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Towards A Comprehensive Understanding of Design Sketch - A Literature Review of Design Sketch Taxonomy and Considerations for Future Research

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ABSTRACT
Taxonomy is an important approach to characterize the roles of the sketch in design. Design researchers have made various attempts to classify design sketches. However, despite the extensive literature on the subject, the roles that sketch play in design are still not fully understood, especially those changing ones in today's design context due to the development of CAD/ sketching software. This study performed a literature review of the design sketch taxonomies published over the last thirty years. The objective is to understand the major drawbacks that limit their effective implementation in the research of design sketch. This study developed a Generic Design Process model and proposed criteria for accessing design sketch taxonomies. This study has found that to achieve a comprehensive understanding of design sketch, many taxonomies have limitations in describing the whole design process and revealing the sub-functions of design sketch, which feature a lack of both integrity and accuracy. In addition, most of the taxonomies overlook the importance of non-working sketch, which is also an obstacle for its implementation in the field.

Key Words: Design Sketch; Design Sketch Taxonomy; Roles of Design Sketch; Design Process

1. INTRODUCTION

Designers often place great emphasis on the sketch. The use of sketch is traditionally believed as an important part of natural processes of designing (Cross, 1999). 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". However, the attempts to understand the importance is something that has only recently become a subject of consideration by design researchers.

Taxonomy can be useful in order to explore classifications and has been applied here to the roles of the sketch in design. To achieve a fully rounded understanding of the design sketch, various sketch taxonomies have been developed. 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 (1994) classifies sketches according to their functions in the design process. Lugt (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.

The exploration and understanding of the roles that sketches play in the design process are expected to bring important implications for both design education and design support tools development. However, despite the extensive literature on the subject, the roles sketches play remains not fully understood. The available sketch taxonomies may be inaccessible for designers to use in the design research. 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 which can involve and describe the use of different types of sketches through the entire design process. Furthermore, although researchers such as Goldschimt (2003), Lugt (2005) and Lawson (2012) have identified several types of non-working sketches, which helped us expanding and refining the understanding of the design sketch, they didn't identify and integrate the whole group of non-working sketches into sketch taxonomy.

There exists an extensive literature on the design sketch, but few of the works focus on sketch taxonomy. 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. There has been no comprehensive review of these sketch taxonomies, and we intend to fill this void. To address the issues mentioned above, this study reviewed and assessed the existing sketch taxonomies. A Generic Design Process (GDP) model and 6 criteria were proposed so that the usability of selected sketch taxonomies can be evaluated in a structured manner to facilitate further design sketch research.

This paper is structured as follows. Firstly, existing sketch taxonomies are reviewed and analyzed according to the design phases to which they can be applied. Secondly, the use of sketch taxonomies on the study of the non-working sketch is discussed. Lastly, the taxonomies are analysed by their utility in facilitating design sketch research. Also, this paper concludes with opportunities and considerations for future research in this area.

2. Methodology

The aim of this research is to identify major works on design sketch taxonomy, revealing their supporting value, and thereafter, to classify and analyze them with certain criteria so as to identify gaps, issues and opportunities for further study and research. Observations of the design sketch are also adopted in this research, as a method to enrich and supplement the theory. A mixed methodology has been adopted, with the cycling of the two above methods, to provide close integration and mutual confirmation.

This review is covered from the perspective of three disciplines: industrial design, engineering design and architectural design. Search terms differed slightly

for the three disciplines owing to the different use of words among designers and engineers. For example, the term 'sketch' gives a relatively large number of hits when searching a design research database, whereas the term 'drawing' is more effective when searching an engineering database. The literature on sketch taxonomy was collected, and the corresponding process of analysis comprises the following steps:

- Defining the unit of analysis: The unit of analysis has been defined as a single research paper/book.
- Collecting publications: A search of six main databases (i.e. Google Scholar, Science Direct, Engineering Village, Research Gate, Scopus, and Wiley) was carried out. Literature from 1989 onwards has been considered, covering a time span of nearly 30 years.
- Reorganising the literature: Development of an overview of the existing sketch taxonomies in the references from the second step.
- Analyzing the literature: Review of sketch taxonomies that have been developed for improving our understanding of the design sketch. Each taxonomy is analyzed and evaluated according to its feasibility, integrity and profundity.

