Research on design sketch from different disciplines: overview and directions

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Abstract

The sketch plays an essential role in different disciplines and industries, not only to visualize the ideas of designers and professionals but also to promote innovation and increase opportunities for reflection. The sketch is also a widely researched approach or tool that stimulates the generation of design thinking using representation, which is different from rational thinking and can facilitate effective communication between different disciplines. However, with the fragmentation of the traditional design disciplines, the boundaries of the traditional design disciplines have gradually become blurred.

In this context, the gaps and conflicts that have always existed in the design disciplines have been exacerbated, such as the huge gap between the traditional educational model with clear disciplinary boundaries in the design disciplines and the rapidly evolving design market, and the increasing conflict between the designers trained in this traditional educational model and the design talent required by the current market. And these conflicts characterize the current state of development of design disciplines, including conflicts between disciplines, within disciplines, and between design tools. Therefore, to improve the situation where these gaps and conflicts are intensifying, this study takes the sketch, a design representation method used in almost all design disciplines, as the object of study.

This study conducts a literature review of taxonomies of sketch in traditional design disciplines and design tools associated with sketch in contemporary design disciplines. Traditional and contemporary design are then categorized according to several empirical classification criteria proposed in this study, followed by a qualitative analysis around the use of sketch in different design disciplines in terms of stage, form, complexity of processing, fidelity, and other parameters. Consequently, differences in the habits, variations, and role of sketch in the context of traditional and contemporary design disciplines were identified.

The study provides recommendations for future models of design education and specific questions about the skills required by future designers, suggesting ways to mitigate and improve existing conflicts between design disciplines and suggesting possible new directions for future research to connect the different design disciplines.

Author keywords

Design sketch, multidisciplinary, traditional design, contemporary design, literature review.

Introduction

In a context where the boundaries of what was once recognized as discrete design disciplines, such as architecture, product, graphics, and fashion design, have been and continue to dissolve (Rodgers, 2008), education and practice in the design disciplines have been experimenting with [the cultivation of knowledge and collaboration across disciplines] (Irizarry, et al., 2016; Elżbieta, 2016), and the split between different disciplines in the field of design has led to a shift in creative practice from being 'discipline based' to 'issue or project based' (Heppell, 2006). We propose that this shift is related to the shift between traditional and contemporary design disciplines in terms of designers, design objects, constantly developing design environments, etc.

We present that traditional academic research-oriented education programs can no longer meet the need for interdisciplinary practical talents in contemporary design disciplines. As educators are asked to be more innovative in today's commercial environment, it becomes critical to weigh in on design thinking (Dym, et al., 2005; Mabogunje et al., 2020), design doing (Sanders and Stappers, 2013), and trans-disciplinary domains (Leavy,2016; Fawcett, 2013). With social development and economic growth, the world continues to promote innovative design, and interdisciplinary disciplines are becoming popular (Norman, 2004).

In the above context, we argue that the field of design research and its investigation methods continue to change and extend beyond the boundaries of the traditional design discipline while also noting the uneven development of the various parts within the design discipline. Therefore, this study argues that several important gaps and conflicts currently characterize the current state of development of the design discipline: (1) conflicts between disciplines (macro level: ambiguous disciplinary boundaries); (2) conflicts within disciplines (meso level: education and business environment); and (3) conflicts between specific tools (micro level: changes in the skills required for design). Therefore, to clarify the above-mentioned gaps and conflicts, this study confines itself to the micro-level of (3), i.e., the gap between the professional skills required by traditional design tools and contemporary design tools as boundary objects. By conducting a multifaceted comparative analysis of sketch-related tools in several typical design disciplines, we expect to contribute to identifying (1) and (2) from the side. Design sketch was chosen for this study because it plays an important role as a method specific to the design discipline, not only in design education and design practice

but also permeates almost all design disciplines. As current research on sketch in the design disciplines is discrete, and contributions are always from different disciplines, research contributions on sketch are mostly scattered in cognition (Tovey, 1989; Schön and Wiggins, 1992), creativity (Hua, 2019; Goldschmidt and Smolkov, 2006), reflective activity (Schön and Wiggins, 1992; Bilda and Demirkan, 2003; Wu, et al., 2012), visual thinking and visual communication (Goldschmidt,1991; Goldschmidt, 1994; Vistisen,2015), human-computer interaction (Buxton, 2007), and digital technology.

