td>
<td>√</td>
<td>√</td>
<td>-</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>ED-11</td>
<td>√</td>
<td>-</td>
<td>√</td>
<td>×</td>
<td>“This booklet is informative and contained some knowledge that I do not know before, especially the knowledge about non-working sketches. I think I would like to change my sketching behaviour, for example, I will try to use ‘warming-up sketch’ before my sketching process in the future”</td>
</tr>
<tr>
<td>VS-12</td>
<td>√</td>
<td>√</td>
<td>-</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>ES-13</td>
<td>√</td>
<td>√</td>
<td>-</td>
<td>√</td>
<td>“…I still have to say that I may need more detailed information to justify certain things…But I think it is inspiring and provides a good start.”</td>
</tr>
</tbody>
</table>

Notes: √ (Yes), × (No), - (No comments)
7.5. Development of the **PD-Sketching Toolkit**

This section describes the second step of the development of the PD-Sketching Toolkit. There were several reasons for developing this support toolkit. The main reasons are two-fold.

1. As mentioned in Section 7.3.1, some of the requirements were not addressed in the development of the *PD-Sketching Primer*, e.g. providing visual stimuli as external support for design ideation and giving instructions on practising sketching skills. These requirements should be addressed in the further development of the supporting tools.

2. The feedback gathered on the *PD-Sketching Primer* indicated that the information included in the *PD-Sketching Primer* could be expanded to provide more details for people who would like to know more about design sketching or to improve their sketching ability. The limitation of the format of *PD-Sketching Primer* (i.e. booklet) suggested the needs for providing alternative formats (e.g. book and website).

The development of the *PD-Sketching Toolkit* followed a typical design tool development process (Pahl and Beitz, 2013). Given the limited time and resources of the study, only a prototype *PD-Sketching Toolkit* was developed. The development process of the *PD-Sketching Toolkit* is illustrated in Figure 7-7.

![Development process of a practical supporting tool](image-url)

*Figure 7-7 Development process of a practical supporting tool*
7.5.1. Components of the PD-Sketching Toolkit

The PD-Sketching Toolkit is composed of four parts, i.e. The Primer, the Taxonomy, the Combinator and the Textbook. These four tools were developed based on the identified preferences (Section 5.3.3 and 6.3.7) and captured requirements (Section 7.2) of supporting tools from design students and professionals. Specifically, the Primer and the Taxonomy were designed to address the perception problems identified from the previous surveys by drawing attention, raising awareness and explaining types of sketches and their roles in supporting the design ideation process; the Combinator was developed to provide external support by searching images from online and local databases and generating combinational images as visual stimuli for inspiration; and the Textbook was included to give instructions on how to learn to be a qualified design sketcher, e.g. the use of various types of sketching tools and media, methods to improve sketching skills and explanation of design sketching case studies. Each part of the toolkit corresponded to a general requirement captured from the descriptive studies (Table 7.8). The prototype I of the PD-Sketching Toolkit is presented in Figure 7-8.

Table 7.8 Toolkit components in relation to requirements

<table>
<thead>
<tr>
<th>Toolkit components</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Primer’</td>
<td>Awareness</td>
</tr>
<tr>
<td>‘Taxonomy’</td>
<td>Understanding</td>
</tr>
<tr>
<td>‘Combinator’</td>
<td>External Stimuli</td>
</tr>
<tr>
<td>‘Textbook’</td>
<td>Instruction &amp; Information</td>
</tr>
</tbody>
</table>
Figure 7-8. the PD-Sketching Toolkit (prototype I)
• The **Primer** (Figure 7-8a). The PD-Sketching Primer booklet was included in the PD-Sketching Toolkit. The Primer was developed aiming to raise awareness of design sketching.

• The **Taxonomy** (Figure 7-8b). A sketching taxonomy (Hua et al. 2018) was developed and a set of card-based tool (Figure 7-5) was then developed based on it, which aimed to provide guidance on how to classify and use different types of sketches in the design process. The features of a wide variety of types of sketches and their functions in the design process were systematically investigated and then explained in this card-based tool. What differentiated the PD-Sketching Taxonomy from the most existing classification systems of design sketches was that the types of sketches included in it were selected from the perspective of supporting the design ideation process. In addition, the non-working sketches were first time put forward as a major category of sketches and involved in a sketching taxonomy.

• The **Combinator** (Figure 7-8c). A CAD tool named Combinator (Hua et al., 2019) was upgraded and included in the toolkit, which can be used to search, organise and generate combinational pictures (e.g. juxtaposed and superimposed pictures) as external stimuli to spur creative thinking and support design sketching process. The Combinator is a flexible tool that could be adjusted to support different purposes by using different databases. In its upgraded version, the users’ digital sketching notebook and stored pictorial materials were involved as their local database. The users could employ their personalized database for producing ‘tailored’ creative combinational stimuli which are composed of their own sketches and images.

• The **Textbook** (Figure 7-8d). A sketching textbook (Ge and Hua, 2016) was revised and included in the toolkit, which can be viewed as a longer version of the ‘*Primer*’ but with a special focus on teaching sketching skills and training methods. It is a ‘knowledge pack’ comprising a general introduction of design sketching, a comprehensive introduction of sketching tools and media, a detailed instruction on sketching skills and training methods, a number of design and sketching case studies, a gallery of design sketching examples, and an informative reference list. The information included in this textbook was tailored specifically to the requirements of education.
Figure 7-9 the 'Primer' (prototype II)

Figure 7-10 the 'Taxonomy' (prototype II)
Figure 7-11 the ‘Combinator’ (prototype II)

Figure 7-12 the ‘Textbook’ (prototype II)
7.5.2. Development of the Taxonomy Cards

The Taxonomy Cards are a set of cards developed for assisting design sketching during the new product design process or facilitating the design sketching teaching/training in design education. When employed, the proposed tool can provide a generic source of information about sketching (e.g. classification, functions, nature and applied design stages) to product designers for improving their understanding of design sketching.

**Considerations on the content**

The amount of knowledge could serve as instruction for designers while they are designing with sketching or learning to sketch. As presented in Chapter 4, a new sketching taxonomy was established and 15 types of sketches commonly used in the current design context were identified. The Taxonomy Cards were developed based on this sketching taxonomy. However, it can be quite confusing for designers which type of sketch they should use during a specific design stage and why they should use it, which is especially the case for novice designers. To address the problem, the information contained in the Taxonomy Cards needs to be well-structured, clear and accessible (Pinto and Pinto, 1990). According to Pei et al. (2009; 2011), the users first need to know how to apply the various types of sketches at different design stages; secondly, the users need to understand the use of types sketches in the communication of specific design and technical information; at last, sketching examples of types of sketches should be included, which could provide the users with important visual references for learning and using the sketching. Therefore, key information that should be presented in the Taxonomy Cards were identified, which can be further summarized as four categories of sketching knowledge, i.e. design stages, design information, technical information and examples of design sketches. Details are presented in Table 7.9.
Table 7.9. Key information to be presented in the Taxonomy Cards

<table>
<thead>
<tr>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>• Concept Design</td>
<td>• Design Intent</td>
<td>• Dimensions</td>
<td>• Defining Sketch</td>
</tr>
<tr>
<td>• Design Development</td>
<td>• Form &amp; Detail</td>
<td>• Construction</td>
<td>• Memory Sketch</td>
</tr>
<tr>
<td>• Detailed Design</td>
<td>• Visual Character</td>
<td>• Assembly</td>
<td>• Idea Sketch</td>
</tr>
<tr>
<td>• Design Presentation</td>
<td>• Usability &amp; Operation</td>
<td>• Components</td>
<td>• Coded Sketch</td>
</tr>
<tr>
<td>• Non-design</td>
<td>• Scenario of Use</td>
<td>• Materials</td>
<td>• Development Sketch</td>
</tr>
<tr>
<td></td>
<td>• Finishing</td>
<td></td>
<td>• Detail Sketch</td>
</tr>
<tr>
<td></td>
<td>• Colour</td>
<td></td>
<td>• Explanatory sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Instruction Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Presentation Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Fabulous Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Storyboard Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Logbook Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Storing Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Practising Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Playing Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Warm-up Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Storing Sketch</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>• Practising Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Playing Sketch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Warm-up Sketch</td>
</tr>
</tbody>
</table>

The target users of the tool were design students or professionals in the product design field or design educators who teach design sketching. This tool was also designed to be open to the other stakeholders related to the design process, including technicians, makers, marketers, manufactures and management.

**Considerations on the format**

A framework of sketching taxonomy was developed based on the findings be discussed in Section 4.3.9. 15 types of sketches were identified, together with their functions, applied stages and sketch examples are presented in Table 4.17. The
card-based taxonomy tool provides an excellent alternative presentation format. For example, the physical card-based tool had the advantage of portability to provide easy access to knowledge and instruction, which is ideal as an instant supporting tool during the design process. From the initial design of the tool, it was found that too much information might lead to difficulty in reading and perception, while too little information would make it less effective. Therefore, the focus of the format design was to balance the information structure and make it easy to read and use.

The design separated content into two sets according to the basic classification of types of sketches (i.e. working sketches and non-working sketches) for more accurate access to sketching knowledge. The tool contains 90 cards in total, 56 cards were colour-coded in green to provided knowledge on working sketches and practice and 34 cards in blue for non-working sketches. A numerical system was put in place to improve access to the tool. Each of the singular-numbered cards contains a piece of key sketching knowledge (e.g. introduction of design stages or definition and illustration of one type of sketch), and the following even-numbered card would list the related information in a bar chart as guidance (e.g. the card No. and relevant types of sketches). For example, if a user wants to know more about a particular piece of information from other cards, they could find the cards by referring to the unique number shown on the bar chart and locate the card according to the number provided on the top right corner (Figure 7-13).

Each set of the cards were further divided into four packs containing different sketching knowledge (refer to the four categories of sketching knowledge), which are briefly described as follows.
1. Pack one: Design Stages

The first pack of cards (Figure 7-14) contained five cards from each colour presenting key design stages of new product development as an introduction of the design process. The singular-numbered cards provided the definition of the design stages and the even-numbered cards provided information and examples of design sketches used for that stage, which was illustrated through bar graphs and numbers.

Figure 7-14. Pack one: Design Stages
2. Pack two: Design Information

The second pack of cards (Figure 7-15) contained seven cards with each colour presenting key design information used by product designers during the new product development process. The singular-numbered cards provided the introduction of key design information and the even-numbered cards presented information and examples of design sketches used for expressing the design information, which was illustrated through bar graphs and numbers. Key design information would include knowledge like form, details, visual character and colour.

![Design Intent Cards](image)

**Figure 7-15 Pack two: Design Information**
3. Pack three: Technical Information

The third pack of cards (Figure 7-16) contained five cards with each colour presenting key technical information used by product designers during the new product development process. The singular-numbered cards provided the introduction of key technical information and the even-numbered cards presented information and examples of design sketches used for expressing the technical information, which was illustrated through bar graphs and numbers. Key technical information would include structure, mechanism, assembly and construction.

Figure 7-16. Pack three: Technical Information
4. Pack four: Design Sketches

The fourth pack of cards (7-17) contained fifteen cards with each colour presenting various types of sketches used by product designers during the new product development process. The singular-numbered cards provided the definition and a sketch example of that type of sketch and the even-numbered cards showed the relevance to design stages, design information and technical information, which was illustrated through bar graphs and numbers.

Figure 7-17 Pack four: Design Sketches
Colour coding was adopted as a solution to make sure that the information contained in the cards could be easily identified. The colour scheme was still limited to a red hue for working sketches and a blue hue for non-working sketches. Moreover, a coloured tab was added and located at the bottom of each card so that to distinguish the different four packs of cards (Design Stages, Design Information, Technical Information and Design Sketches). These tabs were assigned with different colours, i.e. Design Stages cards were designed in red, Design Information cards were in orange, Technical Information cards were in yellow and Design Sketches cards were in brown (Figure 18, 19). The structure of the colour based recognition system was illustrated in (Figure 20). Other design details were presented in Figure 21. The overall view of the card system was illustrated in Figure 22 and a high-resolution version of each card can be found in Appendix E.

![Figure 7-18. The representative colour scheme for cards](image)

![Figure 7-19. Examples of the coloured tabs](image)
Figure 7-20. Structure of the coloured tabs for the four packs
Figure 7-21. The design of Taxonomy Cards
Design Stages

Design Information

Technical Information

Design Sketches

Figure 7-22. The overall card system
7.5.3. Development of the Combinator

The Combinator is a piece of software developed for assisting designers in idea generation during the early stages of the design process. The tool was developed based on the findings from the study conducted by Han et al. (2018) and Hua et al. (2019), which works by stimulating the human brain regarding the aspects of achieving combinational creativity. Specifically, I was responsible for exploring the methods of generating visual stimuli, and Dr Ji Han developed the algorithm and database. The Combinator can be used for supporting design ideation by combining familiar design materials into new combinational visual stimuli for designers. The Combinator is designed for assisting the design idea generation process when the design problem specification has been reached a high degree. Moreover, the tool is also capable of facilitating idea generation at the very early stages of design process when design objectives have not been set. The Combinator could generate various random stimuli that has been proved to be beneficial for design ideation (Howard, Culley and Dekoninck, 2011) and randomness is considered as a crucial element of creativity (Carruthers, 2011).

The basic algorithm of the Combinator

The algorithm of Combinator (Figure 7-23) is a simulation of aspects of the human brain in generating combinational ideas. Therefore, understanding the working mechanism of the human mind and memory is essential for the development of the tool. The human memory, in this research, was regarded as a knowledge database that contains a variety of design information/materials, while the human mind was considered as an associative system where links among stored information/materials were formed to generate combinational ideas.

As shown in Figure 7-23, the algorithm begins with crawling user-defined information from the Internet using a web crawler. The information is then analysed and processed by natural language processing and then stored in the core database. This is similar to how humans gain knowledge from augmented memory such as books and the Internet. A user input (e.g. a design keyword) is first delivered to the Combinator module and a cue is then generated to instruct the retrieval process from the Combinator database to the Combinator module. This is a process simulating how information stored in human long-term memory is retrieved and transferred into short-term memory. The design materials in the Combinator are linked together and then the combinational visual stimuli are generated accordingly. This is similar to the interplay between the human mind short-term memory to achieve combinational creativity.
**The development of the Combinator database and module**

Modelling a rich structured database and an idea linking system is crucial for the development of the *Combinator*. Therefore, natural language processing tools and information retrieval technology were adopted in this research to support the development of the *Combinator* database. An open-source web crawler (i.e. Scrapy) was employed, which is licensed under the BSD License (Berkeley Software Distribution License). Scrapy allows users to define what kind of data to extract and which data format to use. In this study, the web crawler is programmed to retrieve only main body texts describing design related products or ideas from a design website. The core database is created through retrieving and processing text descriptions of a wide range of products from a well-known product design website. The crawled texts are simultaneously processed by a natural language processing tool, i.e. Natural Language Toolkit (Bird, Klein and Loper, 2009). The requisite words are abstracted from the texts retrieved by the web crawler through using NLTK. The core database classifies the information, alternatively words, based on their part-of-speech, such as verbs, adjectives, and nouns. An example of a brief depiction of the core database is shown in Figure 7-24.

To construct a human-like associative knowledge database, the Combinator database, the elements or information in the core database are then associated with a semantic net. This is to simulate the way that the human brain connects associated knowledge in memory. ConceptNet is used here to serve as the semantic net for providing relations between ideas (words) and additional associated ideas. The elements in the core database are unorganised and unrelated, for instance, the elements from the core database shown in Figure 7-24. After connection with the ConceptNet, the elements in the core database are connected to each other as well as linked with additional correlated associated ideas that are not included in the core database. Common-sense relationships employed in the ConceptNet, such as ‘Part of’, ‘At location’ and ‘Used for’, are used to connect ideas in the Combinator database, as shown in Figure 7-25. In the figure, the elements from the core database are connected with each other and additional associated ideas, such as ‘container’ and
‘coffee cup’, which has briefly demonstrated the structure of the Combinator database.

A user input (e.g. a design keyword) is first delivered to the Combinator module and a cue is then generated to instruct the retrieval process from the Combinator database to the Combinator module. This is a process simulating the way that information stored in human long-term memory is retrieved and transferred into short-term memory. The design materials in the Combinator are linked together and then the combinational visual stimuli are generated accordingly. The visual stimuli, namely combinational pictorial stimuli (CPS), is generated by employing a customised live feed image crawler, for retrieving online images, and a vision algorithm library ‘OpenCV’, for producing juxtaposing and superimposing pictorial stimuli. Details of these two CPS delivery strategies were discussed in Chapter 2.

