THE ROLES OF SKETCHING IN DESIGN: MAPPING THE TENSION BETWEEN FUNCTIONS IN DESIGN SKETCHES

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ABSTRACT

This paper examines how the role of sketching in design process has been disseminated previously through a review of prior perspectives into the field. We identify that the studies of design sketching has been dominated by two perspectives: studies into what is known as 'visual thinking' (Goldschmidt 1991, Schön & Wiggins 1992, Tversky et al. 1999), which examines the designers reflective conversation with the sketch, and a second perspective on sketching as way of 'visual communication' with others in the design process (Lugt 2005, Schütze 2003, Buxton 2010). We raise the question of whether it is reasonable to combine the two different roles of sketching to form a more intertwined relationship - seeing the two as sides of the same coin. Based on the terminology of Olofsson & Sjöflen (2005) four functions are identified as being representative for the different roles sketching can take in the design process: investigative, explorative, communicative, and persuasive. We appropriate these categories into a tension field, reflecting how the role of the same sketch may change over the course of time in the design project, based upon the type of knowledge required to gain from the sketch at a given time.

INTRODUCTION

Externalised representations fulfil various functions throughout the design process. They can facilitate a thorough analysis, help generate and evaluate ideas for solutions, and function as a distributed cognition between peers (Hutchins 1995, Römer & Saschse 2000). In fact, external expressions are somewhat near omnipresent throughout the design process. From early free-hand sketches on paper to CAD-renderings on a computer monitor (Cross 2000). Löwgren & Stolterman (2004) emphasises the designer's externalisations, as multiple ways of articulating 'the knowledge construct' that is the primary outcome of the thoughtful design process. This frames design as being not primarily concerned with the making of artifacts, but the construction of new knowledge, which may become the basis of further development. This externalised design thinking is carried out by various forms of representation, not necessarily in the form of writing or spoken words, but more often in forms that can be appropriated and assessed more directly.

Sketching is one such way of working with external expressions in the design process. Sketching turns internal thoughts into external expressions, which makes comprehension and inference easier and less abstract than symbolic representations such as written language (Tversky 1999). The term 'sketch' generally has the meaning of a rough or unfinished drawing, and the activity to sketch is to give a brief account or general outline of something (Goldschmidt 2003, Goel 1995). The English word originates from the Italian schizzo, in turn based on the classic Greek term skhedios signifying 'done extempore - spoken or done without preparation' (Dictionary.com). Goel leans on this etymology in his emphasis on the ambiguity of sketches as their essential quality. Tversky adds that the advantage of sketching lies in their public nature - they are out there in the wild and aids the designer by supporting the limited human memory capacity and mental processing for a detailed

problem analysis in a reflective conversation with the design situation (Schön 1983). A designer sees then moves and sees again. By working in a given medium the designer sees what is 'there' in the representation of an idea, sketch in relation to it, and sees what has been represented, thereby informing further design moves.

WHAT IS THE ROLE OF SKETCHING IN THE DESIGN PROCESS?

Though the process of sketching has been recognised as the archetypical activity in nearly all disciplines that identify themselves with design (Jones 1970, Krippendorf 2005, Schön & Wiggins 1992), there is still a debate between various research perspectives examining the role of sketching in design. One issue is whether the value of sketching is primarily in terms of its internal or external qualities - in other words who gains value from sketching? One perspective positions sketching as the ability to mediate the sensemaking process between the designer and the design problem that is occurring mostly in the early phases of design. From this perspective sketching is thought of as primarily a tool for 'visual thinking' (Goldschmidt 1994, Goel 1995, Arnheim 1969). The studies into the benefits of how visual thinking enables the designer to 'have a conversation with the drawing' are quite extensive (Suwa & Tversky 1997, Goldschmidt 1998, Bilda & Demirkan 2003), and have gained broad recognition as the primary function of sketching.