For understanding and analysis, we propose to divide the design disciplines into two categories - traditional and contemporary - according to certain criteria, and to analyze the role and use of the sketch in the different design disciplines and design tools from this new perspective. Through this new perspective, the role and use of sketch in the different categories of design disciplines and design tools are analyzed. The review and analysis suggest more specific conflicts and gaps in the design disciplines and a series of issues that need further research. Finally, it is expected that the results of this study will contribute, directly or indirectly, to the resolution of the wider conflicts of (1) and (2).

This paper is structured as follows.

Firstly, the history of the design disciplines is briefly reviewed, and the disciplines are broadly divided into two categories based on the empirical classification criteria provided in this study, and their relationships and trends are discussed.

Secondly, an overview of the taxonomy and related tools for sketch in traditional and contemporary design disciplines based on the same set of parametric criteria is discussed.

Finally, through a qualitative analysis of the use and trends of the sketch in the context of the same set of parameters in both traditional and modern design disciplines, some results are derived and summarized in terms of the respective developmental strengths of the two classifications, as well as attributes and experiences worthy of mutual reference between them.

The transition between Design principles

The disciplines of design and design research are rapidly transforming. The definition of design disciplines with a history is constantly changing and expanding in the scope of application. For example, industrial design has traditionally been seen as an applied art and science that seeks to improve a product's aesthetics, ergonomics, functionality, and usability (Noblet, 1993). Moody and Stanley defined industrial design in 1984: 'Industrial design seeks to relate hardware to the dimensions, instinctive responses and emotional needs of the user, where these are relevant requirements' (cited in Design Council of India, 2016). However, this definition seems to limit the potential impact and influence of the creative skills and methods taught to designers.

A moderately expanded version comes from the Industrial Design Society of America (IDSA, 2013), which currently defines industrial design as 'the professional service of creating products and systems that optimize function, value, and appearance for the mutual benefit of users and manufacturers'. This definition encompasses an increasing inclusion of industrial design and shows the expanding boundaries of the traditional design disciplines and the growing importance of multi-scientific and interdisciplinary design. The work of design firms and designers such as Ronan and Erwan Bouroullec (2003) Marti Guixe (2002) and IDEO (2005) now routinely transcends historical disciplinary frameworks such as interior design, fine art, product design and graphic design. In particular, the boundaries between product and service design (SD) are becoming increasingly blurred. Furthermore, because of the increasing relationship between IT engineering and design disciplines, there is a certain overlap and mutual inclusion between the education and practice of Interaction Design (IxD), UX Design (UXD), and SD.

In summary, it can be observed that the relationships and boundaries between the design disciplines of different eras are still blurred. Therefore, this study argues that before summarizing and analyzing sketch-related methods in different design disciplines, it is necessary to make a general categorization of the changing design disciplines. We refer to those disciplines that have clear boundaries between them as 'traditional design disciplines' and those that are inherently intersectional and inclusive as "contemporary design disciplines". A classification principle with several parameters is given for this (Table 1).

Table 1. Classification principle between traditional and contemporary disciplines.

Aspect	Traditional	Contemporary
Historical	Relatively long history	Relatively short history
Educational	The theory is quite well established a full range of courses at the univer-sity	Theoretical research is evolving Gradual integration into curricu-lum
Practical	Examples of practice are abundant	Fewer actual cases but increasing
Boundary	Once clear boundaries between disciplines are beginning to blur	The discipline itself was created with a multidisciplinary background

As the problems that design can address become increasingly complex (Latour, 2008), design research shifts towards a user-centered approach to problem-solving. The emergence of integrated design based on a wide range of disciplines has prompted discussion and exploration among participants. Collaboration and communication between various fields and professions have become more frequent and complex.