The Combinator module produces outputs using two different approaches. The first one is to combine the user input element with an element retrieved from the Combinator database. For example, if the user input element is ‘cup’ and the retrieved element is ‘kettle’, then the output will be ‘cup kettle’ or ‘kettle cup’. In the second approach, the Combinator module will provide a cue, based on the user input element, to retrieve elements that are connected with the input from the Combinator database. The retrieved elements are then used to form combinational outputs with the element retrieved from the Combinator database. For instance, ‘mug’ is connected with ‘cup’ in the database, thereby, the outcome will become ‘mug kettle’ or ‘kettle mug’. These simulate the human associative power, of which human often considers the associated ideas in their long-term memory of the one in their short-term memory. Overall, the Combinator module replicates the interplay between the human mind and short-term memory to achieve combinational creativity.

Figure 7-24. Information elements in the core database
7.5.4. Development of the Textbook

This section provides a brief introduction to the development of the ‘Product Design Sketching’ textbook (Ge and Hua, 2016). This textbook was written by the author and Dr Yanming Ge. The author focused on giving an introduction to design sketching and sketching skills, while Dr Yanming Ge was responsible for introducing the use of different sketching tools, and providing sketching examples and case analysis. This textbook aimed to enhance readers’ understanding of sketching and to provide guidance on sketching skills and their training methods. As mentioned, this textbook can be viewed as a ‘longer version of the Primer’, which has its own focus on teaching sketching skills. Learning to sketch effectively for supporting product design practice is not merely a technical skill, but also requires a deep and comprehensive understanding of “the mechanics of vision, cognition and representation” (Henry, 2012).

Considerations on the content

The requirements list (Table 7.1) specified the contents to be included in the textbook. The central to the textbook is the belief that sketching skills are important for product designers and could have a strong impact on their design performance. Therefore, the textbook is structured around a single narrative that merges theory and actual practice and provides in-depth explanations alongside step-by-step demonstrations.

The textbook was developed as a ‘knowledge pack’ comprising four main sections, i.e. Chapter 1: General Introduction of Production Design Sketching, Chapter 2: Introduction of Sketching Tools & Media, Chapter 3: Basic of Product Design Sketching Skills and Chapter 4: Product Design Sketching Case Studies. Specifically, Chapter 1 provides a general introduction of design sketching, including the definitions, history and trends, types and roles of sketches, and basic principles and characteristics of product sketching.
Chapter 2 provides a comprehensive introduction of traditional sketching tools (e.g. pens, pencils and markers) and digital media (e.g. Inking, Photoshop and Sketchbook) which aims to create a bridge between freehand sketching skills and digital-based visualization tools.

Chapter 3 provides detailed instruction on sketching skills and training methods. It first introduces the particulars of perspective, line and form and explains how important these elements for confident design ideation. Then, this chapter starts to deal with the application considering the issues beyond simple sketching, including shading, colour, material, annotation, layout, articulation and composition. All these skills are essential to take good design ideation to the next level and make it easier for colleagues (i.e. product managers, technical people and other designers in the team) or clients to engage with it. Finally, this chapter discusses how the previously described sketching skills can be combined at the macro level of presenting the design concept in a convincing design scenario.

Chapter 4 provides a number of design sketching case studies and a gallery of design sketching examples. To make the textbook useful, original and inspiring, contemporary materials were adopted wherever possible. For example, most of the sketching examples included in the textbook were collected from the internet, which was produced by design sketchers from all over the world (e.g. Adityaraj Dev, Jimi Brown, Juan Lee, etc.).

7.6. Evaluation of the PD-Sketching Toolkit

In this study, Kirkpatrick’s Model was used for the evaluation of the PD-Sketching Toolkit, because the flexibility of this model allowed the author to determine multiple assessments and methods when applicable. The evaluation of the PD-Sketching Toolkit took place in three stages: a preliminary evaluation and a two-part formal evaluation. The preliminary evaluation aimed to understand the users’ overall perception of the PD-Sketching Toolkit and find out an appropriate way to introduce the toolkit to its target audience. The formal evaluation was carried out aiming to assess the effectiveness of the toolkit in supporting aspects of design sketching (e.g. learning, practice and ideation). The evaluation and data collection was guided by Kirkpatrick’s Model (Donald, James and Wendy, 2016). Methodological triangulation was implemented and multiple sources of evidence were adopted to add the validity of the research findings (Flick, 2004; Yin, 2017). Different evaluation methods were used to verify a single level of evaluation according to the requirements of the model. Data were collected from various research methods including survey, interview and controlled experiment.

7.6.1. Preliminary evaluation

The preliminary evaluation was carried out through a ‘let your creativity fly’ programme, a design training institute (i.e. One Pear) initiative that involved design
students and professionals in a design sketching training course. Part of the PD-Sketching Toolkit (i.e. the Primer, the Taxonomy Cards and the Textbook) was used as the teaching material for improving the participants' understanding and ability of design sketching. The Combinator was not used because it was considered as a real-time auxiliary system that was not relevant to the programme. The author delivered an oral presentation of the PD-Sketching Toolkit, demonstrating each component tool and its use in turn during the presentation. The toolkit was then provided to the tutors/participants as teaching/learning materials. The preliminary evaluation of the PD-Sketching Toolkit was based on oral feedback from the participants, the observation of the participants' reactions to the toolkit, and their understanding of the design sketching reflected by their sketching outcomes. The oral feedback was documented, the observation of reaction was recorded and the sketches were collected. The data were collected according to the framework of Kirkpatrick’s Model, among which the ‘Results Level’ of the evaluation was not included as it was considered not relevant to the research. The results are summarised as follows.

Reaction

The oral feedback from the participants showed that they were interested in the PD-Sketching Toolkit. They thought the toolkit was “a good idea, definitely bring us a better understanding”, especially the taxonomy system, training methods and case studies included in the toolkit. It was considered as one of the few sketching supporting tools available in the field.

The format design of the PD-Sketching Toolkit received positive feedback from the participants. They thought the toolkit was well designed and very easy to use. Therefore, a further enquiry “What makes the toolkit easy to use?” was made. To summarise, what made the PD-Sketching Toolkit ‘easy to use’ were its ‘conciseness & clarity’, ‘effective communication’, ‘good design’ and ‘good format’. However, some participants indicated that the design of the PD-Sketching Taxonomy Cards needs to be improved. It can be summarised that there were two major issues to be addressed. Firstly, there was a need to increase the size of the text and images contained in the cards as several participants suggested it was difficult for them to read. Secondly, the navigation system should be improved so that a particular card could be located easier and faster.

Learning

The participants gave positive feedback on the content of the toolkit. Especially, the novice sketchers said they became aware of design sketching and understand the roles of types of sketches in design. For example, one of the students from the art design background said he used to think sketching is ‘just a special kind of drawing used to express concept, form, feelings, personality, etc’, but now he became to know that sketching could benefit designers in many ways. Therefore, he decided to shift his focus of design sketching learning, from simply care about drawing skills to many other aspects, e.g. communication skills, ideation skills and design analysis skills.
What the student learned from the toolkit was also indirectly reflected by his work during the course (Figure 7-26 and Figure 7-27). The feedback from experienced sketchers showed they were well aware of many aspects of design sketching, but the information contained in this toolkit was still very useful for them, especially those they feel new to them (e.g. the psychology of sketching, the non-working sketches, etc.). This might be because most of the participants were practitioners and have little access to academic recourses of design sketching.

![Figure 7-26. Examples of idea sketches from art design students](image1)

![Figure 7-27. Examples of explanatory sketches from art design students](image2)
Behaviour

The majority of the comments for this level of the evaluation were positive. The participants were known to have tried to apply what they learnt from the toolkit in sketching practice and design projects. Some participants asked the author for a copy of the detailed introduction of design sketching taxonomy because they thought an extended version of the taxonomy with detailed knowledge on the types of sketches and their applied design stages “would be useful as guidance for appropriate use of sketching in design”. It also reminded the author that both formats had their merits and shortcomings. The card-based taxonomy was easier to read and to grab immediate attention, but it was not as informative as a book when the users want to gain more knowledge about the subjects. Therefore, a link to the review paper on sketching taxonomy was added to the final version of PD-Sketching Taxonomy Cards. It should be noted that this level of the evaluation was not specifically addressed by the research question used in the preliminary evaluation because a more accurate assessment should be the long-term observation of the usage of the PD-Sketching Toolkit through the whole process of the training course and identification of a ‘remarkable improvement’ on sketching ability at the individual level of the participants.

The participants said the PD-Sketching Toolkit certainly enhanced their understanding of design sketching. The novice sketchers argued that the lack of awareness was a major barrier to learning and using sketching in design. This statement was echoed by other participants and they made a further enquiry “are there any other barriers than the lack of awareness?” The tutor thought that the sketching classification system in the PD-Sketching Taxonomy Cards and guidance on sketching skills in the PD-Sketching Textbook could help the students break down their barriers, which help them to know which type of sketch to use and how to draw it. A few participants were able to comment on other related questions, for example, one of the participants suggested that “it would be better to include an instant aid tool in the PD-Sketching Toolkit”. She thought that the separation of a ‘quick way to get the information’ from ‘detailed information’ could better support her when she wants to gain an understanding of the topic quickly.

7.6.2. Formal evaluation I

One year after the first introduction of the PD-Sketching Toolkit to education, a formal evaluation was carried out. This evaluation aimed to identify the effectiveness of the PD-Sketching Toolkit in supporting sketching in design and to validate whether it had fulfilled its aim in enhancing understanding of the roles of sketching in today’s design context. The formal evaluation was conducted in two stages: the first stage explored the participants’ overall perception of the usefulness of the toolkit, and the second stage assessed the effectiveness of the component tool (i.e. Combinator) but with a special focus on design creativity. The formal evaluation I is described in the following paragraphs.
The methods adopted for the first stage of the formal evaluation were selected based on the findings from the preliminary evaluation. The preliminary evaluation confirmed that oral presentation was an effective method to introduce the toolkit to the audience. It can be useful in explaining the use of sketching in design, in particular, helped participants better understand the case studies presented in the *PD-Sketching Primer* and *PD-Sketching Textbook*. Therefore it was decided to use the oral presentation as the main method for the formal evaluation I. A survey was given to gauge the reaction of the participants. Three reflection questions were asked the participants to reveal what they have learnt from the materials contained in the toolkit. A follow-up questionnaire was sent to the participants four months later to obtain their perception of any transfer of learning that has occurred during this period of time as part of the evaluation guided by Kirkpatrick’s Model. A standard evaluation form was designed (Appendix G) and PPT slides were made for the oral presentation. The first part of the slides was about the *PD-Sketching Toolkit* and its component tools, other slides were about the explanation of academic research and practical case studies of design sketching. In addition, comments on the toolkit and its component tools gathered from multiple sources were also included in the evaluation.

**Participants**

The selection of the participants was based on the following considerations:

1. A balance between design students, professional designers, and design academicians
2. A balance between participants who were novice with design sketching and experienced with design sketching

Initially, 28 potential participants were contacted and 12 of them were selected for the formal evaluation I according to their availability in a certain period of time. The same ID code was assigned to the participants (refer to Section 7.4.2) and the profiles of the participants are presented in Table 7.10.
### Table 7.10. Profile of the participants in the formal evaluation

<table>
<thead>
<tr>
<th>Participant ID</th>
<th>Major</th>
<th>Years of Sketching Experience</th>
<th>Professional Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS-1</td>
<td>Industrial Design</td>
<td>1</td>
<td>Student</td>
</tr>
<tr>
<td>ES-2</td>
<td>Industrial Design</td>
<td>5</td>
<td>Designer</td>
</tr>
<tr>
<td>LS-3</td>
<td>Engineering Design</td>
<td>1</td>
<td>Student</td>
</tr>
<tr>
<td>VD-4</td>
<td>Industrial Design</td>
<td>8</td>
<td>Designer</td>
</tr>
<tr>
<td>LD-5</td>
<td>Industrial Design</td>
<td>4</td>
<td>Student</td>
</tr>
<tr>
<td>LS-6</td>
<td>Service Design</td>
<td>2</td>
<td>Student</td>
</tr>
<tr>
<td>EA-7</td>
<td>Engineering Design</td>
<td>6</td>
<td>Academic</td>
</tr>
<tr>
<td>LS-8</td>
<td>Industrial Design</td>
<td>2</td>
<td>Student</td>
</tr>
<tr>
<td>EA-9</td>
<td>Industrial Design</td>
<td>5</td>
<td>Designer</td>
</tr>
<tr>
<td>VA-10</td>
<td>Industrial Design</td>
<td>13</td>
<td>Academic</td>
</tr>
<tr>
<td>NS-11</td>
<td>Industrial Design</td>
<td>&lt;1</td>
<td>Student</td>
</tr>
<tr>
<td>LS-12</td>
<td>Engineering Design</td>
<td>2</td>
<td>Student</td>
</tr>
</tbody>
</table>

**Evaluation procedure**

The evaluation took place at the Zhejiang Normal University. It was planned as a 45-minute session, including an introduction with PPT presentation (20 minutes, Figure 7-28a), interaction with the PD-Sketching Toolkit and a follow-up question and answer session (15 minutes, Figure 7-28b), and filling in the evaluation form (10 minutes, Figure 7-28c). When the extra time was available, the interaction with the toolkit and the Q&A session could take a longer time.

*Figure 7-28 Evaluation procedure of the PD-Sketching Toolkit*
Results

The results are described in the following paragraphs according to the evaluation framework (i.e. Kirkpatrick Model). Kirkpatrick proposed a four-level framework that represents a sequence of ways to evaluate new training tools. Level 1 (Reaction) of the Kirkpatrick Model explores how did the participants like the training tool, Level 2 (Learning) identifies whether the participants manage to learn, Level 3 (Behaviour) assesses whether the participants are able to use what they have learned from the tool to improve their working performance and Level 4 (Results) measures the impact of the tool on the organisation. It should be noted Level 4 (Results) was not implemented in this study as previously discussed (refer to Section 7.4.2). This PhD research project aimed to enhance the understanding of the general roles of sketching in today's design context but with a special focus on the role of sketching in supporting design ideation. Therefore, in addition to these three levels of evaluation, ideation was considered as another important level of evaluation. This level of evaluation was carried out to identify the effectiveness of the sketching tool in supporting design ideation. The results of Level 4 (Ideation) are presented in Section 7.6.3 (Formal Evaluation II).

Reaction

A survey was given to the participants to gather their reaction or attitude to the PD-Sketching Toolkit. This is in accordance with Level 1 of Kirkpatrick's Model. The 5-point Likert-type scale survey contained items according to the factors affecting the effectiveness of supporting tools that are commonly found in the literature i.e. format, information quality, satisfaction and perceived usefulness (Seddon, 1997; Hsieh and Cho, 2011; Damnjanovic, Jednak and Mijatovic, 2015; Embi, Neo and Neo, 2017). Participants were asked to select from 1 to 5 according to their perceptions of each sub-options (i.e. 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree and 5-Strongly Agree). The results were analysed using SPSS to determine the reliability of the survey. The Cronbach’s Alpha coefficients were more than 0.6 in all dimensions, so it was considered reliable (Ping et al., 2003).

The results of the survey on the participants’ responses in terms of the four dimensions were shown in Table 7.11. The mean values and standard deviations (SD) of the responses from participants are presented in the table. The grand mean and Cronbach’s Alpha is also shown for every dimension.
<table>
<thead>
<tr>
<th>Item Dimension</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Format</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Different formats are used in the <em>PD-Sketching Toolkit</em></td>
<td>3.87</td>
<td>0.89</td>
</tr>
<tr>
<td>2. Appropriate formats are used in the <em>PD-Sketching Toolkit</em></td>
<td>3.74</td>
<td>0.97</td>
</tr>
<tr>
<td>3. The component tools are organised in a flexible way</td>
<td>3.77</td>
<td>0.56</td>
</tr>
<tr>
<td>4. The toolkit is easy to use</td>
<td>3.74</td>
<td>0.63</td>
</tr>
<tr>
<td><strong>Grand mean = 3.78, Alpha = 0.76</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Information quality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. The <em>PD-Sketching Toolkit</em> provides useful information for supporting design sketching</td>
<td>4.03</td>
<td>0.66</td>
</tr>
<tr>
<td>2. The <em>PD-Sketching Toolkit</em> provides sufficient information for supporting design sketching</td>
<td>4.06</td>
<td>0.68</td>
</tr>
<tr>
<td>3. The <em>PD-Sketching Toolkit</em> provides up-to-date information for supporting design sketching</td>
<td>3.90</td>
<td>0.65</td>
</tr>
<tr>
<td><strong>Grand mean = 4.00, Alpha = 0.73</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Satisfaction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. The use of the <em>PD-Sketching Toolkit</em> gave me a sense of satisfaction</td>
<td>4.03</td>
<td>0.56</td>
</tr>
<tr>
<td>2. I found using the <em>PD-Sketching Toolkit</em> is interesting and engaging</td>
<td>3.97</td>
<td>0.71</td>
</tr>
<tr>
<td>3. I will use the <em>PD-Sketching Toolkit</em> in the future</td>
<td>4.00</td>
<td>0.63</td>
</tr>
<tr>
<td>4. I would recommend the <em>PD-Sketching Toolkit</em> as an ideal sketching support tool</td>
<td>4.03</td>
<td>0.66</td>
</tr>
<tr>
<td><strong>Grand mean = 4.03, Alpha = 0.77</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Perceived usefulness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. The use of the <em>PD-Sketching Toolkit</em> will make sketching learning easier</td>
<td>3.74</td>
<td>0.63</td>
</tr>
<tr>
<td>2. The use of the <em>PD-Sketching Toolkit</em> enhanced the understanding of design sketching</td>
<td>3.77</td>
<td>0.67</td>
</tr>
<tr>
<td>3. The use of the <em>PD-Sketching Toolkit</em> improved my sketching ability</td>
<td>3.94</td>
<td>0.77</td>
</tr>
<tr>
<td>4. The use of the <em>PD-Sketching Toolkit</em> supported the design ideation process</td>
<td>3.90</td>
<td>0.54</td>
</tr>
<tr>
<td><strong>Grand mean = 3.84, Alpha = 0.77</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
It can be seen from the survey results that participants reacted positively towards the PD-Sketching Toolkit in terms of the four dimensions for supporting design sketching. The findings suggest that participants generally liked the toolkit that they could be engaged and motivated to use the toolkit. It was found that the information and its format were appropriate. The component tools of the toolkit were developed in different formats (i.e. a quick guide: booklet, a sketch classification system: taxonomy cards, a real-time CAD tool: Combinator and a comprehensive learning material: textbook), which could meet the needs of the format preferences of different participants and be used in various situations.