The second perspective in sketching studies puts the emphasis on the communicative and inclusive nature of using visual expressions in the design process (Lugt 2005, Schütze et al. 2003, Buxton 2010, Stacy & MacFadzean 1999). Since the design process is strongly influenced by feedback and dialogue, the expressive function of sketching is not only essential to the reflection-in-action by the designer, but is also of great importance by allowing for a broader community of stakeholders to observe, comment on, and revise the ideas in new enactments upon the represented (Frankenberger & Badke-Schaub 1998, Löwgren & Stolterman 2004. This domain of sketching as 'visual communication' has been subjected to fewer studies, but is more commonly ruled out as 'not being sketching' on the argument that it is the process of how the sketches partake in the designer's active reflection, which is of primary relevance (Goldschmidt 1998, Fällman 2003). In other words, the dominant position within sketching studies seems to be a processual focus on 'to sketch' and less focus on the outcome of this process 'the sketch'.

The relationship between the two perspectives leads to the broader question of when is something sketching? In most studies the focus has mainly been on the free-hand sketch, which has been broadly considered the synonym for the term 'sketch' (Goel 1995, Garner 1992, Suwa & Tversky 1997, Cross 1997, Purcell 1998, Tversky 1999, Bilda & Demirkan 2003). Vistisen (2014) made categorisation in which sketching was divided into four expressive dimensions - ranging from 1D (words like met-

aphors a sketching vehicles), 2D (like traditional sketches), 3D (like mock-ups and physical models) and 4D (like video and animation-based sketches). Vistisen's mapping links to contributions from from Buxton (1996), Löwgren (2004), and Arvola and Artman (2007) who among others have opened the discussion for other sketching modalities, such as video, physical materials, and animations, and made valid points for their validity as being claimed as 'sketces'. However, there is still some unclarity for when something is considered sketching, and when it is some other form of external expression, such as a prototype.

This paper reviews the two dominant perspectives on the role of sketching in the design process, and proposes a tension field of the roles of sketching, which illustrate the different functions sketching can serve over the course of time in the design process. We reviewed a selection of the studies into aspects of sketching in design processes, from the mid 1960's until the beginning of the 2010's with regard to the questions: 1) Is sketching to be defined as being primarily concerned with the reflection in the sketching process or the communicative potential of the sketching output? who gains value from sketching? and 2) Does the role of design sketching change throughout time in design process?

We explore the first question in regard to Schön's notion of the design process as a mix between problem setting and problem solving (Schön 1983) and the importance of viewing these as intertwined activities, unfolded by the reflective conversation with the design situation as well-balanced whole. By placing sketching as the archetypical process of working out this coherence we propose that we must both consider how sketching helps generate and form ideas by representing them via a given technique and medium, and how this representation puts the idea into a community of stakeholders to be tested through interpretation. This lead to our discussion of the second question were we discuss how this intertwined role of sketching is often present in how sketching facilitate different functions throughout the design process over time.

DIFFERENT PERSPECTIVES ON SKETCHING

Due to the near-omnipresence of sketching in the design process a multitude of different research interests have emerged, highlighting different key problem areas to be examined an discussed in order to better understand and reflect upon the role(s) of sketching. Common to most studies conducted from the late 1960's until today is an understanding of the design process as a process of tackling ill-defined wicked problems in practice (Rittel & Webber 1973, Buchanan 1996), and making sense out of sets of often ambiguous and incomplete data (Kolko 2010, Krippendorf 2005). Because of the wicked nature of design problems, there is no definite end to the problem solving activity in design, and the designer therefore needs to iterate upon the definition of the problem, the process, and the potential concepts for solutions in order to progress to a feasible solution. Through the

concept of information processing (Simon 1973, Newell & Simon 1972, Hayes 1978), the manipulation of the design problem can be referred to as the exploration of knowledge states in the problem domain and the procedure of decision-making.

Furthermore, the information processing via externalisation constructs the base from which ideas can be evaluated and presented as the representation of new knowledge. Such external representations can be regarded as the concrete performance of designers in the design process. This function of sketching, identified by Fish & Scrivener (1990), is that sketching facilitates the transition from general descriptive knowledge into specific depiction. According to Fish & Scrivener the primary reason for designers to sketch is: "...the need to foresee the results of the synthesis or manipulation of objects without actually executing such operations", which places sketching as a way of externalising knowledge from the design process as a central part of the reflective activity of design (Schön & Wiggins 1992, Goldschmidt 1991). This echoes the emphasis of sketching's visuospatial abilities to add information to reality, and even distort the existing information to generate ideas (Tversky 1999). While we may insert sketching as the principal activity for creating external representations in the design process, its value is regarded differently depending on whether sketching is viewed as primarily concerned with visual thinking or visual communication.