3. Design sketch

Designers often place great emphasis on sketching, but why is it necessary for them to sketch at all? One obvious reason is that, before the high-performance 3D modelling software is applied in the field, design outcomes are normally presented in the form of drawings to communicate with other involved parties (Cross, 2006). Designers are taught to think with their sketches since they were students, which can help them to externalize concepts, communicate ideas and solve complex problems. Other identified functions of sketching includes: supporting idea generation process (Yang, 2003; Lugt, 2005; Bouchard et al, 2006); supporting design communication (Bly, 1988; Tang, 1991; Scrivener & Clark, 1994); externalizing and visualizing problems (McKim,1980; Kernohan, 1981; Snodgrass & McCullough, 1986); facilitating cyclic reinterpretation process (Goldschmidt, 1991; Schon & Wiggins, 1992); facilitating design reasoning (Do & Gross, 1996); facilitating perception and translation of ideas (Suwa & Tversky, 1997; Tversky, 1999); revising and refining ideas (Smith, 1998; Lugt, 2005). However, it is also recognised that many 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 solid modelling as the main tool for the definition of geometry in engineering.

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 sketch, the non-working sketch has received little attention. In practice, designers often produce even more sketches outside the design process, which is mainly because, as a learned skill, expertise in sketch requires lots of practice. A number of empirical experiments have identified the difference between skilled sketcher and unskilled sketcher (Suwa & Tversky, 1997; Verstijnen & Hennessey, 1998; Yang & Cham, 2005). These experiments suggest that sketch skills are linked to design creativity. Secondly, the non-working sketch is rough and fast. This characteristic makes it suitable for recording design information and ideas. In addition, the non-working sketch may bring 'unintended consequences' which can be an essential element of the 'reflective conversation' process (Schon & Wiggins, 1992). The non-working sketch can also be fun as it enables designers to play with the sketches and ideas.

4. Overview of design 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 (1996) 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 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, 14 sketch taxonomies were found in the relevant design fields. Table 1 gives an overview of the taxonomies found in the literature to describe the type of design sketch.

Table 1. A list of different Sketch taxonomies found in the literature.

Author/Year	Taxonomy

Tovey /1989	Diagrammatic drawings; Ideas sketches; Concept drawings; Measured drawings
Radcliffe & Lee /1990	Functional sketches; Geometric sketches; Pictorial sketches
Porter /1992	Orthographic projections; Axonometric drawings; Perspective drawings
Ferguson/1994;Lugt/2005	Thinking sketch; Talking sketch; Prescriptive sketch; Storing sketch
Fraser & Henmi/ 1994	Referential drawings; Diagrams; Design drawings; Presentation drawings; Visionary drawings
Goel/ 1995	Lateral transformations; Vertical transformations
McGown et al. /1998	level 1; level 2; level 3; level 4; level 5
Ching /2003	Multi-view drawings; Praline drawings; Perspective drawings
Olofsson & Sjölén/ 2005	Ideation sketch; Explorative sketch; Explanatory sketch; Persuasive sketch
Menezes /2005	Orthogonal drawings; Axonometric drawings; Perspective drawings
Pipes/ 2007	Thematic sketch; Package-constrained sketch
E. Pei/ 2009	Personal sketch; Shared sketch; Persuasive sketch; Handover sketch
Yang/ 2009	Non-dimensioned sketch; Dimensioned sketch
Lawson/ 2012	Presentation drawings; Instruction drawings; Consultation drawings; Experiential drawings; Diagrams; Fabulous drawings; Proposition drawings; Calculation drawings

5. 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 & Gero 2006). These different types of sketches are associated with different design stages and cognitive processes (Lawson 2004). Design researchers typically share the following stages in the

design process: establishing a need, defining the design task, conceptual design, embodiment design, detailed design, and implementation (Archer, 1965; French, 1985; Pahl & Beitz, 1996; Dominick, 2001; Ulrich & Eppinger, 2003). For example, Cross (2000) presents a generic model of the industrial design process based on divergent and convergent design activities (see Figure 1). 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".