Learning

Level 2 of the Kirkpatrick Model involves evaluating how far the tools that participants used have improved their knowledge and skills. This level of evaluation is typically carried out using assessments or tests before and after the training. However, the pre-and post-test method was considered to be not applicable in this study due to the limitation of time and resources for a PhD project. The PD-Sketching Toolkit was developed to enhance the users’ understanding and ability of sketching, but this process may take years of study and practice to gain the experience and skill set needed for a qualified sketcher. In addition, there are other factors that may influence the evaluation results during this long period of time, i.e. learning to sketch from other sources (books, courses, website or people) and the amount of practice. Therefore, a reflection question method was employed and three evaluation questions relevant to this level of the evaluation were generated and listed as follows.

Question 1: Did you learn anything from the toolkit? If so, what did you learn?

Question 2: Did anything noticeably of the toolkit promote or hinder your ability to sketch?

Question 3: Are there any topics you would like to pursue learning further?

The first question received feedback from all the 12 participants. A summary of the results is presented in Table 7.12, with the keywords about what was learnt in the left column, frequency of mentions in the middle column, and example quotations in the right column. The main issues learnt were summarized as ‘refresher of what is known and unknown’, ‘understanding’, ‘design creativity’, ‘resources’ and ‘design communication’.
Table 7.12. Response to the level 2 evaluation questions 1

<table>
<thead>
<tr>
<th>Keywords</th>
<th>No. of mentions</th>
<th>‘What did you learn from the toolkit?’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Examples (direct quotations)</td>
</tr>
<tr>
<td>“Refresher”</td>
<td>7</td>
<td>“…keeping us up-to-date on what is going on and expanding our knowledge…the changing roles of sketching in the design industry, …so one thing that I certainly learnt from the toolkit is we should keep ourselves on the top of what is actually happening in the industry” (VD-4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“…very few books or tools available in the market contain knowledge about the psychology of sketching…the toolkit is absolutely an eye-opener for me.” (LS-6)</td>
</tr>
<tr>
<td>“Understanding”</td>
<td>3</td>
<td>“The depth and breadth of the subject, in terms of sketching habit, which is a specialised area… I have also learnt that it is something I should be aware of” (LS-8)</td>
</tr>
<tr>
<td>“Design creativity”</td>
<td>2</td>
<td>“I like the Combinator! I’ve never used a creativity tool before… hopefully, more creativity tools could be included in the toolkit!” (VD-4)</td>
</tr>
<tr>
<td>“Resources”</td>
<td>2</td>
<td>“I like the case studies and examples in particular, and the fact that the contained sources of reference are quite useful” (EA-9)</td>
</tr>
<tr>
<td>‘Design communication’</td>
<td>1</td>
<td>“I think that the main thing I’ve learnt is the design communication skills with sketching, especially those related to proposing to the clients are quite useful” (ED-5)</td>
</tr>
</tbody>
</table>

The second question received feedback from nine participants. The results are summarized and presented in Table 7.13, including no. of mentions and examples of comments on ‘promoters’ and ‘hinders’.
### Table 7.13. Response to the level 2 evaluation questions 3

<table>
<thead>
<tr>
<th>Keywords</th>
<th>No. of mentions</th>
<th>‘Did anything noticeably of the toolkit promote or hinder your ability to sketch?’</th>
<th>Examples (direct quotations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Promoters”</td>
<td>7</td>
<td></td>
<td>“The textbook contained in the toolkit is very good! I followed the training methods in the textbook to practice and my skills have improved.” (LS-6)</td>
</tr>
<tr>
<td>“Hinders”</td>
<td>2</td>
<td></td>
<td>“I’m very interested in the Combinator and I think it can be quite useful for me, cause I always like to search for examples or pictures while I’m designing and sketching. However, the current version of the Combinator is in English which is hard for me to use. I hope the author could develop a Chinese version of the Combinator in the future.” (LD-5)</td>
</tr>
</tbody>
</table>

The third question received feedback from eight participants. Table 7.14 lists the topics that the participants were interested in and want to be included in the future. To summarise, what the participants would like to learn more about were ‘the impact of technological progress on sketching’, ‘academic research on sketching’ and ‘other sketching supporting tools available’.

### Table 7.14. Response to the level 2 evaluation questions 3

<table>
<thead>
<tr>
<th>Keywords</th>
<th>No. of mentions</th>
<th>‘Are there any topics you would like to pursue learning further?’</th>
<th>Examples (direct quotations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Technological impact”</td>
<td>4</td>
<td>“As pointed out in the textbook ‘the roles sketching keeps changing’ due to the development of new technologies in the field... this toolkit certainly refocuses our mind,...so we should not be complacent what we’ve known...” (ES-2)</td>
<td></td>
</tr>
<tr>
<td>“Academic resources”</td>
<td>2</td>
<td>“I teach design communication, including sketching, in the university, but I used to ignore the importance of academic research on this topic. Your toolkit is inspiring...If possible, please include more research items in the next version of the toolkit.” (EA-7)</td>
<td></td>
</tr>
<tr>
<td>“Supporting tools”</td>
<td>2</td>
<td>“Whenever I sketch, the most interesting part for me is the interaction with the tools I use. The Combinator is interesting and I want to experience more” (LD-5)</td>
<td></td>
</tr>
</tbody>
</table>
**Behaviour**

Level 3 of evaluation aimed to identify whether participants would like to transfer the knowledge gained from the toolkit to real design practice. Questions were asked to obtain the participants’ willingness to transfer what they have learned according to Kirkpatrick’s Model. Altogether 12 responses were received, among which eight of the responses were positive, three were neutral, and one was negative. According to the survey results, most of the participants felt that all or part of the knowledge and information they gain from the toolkit has been transferred. However, there was also one student who did not feel that he had transferred the knowledge due to several reasons including slow learner and confusion.

The positive examples of feedbacks are as follows:

“Yes, I think it has already changed me. I’ve been thinking about sketching more and also practised more. I could feel this is good for my design.” (ES-2)

“So far, it’s emphasised to me the importance of making our design representations simple and as clear as possible, especially when communicate with engineers and clients.” (LD-5)

“Of course, we have applied all of the skills learnt on the project” (LS-12)

“Yes I’ve used the taxonomy cards and textbook in my class and the feedback from the students were good” (VA-10)

The neutral examples of feedbacks are as follows:

“Some of the contained information was quite new for me, in term of behaviour change, not overall, however, I’m now aware of the use of ‘memory sketch’ and consider using it a bit more” (LS-6)

“Yes, I think half only because cannot master some skills to apply yet. But it will be because I’ve been thinking to practice more” (LS-1)

The negative feedback is as follows:

“I’m not sure. Maybe I’m a bit slow in this, even though I think it is helpful but sometimes confusing” (LS-8)

**7.6.3. Formal evaluation II**

Formal evaluation II was conducted aimed at testing the effectiveness of Combinator on supporting designers’ creative design performance. A laboratory experiment method was adopted in this level of evaluation according to the Kirkpatrick Model. In this experiment, participants were asked to generate a new design solution for holding sorted garbage with high space utilization. Participants were divided into three groups, two of which were respectively supported by exploiting palette or combined display of pictorial stimuli as the source of inspiration, while the controlled group saw no stimuli during their ideation process. We used an outcome-based approach proposed by
Shah et al. (2003) to evaluate the impact of different conditions on the design outputs, while process-based methods, i.e. observation and follow-up interview, were also adopted as a supplementary. Detailed information about the experiment is given in the following paragraphs.

**Participants and Conditions**

A total of 36 participants, who were familiar with the predetermined design object ‘dustbins’, were involved in this experiment and the follow-up interview. The participants were interested in the research problem and therefore motivated and volunteered their time to join the experiment. They agreed to standard experimental and ethical protocols concerning the use of data and giving permission for the use of HD video recording. The background of the participants may vary in terms of their gender, age, speciality and design experience. For example, six of the participants are considered as experienced designers having over three years of design experience, while the rest of them are design students who are regarded as novice designers. In order to have a fair competition, the participants were evenly divided into three groups based on their experience and background and thereby constituted three categories (see below) possessing similar capabilities. The three groups of participants were regarded as the No-tool participants, the Combinator participants, and the Google Image participants, respectively. Details of the participants are presented in Table 7.15.

No pictorial stimuli condition (No-tool Group, N=12)

Subjects were provided with general instructions and a description of the design problem. The participants did not have access to the search tool or any other information, other than the design brief. They were also not aware of the existence of the search tool.

Combinational pictorial stimuli condition (Combinator Group, N=12)

The participants had access to CPS by adopting a search tool called the Combinator. The participants were allowed to use the Combinator at any point during the ideation process with no time constraints so that they could organize the ideation time as desired. However, no extra time was given to the stimuli search.

Palette pictorial stimuli condition. (Google Image Group, N=12)

The same instructions and design requirements were assigned to participants. They can use Google Image as the search tool for pictorial stimuli. They were also allowed to use the Google Image at any point during the ideation process with no time constraints. However, no extra time was given for stimuli searching.
### Table 7.15. Basic information of participants

<table>
<thead>
<tr>
<th>Group of Participants</th>
<th>Gender</th>
<th>Age</th>
<th>Major</th>
<th>Professional design experience</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>18-25</td>
<td>26-30</td>
</tr>
<tr>
<td>The No-tool Group</td>
<td>8</td>
<td>4</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>The Combinator Group</td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>The Google Image Group</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>9</td>
<td>8</td>
<td>24</td>
</tr>
</tbody>
</table>

ID: Industrial Design, DE: Design Engineering

**Equipment and Materials**

All of the participants were provided with a pen and enough A3-size paper for sketching and writing down their ideas. The Combinator Group and Google Image Group were informed that they would have access to a desktop in front of them so that they could use it to run their search tool. Like many researchers who conducted studies on visual stimuli and took a step further to develop or test an applied computational tool (Yang, Wood and Cutkosky, 2005; Mougenot et al., 2008; Cheng, 2016; Han, Shi and Childs, 2016), our stimuli search tool (i.e. Combinator) was developed and adopted a platform for studying the interplay between the manner of stimuli delivery and designers’ creative performance. Moreover, the mainstream image searching engine, i.e. ‘Google Image’, was also involved as the inspiration search tool to facilitate the comparison. The interface and an example of the use of Combinator are as shown in Figure 7-29, detailed instruction on the use of the Combinator can be found in (Han et al., 2018).

![Interface of Combinator](image1.png)
![Juxtaposed images](image2.png)
![Superimosed images](image3.png)

*Figure 7-29. An example of the operating Combinator (Hua et al., 2019)*
**Task and Procedure**

Waste sorting and recycling is a challenging problem that needs to be tackled in both home and work environments. The typical way to handle this is to use two or more dustbins which are often space-consuming and messy. The main design task in this experiment was to generate a new solution to address the challenge, which can provide sustainable waste disposal and efficient use of space. Other customer needs, e.g., waste separation, easy to use, no unpleasant odours and stylish appearance, were also provided as design specifications in this design challenge.

The participants were asked to join the design session one at a time in a quiet room without any interruptions, as one can be influenced by others in the group (Perttula and Sipilä, 2007). The participants were asked to sketch and work on the assigned design task lasted for 45 min. The duration was long enough for participants to design for the task and finish the sketching (Christensen, 2010; Chan et al., 2011). Before the experiment started, each participant was given a description of major design needs and requirements, and then was randomly assigned to one of three groups, namely Combinator Group, Google Image Group and No-tool Group. The instruction given to them may vary slightly due to the different experiment condition of each group. The Combinator participants were asked to use Combinator for stimuli searching while undertaking ideation, Google Image participants were asked to use Google Image, and No-tool participants were asked to come up with ideas based on their intuition and experience. The observations were conducted silently in order to minimise the impacts on the participants. Interviews were conducted after each participant had accomplished the design challenge.

**Criteria for the Evaluation of the Outcomes**

Psychometric measurements are the most commonly used method for creativity evaluation. The evaluation of outcomes can objectively reflect the effectiveness of an idea generation method/tool by assessing creativity psychometrics. Researchers have proposed numerous sets of psychometrics to evaluate design creativity (Shah, Smith and Vargas-Hernandez, 2003; Douglas et al., 2006; Plucker and Makel, 2010; Diedrich et al., 2015). We adopted the widely acknowledged psychometric evaluation method developed by Shah et al. (2003) including four metrics of creativity, namely quantity, quality, novelty, and variety.

According to Shah et al. (2003), the four metrics can be introduced and calculated respectively as follows. Quantity is a measure of the total number of ideas generated which was calculated by direct counting. Variety is a measure of the exploration of solution space during the ideation process. The variety score was calculated by counting the number of idea groups. The idea group was classified according to the different design thinking or physical principles that made the grouped ideas were very different from the others. For example, using one dustbin with divided internal space and using a combination of several small dustbins for satisfying waste separation were grouped into two categories, and thereby were counted as two idea varieties.
Quality is a measure of the feasibility and appropriateness of an idea with regards to the established design specifications. The quality of an idea was evaluated by rating each of its attributes (i.e. feasibility, waste separation, space-saving, easy to use, no odours, and stylish appearance) 1 to 10 from worst quality to best quality. A total weight of 1 was assigned to 6 key attributes according to their importance to the idea as follows, feasibility (0.25), waste separation (0.25), save space (0.25), easy to use (0.1), no odours (0.1), and stylish appearance (0.05). The overall quality of each idea can be calculated from (1). $M_1$ is the overall quality score of an idea, $m$ is the number of attributes, $f_i$ is the weight assigned to the function $i$, $S_i$ is the score of attribute $i$. The quality score of a participant was the mean quality score of all the ideas generated.

$$M_1 = \sum_{i=1}^{m} f_i S_i$$  \hspace{1cm} (1)

Novelty is a measure of the unusualness or unexpectedness of an idea comparing to the others. The novelty of an idea was evaluated by rating each of its key functions (i.e. waste separation and space-saving) 1 to 10 from least novelty to most novelty. These two functions were applied with the same weight of 0.5 (total weight 1), as they are equally significant to a new dustbin design. The overall novelty of each idea can be calculated from (2). $M_2$ is the overall novelty score of an idea, $n$ is the number of attributes, $f_j$ is the weight assigned to the function $j$, $S_j$ is the score of attribute $j$. The novelty score of a participant was the mean novelty score of all the ideas generated.

$$M_2 = \sum_{j=1}^{n} f_j S_j$$  \hspace{1cm} (2)

It should be noted that new functions or attributes, other than the ones stated for evaluation, were not considered. This is because only key functions or attributes should be used for evaluation according to Shah et al.’s (2003) psychometric method. In addition, subjectivity and biases might originate during the evaluation due to a number of issues, e.g. misunderstanding of design concepts caused by vague design idea presentation or subjective ratings caused by an evaluator’s personalized understanding and perception of the attributes. Therefore, two design experts were involved as raters in the evaluation, who were asked to evaluate the ideas respectively under the same guidance of scoring: 10 for excellent, 8 for good, 5 for fair, 3 for poor, and 1 for bad, so that to reduce the subjectivity. A Kappa test was carried out to measure the agreement between the two raters. The test result showed that the $K$ coefficients of quantity, novelty, quality and variety were 1, 0.57, 0.72, and 1, respectively. These indicated that the two raters had an almost identical agreement on quantity and variety, a substantial agreement on quality, and a moderate agreement on novelty. This has shown the robustness of the evaluated scores.