1ST PERSPECTIVE: SKETCHING IS ABOUT VISUAL THINKING

The dominant perspective on sketching studies has been to think of sketching as way of applying visual thinking, which enables the designer to re-interpret the representation from sketching into new knowledge. Various researchers propose models of re-interpretation, each with a slightly different connotation, ranging from a dialectic type of argumentation between modes of seeing (Goldschmidt 1994), moves (Schön & Wiggins 1992), lateral transformation (Goel 1995), and focus shifts (Suwa & Purcell 1998). Though the methods of inquiry and interpretations of concepts differ, all four have suggested that designers are able to see more information in sketches than was invested in their making, labeling it as the cognitive process of 're-interpretation' (Fish & Scrivener 1990, Suwa & Tversky 1997, Purcell & Gero 1998). Re-interpretation refers to the ability to transform, develop and generate new images in the mind while sketching. There is considerable experimental evidence (Goldscmhidt 1991, Suwa & Tversky 1997, Lawson 1980, Menezes & Lawson 2006) that suggest that the generation of ideas in design depends heavily on this interaction between the designer and the external representation.

Goldschmidt's seminal work on the dialectic between designer and sketch comes from an investigation into what she labels 'visual thinking' (Goldschmidt 1994). Visual thinking is separated into three behaviours; see-ing, imaging and drawing. Sketching is hence a matter of "…externalising ideas and interpreting external representations as ideas" a process Goldschmidt sees as a dialectic between different modes of 'seeing', between seeing-as and seeing-that. The sketch becomes the middle ground between the designer's idea and how it is realised into a coherent whole - an external representation. The sketch is a reflection of the guiding idea, but with which it is not and cannot be identical to. This interactive imagery form the basis for the material 'talk back' to the designer, which informs the next 'move' in the sketching process - thus echoing the reflective practice of sketching highlighted by Schön & Wiggins (1992). Sketching in this perspective grows to be both the way designers 'work' and 'think'.

One of the most detailed studies of how sketching enables visual thinking was conducted by Goel (1995). He identifies two types of operation occurring between successive sketches in the problem-solving phases; lateral transformations and vertical transformations. In a vertical transformation, movement is from one idea to a more detailed and exacting version of the same idea. In a lateral transformation, movement occurs from one idea to a slightly different idea. Suwa and Tversky (1997) suggest that designers are able to understand different aspects of a design idea, whether it is branches of or iterations of the idea, only through sketching them, and thus being able to shift focus onto different parts of design problem. In his categorisation of active ingredients in idea generation techniques, Smith (1998) presents the use of making graphic representations of the ideas as a 'display stimulation tactic'. He mentions that: "Presumably, when visually depicted, ideas are more able to inspire new ones" (ibid: 125). Sketching enables the designer to ''experiment with reality'', to learn from the experiment and to iterate the solution space in a sequence of seeing-moving-seeing (Schön & Wiggins 1992) in which the re-interpretation aids to extract new information from the expressed sketch. Oxman (1995) makes the important addition to this view of re-interpretation in sketching, that where graphic media such as traditional pen and paper sketches are the medium whereby the design is evolved, the design moves are 'the series of actions' by the designer which result in transformations of a representation. Oxman's notion separates the epistemology of sketching from the mediums of sketching, and opens for a larger scope of sketching mediums ranging from 1-dimensional words to 4-dimensional video sketches. Thus, no single medium can be defined as 'the sketching medium', but rather a range of mediums can facilitate the generation of new interpretations of the problem setting and problem solving.

This transformation makes the circle complete in terms of Löwgren & Stolterman's notion of the importance of viewing design as not being oriented around artifacts, but around knowledge construction, which is generated through applying sketching as a process of visual thinking.