In addition, interdisciplinary collaboration has been emphasized in traditional design disciplines. For example, Pierre (2003) argues that integrating interdisciplinarity into the industrial design process can solve the problem of establishing sustainable design and consumerism. And according to Doerry, et al. (2001), in the 21st century, modern engineering design is approached as an interdisciplinary endeavor, which requires each engineer to work as part of a team that includes a range of specialists. We consider that the contemporary design discipline's ongoing value on multidisciplinary, interdisciplinary, and even trans-disciplinary collaboration is a major reason for this trend. There are also overlapping fields between their disciplines, such as theory and design process, as is recognized by the overlap between fields such as UX and service design (Forlizzi, 2010). Furthermore, excellence in experience creation and customer value in contemporary design projects requires 'design team members' to bring in expertise from their disciplines, such as service management, UX design, SD, and technology, among others (Khambete, 2011). Don Norman (2016) is critical of traditional design courses when discussing design education because they focus on craft skills rather than requiring a broader systems view, i.e., involving social or scientific competencies.

Parameter	Definition	Detailed Explanation For Criteria				
Dimension	The dimensions used in sketch, which are classified according to Gillian Smith	1D	2D	3D	4D	
		thoughts, words	paper sketches, images, journey maps, scenarios	modeling, rapid prototypes, mock-ups, object theater	enactments, video, animation	
Complexity	The complexity of handling sketch in the design process	Level 1	Level 2	Level 3	Level 4	Level 5
		just collect	just select and print/ create	devise for ease of understanding	categorize and prioritize what you create	identify relationships between selected outputs
Fidelity	This parameter only considers the extent to which the sketch reflects the design of the final product, not the proximity to the final design	Design	Low	Middle	High	
		Traditional	ideal to quickly solidify ideas, to estimate effort on concepts and to test navigation	ideal to show a high functional version of the concept, while still quick to design and cheap to discard	ideal to get feedback on visuals, estimate effort on interactions (e.g., animations) and to help as guide for implementation	
		Contemporary	simple in form and function but can be represented to some tent by imagination	simple in form, but reasonably represents the form and structure of the final deliverable	except for function, the form or structure may be fairly close to the final deliverable	

Figure 1. Certain criterias for dimension, complexity, and fidelity of sketch proposed by this study.

The direction of contemporary design education and research has shifted from artifact-based design and production to integrating different knowledge and disciplines at each stage. Thus, both traditional and contemporary design disciplines, from the focus on the cultivation of multidisciplinary and interdisciplinary models in design education and the increase in inter- and trans-disciplinary design projects in design practice, show a consistent trend towards the dissolution of boundaries between design disciplines.

Sketch as a universal method in design disciplines

Sketch, one of the most important conceptual design tools, is the most widely used in design practice and is the design representation most often associated with designer activity (Bar- Eli, 2013; Goel, 1995). It is generally accepted that design representation through sketch is fundamental to conceptual design activity (Cross, 1990; Lawson, 2006). Most designers have adopted freehand sketching as a valuable part of the design process (Lawson, 1994; Pipes, 1990). This study aims to use the role and use of sketch in different design disciplines as an entry point to further observe the similarities and differences between design disciplines born in different eras, as well as the design patterns and directions worth learning from each other from an unusual, microscopic perspective.

To fully understand the purpose and changing history of the use of sketches in the design discipline, we begin by reviewing and analyzing the sketch taxonomy that has evolved from the traditional design disciplines. This is done by identifying the different sketch taxonomies in terms of design phases and design purposes, including the role and use scenarios in the traditional design disciplines. In 3.2 we present an overview and analysis of design tools in contemporary design disciplines that use the sketch method according to the same criteria as in 3.1.