**RESULTS**

The following sections present the results from two data sources: the design task (composed of the participants’ idea sketches, observation/videos of the design process, and the recordings of the searching tools) and follow-up interviews.
Statistical analysis

According to the psychometric evaluation method presented in section 7.3.6, the mean values of raring scores of quantity, quality, novelty and variety at the individual level of each category were calculated and presented in Figure 7-30. The Combinator Group generated 53 ideas having access to CPS, which is much higher than 26 and 21 ideas produced by No-tool Group and Google Image Group. On average, each participant in the Combinator Group generated 4.42 ideas (SD=1.97), while the participants from No-tool Group and Google Image Group produced 2.17 ideas (SD=1.34) and 1.75 ideas (SD=0.97) on the individual level respectively. Participants from the Combinator Group demonstrated the most ideas categories (M=3.42, SD=1.38), followed by participants from the No-tool Group (M=1.67, SD=0.98) and Google Image Group (M=1.50, SD=0.67). In terms of quality, the difference between the No-tool condition (M=5.87, SD=0.92) and the Google Image condition (M=5.83, SD=0.76) was not significant, while the participants in the Combinator group scored much higher (0.80 and 0.84) than the participants from the former two groups (M=6.67, SD=0.52). The mean novelty score of the No-tool participants and Google Image participants were 6.35 (SD=0.71) and 5.96 (SD=0.96) respectively, while the Combinator participants scored 6.78 (SD=0.74).

To identify whether there are statistically significant differences between the means, statistical analysis was conducted by using SPSS Statistics software and the significance levels of the statistical tests are set as 5% (α=0.05) as a convention. A Shapiro-Wilk test was conducted to analyse whether the data of each metric of the three participant groups are normally distributed. According to the result, the data of the Combinator Group are normally distributed, while only the novelty and quality values of the No-tool Group and the Google Image Group are normally distributed, respectively.

As shown in Table 7.16, an independent sample T-test was conducted to analyse the
statistically significant differences in terms of Novelty and Quality, as the data of the entire novel and quality scores were normally distributed. As shown in Table 7.17, a Mann-Whitney U test was conducted to identify the statistically significant differences regarding Quantity and Variety scores, as the scores were not normally distributed. In addition, Cohen’s d was introduced to measure the effect sizes of the significant differences resulting from the independent sample T-test and the Mann-Whitney U test.

Table 7.16. Independent sample T-test result of ‘Novelty’ and ‘Quality’ (Hua et al., 2019)

<table>
<thead>
<tr>
<th>Metrics</th>
<th>The Combinator Group and the No-tool Group</th>
<th>The Combinator Group and the Google Image Group</th>
<th>The No-tool Group and the Google Image Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novelty</td>
<td>t =1.446, p =0.162, d=0.61</td>
<td>t =2.336, p =0.029, d=0.96</td>
<td>t =1.127, p =0.272, d=0.46</td>
</tr>
<tr>
<td>Quality</td>
<td>t =2.606, p =0.016, d=1.07</td>
<td>t =3.150, p =0.005, d=1.29</td>
<td>t =0.117, p =0.908, d=0.05</td>
</tr>
</tbody>
</table>

Cohen's d value: 0.20 = small, 0.50 = medium, 0.80 = large

Table 7.17. Mann-Whitney U test result of ‘Quantity’ and ‘Variety’ (Hua et al., 2019)

<table>
<thead>
<tr>
<th>Metrics</th>
<th>The Combinator Group and the No-tool Group</th>
<th>The Combinator Group and the Google Image Group</th>
<th>The No-tool Group and the Google Image Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>p = 0.006, d=1.33</td>
<td>p = 0.001, d=1.71</td>
<td>p = 0.479, d=0.36</td>
</tr>
<tr>
<td>Variety</td>
<td>p = 0.003, d=1.46</td>
<td>p = 0.001, d=1.77</td>
<td>p = 0.844, d=0.60</td>
</tr>
</tbody>
</table>

Cohen's d value: 0.20 = small, 0.50 = medium, 0.80 = large

In Table 7.16, the p-values of the novelty scores between the Combinator Group and the No-tool Group, and between the No-tool Group and the Google Image Group, are >0.05, while the p-value of the novelty scores between the Combinator Group and the Google Image Group is <0.05. This demonstrates that there are no statistically significant differences in novelty between the Combinator Group and the No-tool Group (t=1.446, p=0.162) with medium effect size and between the No-tool Group and the Google Image Group (t=1.127, p=0.272) with medium effect size, but a significant difference between the Combinator Group and the Google Image Group (t=2.336, p=0.029) with a large effect size. In terms of quality, there are statistically significant differences between the Combinator Group and the No-tool Group (t=2.606, p=0.016), as well as the Combinator Group and the Google Image Group (t=3.150, p=0.005), with large effect sizes. However, there are no significant differences between the No-tool Group and the Google Image Group (t=0.117, p=0.908) with a small effect size.

According to table 7.17, there are statistically significant differences between the Combinator Group and the No-tool Group in terms of quantity (p=0.006) and variety (p=0.001) with large effect sizes. Also, there are significant differences between the
Combinator Group and the Google Image Group with regards to quantity \((p=0.003)\) and variety \((p=0.001)\) with large effect sizes. However, there are no significant differences between the No-tool Group and the Google Image Group in quantity \((p=0.479)\) and variety \((p=0.844)\) with medium effect sizes.

According to the statistical analysis above, there is a significant improvement in quantity, quality and variety can be found when comparing the Combinator participants with the Google Image participants and No-tool participants at the individual level. There are no significant improvements in novelty while comparing the Combinator Group and the No-tool Group, but a significant difference between the Combinator Group and the Google Image Group. This indicates that, concerning the conducted design challenge, CPS had considerably improved the designers’ fluency, usefulness and flexibility in idea generation while slightly enhanced the originality. In addition, comparing the Google Image participants and No-tool participants, there are slight decreases in all of the four aspects, but with no statistically significant differences. Our results suggest that designers can benefit more from pictorial stimuli presented in a combinational way, while palette pictorial stimuli might have little/no impact on design creativity.

Observations and Interviews

Observations and video analysis were adopted in our study as process-based evaluation methods. According to a thinking-seeing-moving structure (Cheng, 2016), the design behaviour sequence of each participant and the amount of time they spent on these design behaviours were recorded (e.g. thinking, searching and sketching). The reactions of each participant and the images he/she saw were also recorded. The results suggest that the participants supported by Combinator spent less time than the other participants on the thinking process. This might be because participants from the other two groups had to retrieve relevant knowledge before they generate creative ideas, while this process could be challenging as well as time-consuming, especially for novice designers. This might also be caused by the overloaded design information that Google Image participants received too many images at one time while some of the presented images even not relevant. They had to select the useful images before using them for ideation, and this time-consuming process might lead to low design efficiency. In addition, the Combinator participants could always come up with new ideas after being stimulated by the combinational images. This observation is in line with the statistics results which further implies a better chance for creative ideas (Shah, Smith and Vargas-Hernandez, 2003).

After the design task, a follow-up interview was conducted with each of the participants. The participants were asked to reflect on their ideation process and grade themselves from 1 to 10 to describe how creative they feel during this session. A scatter chart method was employed to illustrate the participant evaluation results. As shown in Figure 7-31, in general, the participants from the Combinator Group had graded themselves with higher scores on creativity level comparing with the other two groups. This indicates that CPS generated by Combinator had a positive and more
significant influence on their ideation process. All of the twelve Combinator users gave high positive feedback regarding the usefulness of Combinator as computer-aided creativity supporting tool. Only some Combinator participants advised that the quality of several images provided by the Combinator were poor, which were hard to perceive the images and even interfered with their thinking process. Compared with the other two groups, Google Image participants considered Google Image as a useless tool, but the images provided by the tool were monotonous and sometimes even irrelevant. In terms of the No-tool participants, some of them thought the assigned design task was difficult, and thus it was challenging for them to come up with many creative ideas. Moreover, most of the No-tool participants acknowledged that they need some stimuli, especially visual stimuli, to help them in idea generation.

The Combinator participants also reported that Combinator became even more supportive when they have experienced a long-time ideation session, as the Combinator can continuously generate visual stimuli to inspired users during the ideation process. This supports the findings from previous studies (e.g. Howard, Culley and Dekoninck, 2011) that the use of stimuli during brainstorming could maintain the idea generation rate and quality during the ideation process. Empirical evidence shows that the idea generation rate commonly declines after 30 minutes of ideation activity, and the quality of the generated ideas decreases dramatically after 20 minutes. These indicated a significant advantage of Combinator, as it can work continuously to provide users with inspiring CPS to assist them in ideation. In addition, it is highly possible that the longer the time of the ideation session, the more supportive of using the Combinator.

![Figure 7-31. Participants evaluation of creativity level: the Combinator VS Google Image VS No-tool (Hua et al., 2019)](image-url)

**Further analysis of design samples**

Three design samples produced by participants from the Combinator Group were selected, as shown in Figure 7-32. The mechanisms of how combinational stimuli were supporting the ideation process of these selected design samples are briefly
described as follows. Figure 7-32 (a) shows a combinational idea for a ‘Tangram Bin’. In the follow-up interview, the originator of this idea referred back to his ideation process and explained that he was inspired by a superimposed image generated by the Combinator. This inspirational image is made by merging two images of a tangram and a plastic bin. The tangram bin can work similarly to a tangram puzzle which allows the users to arrange them freely according to the size of their indoor space. In addition, the process of using this product is also a process for recreation, as it gives users so many possibilities of a wide range of combinational shapes and layouts. Besides, a ‘slide bin’ and a ‘stair bin’ are illustrated in Figure 7-32 (b) and Figure 7-32 (c) respectively. These two ideas were also generated by using combinational pictorial stimuli. These three design samples indicate that combinational pictorial stimuli are an effective source of inspiration for improving creative design performance.

Figure 7-32. Design samples generated by Combinator participants (Hua et al., 2019)

7.7. Discussion

The PD-Sketching Primer and PD-Sketching Toolkit were developed to enhance the users’ understanding of sketching in product design and support aspects of the design process through sketching, in particular, to support the design ideation process. Feedback from education was positive.

The development of the PD-Sketching Primer and PD-Sketching Toolkit was based upon the findings from the descriptive studies. The development and evaluation process of the primer and toolkit followed an iterative procedure. Therefore, the findings and insights gained from the evaluation process were incorporated and transferred into further development. This iterative development-evaluation process was essential for improving the quality of the toolkit, making sure to fulfil its aim of providing effective support for design sketching.

The development of the PD-Sketching Toolkit consisted of three major steps (i.e. identification of requirements, development of the PD-Sketching Primer, and development of the PD-Sketching Toolkit), and details of each step and involved research tasks are presented in Table 7.18. A large proportion of effort was spent on the selection of appropriate contents and presenting them with the right formats. The considerations of content and format were presented in detail in Section 7.3 and
Section 7.5. Especially, to avoid “information overload”, only a “small” amount of detailed knowledge was included in the *PD-Sketching Primer* and *PD-Sketching Toolkit*. Feedback from the education suggested that the level of details of the tools were appropriate.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification of requirements</td>
<td>Identify requirements from the literature</td>
</tr>
<tr>
<td></td>
<td>Extract requirements from think-aloud experiment data</td>
</tr>
<tr>
<td></td>
<td>Extract requirements through questionnaire survey (student category) data</td>
</tr>
<tr>
<td></td>
<td>Extract requirements through questionnaire survey (professional category) data</td>
</tr>
<tr>
<td></td>
<td>Summarize and select requirements</td>
</tr>
<tr>
<td>Development of the <em>PD-Sketching Primer</em></td>
<td>Conceptualising</td>
</tr>
<tr>
<td></td>
<td>Embodying (initial design)</td>
</tr>
<tr>
<td></td>
<td>Detailing (making booklets and preliminary evaluation)</td>
</tr>
<tr>
<td></td>
<td>Iterative evaluation and improvement</td>
</tr>
<tr>
<td></td>
<td>Final design</td>
</tr>
<tr>
<td></td>
<td>Formal evaluation</td>
</tr>
<tr>
<td></td>
<td>Transcription, coding and initial analysis</td>
</tr>
<tr>
<td>Development of the <em>PD-Sketching Toolkit</em></td>
<td>Conceptualising</td>
</tr>
<tr>
<td></td>
<td>Embodying (initial design)</td>
</tr>
<tr>
<td></td>
<td>Detailing (making component tools)</td>
</tr>
<tr>
<td></td>
<td>Iterative evaluation and improvement</td>
</tr>
<tr>
<td></td>
<td>Final design</td>
</tr>
<tr>
<td></td>
<td>Formal evaluation</td>
</tr>
<tr>
<td></td>
<td>Conceptualising the Web-based Toolkit</td>
</tr>
</tbody>
</table>

The Kirkpatrick Model (Donald, James and Wendy, 2016) was employed for the evaluation. It was useful as it served as a framework providing guidance for method selection and data collection. The *PD-Sketching Toolkit* was introduced to education for evaluation, which provided a chance to observe the reaction of the participants and their feedback were positive. The formal evaluation of the *PD-Sketching Toolkit*
was deliberately conducted one year after its first introduction to the education world. The formal evaluation was conducted in two stages: the first stage explored the participants’ overall perception of the usefulness of the toolkit, and the second stage assessed the effectiveness of the component tool (i.e. Combinator) but with a special focus on design creativity. In terms of the formal evaluation I, it was hardly possible to directly observe or assess the influence of the Primer and PD-Sketching Toolkit on the users. Because understanding is difficult to measure by observation and pre-and post-test is also not applicable to evaluating the improvement of sketching ability in this study due to the limitation of time and resources for a PhD project. In addition, other factors like sources of learning material and tools may also influence the evaluation results during a long period of time (Section 7.6.2). Therefore, the impact had to be judged based on the users’ self-reporting data. According to the results, participants were generally satisfied with the toolkit and thought they have actually made significant progress in their learning process after using the toolkit. They also perceived that they were able to transfer the knowledge gained from the toolkit.

According to the statistical analysis of the formal evaluation II, significant improvements were identified on quantity, quality and variety when comparing the ideas generated by the Combinator participants with the ideas generated by the No-tool participants and the Google Image participants. There was a significant improvement in novelty when the comparison was made between the Combinator participants and the Google Image participants, while no significant difference was found when comparing with the No-tool participants. The statistical analysis suggests that the CPS provided by the Combinator had significantly improved the design space exploration, better ideas occurrence and design success rate. According to Westerlund (2009), design space exploration is a process facilitated by the exploration of possible solutions. In this sense, we assumed that the adoption of the Combinator had significantly increased the number of possible solutions which was beneficial for the design of space exploration. The CPS produced by the Combinator had stimulated the participants to generate more ideas, which might lead to a higher number of better ideas and a greater chance of design success. However, the use of CPS only slightly expanded the design space. Previous studies indicated that design space can be expanded by involving new design variables and stimuli (Gero and Kumar, 1993; Howard, Culley and Dekoninck, 2011). Considering the conducted design challenge, there was a low possibility for adding new design variables because the design specification had reached a high degree. In addition, some participants might have difficulties in recognising the stimuli produced by Combinator or transforming these stimuli into novel ideas. This might be because they were incapable or less capable of adopting the homospatial thinking process to produce effective metaphors (Rothenberg and Sobel, 1981)
7.8. Verification of the research hypotheses

The five research hypotheses generated from the literature review (Section 3.2.1) were tested and verified with data collected from the descriptive studies and the feedback on the *PD-Sketching Primer* and *PD-Sketching Toolkit*. This section provides a summary of the verification of the hypotheses. Data and facts that support the five hypotheses are summarised and presented in the right column of Table 7.19-7.23 respectively. The sources of the supporting data were abbreviated and listed in the left column of the tables. Specifically, the three descriptive studies are referred to as ‘D1’ (descriptive studies 1: a pilot study with design students), ‘D2’ (descriptive studies 2: a survey with design students) and ‘D3’ (descriptive studies 3: a survey with design professionals). The prescriptive studies consisted of stages of evaluation, i.e., the evaluation of the *PD-Sketching Primer* is referred to as ‘E1’ and the evaluation of the *PD-Sketching Toolkit* is referred to as ‘E2’.