All of these studies have provided considerable value to the understanding of sketching in the design process. Through a multitude of studies and experiments many of the same conclusions have been reached, regarding how the dialectic process of visual thinking aids the designer's reflection in action. While the studies into visual thinking through sketching also mentions external representations used for visual communication, these are often disregarded as not being sketching, but belonging to other rendering styles or fidelities of design representations (Goldschmidt 1994, Fällman 2003). In the next section we shall examine the arguments for viewing this type of representations as equally valid parts of the sketching process.

2ND PERSPECTIVE: SKETCHING IS VISUAL COMMU-
NICATION
Sketches used for communication differ from sketches used to aid visual thinking in two major areas: the viewer does not entirely know the designers intentions, and does not know the context for the situation that sparked the creation of the sketch (Schön & Wiggins 1992, Scrivener & Clark 1994. However, this ambiguity is what Goel (1995) talks about as the central strength of sketches, which enables the lateral transformation between branches of ideas. Buxton includes ambiguity as a central criterion for what makes an external representation of design ideas a sketch and not a prototype (Buxton 2010). Ambiguity is framed as being of special importance in terms of letting the visual communication "...leave big enough holes for interpretation" (ibid:115). In Buxton and Goel's framing we still see an emphasis on the activity of sketching over the physical object of sketch itself. Nevertheless, there seems to be a difference in the way the activity of sketching is interpreted. While the field of visual thinking sees sketching in the light of Schön's dialogue with the material, Buxton also sees the sketching process as a broader conversation that facilitates others than the designer in obtaining a visceral as well as intellectual understanding of a concept. As a form of communication, Buxton places sketches as shared points of reference against which we can compare other ideas or re-interpretations of the existing. Perspectives from Hutchins (1995) supports this notion by viewing sketches as artifacts which may act as a form of distributed cognition - putting the design ideas 'out there' for debate, critique, and most importantly new interpretations.

Thus, seeing sketching as visual thinking and visual communication seems to be two sides of the same function of sketching - it aids the construction of knowledge in the design process by generating new and more sophisticated information than was put into the sketch in the first place. Whether this knowledge is gained from the dialectic between the designer and the sketch, or by the inter-subjective re-interpretation upon a shared point of reference seem to produce the same value of sketching as an aid to knowledge construction, while not being the desired knowledge output by itself.

As we begin to see, the important discussion might not be as much about whom the value of sketching is for, but more a discussion of when an external expression is used as a sketch and for what purpose? When sketching is considered as visual thinking, we see a often implicit understanding of sketching as being free-hand sketches, as opposed to different types of prototypes and higher fidelity renderings like CAD drawings. When considered from the external perspective the definitions loosen up a bit to encompass a set of other criteria, where speed, ambiguity and the non-committing nature seem to be the most important (Goel 1995, Buxton 2010, Lugt 2005).

When considering tools, materials and techniques other than free-hand sketching Buxton makes the note that "how a technique is used is the ultimate determinant of whether one is sketching." (Buxton 2010: 249). Buxton makes this distinction in contrast to prototypes, but does only vaguely specifies a set of characteristics of the distinction, but no clear semantic divide. In the light of the review of the two sketching positions above we might elaborate on this by further differentiating the difference between when something is a sketch, and when something is a prototype. Following Löwgren & Stolterman's notion of 'knowledge generation' as the driver for the design process we argue that wether something is sketching or prototyping differs in the type of knowledge we seek from the process. When the designer uses sketching it can be seen as the explorative generation of new information. This process adds knowledge through filling out gaps of information about what possible ideas might be feasible, and thus reduces the uncertainty of the design situation. On the other hand, the generated information through sketching also increases the complexity of the design situation, because new information has been added, and the designer has to choose between a series of alternatives as the best fit. Hence prototyping is the process where we reduce complexity by putting the most promising bits information to the test.

Our distinction is akin to Nolte's (2001) suggestion that the important part of design sketching is not the 'sketch' itself. Instead the representation of ideas is the surface structure whereas the meaning of ideas is embedded in a sensemaking activity that is not tied to any particular conceptual tool, but to different ways of articulating and processing information. Sketching, as the process of generating new information to reduce uncertainty, may now be discussed in relation to how the sensemaking activity changes throughout the timeframe of the design process.