Domain	Authors	Sektch taxonomy	Investigation phase	Ideation phase	Prototyping Phase	Dimension	Complexity	Fidelity
Archite--ctural Deisgn	Fraser & Henmi (1994)	Diagram; Referential; Design; Presentation; Visionary Drawings		○	○	1, 2d	-	-
	Lawson (2012)	Presentation Drawings			○	1, 2d	3~4	Low
		Instruction Drawings			○	1, 2d	4	Low, middle
		Consultation Drawing		○	○	2d	3~4	Low
		Experiential Drawings	○	○		1, 2d	2~3	Low
		Diagram	○	○		1, 2d	2~5	Low
		Fabulous Drawings		○		1, 2d	2~3	Low
		Proposition Drawings		○	○	1, 2d	2~3	Low, middle
		Calculation Drawings		○	○	1, 2d	2~3	Low, middle
Engine--ering Design	Ferguson (1994) & Lugt (2005)	Thinking Sketch	○	○		1, 2d	3	Low
		Talking Sketch		○		1, 2d	4	Low
		Prescriptive Sketch		○	○	1, 2d	4	Middle
		Storing Sketch		○		1, 2d	2	All
	Pei (2009)	Personal Sketch	○	○		1, 2d	2	Low
		Shared Sketch		○		1, 2d	4	Low, middle
		Persuasive Sketch			○	2d	3~4	Middle
		Handover Sketch			○	2d	5	Middle, high
Industrial Design	Tovey (1989)	Diagrammatic Drawings		○		1, 2d	2~3	Low
		Ideas sketches		○		1, 2d	3	Low
		Concept drawings		○	○	1, 2d	3	Low, middle
		Measured drawings			○	1, 2d	3~4	Middle
	Olofsson & Sjolen (2005)	Investigation Sketch	○			1, 2d	2~3	Low
		Exploration Sketch		○		1, 2d	2~3	Low
		Explanatory Sketch			○	1, 2d	3~4	Middle
		Persuasive Sketch			○	1, 2d	4	Middle

Figure 2. Review and analysis of sketch taxonomies in traditional design disciplines.

Sketch used in traditional design disciplines

The design sketch originated in the academic discourse of architecture and industrial design (Schön, 1992). As different applications of the sketch taxonomy have been proposed and discussed in the traditional design disciplines, it is considered necessary to compare the different taxonomies to understand the role and use of sketch in the traditional design disciplines. Therefore, this chapter begins with a review of the role and use of sketch at different stages of the three traditional design disciplines - architectural, engineering, and industrial design.

In this study we have categorized the design process into 3 general phases. The RESEARCH PHASE includes investigation and problem definition, the IDEATION PHASE includes ideation and developmental design, and the PROTOTYPING PHASE includes detailed design and prototyping. We then summarized the phases in which each sketch taxonomy would work and classified them according to certain criteria for dimension, complexity, and fidelity (see Figure 1 for criteria).

For each of the three traditional design disciplines that are the subject of this study, we selected the most representative sketch taxonomies as the object of analysis. Two of these taxonomies are from the field of architecture (Fraser & Henmi, 1994; Lawson, 2012). There are also two taxonomies from the field of engineering design, one of which was first proposed by Ferguson (1994) to classify sketches according to their function in the design process, while Lugt (2005) builds on this by adding " storing sketch ". Another taxonomy was proposed by Pei (2009), based on the needs and intentions of designers when sketching. Finally, there are taxonomies from industrial design, one of which is Tovey (1989) classified sketches according to their functions and corresponding forms, while another, like Pei's, is based on Olofsson & Sjolen (2005) classified sketches according to the designer's needs or intentions when sketching.

Sketch adopted in contemporary design disciplines

As the contemporary design discipline represented in this study, UXD is about shaping the experience of using a product. Much of this experience involves some interaction between the user and the product. Although these contemporary design disciplines all have different origins, there is a mutual inclusion between their respective fields. Given that IxD is generally considered to be contained within UXD and UXD within SD, we follow this hierarchical classification to review and analyze the design tools that include sketch. The analysis results are then compared with the results of the traditional design sketch.