<table>
<thead>
<tr>
<th>H1</th>
<th>There is a need to get a better understanding of the roles of sketching in the product design field</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>There is a tendency to associate design sketching with drawing and the misunderstanding is due to the lack of awareness of design sketching</td>
</tr>
<tr>
<td>D2&amp;D3</td>
<td>To design students and professionals, the prevalent barriers are ‘perception barriers’, and most of the barriers are relevant to the lack of comprehensive understanding of sketching in design.</td>
</tr>
<tr>
<td>E1&amp;E2</td>
<td>Evaluators of the <em>PD-Sketching Primer</em> and <em>PD-Sketching Toolkit</em> suggested that the roles of sketching in today’s design context were not fully understood</td>
</tr>
<tr>
<td>E2</td>
<td>Evaluators of the <em>PD-Sketching Taxonomy Cards</em> suggested that they were not clear with the types of sketches, which is especially the case for non-working sketches</td>
</tr>
</tbody>
</table>

The roles of sketching in today’s design context were not fully understood for design students and professionals, for example, a significant proportion of design sketchers did not know the classification and corresponding implications of types of sketches. Therefore, there is a need to enhance the understanding of design sketching.
Table 7.20. Data and facts support Hypothesis 2

<table>
<thead>
<tr>
<th>H2</th>
<th>The perception of design sketching may be different for designers with different expertise</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2</td>
<td>Expert design students and novice design students tend to perceive both roles of sketching and sketching expertise in design differently</td>
</tr>
<tr>
<td>D2</td>
<td>The perception of sketching expertise differed between industrial design students and engineering design students</td>
</tr>
<tr>
<td>D3</td>
<td>Two significant differences in perception of roles of sketching in design were identified between design students and design professionals, i.e. ‘recalling design elements from previous experience’ and ‘sketching as a practice to improve their sketching techniques’.</td>
</tr>
<tr>
<td>D3</td>
<td>Professional designers attached more importance to non-working sketches than design academics</td>
</tr>
</tbody>
</table>

The three descriptive studies indicated that the perception of design sketching differed for design sketchers with different level of experience and from different backgrounds.
### H3
**Understanding the cognitive interplay between sketching and design ideation process may be of use to both design academics and practitioners**

| D1 | It was found design students thought design sketching was essential for ‘supporting idea generation’ and ‘recording the fleeting design ideas’) of design sketching. In addition, the proposed ‘Ideation Segment’ model might serve as a useful framework for both design researcher and educators. |
| D2 | The top three roles of sketching in design perceived by design students all belonged to the ‘creative roles’ category, i.e. ‘promoting idea generation and exploration’, ‘investigating the aesthetic details’ and ‘promoting creative design communication’. |
| D2 | The most significant sketching ability perceived by design students was the ‘ability to sketch to visualise ideas’ |
| D3 | The major comments on and ratings of the roles of design sketching, i.e. ‘expanding designer’s thoughts using mind maps, notes and annotations’, ‘recalling design elements from previous experience’ and ‘promoting idea generation and exploration’, all highlighted the importance of sketching in supporting design creativity. |
| E1 | In general, students and professionals involved in the evaluation of the PD-Sketching Primer were found to be interested in the content about the psychology of sketching. |
| E1&E2 | The Primer and Toolkit developed based on the Ideation Segment Model were tested through two rounds of evaluation and feedback received from the involved participants was positive. |

The top roles of design sketching and sketching ability were common for both design academics and practitioners, and they all relevant to the design ideation.
Table 7.22. Data and facts support Hypothesis 4

<table>
<thead>
<tr>
<th>H4</th>
<th>External stimuli and sketching instruction can be helpful in supporting the design sketching process</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>It was found that design students always like to search for images and design examples as a reference while they were sketching</td>
</tr>
<tr>
<td>D1</td>
<td>All of the involved design students thought designers can benefit from good sketching skills in many ways, e.g. facilitate efficient design communication, support fluent ideation process, etc.</td>
</tr>
<tr>
<td>D2</td>
<td>65.8% of involved design students regarded ‘searching for visual reference’ as an effective sketching habit to facilitate their design process</td>
</tr>
<tr>
<td>D2</td>
<td>A high percentage of respondents (i.e. 78.5%) showed their interests in receiving different types of sketching instruction</td>
</tr>
<tr>
<td>D2</td>
<td>The engineering design students rated a high score of 4.8 to the sketching ability that ‘sketch from reference’ and the industrial design students rated it 4.3 (4.0 was defined as significant)</td>
</tr>
<tr>
<td>D3</td>
<td>The top two preferences for the content of a practical supporting tool, i.e. 34 out of 51 respondents (66.7%) were interested in ‘instruction on drawing skills’ and 31 out of 51 respondents (60.8%) selected ‘pictorial/textual stimuli’.</td>
</tr>
<tr>
<td>D3</td>
<td>In terms of sketching habits, 33 out of 51 respondents (64.7%) chose that they have the habit of ‘searching for visual reference’ during the design and sketching process</td>
</tr>
<tr>
<td>E2</td>
<td>The Combinator (providing CPS) was tested in formal evaluation II and significant improvements were identified on quantity, quality and variety when compared with the other two groups.</td>
</tr>
<tr>
<td>E2</td>
<td>Both of the participants in the evaluation and the users of the PD-Sketching Textbook gave positive comments on the textbook, which was regarded as useful in helping them to improve their sketching skills.</td>
</tr>
</tbody>
</table>

Providing external stimuli and sketching instruction were perceived as useful in the descriptive studies, and proved to be useful through the two rounds of evaluation on *PD-Sketching Primer* and *PD-Sketching Toolkit*. 
Data and facts support Hypothesis 5

<table>
<thead>
<tr>
<th>H5</th>
<th>Effective support of design sketching is critically dependent on the presentation of supporting materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2&amp;D3</td>
<td>Design students and professionals have certain preferences for information and its format of the practical supporting tool</td>
</tr>
<tr>
<td>E1</td>
<td>The oral presentation was identified as helpful in explaining the design sketching case studies</td>
</tr>
<tr>
<td>E1&amp;E2</td>
<td>The quality of graphic design was perceived as important for making the \textit{PD-Sketching Primer} and \textit{PD-Sketching Taxonomy Cards} easy to use, contributing elements including size and length, colour-coding and numerical system, use of images charts and texts, layout, etc.</td>
</tr>
<tr>
<td>E2</td>
<td>The component tools are presented in different formats and organised in a flexible way, which received positive feedback from the participants</td>
</tr>
<tr>
<td>E2</td>
<td>The physical card-based tool was found to have the advantage of portability to provide easy access to knowledge and instruction, which is ideal as an instant supporting tool during the design process</td>
</tr>
<tr>
<td>E2</td>
<td>Designers were found to benefit more from pictorial stimuli when they are presented in a combinational way</td>
</tr>
</tbody>
</table>

Data collected from the descriptive studies and the evaluation of tools identified the importance of information presentation methods. Therefore, the information contained should be presented in an appropriate way, which was found to be essential for the success of design sketching supporting tool development.
7.9. Conclusions

To summarise, this chapter has described:

1. The generation of a requirements list based on the findings from the three descriptive studies

2. The development of the practical supporting tool (i.e. PD-Sketching Primer and PD-Sketching Toolkit) for design sketching, which consisted of three stages:
   - identification of requirements
   - development of the PD-Sketching Primer
   - development of the PD-Sketching Toolkit

3. The evaluation of the PD-Sketching Primer and PD-Sketching Toolkit, which consisted of five steps:
   - preliminary evaluation of PD-Sketching Primer
   - formal evaluation of PD-Sketching Primer
   - preliminary evaluation of PD-Sketching Toolkit
   - formal evaluation I of PD-Sketching Toolkit
   - formal evaluation II of PD-Sketching Toolkit

4. Verification of the research hypotheses

In total, 104 participants were involved in the evaluation of the practical supporting tool (i.e. PD-Sketching Primer and PD-Sketching Toolkit), including students, professional designers, teachers and researchers from the design field. In summary, feedback received on the support was positive and indicate that they had an impact on education. According to the evaluation results using Kirkpatrick Model, the PD-Sketching Primer and PD-Sketching Toolkit were proved to be effective in enhancing the understanding of roles of sketching in today’s design context and providing support for design sketching, especially in supporting the design ideation process through sketching. The evaluation consisted of five steps and this iterative evaluation process gave the author the chance to incorporate findings and insights into further development of the supporting tool. The data gathered from the evaluation provided evidence to support the research hypotheses 1, 3, 4 and 5, and partially support research hypothesis 2.
Chapter Eight: Conclusions and Future Work

This chapter summarises the overall conclusions drawn from the research and suggests future work to be carried out.

8.1. Meeting the initial research objectives

This section describes how the research objectives identified at the start of the PhD project (Section 1.3) have been addressed.

**Objective 1: To gain a comprehensive understanding of the roles that sketching plays in product design.**

Three descriptive studies were conducted to identify and understand the roles of sketching in product design. In total, 21 supporting roles of sketching in design were identified (Table 4.8) through the pilot study. The survey of design students and professionals showed that they were agreed on three of the major roles of sketching in design, i.e. ‘promoting idea generation and exploration’, ‘promoting design communication with other designers for design collaboration’ and ‘expanding designer’s thoughts using mind maps, notes and annotations’. Two significant differences in perception of roles of sketching were also identified between design students and design professionals, i.e. ‘recalling design elements from previous experience’ and ‘sketching as a practice to improve their sketching techniques' (Section 5.3.5 and 6.3.5). In addition, it was found that sketching for supporting design ideation formed the major roles of design sketching and was the most significant, followed by sketching for supporting design communication (Section 6.5).

**Objective 2: To explore the cognitive interplay between sketching and design creativity.**

A think-aloud experiment was carried out to investigate the interplay between sketching and the ideation process. Section 4.3.10 presents the analysis and findings on how sketching was used to support the design ideation process in the assigned design task. An ‘Ideation Segment’ structure was proposed by the author to describe the design sketching and ideation process. Figure 4-20 illustrates the basic structure of an Ideation Segment. It was found that the sketching and ideation process can be described as an ‘ideation tree’ with the design paths represented by branches. This ideation tree grows with new ideas emerging as branch points (i.e. lateral transformation) and ideas finally evolving to alternative design solutions (i.e. vertical transformation). The Ideation Segment model was proposed based on this ideation tree structure, which is illustrated in Figure 4-27. This model explains how design concepts emerge during the sketching process and were developed into the design outcomes. It also highlights the importance of various types of ‘Influences’ (e.g. context and domain knowledge, reference & stimuli, sketching expertise and
supporting tools) and illustrates their applied stages during the design sketching process.

**Objective 3: To identify the requirements of product design students and professionals for supporting the design sketching process.**

Three descriptive studies were carried out to identify the requirements for developing sketching supporting tools. The key elements for supporting the design sketching process, together with detailed findings from the three descriptive studies, were adopted to capture requirements for the practical supporting tool. For example, the pilot study (reported in Chapter 4) identified a number of important issues related to design sketching, e.g. the lack of understanding of non-working sketches and supporting materials should be provided for enhancing the sketching process (Section 7.2). These issues were further studied through two surveys (reported in Chapter 5 and 6) of design students and professionals, e.g. “searching for visual reference was among the most welcomed sketching habits for designers” (Table 5.8 and Table 6.10). The requirements were then derived from these findings, and major requirements (i.e., grabbing attention, enhancing understanding, providing external stimuli and providing instruction & information) and sub-requirements were summarised and presented in Table 7.1.

**Objective 4: To develop a practical supporting tool for product designers to facilitate the creative design process through sketching.**

The PD-Sketching Toolkit was developed based on the findings and requirements identified from the descriptive studies. The development of the PD-Sketching Toolkit followed a three-step design tool development process (Figure 7-7), which consisted of four components (i.e., the Primer, the Taxonomy Cards, the Textbook and the Combinator) to address the requirements for design sketching supporting tools (Table 7.8). The evaluation of the toolkit consisted of five steps and this iterative evaluation process helped to incorporate findings and insights into further development of the supporting tool (Section 7.9). Evaluation feedback received on the toolkit was positive and indicate that the toolkit was proved to be effective in enhancing the understanding of roles of sketching and providing support for design sketching, especially in supporting the design ideation process through sketching (Section 7.7).

8.2. Conclusions

This section presents the overall conclusions from the descriptive studies, prescriptive studies and the evaluation and the verification of the research hypotheses.

8.2.1. Main conclusions from the descriptive studies

The main findings and outcomes of descriptive studies were concluded as follows and discussed in turn:
• Design students and professionals tend to perceive the major roles of ‘thinking sketches’ and ‘non-working sketches’ differently but shared similar opinions on the major roles of ‘talking sketches’

• The perceptions of the major roles of sketching expertise were similar for design students and professionals

• The perceptions of influences for design sketching were similar for design students and professionals

• A product design sketching taxonomy was developed, which identified 15 types of sketches and described their roles and usage in the design process

• An Ideation Segment model was proposed to describe how design ideas emerge and evolve to the final design outcomes in the design sketching process

The method of multi-comparisons was adopted to facilitate data analysis. Comparisons were made between the following groups: 1) novice student sketchers, expert student sketchers and professional design sketchers; 2) design sketchers from the fields of industrial design, engineering design and graphic design; 3) professional designers and design academics. It was found that the major roles of sketching in design perceived by novice design students, expert design students and design professionals were different. For novice design students, the top three roles of sketching in design were ‘promoting design communication with other designers for design collaboration’, ‘promoting design communication with engineers regarding technical points’, and ‘promoting design communication with clients regarding product appearance, function and scenario’; for expert design students, the top three roles of sketching in design were ‘promoting idea generation and exploration’, ‘expanding designer’s thoughts using mind maps, notes and annotations’ and ‘promoting design communication with other designers for design collaboration’; and for design professionals, the top three roles of sketching in design were ‘expanding designer’s thoughts using mind maps, notes and annotations’, ‘recalling design elements from previous experience’, and ‘promoting design communication with other designers for design collaboration’. In terms of non-working sketches, novice design students, expert design students and design professionals all tend to consider that ‘sketching for fun and enabling designers to play with sketches and ideas’ was an important role of non-working sketches for them. In comparison, novice design students attached more importance to the role of ‘sketching for the emotional and aesthetic expression’, expert design students thought ‘sketching as practice to improve their sketching techniques’ was more relevant to them, and design professionals chose to use non-working sketches ‘as records of ideas and design information for future reference’. These findings partially support the hypothesis that perceived roles of design sketching might differ for sketchers with different levels of experience. Specifically, novice design students, expert design students and design professionals tended to agree on the major role of ‘talking sketches’ (i.e. ‘promoting design communication
with other designers for design collaboration’), while they held divergent views on the major roles of ‘thinking sketches’ and ‘non-working sketches’.

The similar major roles of sketching expertise were perceived by novice design students, expert design students and design professionals. They tended to agree on the top three roles of sketching expertise, namely ‘ability to sketch to organise ideas’, ‘ability to use sketches to communicate design thoughts to others’ and ‘skill in perspective drawings’. The only exception was design professionals perceived ‘ability to sketch from memory’ as a significant sketching ability, while for design students were ‘ability to sketch to visualise ideas’.

Two statistically significant differences in perception of roles of sketching in design were identified between design students and design professionals, i.e. ‘recalling design elements from previous experience’ and ‘sketching as a practice to improve their sketching techniques’. Design professionals were found more likely to use sketching to retrieve design information from previous experience during the design process while design students attached more importance to the role of ‘practicing sketch’ for improving their skills.

In terms of sketching expertise, two significant differences in perception of sketching ability (i.e. ‘to sketch from external reference’ and ‘to sketch from memory’) were identified, while no significant differences were found regarding the perception of sketching skill. These suggest that the provision of ‘external reference’ could be useful to design students, while the provision of ‘memory aids’ could be helpful to design professionals. The study with design students and design professionals suggested that ‘supporting design collaboration’ were perceived as the most significant role of sketching in design, followed by ‘supporting idea generation and exploration’ and ‘expanding designer’s thoughts’.

In contrast to differing perceptions of roles of design sketching, it was found that perceptions of influences for design sketching were similar for design students and professionals, with top influences include ‘external stimuli’, ‘instruction on drawing skills’, and ‘examples of design sketches’ and ‘design sketching case studies’. When it comes to the format of a practical supporting tool, textbooks, CAD/CAS tools and websites were preferred. When compared with the survey of design students, design professionals clearly knew the types of supporting tools they needed for sketching while design students did not have specific preferences for the formats of supporting tools.

The results from the cross-disciplinary comparison showed that the ‘ability to sketch for design analysis’ was perceived by a larger percentage of industrial/engineering design students as major sketching ability when compared with graphic design students. ‘Ability to sketch from imagery’ was perceived to be less important by engineering design students compared with industrial design students and graphic design students. In terms of sketching skill, more industrial/engineering design students tend to regard the ‘skill in using 3D drawing’ as an effective sketching skill for the design process compared with graphic design students. These may be due to the
differences in the design objects and focus between industrial/engineering design and graphic design.

It was found that professional designers’ perceptions of the role of sketching and sketching expertise in design were similar to those of design academics’. In addition, the preferences regarding the practical supporting tools of design academics differed from professional designers. Design academics were more in favour of ‘instruction on drawing skills or training methods’, ‘the sketching taxonomy’ and ‘examples of design sketches’, and they tend to regard sketching as a set of ‘learned skills’ in the design education. Professional designers were more interested in receiving ‘design sketching case studies’ and ‘instruction on sketching tools/media’, this might be because designers shared different perspectives with design academics, who were more likely concerned with the effective use of sketching in the design practices.

In total, 15 different types of sketches were identified according to the findings from the literature study and pilot study. A new sketching taxonomy has been proposed, defining the types and corresponding roles of sketches in the product design. This taxonomy consists of thinking, talking and non-working sketches, which are defined as the top-level categories and further, expanded into 15 sub-categories. It was found that the most frequently used types of sketches were related to design ideation, i.e. ‘idea sketch’ for supporting idea generation and ‘development sketch’ for supporting idea development. The other four commonly used types of sketches were ‘defining sketch’, ‘explanatory sketch’, ‘practicing sketch’ and ‘playing sketch’.