A THIRD PERSPECTIVE: A TENSION BE-
TWEEN FUNCTIONS OVER TIME
Nolte's notion of the role of sensemaking in the sketching process suggest and overlap between the reflective practice of visual thinking, and the visual communication of articulating information for others to process. A third perspective on the role of sketching might then be

worth considering in terms of not what sketching is, but how sketching supports different activities.

Ferguson (1992) identifies three kinds of sketches, which may be useful for identifying the role of sketches: the thinking sketch, the talking sketch, and the prescriptive sketch. The thinking sketch refers to the perspective of visual thinking, where the sketch is used to "…focus and guide thinking". Talking sketches on the other hand refer to the shared points of reference from the perspective of visual communication, which supports dialogue and peer-feedback. The prescriptive sketch is stated as a more formal rendering of the talking sketch, with which the designer can communicate effectively with stakeholders outside the design process. Ferguson's categorisation is a very concrete way to elaborate upon different types of sketches, and encompasses both the visual thinking and communicative parts. However, the types do not relate much to each other in Ferguson's perspective, but states distinctive types of sketches for distinctive activities in the process of design. Instead, we might examine these sketching genres as functions which the sketch can have a different times. To examine this, it may be beneficial to develop a categorisation that addresses the different kinds of interactions the designer and other stakeholders may have with or through sketching.

Inspired by the same combination of visual thinking and visual communication as Ferguson, Olofsson & Sjöflen (2005) uses a set of four genres as headlines for their work on design sketches: investigation, exploration, explanation and persuasion. The investigative function of sketching is tightly connected to the early phase of the design process. The designer is examining the problem space, thus making this activity belong to the visual thinking perspective of sketching. Explorative sketching is used when proposals of design solutions are expressed in order to be evaluated, and seldom make much sense for others than the people directly involved in the design process. This function belongs somewhere in-between the two perspectives of visual thinking and visual communication. The Explanatory function on the other hand is about communicating a clear message to others than the designer and the team, in contrast to the explorative sketches - in others words relating primarily to the visual communications perspective. These sketches describe and illustrate proposed concepts in a neutral and straightforward manner, to get feedback from users, clients and external experts. The Persuasive function uses sketches in a more rhetorical matter, showing less ambiguity, and more details than the other types. The main purpose with these drawings is to 'sell' the proposed design concept to influential stakeholders, which is why we might criticise the persuasive function for being in conflict with many of discussed characteristics of sketching as a reflective process of ideation, not marketing. The risk of using a sketch in this regard is stated by Houde & Hill's (1997) discussion about the tendency to focus on attributes of the representation itself (i.e. the sketch), and in doing so, the vital dialogue

becomes concealed under the sketch itself. But, if the persuasive function is interpreted in line with Do's (1996) notion of the requirement of different visual representations for different stages of design, we may see it as a way of using the sketch to propose a clearly stated argument of the relationship between problem setting and a solution to the problem. By doing so, it seems reasonable to agree with Olofsson and Sjöflen in their addition of this function as possible role of a design sketch since it invites to a conversation about the represented, but one in which clues of the designers intentions are clearly conveyed and expressed.

A FRAMEWORK FOR EVALUATING THE FUNCTIONS OF SKETCHES IN DESIGN PROCESSES

In Olofsson & Sjöflen four functions we identify a possibility to map the two research perspectives on design sketching: visual thinking as primarily related to investigative and explorative functions, and visual communication as primarily related to explanatory and persuasive functions of sketches. The four genres were originally not intended to this type of scrutiny but were meant as way to index the chapters of the author's book publication. However, we propose that the four genres could be further suspended into a tension field, which would enable us to better illustrate how different sketching activities and techniques are used to support different aspects of the knowledge generation in the design process. The first 'sketch' of this tension field would look something like the following:
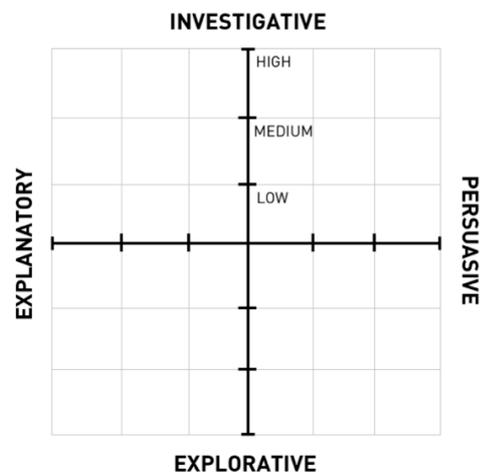

Figure 1: The four functions are framed as being suspended in a tension field, and uses the values of 'low', 'medium' and 'high' to depict in which degree a given function is present.