Here, this study follows Buxton's (2007) suggestion that sketch is not just an archetypal way of using paper and pen to support what Kolko (2009) and Brown (2009) and Martin (2009) call the 'reductive feeling' of design but can be used as a much broader way of thinking. As such, this study decided to adopt the approach proposed by Vistisen (2015) from the perspective of the spatial and temporal dimensions involved in the sketch, using Gillian Smith's (Smith in Moggridge 2006) classification of dimensions in IxD, between 1D-4D, as a suggestion for what designers can call 'sketching' of dimensions (1D: thoughts, words; 2D: paper sketches, images, scenarios; 3D: modelling, rapid prototypes, object theatre; 4D: enactments, videos, animations). In addition, UX designers usually create content such as wireframes, personas, and prototypes. Service designers end up creating service blueprints, customer journey maps and service ecosystem maps, but many of the tools they use are the same.

Considering that the definitions and descriptions of these design tools involving sketch vary somewhat from publication to publication, for the sake of consistency we will focus on the following two highly recognized publications as references for the analysis of sketch-related tools in contemporary design: a guide to service design practices by Marc Stickdorn et al. -- "This Is Service Design Doing: Applying Service Design Thinking in the Real World"; and the workbook by Buxton et al. – "Sketching User Experiences: Getting the Design Right and the Right

Domain	Authors	Design Tool	Investigation Phase	Ideation Phase	Prototyping Phase	Dimension	Complexity	Fidelity
Contem--porary Design (e.g., IxD, UXD, SD)	Research data	Research wall	○			All	3	Low
		Journey, system map	○			1, 2, 3d	5	Low, Middle
		Key insight	○			1d	3	Low
		User story	○			1d	5	Low
	Journey map	Storyboard (value, activity, interaction)	○	○	○	1, 2d	5	Middle
		Persona	○	○	○	1, 2d	4	Middle
		Service blueprint		○	○	1, 2d	5	Middle
	System map	Stakeholder map	○		○	1, 2d	5	Middle
		Value network map	○		○	1, 2d	5	Middle
		Ecosystem map	○		○	1, 2d	5	Middle
	Prototyping tool	Desktop walkthrough			○	2, 3d	4	Low
		Cardboard prototyping			○	2, 3d	4	Low
		Paper prototyping			○	1, 2d	4	Low
		Wire framing			○	1, 2d	4	Low
		Business model canvas			○	1d	5	Middle
	Others (various storyboards)	Sequntial storyboard		○		1, 2d	4	Low
		State transition diagram		○		1, 2d	4	Low
		Branching storyboard		○		1, 2d	4	Low
		Narrative storyboard		○	○	1, 2d	4	Low
		Animation-based sketch		○	○	4d	4, 5	Low, Middle

Figure 3. Review and analysis of sketch-related design tools in contemporary design disciplines.

Design", which introduces how sketching can be considered as a concept and used flexibly in UX design.

The result of the analysis between traditional and contemporary design

This chapter compared and discussed the results of the analysis in Figures 2 and 3. Relatively deep insights are gained into the transformation and differences in the roles and functions of the sketch in different design disciplines, and a contribution is made to improving and resolving possible gaps and conflicts in all design disciplines.

Firstly, no clear trends or differences were observed in the use of sketch in the different design phases. This may be due to the fact that designers have developed a sufficient number and variety of sketch taxonomies and sketch-related tools to suit the different design scenarios and phases.

However, there are some patterns and according to Smith's classification of dimensions in IxD, most sketch dimensions in the different taxonomies and design tools are concentrated in 2D and 1D. Traditional and contemporary design disciplines are similar in terms of dimensions. However, with the development of various smart devices and design software, the use of sketches in the ideation and prototyping phases of contemporary design has expanded to include 3D and 4D.

Secondly, in terms of sketch complexity, the taxonomy in traditional design disciplines tends to focus on 2,3,4 (with 3 being the most common). In contrast, contemporary design disciplines tend to focus on 4,5. The taxonomy of the sketch is therefore thought to favor the visualization of individual ideas about physical products and the facilitation of innovation, iteration, and communication through such easily understood visualizations. In the contemporary design discipline of design tools, however, the sketch is more oriented towards visualizing the overall structure of the system, the set of interactions of the service being provided, and so on. This makes it easier for designers and stakeholders to understand the complex relationship between the intangible service/system and the tangible product/interface in the design process. In addition, although the average of contemporary design disciplines is higher than traditional design in terms of sketch complexity, traditional design may require more sketch skills than contemporary design.