In addition, an Ideation Segment model was proposed, which provides a comprehensive description of the design sketching process. It describes the process that sketching ideas evolve into final design outcomes and locates the potential supporting tools in the sketching process. It also explains how design ideas are expressed and perceived by designers, which is crucial for enhancing the understanding and usage of sketching in design. This model incorporates the findings presented in the former sections (i.e. Section 4.3.6 – 4.3.8), and highlights the importance of various types of ‘Influences’ (e.g. context and domain knowledge, reference & stimuli, sketching abilities & skills, and supporting tools) and illustrates their applied stages during the design sketching process. These findings were adopted in the subsequent prescriptive studies for the development of a practical supporting tool for design sketching.

The descriptive studies were carried out to contribute towards understanding the roles of sketching and their interplay with design ideation. It integrated several current research streams and also shed light upon the unknown roles of sketching (e.g. non-working sketch). The findings from the descriptive studies were not only useful for the development of supporting tools for design sketching but also could be useful as a basis for other studies in the field.
8.2.2. Main conclusions from the prescriptive studies and the evaluation

The prescriptive studies were carried out based on the findings from the literature review and three descriptive studies. The main findings and outcomes of prescriptive studies were as follows:

- Key issues that should be addressed by the supporting tools include: 1) grabbing attention, 2) enhancing understanding, 3) providing external stimuli, 4) improving sketching expertise, and 5) providing useful information

- A total of 28 detailed requirements for the development of supporting tools were captured

- The supporting tools (i.e. *PD-Sketching Primer* and *PD-Sketching Toolkit*) were developed based on the requirements, which were then tested with education and the feedback received from the users was positive

The prescriptive studies focused on capturing requirements from product designers for sketching supporting tools and addressed key issues around design sketching (i.e. grabbing attention, enhancing understanding, improving sketching ability and providing useful information) through the provision of a practical supporting tool for them, namely the *PD-Sketching Primer* and the *PD-Sketching Toolkit*. The PD-Sketching Primer and the PD-Sketching Toolkit were then introduced to both design schools and professional training institutions for evaluation, which provided a chance to observe the reaction of the users and their feedback was positive. The involved design students and professional designers found the primer was informative and helped raise their awareness of design sketching. In particular, the knowledge about the roles of different types of sketches and their use during the design process were found useful. It was also found that the *PD-Sketching Primer* was properly designed according to the feedback which made it easy to use for the target users. The *PD-Sketching Toolkit* also received positive feedback, it was thought to be useful in enhancing the understanding of design sketching (e.g. the average rating score on format, information quality, satisfaction and perceived usefulness were 3.78, 4.00, 4.03 and 3.84 respectively, while 3.0 was defined as significant in the study) and serving as a toolkit for supporting the sketching process (e.g. significant improvement was identified on designers’ fluency, usefulness and flexibility in idea generation while slightly improvement on the originality).

The *PD-Sketching Toolkit* was one of the few available toolkits developed for supporting the sketching process in the product design field. The development of the *PD-Sketching Primer* and the *PD-Sketching Toolkit* was based on the findings from descriptive studies and the close collaboration with target users. In summary, feedback received on the supporting tool was positive and indicate that they had an impact on education. According to the evaluation results, the *PD-Sketching Primer* and *PD-Sketching Toolkit* were proved to be effective in enhancing the understanding of roles of sketching in today's design context and providing support for design sketching, especially in supporting the design ideation process through sketching.
8.2.3. Conclusions from the verification of the research hypotheses

Data collected from both the descriptive studies and the evaluation provided evidence to support the five research hypotheses. A summary of the verification of the hypotheses was presented in Section 7.8. Data support the five research hypotheses and links to the relevant studies are summarized and presented in Table 7.19-7.23. The five research hypotheses are listed as follows.

- There is a need to get a better understanding of the roles of sketching in the product design field.
- The perception of design sketching may be different for designers with different expertise.
- Understanding the cognitive interplay between sketching and the design ideation process may be of use to both design academics and practitioners.
- External stimuli and sketching instruction can be helpful in supporting the design sketching process.
- Effective support of design sketching is critically dependent on the presentation of supporting materials.

8.2.4. Contributions of the research

This research has contributed towards advancing knowledge of design sketching and developing tools for supporting the use of sketching in the product design field. The key original contributions derived from the research are as follows:

1. This research explored the roles sketching plays in design. In total, 21 supporting roles of sketching in design were identified (Table 4.8). The major roles of design sketching were identified, sketching for supporting design ideation formed was the most significant, followed by sketching for supporting design communication (Section 6.5).

2. Despite various attempts by researchers to classify design sketches (Ferguson, 1992; Van der Lugt, 2005; Pipes, 2007; Schenk, 2007; Pei, 2009; Ullman, 2010; Pei, Campbell and Evans, 2011), existing sketching taxonomies have been incomplete and failed to incorporate both working and non-working sketches. This project identified 15 different types of product design sketches, including four types of non-working sketches. Each type of these sketches was clearly defined and visual examples were provided accordingly.

3. The exploration of non-working sketches could be seen as an important and the most original contribution to this project. Four types of non-working sketches (i.e. playing sketch, storing sketch, warming-up sketch and practicing sketch) and their roles in design were identified. This line of research is crucial and need to be further studied, which may lead us to a better understanding of the non-working
sketches but also to give us a more complete picture of the field.

4. A new sketching taxonomy was proposed, visually illustrating and linking three categories of sketches, i.e. thinking sketches, talking sketches and non-working sketches. The taxonomy identified and hierarchically classified 15 types of design sketches used by product designers in the current design context.

5. The development of the Ideation Segment model, which describes the process that sketching ideas evolve into final design outcomes, and locates the important influences and potential supporting tools in the sketching process (Figure 4-27). This is crucial for enhancing the understanding of the roles of sketching in supporting design creativity. It is expected to be a useful framework providing guidance for both design practitioners and academics to use.

6. Redesigned two forms of image combination methods (i.e. juxtaposing and superimposing) for delivering combinational pictorial stimuli (CPS) to designers (Figure 2-6). The Combinator was developed based on the two CPS generation methods. The Combinator is a piece of software developed for assisting designers in idea generation by providing them with CPS during the early stages of the design process. The results of the evaluation implied the effectiveness of CPS in triggering creative design thinking (Section 7.6.3) and also highlight the importance of studies into the methods of presenting external stimuli.

7. The PD-Sketching Toolkit was developed to enhance the users’ understanding of sketching in product design and support aspects (e.g. providing instruction and external stimuli) of the design sketching and ideation process. It was one of the few available toolkits developed for supporting the sketching process in the product design field. Feedback received on the supporting tool was positive and indicate that they had an impact on education.

8.3. Further work

This research has revealed the roles of sketching in the product design field based upon the investigation of design students, professional designers and design academics. It helped identify a number of issues that need to be addressed in further study. These issues are listed as follows and discussed in turn:

- Further development of the PD-Sketching Toolkit
- Enhancing the understanding of visual stimuli for supporting design sketching
- Enhancing the understanding of non-working sketches
- Enhancing the understanding of sketching habits

8.3.1. Further development of the PD-Sketching Toolkit

Feedback received from the evaluation on the PD-Sketching Primer and
**PD-Sketching Toolkit** has identified a number of areas for further improvement. In terms of the contents, the ‘Primer’ and ‘Textbook’ could be expanded with knowledge about the psychology of sketching, introduction of new sketching tools and media, updated references, latest sketching examples and case studies. In addition, the ‘Taxonomy’ could be further tested and improved in education. Future work requires discussion with design educators and researchers about the practical use of the sketching taxonomy as well as testing of the proposed criteria (Section 2.4.2) to better understand how the sketching taxonomy can best be implemented.

In terms of formats, a Web-based Toolkit should be developed. Through the evaluation of the *PD-Sketching Primer* and the *PD-Sketching Toolkit* with education, a better understanding of the designers’ requirement for a practical supporting tool was obtained. It was found that designers often share different levels of understanding of sketching due to a number of factors, including their expertise, experience and backgrounds. According to our descriptive studies, the presentation of information is crucial for the effective implementation of supporting tools. Therefore, alternative presentations should be provided available and the information provides for designers should be presented in layers accordingly, i.e. from simple to in-depth. The Web-based Toolkit is designed as a flexible framework for presenting new information about design sketching. The use of multi-layer designs was thought to be appropriate. In this way, the Web-based Toolkit may have the potential to meet all these requirements.

In general, the current version of the *PD-Sketching Toolkit* was developed to address the common requirements of designers and design educators. For future work, different requirements will be taken into consideration for tailoring the *PD-Sketching Toolkit* for divergent groups of potential users. It would be beneficial to collect the needs of target users for improving the sketching toolkit through case studies. Due to the complicated nature of the design sketching, the development of a useful sketching toolkit is often an iterative modification process. It could be a challenging task that requires in-depth understanding and massive user involvements. The feedback on the *PD-Sketching Toolkit* was positive, and therefore, it confirms the value of the toolkit and the further studies needed for its improvement.

### 8.3.2. Enhancing the understanding of visual stimuli for supporting design sketching

The CPS provided by the Combinator were proved to be useful in supporting both the design ideation and sketching process. The results of the evaluation implied the effectiveness of CPS in triggering creative design thinking and also highlight the importance of studies into the methods of presenting external stimuli. However, there were only two forms of image combination methods (i.e. juxtaposing and superimposing) for delivering pictorial stimuli to designers involved in the study. The study with both design students and professionals indicated that various types of stimuli and their combination were found to be used as sources of inspirations.
Therefore, a broader understanding of how to effectively generate stimuli and present them to a designer is required. Preliminary studies have been conducted to evaluate the insight. For example, the new version of Combinator tried to combine the text-based materials and image-based materials together to produce hybrid stimuli as inspiration. Although current findings are not sufficient to facilitate in-depth comparisons with previous studies, they confirm that the research direction merits further investigation. In addition, the evaluation also suggested that there is a need for an in-depth understanding of combination methods of pictorial stimuli. Therefore, future research can be carried out to explore the differences between various combination methods of pictorial stimuli (e.g. ‘combined-composite’, ‘conjunction’ and ‘concatenation’) and their impact on design ideation outputs. This line of research may give us a better understanding of visual stimuli and their implication in supporting design creativity, which is expected to bring us important implications for design supporting tool development.

8.3.3. Enhancing the understanding of non-working sketches and sketching habits

Two issues that were identified as potentially important were not explored in-depth in this PhD project, i.e. the roles of non-working sketches and sketching habits in product design sketching. Studies with design students and professionals suggested that influences that emerge outside the design process might also have an impact on the design process. For example, non-working sketches and sketching habits are two influences closely related to each other as several types of non-working sketches were identified through the observation and investigation of sketching habits. Specifically, the warming-up sketch was identified together with Student E’s sketching habit that she likes to draw intensively before the design process to quickly enter the flow sketching state. In addition to this, the other three types of non-working sketches, i.e. playing sketch, storing sketch and practicing sketch, were identified in the follow-up interviews when asking the participants about the sketching habits in their spare time. However, as far as one can tell from the literature, this PhD project is the first empirical study that systematically explored non-working sketches and sketching habits in the product design field. Future research is planned to explore whether there are new types of non-working sketches and sketching habits that have not been found and to further explore how they could influence the design sketching process. This further investigation is crucial, not only to achieve a better understanding of the non-working sketches and sketching habits but also to give us a more complete picture of the field.

8.4. Summary

This research proposed five hypotheses set out in Section 3.2.1 which were tested through descriptive studies and prescriptive studies. It was found that there were
shared preferences for the contents of supporting tools but different perceived major roles of sketching between design students and professionals.

Two unique tools were developed for enhancing understanding of design sketching and supporting the sketching process in the product design field, namely the *PD-Sketching Primer* and *PD-Sketching Toolkit*. The feedback on the *Primer* and *Toolkit* were positive.

In summary, this research was carried out focusing on enhancing understanding of sketching in product design and future work will further explore the influence and implication of non-working sketches and types of visual stimuli in the design sketching process. This research also developed individual tools to provide supporting tools at certain stages of the design process, and future work will try to develop new tools and integrate them into the revised toolkit for the whole design process.
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Glossary of Terms

**Creativity:** refers to the imagination or invention of something new and also useful.

**Design:** the process of conceiving, developing and realising products, artefacts, processes, systems, services and experiences with the aim of fulfilling identified or perceived needs or desires typically working within defined or negotiated constraints.

**Designer:** refers to industrial designers and engineering designers unless otherwise specified.

**Design academician:** refers to design researchers and educators in the industrial/engineering design field unless otherwise specified.

**Design ideation:** refers to the creative process of generating, developing, and communicating new ideas, where an idea is understood as a basic element of thought that can be either visual, concrete, or abstract.

**Design process:** refers to the development process of the design and the order in which the design tasks are completed.

**Design professional:** refer to a designer or academic who is duly licensed or registered for professional practice in industrial or engineering design unless otherwise specified.

**Design sketching:** refers to the freehand drawings or renderings generated by designers facilitating the design process.

**Design student:** refers to design students who major in the industrial design or engineering design unless otherwise specified.

**Engineering design:** the fusion of design thinking, engineering thinking and practice within a culture of innovation and enterprise, it is a process where engineering approaches are applied in the realization of activities that begin with a design concept or proposal.

**Generic Design Process (GDP) model:** presents the product design process in three main stages: early, middle and late, which can be further broken into the following sub-processes: define design task, conceptual design, development design, embodiment design, detail design, design presentation and manufacturing.

**Interpretation:** this broadly refers to the process of taking a pre-inventive structure and finding an abstract, metaphorical, or theoretical interpretation of it.

**Industrial design:** can be defined as the professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer.

**Ideation segment:** can be viewed as a loop of the thinking process enabling new idea generation, development and expression for possible design solutions.

**Juxtaposing:** refers to a method to generate combinational pictorial stimuli by
cropping images first and then merging the cropped images next to one another.

**Kirkpatrick Model**: is a widely used framework for evaluating new methods, tools and training programmes, which collects data in respect of reaction, learning, behaviour and validation.

**Lateral (divergent) transformations**: is defined as the ‘incremental changes’ which can promote idea generation by moving from one idea to a slightly different idea.

**Mental synthesis**: mentally blend and synthesize component parts to create something new.

**Non-working sketches**: can be defined as a group of sketches that are produced by designers outside the design process in their spare time.

**Product design**: refers to the process of defining, imagining, creating, and iterating products that solve users' problems or address specific needs in a given market.

**Product design process**: could be described as a creative process which involves various design activities to transform initial design ideas into real products through a number of stages, beginning with design problem definition and ending with manufacturing.

**Sketching abilities**: refer to the sketching expertise that relates to cognitive and intellectual abilities and the awareness of appropriate use of sketching in the design process, e.g. ability to sketch from memory.

**Sketching skills**: refer to the sketching expertise that relates to the practical drawing techniques, e.g. drawing skill in using of drop shadow.

**Superimposing**: refers to a method to generate combinational pictorial stimuli by making images semi-transparent first and then superimposing the images on one another.

**Taxonomy**: can be defined as the practice and science of classification.

**Talking sketches**: refers to a group of sketches that designers use for facilitating design communication and collaboration in the design process.

**Thinking sketches**: refers to a group of sketches that designers use to support their individual thinking process in design.

**Tools**: refers to instruments that support the adoption and implementation of sketching in design.

**Vertical (convergent) transformations**: can be viewed as the actions that transform earlier generated ideas into more detailed and refined versions in the design process.
Appendix A: Interview topics for the pilot study

1. General understanding of design sketching
   - What types of sketches do you usually use in the design?
   - Can you describe how you went about the design sketching process?
   - What are the factors that may influence the effective use of sketching in design?

2. The importance of sketching and sketching expertise in design
   - How important is sketching in your design process? And what is the importance?
   - How important is sketching ability in your design process? And what is the importance?
   - How important is sketching skill in your design process? And what is the importance?

3. The influence of sketching on design ideation
   - Do you think sketching can have an impact on the design ideation process? If so, what are the roles of sketching may play in the design ideation process?
   - Do you have any suggestions for the use of sketching in supporting design ideation process?

4. The students’ preferences about sketching
   - Do you like to use external supports for enhancing design sketching process? If so, what are the types of these supports?
   - Do you have any sketching habits? If so, tell me something about it?

5. The use of non-working sketches
   - Do you often sketch during your spare time? If so, why do you make these sketches?
   - What are these types of non-working sketches?

6. Do you have any further comments on design sketching?
Appendix B: Questionnaire for the design students

This questionnaire aims to investigate the roles of sketching and sketching abilities in industrial design. Some basic information is required for further contact and analysis. The questionnaire will take you less than 15 minutes.

All information given will be treated as confidential and only be used for academic research purposes. Great care will be taken in data management in order to avoid any loss of data or misuse of data collected.