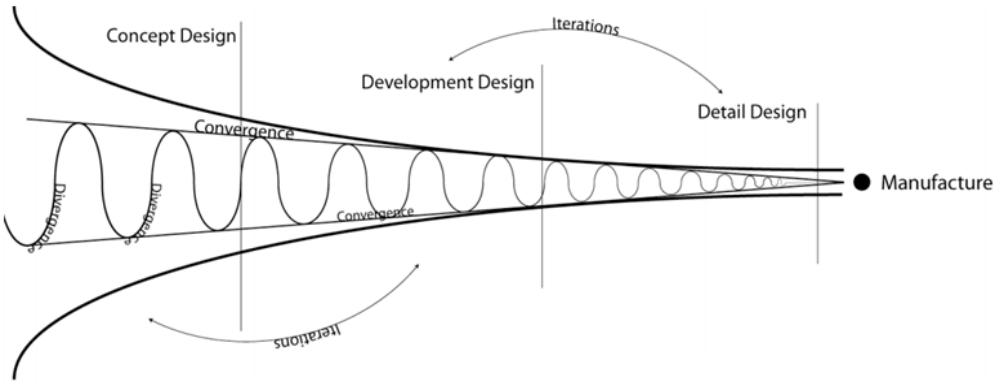

Figure1: Generic model of design process

A Generic Design Process (GDP) model is proposed in this study. In general, it presents the 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, and implementation, 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.

The selected 9 sketch taxonomies are analyzed according to their applied stages in the design process (Table 2). It should be noted that only the taxonomy classifying sketches with regards to their applied design phased 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) develop their taxonomy based on the complexity of the sketch. The following sections will look at how each taxonomy could achieve its aim by analysing its functions along the design process.

Table2. Analysis of sketch taxonomy according to their applied phase in the design process

Sketch taxonomy	Early design stage		Middle design stage		Late design stage	
	Define the task	Conceptual design	Development design	Embodiment design	Detail design	PRST & IMPL
/1989Tovey		√		√		√
Fraser & Henmi/ 1994			√	√		√
Ferguson/1994; Lugt/ 2005		√	√			√
Goel /1995		√	√			
Olofsson & Sjölén/ 2005	√	√		√		√
Pipes /2007		√		√		√
Yang/ 2009		√	√			√
E. Pei /2009	√	√	√	√	√	√
Lawson/ 2012			√			√

5.1. Early to middle design stage

Most of the listed taxonomies can be applied in the early and middle design stages and most of them pay more attention to concept design and development design. The reason for this is that these two stages are naturally connected with each other and they together make up the design ideation process. Design ideation is considered as an essential part of the design process (Jonson, 2005) and is often synonymous with drawing (Orthel & 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 sketch 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 (1994) suggested 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 sketch named 'visionary drawings' and the 'fabulous sketch' which are believed associated with idea development process. Ferguson (1994) associated the thinking sketch and talking sketch with the early-to-middle design stage. A 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 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 design sketch, namely "lateral transformation" and "vertical transformation". Lateral transformation refers to the movement from one idea to a slightly different idea. The 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 start to generate ideas. Pipes (2007) and Yang (2009) broadly grouped these two types sketch respectively as thematic sketch and Non-dimensioned sketch. The difference is Pipes (2007) emphasises the aesthetic qualities of the sketch, while Yang (2009) focuses heavily on the role of sketch as a representation of design thinking.

5.2. Late Design Stage

Design sketches produced at the late design stage mainly serves three purposes, i.e. improving the design details, selling design ideas and guiding manufacturing. Among all of 9 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 him, 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 drawing' to precisely present the design idea. This type of sketch is also known as 'presentation drawings' (Fraser & Henmi, 1994; Lawson, 2012), 'persuasive sketch' (Olofsson & Sjölén, 2005), 'package-constrained sketch' (Pipes, 2007) and 'persuasive sketch' (Pei, 2009). Ferguson defined a type of sketch named 'prescriptive sketch', which is used by engineers to provide instructions to drafter at the last stage. This type of sketch is also known as 'handover sketch' (Pei, 2009) and 'instruction drawings' (Lawson, 2012).