Thirdly, the contemporary and traditional designs of this paper are judged differently in terms of fidelity. Traditionally, fidelity is judged by how close it is to the final design in terms of appearance and function. Contemporary design, however, considers whether the sketch represents a system diagram or storyboard that is close to the intended composition of the final design, the expected interaction, the experience, and so on. In other words, traditionally the sketch represents the construction and form of a specific design (micro level). In contrast, in contemporary design, the sketch is used to describe the system framework of the design (macro level), the specific experience to be realized (meso level) through storyboards, etc., and the interaction required to realize that experience (micro level).

Because of the fast and rough nature of the sketch, the analysis of sketch taxonomies and design tools that use the sketch method in relation to fidelity is concentrated in the low and middle levels, with the high level rarely occurring. The reason for the high level is the application of the sketch method to the final prototype or finished product, and the reason for the middle level is the application of sketch to prototyping. In general, however, both the sketch taxonomy and the sketch-related design tool take advantage of sketch's ability to simply represent ideas or concepts and its ability to quickly externalize them. Also, as digital technology develops, sketch's property of being vague and allowing for reinterpretation and the ability to offer designers new solutions may enable sketch to be used in fields of high fidelity in the traditional design disciplines.

Whereas in the contemporary design discipline, although the design objects include specific products, most of the design tools analyzed in this study are used in the context of UX or the frameworks that make up the service. Even though the threshold for sketch use has been lowered by the addition of new technologies, it is observed that sketch fidelity is at the middle level in most tools, besides the general low level, according to our definition in table1. Despite the differences in design objects in different design disciplines, the ability of sketch to support efficient and rapid visual representation of objects that become more complex. The ability to represent and convey a degree of fidelity (2d) may still be difficult to replace by other simpler (1d) or more complex approaches (3, 4d).

Discussion and future work

This study has explored the changes and differences in the role and function of the sketch in traditional and contemporary design. It provides some preliminary findings and insights into how to address and improve some of the current gaps and conflicts between design disciplines. It also gives some ideas about changes in design education and the professional skills or knowledge that designers will need in the future.
Regarding the dimensional expansion of the sketch. For traditional design, the techniques to be learned and the knowledge of design theory from interdisciplinary sources has increased. And for modern design, the understanding of sketch characteristics may need to be improved to save time and cost in the design process.

Based on the analysis of the complexity of sketch, some possible gaps can be identified, i.e., traditional design disciplines can be educated more towards the development of design representation skills, while contemporary design disciplines are educated more towards the development of logical thinking and the training of design tools with a fixed framework and practical team exercises. Therefore, a mutual learning process between the contemporary design disciplines, with their emphasis on logical and systematic thinking, and the traditional design disciplines, with their emphasis on practical training, could help to mitigate the conflicts within the disciplines (i.e., the gap between the slowly changing design disciplines and the rapidly changing business environment that demands design talent).

This study argues that the difference in criteria for judging sketch fidelity is largely due to the difference in design objects between traditional and contemporary design. The contemporary design discipline is more concerned with designing services to meet a range of customer needs and incorporating products that enhance customer satisfaction. In contrast, traditional design is concerned with designing products to solve customer problems, focusing on practicality, design, durability, etc. While each has a strong focus on interdisciplinary collaboration, modern design is more likely to integrate the experience and knowledge of different disciplines than traditional design, which once had clear disciplinary boundaries.

Therefore, a more inclusive and open-minded approach to the traditional design education model, such as the development of courses in modern design disciplines (e.g., Service Design, Transformative Design), may open more opportunities for future designers in traditional design disciplines and contribute to the resolution of (2) conflicts within disciplines or even (1) conflicts between disciplines.

In summary, based on the review and analysis of sketch in various design disciplines from the perspective of (3) conflicts between specific tools, this study argues that traditional design education and practice need to introduce the attributes and experiences of contemporary design disciplines that focus on multidisciplinary collaboration. And in contemporary design education and practice, there is a need to focus on developing a certain level of theory and knowledge of traditional disciplines to help build a foundation of knowledge systems in multidisciplinary collaboration.