1. I agree to take part in the above Imperial College London research project. I have had the project explained to me. I understand this will involve a survey questionnaire completed by the participant.

☐ Yes
☐ No

2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

☐ Yes
☐ No

3. I understand that any information I provide is confidential, and none of my personal information during this research will be published without my consent. No identifiable data will be shared with any other organisations without my consent.

☐ Yes
☐ No
## Section 1 (Background information)

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Min HUA, PhD Candidate  
Dyson School of Design Engineering, Imperial College of London  
10 Princes Gardens, South Kensington, London, SW7 1NA  
E-mail: m.hua15@imperial.ac.uk • Tel. No.: 0044 (0)7729039501
Second 2 (General questions about sketching)

1. How do you rate the importance of sketching to industrial designers?
   □ Essential
   □ Useful
   □ Irrelevant
   □ Detrimental

2. How do you rate the importance of sketching ability* to industrial designers? (*I am using the term ' sketching abilities ' to mean any and every know-how and drawing techniques in practice, appreciation and understanding of design sketching)
   □ Essential
   □ Useful
   □ Irrelevant
   □ Detrimental

3. Do you regard yourself as experience in sketching?
   □ Very experienced
   □ Experienced
   □ Less experienced
   □ Novice

4. How long have you been sketching in order to develop designs or ideas as a student or professional?
   □ Less than 1 year
   □ 1-4 years
   □ 4-10 years
   □ Over 10 years

5. How often do you sketch?
   □ Sketching everyday
   □ Sketching frequently
   □ Sketching occasionally
   □ Sketching during project work only

6. What media are you comfortable with (using) when you are sketching?
   □ Pencil and paper
   □ Pen and paper
   □ Colours and paper
   □ CAD systems (e.g. Photoshop, Sketchbook ... etc)

7. Do you have any personal sketching habits? (You may choose more than one answer)
   □ Listen to music while sketching
   □ Eating snacks while sketching
   □ Searching for visual reference
   □ Doing some form of physical activity (e.g. pen spinning, crack knuckles ... etc)
   □ Drawing something irrelevant (e.g. line practice, doodle, cartoon figures ... etc) as a warm-up exercise for designers to quickly enter the drawing state
   □ Others
If others, please specify: ____________________________

8. How do you think these habits may help you while you are sketching? (You may choose more than one answer)
   □ Helping you to calm down and relax
   □ Helping you to focus and concentrate on the task
   □ Helping you to warm up and quickly enter the drawing state
   □ Helping you feel comfortable and confident with the task ahead
   □ Don’t know, simply like to do it
   □ Others

If others, please specify: ____________________________

9. How do you develop your sketching techniques? (You may choose more than one answer)
   □ By your own practice
   □ By learning from books
   □ By learning from website
   □ By learning from videotape
   □ By learning from course/training
   □ By learning from tutors/friends/colleagues
   □ Others

If others, please specify: ____________________________

10. Do you refer to any source available when you are doing your sketch? (You may choose more than one answer)
    □ Reference from internet
    □ Reference from memory
    □ Reference from observation in daily life
    □ Reference from the natural environment
    □ Reference from books/magazines
    □ Reference from imagination
    □ Others

If others, please specify: ____________________________
Second 3 (The importance of design sketching)

11. Please rate how significant you consider the following roles of sketches to industrial designers/design process. (1: least effective 7: most effective)

1 2 3 4 5 6 7  Defining and clarifying the design task
1 2 3 4 5 6 7  Expanding designer’s thoughts using mind maps, notes and annotations
1 2 3 4 5 6 7  Recalling design elements from previous experience
1 2 3 4 5 6 7  Promoting idea generation and exploration
1 2 3 4 5 6 7  Facilitating idea evaluation and selection
1 2 3 4 5 6 7  Investigating the aesthetic details such as appearance, proportion and scale
1 2 3 4 5 6 7  Exploring the technical details such as function, structure and manufacturing
1 2 3 4 5 6 7  Promoting design communication with other designers for design collaboration
1 2 3 4 5 6 7  Promoting design communication with engineers regarding technical points
1 2 3 4 5 6 7  Promoting design communication clients regarding product appearance, function and scenario

If others, please specify, and rate:

1 2 3 4 5 6 7

__________________________________________________
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12. Please rate how significant you consider the following roles of non-working sketches* to industrial designers/design process. (*I am using the term 'non-working sketches' to mean all kinds of sketches produced by designers in their spare time; 1: least effective 7: most effective)

1 2 3 4 5 6 7  Sketching as practice to improve their sketching techniques
1 2 3 4 5 6 7  Sketching as a warm-up exercise at the initial design stage to
let designers quickly enter the sketching state

| 1 2 3 4 5 6 7 | Sketching for fun and enabling designers to play with sketches and ideas |
| 1 2 3 4 5 6 7 | Sketching for emotional and aesthetic expression |
| 1 2 3 4 5 6 7 | Keeping sketches as records for future reference (e.g. sketch notebooks, sketch diaries etc) |

If others, please specify, and rate:

| 1 2 3 4 5 6 7 |
| ____________________________ |
| ____________________________ |
| ____________________________ |
| ____________________________ |
13. Please rate how significant you consider the following sketching abilities to industrial designers. (1: least effective 7: most effective)

1 2 3 4 5 6 7 Ability to sketch from memory
1 2 3 4 5 6 7 Ability to sketch from reference
1 2 3 4 5 6 7 Ability to sketch from imagery
1 2 3 4 5 6 7 Ability to sketch from observation
1 2 3 4 5 6 7 Ability to sketch to visualise ideas
1 2 3 4 5 6 7 Ability to sketch to organise ideas
1 2 3 4 5 6 7 Ability to sketch to explore and evaluate ideas
1 2 3 4 5 6 7 Ability to sketch for recording ideas and related design information
1 2 3 4 5 6 7 Ability to sketch for design analysis
1 2 3 4 5 6 7 Ability to use sketches to communicate design thoughts to others
1 2 3 4 5 6 7 Ability to use sketches to instruct others
1 2 3 4 5 6 7 Ability to sketching quickly
1 2 3 4 5 6 7 Ability to master various kinds of technical drawing techniques
1 2 3 4 5 6 7 Ability to master various kinds of artistic drawing techniques
1 2 3 4 5 6 7 Ability to sketch with proper style
1 2 3 4 5 6 7 Ability to access and understand the quality of a sketch
1 2 3 4 5 6 7 Ability to enjoy the process of sketching

If others, please specify, and rate:

1 2 3 4 5 6 7

14. Please rate how significant you consider the following drawing techniques may affect the quality of a design sketch. (1: least effective 7: most effective)
Skill in drawing contour lines
Sill in line quality control
Skill in using of shading
Skill in using of drop shadow
Skill in using of colour/tone
Skill in using of annotation
Skill in using 2D drawing
Skill in using perspective drawing
Skill in using primitive objects (e.g. box, cylinder ‥‥etc) to simplify your drawing
Skill in using assistant lines while sketching
Skill in drawing human figures and scenario
Skill in quick sketch
Skill in arranging the layout
Skill in handling a range of media

If others, please specify, and rate:

____________________________________________________________________

________
15. Would you be willing to help with our research project?
Yes           No

16. If yes, in what way would you be prepared to contribute?

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17. Would you like to give further comments and suggestions in relation to the role of sketching/ sketching ability in design? If so, please use the space below.

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Your contribution is very greatly appreciated. Thank you very much!
Appendix C: Questionnaire for the design professionals

This questionnaire aims to investigate the roles of sketching and sketching abilities in industrial design. The questionnaire will take you less than 15 minutes. All information given will be treated as confidential and only be used for academic research purposes. Great care will be taken in data management in order to avoid any loss of data or misuse of data collected.

1. I agree to take part in the above Imperial College London research project. I have had the project explained to me. I understand this will involve a survey questionnaire completed by the participant.
   □ Yes
   □ No

2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.
   □ Yes
   □ No

3. I understand that any information I provide is confidential, and none of my personal information during this research will be published without my consent. No identifiable data will be shared with any other organisations without my consent.
   □ Yes
   □ No
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**Second 2 (General questions about sketching)**

1. How do you rate the importance of sketching to industrial designers?
   - □ Essential
   - □ Useful
   - □ Irrelevant
   - □ Detrimental

2. How do you rate the importance of sketching ability* to industrial designers? (*I am using the term 'sketching abilities' to mean any and every know-how and drawing techniques in practice, appreciation and understanding of design sketching)
   - □ Essential
   - □ Useful
   - □ Irrelevant
   - □ Detrimental

3. Do you regard yourself as experienced in sketching?
   - □ Very experienced
   - □ Experienced
   - □ Less experienced
   - □ Novice

4. How long is it since you initially start sketching?
   - □ Less than 1 year
   - □ 1-4 years
   - □ 4-10 years
   - □ Over 10 years

5. Do you have any personal sketching habits?
   
   Please write down the first couple you immediately think of below.

   _____________________________________________________________
   _____________________________________________________________

   Please select the sketching habits you have (You may choose more than one answer)
   - □ Listen to music while sketching
   - □ Eating snacks while sketching
   - □ Searching for visual reference
   - □ Doing some form of physical activity (e.g. pen spinning, crack knuckles ... etc)
   - □ Drawing something irrelevant (e.g. line practice, doodle, cartoon figures ... etc) as a warm-up exercise for designers to quickly enter the drawing state
   - □ Others
6. How do you think these habits may help you while you are sketching?

Please write down the reasons why you keep these sketching habits.

_________________________________________________________________
_________________________________________________________________
_________________________________________________________________

Please select the reasons listed below (You may choose more than one answer)
☐ Helping you to calm down and relax
☐ Helping you to focus and concentrate on the task
☐ Helping to inspire new ideas
☐ Helping you to warm up and quickly enter the drawing state
☐ Helping you feel comfortable and confident with the task ahead
☐ Don’t know, simply like to do it
☐ Others

Second 3 (The importance of design sketching)

7. What do you think are the roles of sketching in supporting design process?

Please describe several major roles of design sketching briefly:

_________________________________________________________________
_________________________________________________________________
_________________________________________________________________

Please rate how significant you consider the following roles of sketches to industrial designers/design process. (1: least effective 7: most effective)

1 2 3 4 5 6 7  Defining and clarifying the design task
1 2 3 4 5 6 7  Expanding designer’s thoughts using mind maps, notes and annotations
1 2 3 4 5 6 7  Recalling design elements from previous experience
1 2 3 4 5 6 7  Promoting idea generation and exploration
1 2 3 4 5 6 7  Facilitating idea evaluation and selection
1 2 3 4 5 6 7  Investigating the aesthetic details such as appearance, proportion and scale
1 2 3 4 5 6 7  Exploring the technical details such as function, structure and manufacturing
1 2 3 4 5 6 7  Promoting design communication with other designers for design collaboration
1 2 3 4 5 6 7  Promoting design communication with engineers regarding
8. What do you think are the roles of non-working sketches (I am using the term 'non-working sketches' to mean all kinds of sketches produced by designers in their spare time) for designers? Please describe several major roles of non-working sketches briefly:

_________________________________________________________________
_________________________________________________________________

Please rate how significant you consider the following roles of non-working sketches to designers/design process. (1: least effective 7: most effective)

1 2 3 4 5 6 7 Sketching as practice to improve their sketching techniques
1 2 3 4 5 6 7 Sketching as a warm-up exercise at the initial design stage to let designers quickly enter the sketching state
1 2 3 4 5 6 7 Sketching for fun and enabling designers to play with sketches and ideas
1 2 3 4 5 6 7 Sketching for emotional and aesthetic expression
1 2 3 4 5 6 7 Keeping sketches as records for future reference (e.g. sketch notebooks, sketch diaries …etc)

**Second 4 (The importance of design sketching expertise)**

9. What do you think are the roles of sketching ability in design? Please describe several major roles of sketching ability in supporting design process briefly:

_________________________________________________________________

Please rate how significant you consider the following sketching abilities to industrial designers. (1: least effective 7: most effective)

1 2 3 4 5 6 7 Ability to sketch from memory
1 2 3 4 5 6 7 Ability to sketch from reference
1 2 3 4 5 6 7  Ability to sketch from imagery
1 2 3 4 5 6 7  Ability to sketch from observation
1 2 3 4 5 6 7  Ability to sketch to visualise ideas
1 2 3 4 5 6 7  Ability to sketch to organise ideas
1 2 3 4 5 6 7  Ability to sketch to explore and evaluate ideas
1 2 3 4 5 6 7  Ability to sketch for recording ideas and related design information
1 2 3 4 5 6 7  Ability to sketch for design analysis
1 2 3 4 5 6 7  Ability to use sketches to communicate design thoughts to others
1 2 3 4 5 6 7  Ability to use sketches to instruct others
1 2 3 4 5 6 7  Ability to sketching quickly
1 2 3 4 5 6 7  Ability to master various kinds of technical drawing techniques
1 2 3 4 5 6 7  Ability to master various kinds of artistic drawing techniques
1 2 3 4 5 6 7  Ability to sketch with proper style
1 2 3 4 5 6 7  Ability to access and understand the quality of a sketch
1 2 3 4 5 6 7  Ability to enjoy the process of sketching

10. What do you think are the roles of sketching skill in design?

Please describe several major roles of sketching skill in supporting design process briefly:

_________________________________________________________________
_________________________________________________________________

Please rate how significant you consider the following sketching skills may affect the quality of a design sketch. (1: least effective 7: most effective)

1 2 3 4 5 6 7  Skill in drawing contour lines
1 2 3 4 5 6 7  Skill in line quality control
1 2 3 4 5 6 7  Skill in using of shading
1 2 3 4 5 6 7  Skill in using of drop shadow

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Second 5 (Requirements regarding supporting tools)

11. What media are you comfortable with (using) when you are sketching?
   □ Pencil and paper
   □ Pen and paper
   □ Colours and paper
   □ CAD systems (e.g. Photoshop, Sketchbook ... etc)

12. Do you refer to any source available when you are doing your sketch?
   Please write down several sources of references you like to use.

_________________________________________________________________
________________________________________________________

Please select the sources of references you may use while sketching (You may choose more than one answer)
   □ Reference from internet
   □ Reference from memory
   □ Reference from observation in daily life
   □ Reference from the natural environment
   □ Reference from books/magazines
13. What content of supports for design sketching would you prefer?

Please write down the knowledge or materials of sketching you are interested in.

_________________________________________________________________
_________________________________________________________________

Please select the content of supports (You may choose more than one answer)
☐ Introduction to sketching
☐ The basic theory of sketching (e.g. the psychology of sketching)
☐ Sketching taxonomy
☐ Pictorial stimuli
☐ Textual stimuli
☐ Instruction on sketching tools/media
☐ Introduction to sketching abilities
☐ Instruction on drawing skills
☐ Instruction on practise methods (e.g. sketching abilities/skills)
☐ Basic principles of design sketching
☐ Instruction on developing sketching habits
☐ Examples of design sketches
☐ Design sketching case studies
☐ Useful information (e.g. useful links, reading list)

14. What format of supports for design sketching would you prefer?

Please write down the formats of supports you use or you are interested in.

_________________________________________________________________
_________________________________________________________________

Please select the format of supports (You may choose more than one answer)
☐ A textbook
☐ A booklet
☐ A course/training
☐ A website
☐ A videotape/CD-Rom
☐ A CAD tool
Second 6 (Other information of interest)

15. Would you be willing to help with our research project?
   Yes          No

16. If yes, in what way would you be prepared to contribute?

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17. Would you like to give further comments and suggestions in relation to the role of sketching/ sketching ability in design? If so, please use the space below.

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Appendix D: The PD-Sketching Primer
PD-Sketching

Sketching for Design

Freehand sketching has traditionally been considered an essential part of the design process. Designers are generally taught to think with their sketches in order to externalise concepts, communicate ideas and solve complex problems.

**Thinking sketches** are a group of sketches that designers use to support their individual thinking processes, i.e. focusing and guiding nonverbal thinking.

**Talking sketches** are used for facilitating design communication. They encourage discussion and build a common understanding of the design idea among the parties involved.

**Non-working sketches** can be defined as a group of sketches that are produced by designers outside the design process in their spare time.

2

PD-Sketching

Design thinking

As a form of thinking, sketching serves the designer in various ways, e.g. lateral/vertical transformations. This is seen as cognitive benefits that sketching provides and is believed to be curial for fostering design creativity (Goel, 1995).

![Lateral and Vertical Transformations](image)

Lateral (divergent)

Vertical (convergent)

3

PD-Sketching

Examples: design analysis

These sketches are produced for supporting design analysis process.
PD-Sketching

Examples: design ideation

These sketches are produced for supporting design ideation process.

From top left to bottom right:
1. Exploring auto-body design (by Pratikbhai Desai)
2. Exploring form design (by David Sweeney)
3. Exploring handle design (by Aditya Raj Dev)
4. Exploring colour scheme (by Son Nguyen)
5. Exploring accessories (by Jesse Han)
6. Exploring details (by Aditya Raj Dev)
7. Exploring material of watchband (by Victor Vu)

PD-Sketching

Design communication

“One picture is worth ten thousand words”

The easiest and most efficient way to stay in sync is to represent and share an idea with a sketch. Sketching adds a tangible element to the conversation that everyone in the group can see, point to, discuss, and build on.