Evident in the model is the arbitrary notation of using 'low-high' as the label for how mapping different sketching activities would be done, which in turn makes the evaluation seemingly qualitative and subjective. However if this qualitative mapping is done to evaluate the role of sketching through the same design process, the notations will at least be based on the same ground, and become more comparable. Consider the example

below, where the digital sketching of a new social web site as case (right side):

Figure 2: The digital representation made in the digital sketching software 'Balsamiq' (www.balsamiq.com)

When sketching the first concept for the web site, the designer engaged in a reflective conversation with the sketch and the design tool, making investigations into the problem setting based upon the re-interpretation of the sketching output, while also continuously getting feedback by involving other design peers in the exploration of possible solutions within the problem space. This activity can be mapped in the framework as being mostly investigative, with a supporting explorative function:
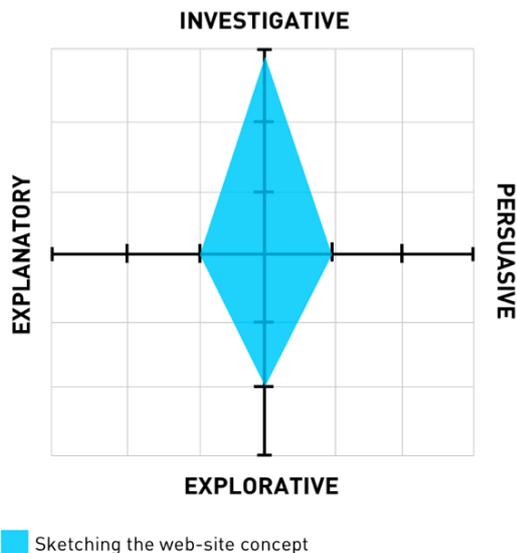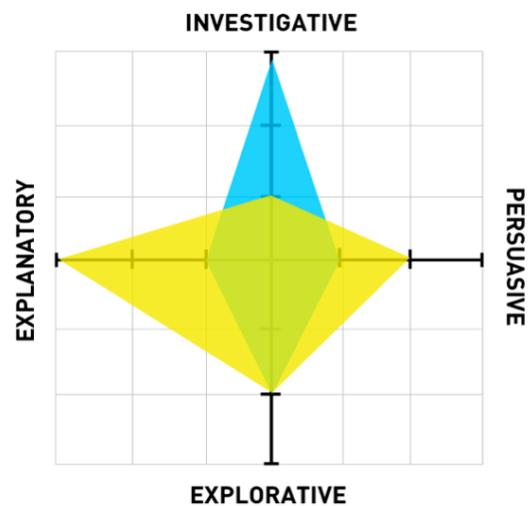

Figure 3: The visual thinking process, combined with the visual communication with the design teams, mapped into the framework.

Later when the same sketch was used to gather feedback and communicate the initial idea to the potential users of the site the sketching functions in the activity combined explanation, persuasion and further exploration:

Figure 4: The feedback activity with the users mapped into the framework

When the same visual representation was used to create a shared point of reference with the potential user of the site, the functions of the re-interpretations changed into a mix. The sketch as an explanatory vehicle, a persuasive statement of the designers intention with the idea, and finally a partially new explorative activity of getting the users to further explore what the desirable outcome of the design process ought to be.

The epistemological foundations for sketching remained present throughout both activities: working in a external medium were the designer and peers sees what is 'there' in some representation of the idea, sketches in response to it, and sees what has been represented, thereby informing further re-interpretation - adding to the knowledge generating process. What however changed during the two activities were the functions of sketching, and the relationship between the functions in play. The framework's use of Olofsson and Sjöflen's genres potentially add a more detailed view of the often intertwined tension between the perspectives of sketching as visual thinking, and as visual communication, and how this relationship changes during the course time in the design process.