In the future, the disciplinary boundaries between traditional and contemporary design will become increasingly blurred. The unique theories and tools of each discipline may become increasingly uncertain, ineffective, or even conflicting in their educational and practical applications. To effectively address the potential confusion and conflict of theories and design models that may arise in the future because of the dissolution of design disciplinary boundaries, this paper provides a more general review and analysis of design disciplines from different fields and origins by offering a new perspective on specific tools at a micro level. More detailed studies exploring (i) future models of design education and (ii) the skills required by designers will require more comparative studies with examples of overlaps and gaps between specific disciplines (e.g., Industrial and UX Design).

References

Bar-Eli, S. (2013). Sketching profiles: Awareness to individual differences in sketching as a means of enhancing design solution development. Design Studies, 34(4), 472–493.

Bilda, Z., & Demirkan, H. (2003). An insight on designers' sketching activities in traditional versus digital media. Design Studies, 24(1), 27–50

Bilda, Z., John, G., Purcell, T. (2006). To Sketch or Not to Sketch? That Is the Question. Design Studies 27 (5): 587–613. Elsevier.

Bouroullec, R. & Bouroullec, E. Ronan and Erwan Bouroullec. London, UK: Phaidon Press Ltd., 2003.

Brown, T. (2009) Change by Design, Harper Collins.

Buxton, B. (2010). Sketching User Experiences: Getting the Design Right and the Right Design. Morgan Kaufmann.

Cross, N. (1990). The nature and nurture of design ability. Design Studies, 11(3), 127-140. de Noblet, J. (1993) Industrial Design, Paris: A.F.A.A.

Doerry, E., Bero, B., Larson, D. & Hatfield, J. (2001). Northern Arizona University's Design 4 Practice Sequence: Interdisciplinary training in engineering design for the global era, in Educating the Engineer for the 21st Century, D. Weichert, B. Rauhaut and R. Schmidt, Eds. Norwell, M.A.: Kluwer Academic Publishers, 2001.

Dym, C.; Agogino, A.; Eris, O.; Frey, D.; Leifer, L. (2005). Engineering design thinking, teaching, and learning. Eng. Educ. 2005, 94, 103–120.

Elżbieta D. Ryńska (2016). Interdisciplinary training within the education curricula for architects and engineers, Warsaw University of Technology Warszawa, Poland.

Eugene S. Ferguson. (1994). Engineering and the Mind's Eye. MIT press.

Fawcett, J. (2013). Thoughts about multidisciplinary, interdisciplinary, and transdisciplinary research. Nurs. Sci. Q. 2013, 26, 376–379.

Forlizzi, J. (2010). All Look Same? A Comparison of Experience Design and Service Design. Interactions, 17(5), pp. 60-62.

Frankenberger, E., & Badke-Schaub, P. (1998). Integration of Group, Individual and External Influences in the Design Process. In D.-I. E. Frankenberger, P. H. Birkhofer, & D. P. Badke- Schaub (Eds.), Designers (pp. 149–164). Springer London.

Fraser, I., & Henmi, R. (1993). Envisioning architecture: An analysis of drawing. John Wiley & Sons.

Gnaur, D., Svidt,K., & Kaae, T. (2012). Building interdisciplinary collaboration skills through a digital building project. In SEfI 40th annual conference. Thessaloniki, Greece.

Goel, V. (1995) Sketches of Thought. London: MIT Press.

Heppell, S. "RSA Lectures: Stephen Heppell: Learning 2016,"RSA Lectures, 30 June, 2006. Online. Available at: http://www.teachers.tv/video/4957 (Accessed December 22, 2010).

Hua, M. (2019) The Roles of Sketching in Supporting Creative Design. The Design Journal.

IDSA. (2013). What is Industrial Design?. Retrieved from IDSA website: http://www.idsa.org/what-is-industrial-design.