Sketching can be mainly used to support design communication in three ways, i.e. facilitating collaboration with other designers and engineers, and design presentation to clients (Hsu, 2018).

PD-Sketching

Examples: design communication

These sketches are produced for communicating with designers.

Commonly involves a group of sketches during the design meeting. These sketches are produced to share and explore design concepts to other designers for supporting new ideas, generation and further development.

C-Sketching

Collaborative sketching, or C-sketching, is a rapid way to generate and build upon ideas that you and your team members have. C-sketching is effective because it helps provide different perspectives or insights into the solutions that are hidden from the sketches.

Capture of concept

Presentation sketch

Explanatory sketch

Descriptive sketch

Prescriptive sketch
**PD-Sketching**

**Examples: technical communication**

These sketches are produced for communicating with engineers for technical designs:

- Communicating the underlying principle of a scheme with informal coded sketches
- Communicating technical details with techniques, e.g., mechanisms, manufacturing, material and dimensions
- Communicating the structural design, operating principles and relationship of components, e.g., exploded views
- Contains detail of components for instructing the final manufacture.

Technical sketches for facilitating design communication with engineers regarding technical points.

**PD-Sketching**

**Examples: design presentation**

These sketches are produced for communicating with clients and other involved parties for design decision making:

- Rendered and realistic sketches to help designers to communicate the design idea to clients
- Describing the interaction between users and products, sometimes in an appropriate context
- Illustrating the appearance design of the product, using the colour, base and even artistic draughting skills to express the wonderfull or fantastic qualities of the design.

The roles of types of sketches used for design presentations are changing due to the development of design visualization technology. Rendering skills is no longer enough, but an alternative for designers to deliver presentations.

**PD-Sketching**

**Defining sketching**

By definition, a sketch is a quick and rough drawing and gives a brief account or general outline of something. Design sketching is a rapidly executed freehand drawing that is not usually intended as a finished work but is an amazing tool as it allows designers to quickly visualize multiple design concepts.

Due to the complicated nature of design activities, there is no universally accepted definition of design sketching. Numerous definitions of design sketching were proposed by researchers in the literature, e.g., Sammer (2002), Rosvall et al. (2003), Bastian (2010) and Lithecoin (2012).
Design process

Crass (2000) presented a generic model of the industrial design process based on divergent and convergent design activities (see Figure 5). He described about the design process in four phases: 1) 'concept design', 2) 'development design', 3) 'detail design', and 4) 'manufacture'.

Types of sketches

Classification system of product design sketches

Roles of sketches in design

A summary of types of sketches and their roles in design

References:


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**PD-Sketching**

**The psychology of sketching**

The Ideation Segment model of design sketching process

Other psychological theories of design sketching:
1. Reflective conservation (by Schön)
2. Diakritics of sketching (by Goßmann)
3. Laboral vertical transformations (by Geel)
4. Individual interpretive codes (by van der Lugt)

**PD-Sketching**

**Sketching tools**

Classification and examples of sketching tools:

- **Line drawing tools**
- **Coloured drawing tools**
- **Digital tools**
- **Assistive tools**

Summary of sketching tools:

- Line drawing tools: Pencil, pen, marker, felt-tipped pens, ball-point pens, and gel pens.
- Coloured drawing tools: Coloured pencils, marker and brushes.
- Digital tools: Software, tablets, sketching and graphic tablet, and stylus pens.
- Assistive tools: Drawing ruler, sketchbook, texturing tools, paper, eraser and highlighters.

**PD-Sketching**

**Lines**

Basics of lines and practice methods:

- **Advanced lines**: Construction line, parallel line, construction lines, oblique line, auxiliary line.
- **Line weight**: Using lines of differing thickness can help to clarify a form and add dynamics to pictures. Line weight can be used to emphasize chosen parts of an object, strengthen the perspective, and create depth.

<table>
<thead>
<tr>
<th>SQUARE GRID</th>
<th>TARGET CIRCLES</th>
<th>ELLIPSE TREES</th>
</tr>
</thead>
<tbody>
<tr>
<td>TARGET LINES</td>
<td>SLOPING LINES</td>
<td>BEACH BALL</td>
</tr>
</tbody>
</table>
**PD-Sketching**

### Perspective

**One-point perspective**
1. Begins one point perspective by drawing a horizon line.
2. Place a vanishing point on the horizon line.
3. Draw a line to represent the building that you want to draw in perspective.
4. Draw lines from all lines coming back to the vanishing point.
5. Draw a smaller box that touches each of the lines coming back to the vanishing point.
6. Erase lines that you no longer need to round a 3D form.

**Two-point perspective**
1. Define the horizon line and the vanishing points.
2. Draw the center of the object in between the vanishing points.
3. Draw lines from each of the center to each of the vanishing points.
4. Draw parallel, vertical lines to indicate where the object will be.
5. Erase the lines you no longer need to round your 3D form.

---

**PD-Sketching**

### Form

**Basics forms:**
- Cuboid & Cube
- Cylinder
- Sphere & Organic shapes
- Torus & Tube
- Combination of basic forms

---

**PD-Sketching**

### Material

The sketches below show only a few of the many ways that materials can be illustrated:

- **Rubber**
  - materials are characterized by surfaces with soft gradients and low contrast. These effects can be produced by colour pencils or a layer of varnish.

- **Transparent material**
  - Light passes through the material, where the outline is clear. This drawing can help to show the object that is visible through the material and useful in techniques.

---

**PD-Sketching**

Other materials include:
- Shiny plastic, matte plastic,
- metal, leather, bamboo, etc.
PD-Sketching

Shading & Colour

The use of shading & colour in product design sketching:

Advanced lines:
Shading appears on an object in areas where the lighting is
blocked or indirect. Before shading an object, the lighting
should be chosen visually, as the shadows can help to describe
the object’s form.
Colour is an advanced technique, which can describe
the colour design and the shading at the same time. It
may also provide extra information to the makers, e.g.
a specific mood, brand style and design highlights.

PD-Sketching

Cast shadows

Examples of good sketches

Other commonly used shadows:

Area between edge
of cuboid base and
where lines cross

PD-Sketching

Analysis

Sketching process of backpack design (by Tu Nguyen)
PD-Sketching

Appreciation

Examples of good sketches

PD-Sketching

Tools

A number of methods and tools are available for supporting design sketching process, for example:

- Instruction on sketching classification and application throughout the process [https://www.uksa.org/education/how-they-do-it/]
- Supporting education and collaboration for engineering designers and industrial designers during new product development [http://www.cadlab.dhaka.ac.uk/index.php/page-sponsor]
- Transferring 2D sketches into 3D ideas in real-time, at any scale, from initial concepts through to detailed 3D models to remove friction from the workflows and enhance team collaboration [https://www.gravitysketch.com/]

PD-Sketching

Books

Sketching: The Basics

Creative Sketching in Product Design
SequinPress Publishing Co., 2013, ISBN 978-0-98790334-3, by Simon Hines (This book includes perspective theory, basic sketching skills, and includes over 50 outstanding sketches from all around the world)

Drawing for Product Designers

Sketching and Drawing Techniques for Product Designers
BSH Publishers Ltd., 2012, ISBN 13: 978-0-96606125-7, by Ross Bloom (This book examines key sketching techniques and provides step-by-step example drawings, which is suitable for students and professionals to become better sketchers.)
PD-Sketching

Web-sites

Drawing Gym-Teaching Engineers to Draw
https://www.uci.ac.uk/drawing-gym/about/

Drawing At Work
http://www.drawingatwork.co.uk/index.php

Introduction to Design Sketching
https://www.udemy.com/course/introduction-to-design-sketching/

Design Sketching Class
https://www.instructables.com/class/Design-Sketching-Class/

Online sketch training for all!
https://www.designsketchingcourses.com/

Design Sketching
https://vimeo.com/designdrawing

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Appendix E: The PD-Sketching Taxonomy Cards
**Detail Design**

The most visually creative stage, which involves generating ideas based on form, function, features, specifications, benchmarking and economic justification.

**Design Presentation**

The most visually creative stage, which involves generating ideas based on form, function, features, specifications, benchmarking and economic justification.

---

**Design Stages**

**Card No.**  | **Type of sketch**  
--- | ---  
Card 93-46 | Defining Sketch  
Card 61-44 | Memory Sketch  
Card 63-56 | Idea Sketch  
Card 61-64 | Coded Sketch  
Card 67-64 | Development Sketch  
Card 67-74 | Detail Sketch  
Card 74-74 | Explanatory Sketch  
Card 75-74 | Prescriptive Sketch  
Card 75-74 | Presentation Sketch  
Card 74-74 | Fabulous Sketch  
Card 78-86 | Scenario & Storyboard  

**Card No.**  | **Type of sketch**  
--- | ---  
Card 93-46 | Defining Sketch  
Card 61-44 | Memory Sketch  
Card 63-56 | Idea Sketch  
Card 61-64 | Coded Sketch  
Card 67-64 | Development Sketch  
Card 67-74 | Detail Sketch  
Card 74-74 | Explanatory Sketch  
Card 75-74 | Prescriptive Sketch  
Card 75-74 | Presentation Sketch  
Card 74-74 | Fabulous Sketch  
Card 78-86 | Scenario & Storyboard
Detail Design

The most visually creative stage, which involves generating ideas based on form, function, features, specifications, benchmarking and economic justification.

Design Presentation

The most visually creative stage, which involves generating ideas based on form, function, features, specifications, benchmarking and economic justification.
Non-design

The most visually creative stage, which involves generating ideas based on form, function, features, specifications, benchmarking and economic justification.

Card No. Type of sketch
Card 81-82 Storing Sketch
Card 83-84 Practising Sketch
Card 85-86 Playing Sketch
Card 87-88 Warming-up Sketch
Design Intent

Identifies the design concept and product purpose including aesthetics, safety and usability.
Form & Detail

Identifies the products' appearance with respect to form, including structure, shape, proportion and size.
Visual Character

Identifies the visual character that a product conveys to the user through external form, materials, texture and finishing.
Usability & Operation

Describes how well a product is capable of being used, including functional effectiveness, ergonomics and operational efficiency.
Finishing

Identifies the texture (sense of touch of external surface) and surface finish (coating applied to the product) of the product.
Colour

Identifies the visual attributes of the product’s appearance in terms of hue, lightness and saturation.
Dimensions

Generally comprise measurements of parts, including angles and tolerances with a specified unit of measurement.
Construction

Describes the detailed method for attaching individual components, including the use of adhesives, fasteners and...
Assembly

Describes the systematic sequence of putting the manufactured components together to make the final product.
Components

Describes the individual parts that used to construct the final product.

Technical Information
Materials

A specification of various materials used for the product manufacturing, e.g. plastics, metals, woods and textiles.
Presentation Sketch

Rendered and realistic sketches to help designers communicate the design concept with clients.

Fabulous Sketch

Used to present design ideas in a way that intend to express wonderful or fantastic qualities.
Development Sketch

Used to evaluate design ideas and further investigate the appearance, proportion and scale in greater detail.

Detail Sketch

Illustrates detailed information of components of products to facilitate detailed communication or further improvement.

Card No. 67

Development Sketch

Card No. 68

Development Sketch

Card No. 69

Detail Sketch

Card No. 70

Detail Sketch
Idea Sketch

Promotes idea generation and exploration of alternatives with simple line drawings

Coded Sketch

Informal coded representation used for categorizing information to demonstrate an underlying principle or scheme
Defining Sketch

Helps the designers to define and clarify the design task

Memory Sketch

Used by designers to expand their thoughts and recall elements from previous work
Scenario & Storyboard

Describes interaction between user and product and portrays the use in the context

Logbook Sketch

Drawing records of design project related information for future reference
Storing Sketch

Drawing records of relevant design information for future reference, e.g., design examples, landscapes, living creatures or any relevant observations.

Practicing Sketch

Extensively produced by designers for the purpose of improving their sketching skills.
Playing Sketch
Simply produced by designers for fun, enabling them to play with sketches and ideas

Warming-up Sketch
Produced as a warm-up exercise (e.g. lines, ellipse and basic shapes) for designers to quickly enter the drawing state
Appendix F: Questionnaire for preliminary evaluation of PD-Sketching Primer

This questionnaire aims to verify whether the PD-Sketching Primer contained the appropriate information and was presented in an appropriate format. The questionnaire will take you less than 10 minutes. All information given will be treated as confidential and only be used for academic research purposes. Great care will be taken in data management in order to avoid any loss of data or misuse of data collected.

1. I agree to take part in the above Imperial College London research project. I have had the project explained to me. I understand this will involve a survey questionnaire completed by the participant.
   □ Yes
   □ No

2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.
   □ Yes
   □ No

3. I understand that any information I provide is confidential, and none of my personal information during this research will be published without my consent. No identifiable data will be shared with any other organisations without my consent.
   □ Yes
   □ No
Preliminary evaluation of *PD-Sketching Primer*

1. Evaluation of the contents, i.e. the content of the booklet, quality of the content and quality of the reference

   Please rate how good you consider the following aspects of content of the booklet. (on a 1 - 5 point scale, 1 - poor, 2 – adequate, 3 - good, 4 – very good, 5 – excellent)

   | 1 2 3 4 5 | The content of the booklet |
   | 1 2 3 4 5 | Quality of the content |
   | 1 2 3 4 5 | Quality of the reference |

2. Evaluation of the format, i.e. layout of the booklet and visual quality and clarity (on the same 1 - 5 point scale)

   Please rate how good you consider the following aspects of format of the booklet. (on a 1 - 5 point scale, 1 - poor, 2 – adequate, 3 - good, 4 – very good, 5 – excellent)

   | 1 2 3 4 5 | Layout of the booklet |
   | 1 2 3 4 5 | Visual quality and clarity |

3. Overall impression of the booklet (on the same 1 - 5 point scale)

   | 1 2 3 4 5 | Overall impression of the booklet |

4. Suggestions for improvement

   Please write down the suggestions that you think can help to improve the primer.

   __________________________________________________________
   __________________________________________________________
   __________________________________________________________
   __________________________________________________________

5. Would you be willing to help with our research project?

   Yes           No

Your contribution is very greatly appreciated. Thank you very much!
Appendix G: Evaluation form for the PD-Sketching Toolkit

<table>
<thead>
<tr>
<th>University/Company:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start:</td>
<td>End:</td>
</tr>
<tr>
<td>Duration:</td>
<td></td>
</tr>
<tr>
<td>Background:</td>
<td>Year of Design Experience:</td>
</tr>
</tbody>
</table>

Experience on design sketching (please tick √)
- □ Very experienced
- □ Experienced
- □ Less experienced
- □ Novice

<table>
<thead>
<tr>
<th>Item Dimension</th>
<th>Rating (please select from 1 to 5, 1: strongly disagree, 5: strongly agree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different formats are used in the PD-Sketching Toolkit</td>
<td>1 □ D 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>Appropriate formats are used in the PD-Sketching Toolkit</td>
<td>1 □ p 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>The component tools are organised in a flexible way</td>
<td>1 □ h 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>The toolkit is easy to use</td>
<td>1 □ h 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>The PD-Sketching Toolkit provides useful information for supporting design sketching</td>
<td>1 □ h 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>The PD-Sketching Toolkit provides sufficient information for supporting design sketching</td>
<td>1 □ h 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>The PD-Sketching Toolkit provides up-to-date information for supporting design sketching</td>
<td>1 □ h 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>The use of the PD-Sketching Toolkit gave me a sense of satisfaction</td>
<td>1 □ h 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>I found using the PD-Sketching Toolkit is interesting and engaging</td>
<td>1 □ 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>I will use the PD-Sketching Toolkit in the future</td>
<td>1 □ 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>I would recommend the PD-Sketching Toolkit as an ideal sketching support tool</td>
<td>1 □ 2 □ 3 □ 4 □ 5 □</td>
</tr>
<tr>
<td>The use of the PD-Sketching Toolkit will make sketching learning easier</td>
<td>1 □ h 2 □ 3 □ 4 □ 5 □</td>
</tr>
</tbody>
</table>
The use of the PD-Sketching Toolkit enhanced the understanding of design sketching

<table>
<thead>
<tr>
<th>Questions</th>
<th>Answers (please tick ‘1’ or ‘2’ and write down your comments)</th>
</tr>
</thead>
</table>
| Did you learn anything from the toolkit? If so, what did you learn? | 1. Yes, I will
   Comments: |
| Did anything noticeably of the toolkit promote or hinder your ability to sketch? | 2. Yes, I will
   Comments: |
| Are there any topics you would like to pursue learning further? | 3. Yes, I will
   Comments: |
| Will you change your behavior based on what was learnt | 4. Yes, I will
   Comments: |
| Other comments: | |