FURTHER PERSPECTIVES
In this paper, we have presented a review of the two most common perspectives on the roles of sketching in design processes. From determining that the position of examining sketching as primarily valued by its ability to aid visual thinking, to the less studied position of how sketching supports communications and dialogue between the designer and other stakeholders in the design process. In extension to the two positions we raised the question of when something is sketching. We proposed to separate sketching from prototyping based on which type of knowledge the activities generate in the design

process. Having this more precise characteristic of sketching in place, we proposed that the two position of sketching epistemologies in praxis are intertwined and in a tension between different ways sketching can generate new information and help reduce uncertainty in the design process. To reflect this, four genres of sketching by Olofsson & Sjöflen were appropriated into a new tension field framework in a new framework, which maps the tension between the different functions of sketching, and how different activities correlate to these functions.

The framework is currently in a preliminary state, in which the importance is to define its relevance based upon the current state of sketching studies into the role of sketching in design. Further studies are needed based on this first step, where different sketching techniques might be evaluated in terms of their supporting role for the different functions mapped in framework. Especially sketching techniques that differ from the classic free-hand sketching, or the digital metaphor of free-hand sketching as we used in our example, would be of special interest to analyse further in order to map the relationship between different ways of articulating design knowledge with how they support the different functions in the framework, and how the tension of the sketch's knowledge generation changes over time.

The conclusion is therefore tentative in our proposition of studying sketching further in an integrated perspective of how different sketching activities and techniques support different functions of sketching in the knowledge generation of design.

REFERENCES

Arnheim, R., 1969. Visual Thinking University of California Press, Berkeley and Los Angeles

Arvola, M. & Artman, H., 2007. Enactments in Interaction Design: How Designers Make Sketches Behave. Artifact 1, 106–119

Bilda, Z and Demirkan, H., 2003. An insight on designers' sketching activities in traditional versus digital media Design Studies Vol 24 No 1

Buchanan, R, 1996. Wicked Problems in Design Thinking, in Buchanan, R., Margolin, Idea of Design, Design Issues No. 9, MIT Press

Buxton B., 2007 Sketching User Experiences: Getting the Design Right and the Right Design: Getting the Design Right and the Right Design. Morgan Kaufmann,

Cross N., 2000. Engineering design methods: Strategies for product design (3rd ed). Chichester: Wiley

Cross, N., 1999. Natural intelligence in design Design Studies Vol 20 No 1

Dictionary.com - search terme: 'sketching',

http://dictionary.reference.com/browse/sketch?s=t. accessed april 24th 2014

Do, E.Y., 1996. Right Tools at the Right Time, National Conference of the Association for Computer Aided Design in Architecture

Fallman D., 2003. Design-oriented human-computer interaction. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '03). ACM, New York, NY, USA, 225-232.

Ferguson E S, Engineering and the mind's eye MIT Press, Cambridge, MA (1992)

Fish, J and Scrivener, S, 1990. Amplifying the mind's eye: sketching and visual cognition Leonardo Vol 23 No 1

Frankenberger E, Badke-Schaub P., 1998. Integration of group, individual and external influences of the design process. In: Frankenberger E, Badke-Schaub P, Birkhofer H (eds) Designers - The key to successful product development. Springer, London, pp 149–164

Garner, S, 1992. The undervalued role of drawing in design,, in D Thistlewood (ed) Drawing research and development, Longman, London

Goel, V., 2003. Sketches of Thought. MIT Press

Goldschmidt G., 1991. The Dialectics of Sketching, Creativity Research Journal Vol. 4

Goldschmidt G., 2003. The Backtalk of Self-Generated Sketches, Design Issues, Winter 2003, Vol. 19, No. 1, MIT Press Journals

Goldschmidt, G., 1994. On visual design thinking: the vis kids of architecture. Design Studies Vol 15 No 2 158–174

Goldschmidt, G., 1998. Sketching and creative discovery Design Studies Vol 19 pp 519e546

Hayes, J.R., 1978. Cognitive Psychology: Thinking and Creating. Homewood, Illinois: Dorsey.