5.3. Outside the Design Process

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 which can involve the group of the non-working sketch. As their names suggest, non-working sketch refers to the group of sketches which 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) sub-divided 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".

5.4. Improving the 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 (Pugh, 1991; Goel, 1995; Liu, Bligh et al. 2003; Cross, 2006; Yang and Macomber, 2011) revealed that sketching in the design process supports design creativity, e.g. facilitating 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 which can be used for searching of numerous sketches and their sequence may well provide further data and a good starting point for researchers to observe that particular phenomenon. Also, as indicated by Lugt (2005), a single type of sketch defined by a taxonomy may serve multiple purposes, but we will not be regarded as satisfying certain criteria if that is not its main purpose. Through reviewing the literature, criteria for improving the understanding of design sketch have been proposed as follows:

1. Whether the taxonomy helps to describe the sketching process?

– Sketching is an essential part of the natural design process. Sketch taxonomy should help design researchers to set up the starting point and theoretical framework so that to achieve a general understanding of the sketching and design process.

2. Whether the taxonomy helps to reveal the functions of 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.

3. Whether the taxonomy helps to reveal the function and complexity of drawing elements?

– This line of research mainly focuses on the sketch outcomes, drawing elements and attributes. Sketch taxonomy developed from this perspective may give design researchers the insights on those aspects and their relationship with design.

4. Whether the taxonomy takes the whole design process into consideration?

– The taxonomy should take a holistic overview of the whole design process with regard to 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.

5. Whether the taxonomy involves non-working sketch 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 take non-working sketch into consideration while developing a new taxonomy.

6. 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 a more detailed and in-depth understanding of the supporting value of design sketch.

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Table 3. Sketch Taxonomies are Analyzed According to whether They Fulfil the Criteria.

Sketch taxonomy	1	2	3	4	5	6
Tovey /1989	√	√	√			√
Pugh /1991	√	√				
Fraser & Henmi/ 1994		√	√			
Ferguson/1994;Lugt/ 2005		√			√	
Goel /1995	√	√				
Olofsson & Sjölén/ 2005	√	√				
Pipes /2007			√			√
Yang/ 2009			√			√
E. Pei /2009	√	√		√	√	√
Lawson/ 2012		√	√		√	

The taxonomies have been screened based on the above criteria and the results are shown in Table 3. It is clear that few of the taxonomies can cover various types of sketches both in and outside the design process. Also, few of them demonstrate hierarchy for design sketches. This may cause confusion when studying a certain type of sketch with multiple functions.

6. Conclusions

Sketch taxonomy is both an early step and a crucial research tool for researchers to explore the roles of the sketch in design. This paper reviewed the existing sketch taxonomies from three major design fields, namely architectural design, engineering design and industrial design. The current status of studies features a lack of integration and completeness. Reviewed bodies of literature are

somewhat scattered and disconnected from each other. For example, personal sketch and collaborative sketch seem to be far apart.

The thorough analysis of the literature on sketch taxonomy confirms that existing sketch taxonomies are inadequate methods when used to facilitate analysis of the roles of design sketch. They tend to group sketches in a way which is fairly broad and fail to analyse sketch in detail or subdivide the category. That means a certain category of sketch needs to serve multiple design purposes, which may become an obstacle for design researchers to achieve a more in-depth understanding of the design sketch. It is also noteworthy that nearly all of the taxonomies have struggled to describe the use of different types of sketches through the entire design process, which has highlighted the need for a comprehensive taxonomy to address this point. Related to this, the non-working sketch also should be integrated into the taxonomy. This further integration is critical, not only to identify the functions of the non-working sketch but also to give us a complete picture of the field.

Future work also requires discussion with design researchers about the practical use of these taxonomies as well as testing of the proposed criteria in the real research context to better understand how sketch taxonomies can best be implemented. It would be beneficial to collect design researchers' real needs for improving the sketch taxonomies through case studies. Due to the complicated nature of the design sketch, how design researchers classify and identify the type of a sketch when they analyze the research materials might provide fruitful opportunities for research.

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