Martin, R. L. (2009) The Design of Business: Why Design Thinking is the Next Competitive Advantage (Third Edition edition). Boston, Mass: Harvard Business Review Press.

Goldschmidt, G. (1991). The dialectics of sketching. Creativity Research Journal, 4(2), 123– 143.

Goldschmidt, G. (1994). On visual design thinking: the vis kids of architecture. Design Studies, 15(2), 158–174.

Goldschmidt G. and Smolkov, G. (2006). Variances in the impact of visual stimuli on design problem solving performance. Design studies, 27 (5): 549-569.

Irizarry, J., Meadati, P., Gheisari, M. (2010). The need and challenges for interdisciplinary education in AEC. In: Construction Research Congress, Innovation for Reshaping Construction Practice, pp 226–235.

Jutra, A., Zupancic, T. (2014). The Role of Architect in Interdisciplinary Collaborative Design Studios. Article in Igra ustvarjalnosti - Creativity Game · October 2014

Khambete, P. (2011). Pattern Language for Touch Point Ecosystem: A Potent Framework for Multidisciplinary Design. 1ST CAMBRIDGE ACADEMIC DESIGN MANAGEMENT CONFERENCE, 7 – 8 SEPTEMBER 2011.

Kolko, J. (2009). Abductive Thinking and Sensemaking: The Drivers of Design Synthesis. Design Issues, 26(1), 15–28.

Lawson, B. (2006) How designers think: the design. process demystified (4 ed.), Oxford University Press.

Latour, B. (2004). A Cautious Prometheus? A Few Steps Toward a Philosophy of Design (With Special Attention to Peter Sloterdijk)" in F. Hackne, J. Glynne and V. Minto (Editors), Proceedings of the 2008 Annual International Conference of the Design History Society, Universal Publishers, pp. 2 - 10.

Law, J. & URRY, J. (2004). Enacting the Social. Economy and Society, Vol. 33, No. 3, 2004, pp. 390 - 410.

Leavy, P. (2016) Essentials of Transdisciplinary Research: Using Problem-Centered Methodologies, Routledge: Abingdon, UK, 2016.

Lévy, P. & guénand, a. (2003). Including interdisciplinary to industrial design. International conference on engineering design iced 03 Stockholm, august 19-21, 2003

Mabogunje, A.; Sonalkar, N.; Leifer, L.; Parasker, N.; Beam, M. (2020). Regenerative learning: A process based design approach. Eng. Educ. 2020, 36, 732–748.

Moggridge, B. (2006). Designing Interactions. The MIT Press.

Myerson, J. (2005) IDEO: Masters of Innovation. London, UK: Laurence King Publishing, 2005.

Norman, D. (2004). Reflections on design. Hum. Factors Comput. Syst. 2004, 41, 1053–1054.

Olofsson, E., & Sjolen, K. Design Sketching, 2005.

Pei, E. (2009). Building a common language of design representations for industrial designers and engineering designers.

Pipes, A. (1990) Drawing for 3- Dimensional Design: concepts, illustration, presentation, Thames and Hudson, London

Sanders, L.; Stappers, P.J. (2013) Convivial Toolbox: Generative Research for the Front End of Design; BIS Publishers: Amsterdam, The Netherlands, 2013.

Schön, D. A., & Wiggins, G. (1992). Kinds of Seeing in Designing. Creativity and Innovation Management, 1(2), 68–74.

Tovey, M. (1989). Drawing and CAD in industrial design. Design Studies, 10(1), 24-39.

Van der Lugt, R. (2005). How sketching can affect the idea generation process in design group meetings. Design studies, 26(2), 101-122.

van Hinte, E., ed. 1:1 Marti Guixe. Rotterdam, The Netherlands: 010 Publishers, 2002.

Vistisen, P. (2015). The Roles of Sketching in Design: Mapping the Tension between Functions in Design Sketching. Nordic Design Research Conference

Wu, J.-C., Chen, C.-C., & Chen, H.-C. (2012). Comparison of Designer's Design Thinking Modes in Digital and Traditional Sketches. Design and Technology Education: An International Journal, 17(3).