Houde, S. & Hill, C., 1997. What do Prototypes Prototype?. In Helander, M., Landauer, T. K., & Prabhu, P. (Eds.) Handbook of Human—Computer Interaction. 2nd Ed, Elsevier Science, Amsterdam Netherlands,

Hutchins E., 1995. Cognition in the Wild. by Edwin Hutchins, MIT Press

Jones J.C., 1970. Design Methods. Van Nostrand Reinhold, New York NY

Kolko, Jon, 2010. Abductive Thinking and Sensemaking: The Drivers of Design Synthesis. InDesign Issues: Volume 26, Number 1. MIT Press

Krippendorff K., 2005. Semantic turn: new foundations

for design. Boca Raton, Fla.; London

Lawson. B., 1980. How Designers Think. Butterworth Architecture, Oxford UK

Lugt van der R., 2005. How sketching can affect the idea generation process in design group meetings Design Studies, Vol. 26, No. 2., pp. 101-122

Löwgren J., 1996. Visualization and HCI: A brief survey, Draft, Linköping University

Löwgren, J. 2004. Animated Use Sketches as Design Representations. Interactions Vol. 11. Issue 6, ACM

Löwgren J., Stolterman E., 2004. Thoughtful Interaction Design: A Design Perspective on Information Technology. MIT Press

Menezes A., Lawson B., 2006. How designers perceive sketches, Design Studies, Volume 27, Issue 5, September 2006, Pages 571-585

Newell, A. & Simon, H.A., 1972. Human problem solving. Englewood Cliffs, NJ: Prentice mall.

Nolte, D, Mind at light speed e a new kind of intelligence The Free Press, New York, NY (2001)

Olofsson E. & Sjöflen K., 2005. Design Sketching, 3rd edition. ed. KEEOS Design Books AB

Oxman, R M 'The reflective eye: visual reasoning in design' in A KoutBmanls, H TImmer- man and I Vermeulen (eds) Vis- ual data bases in architecture Averbury, Aldershot, U.K. (1995)

Purcell T & Gero J S., 1998. Drawings and the design process Design Studies Vol. 19 No. 4

Purcell, T., 1998. Editorial. Special issue: sketching and drawing in design Design Studies Vol 19 No 4

Rittel, H. and Webber M., 1973. Dilemmas in a General Theory of Planning, Policy Sciences 4, Elsevier Scientific Publishing, Amsterdam, pp. 155 159.

Romer A, Leinert S., Sachse P., 2000. External support of problem analysis in design problem solving. Res Eng Des12:144–151

Schütze M., Sachse P., Römer A., 2003 Support value of sketching in the design process, Research in Engineering Design Volume 14, Issue 2, pp 89-97

Schön D. A. and Wiggins G., 1992. Kinds of Seeing in Designing," Creativity and Innovation Management, vol. 1, no. 2

Schön D., 1983. The reflective practitioner Temple-Smith, London

Scrivener S A R and Clark S M, 1994. Sketching in collaborative design In. MacDonald L and Vince J (Eds.) Interacting with Virtual Environments Wiley, Chichester, U.K

Simon, H. A., 1973. The structure of ill structured problems. Artificial Intelligence, 4,3-4, 181-201.

Smith G F, 1998. Idea-generation techniques: A formulary of active ingredients. Journal of Creative Behavior Vol. 32 No 2 pp 107-133

Stacey M., Eckert C., McFadzean J., 1999. Sketch Interpretation in Design CommunicationProceedings of the 12th International Conference on Engineering Design Technical University of Munich, Munich, 1999, volume 2 pp. 923-928

Suwa M, Gero JS, Purcell T, 1998. The roles of sketches in early conceptual design processes. In: Proceedings of the Twentieth Annual Meeting of the Cognitive Science Society. Erlbaum, Hillsdale

Suwa, M and Tversky, B, 1997. What do architects and students perceive in their design sketches? A protocol analysis Design Studies Vol 18 No 4 pp

Tversky, B, What does drawing reveal about thinking,, in J S Gero and B Tversky (eds), 1999 Visual and spatial reasoning in design, University of Sydney

Vistisen P. 2014. Abductive sensemaking through sketching: A categorization of the dimensions in sketching capacities in design. Akademisk kvarter / Academic Quarter. Aalborg University Press