

Sketching Versus Digital Design Tools in Architectural Design

Nurcan Yıldızođlu¹

ORCID NO: 0000-0002-4072-0366¹

¹ Antalya Belek University, Architectural Restoration, Vocational School, Antalya, Türkiye

Sketching is a design tool that can be assumed to be ill-structured, does not offer exact solutions, is intuitive, and is open-ended in the initial stages of architectural design. Sketching creates an opportunity for architects to release their creativity and intuition, giving rise to spontaneous ideas and concepts in an organic and natural way. During the initial design phases, like in the conceptual stage of the design, designers receive aid from conventional sketching as their concepts and ideas can easily transform into tangible, real-world forms. With the development of digital design methods like CAD (computer-aided design) in pursuit of AI (artificial intelligence), it has been accepted that manual sketches are no longer the only tools used in the architectural design, and adaptation of new methods such as digital and AI-assisted tools. The diversity and evolution of tools used in architectural design, together with the integration of CAD, AI, and traditional sketching techniques, have contributed to the development of architectural design and facilitated enhanced collaboration, visualization, and efficiency across the design process. As a result, it has evolved to embrace the use of CAD, which was the first method adopted from these developments, as a basic skill in the field of architectural design education. This shift places a strong emphasis on the professional field of architectural design while also encouraging students to explore the innovative potential of CAD for design purposes. CAD presents architects with a robust platform that facilitates the creation of intricate designs and precise measurements during the initial parts of the architectural design process. Following CAD, the development of generative AI-driven tools motivates architecture students and designers to make their conceptual work more efficient and create more alternatives. Although it is known that each method mentioned has its own positive or negative aspects, it is not possible to say that any of them is used alone in architectural design processes. At this point, combining the design process with CAD and AI-supported design tools, as well as traditional manual sketching in architecture, helps develop a diverse and adaptable skill set in design. Integrating digital design tools into the architectural field emphasizes the enduring importance of traditional sketches, especially in terms of inspiration and conceptualization in architectural design, while also updating the process of design. The purpose of this paper to explore the progression of employing diverse design tools, namely manual sketching, CAD, and AI-driven design tools, throughout the architectural design process. This paper aims to understand why designers continue to use traditional sketching methods by comparing digital design tools and traditional sketching. This paper undertakes a comparative analysis of using computational design tools instead of traditional sketching with pen and pencil, aiming to juxtapose their respective benefits and drawbacks. In conclusion, although it is not yet possible to assert the superiority of one method over the other, it is evident that traditional sketching continues to hold significant relevance and effectiveness in the design process despite its long-term use.

Received: 25.06.2024

Accepted: 27.08.2024

Corresponding Author:

nurcanyildizoglu@belek.edu.tr

Author, A. & Author, A. (2024). Sketching Versus Digital Design Tools in Architectural Design. *JCoDe: Journal of Computational Design*, 5(2), 301-316.
<https://doi.org/10.53710/jcode.1504947>

Keywords: Design Process, Manual Sketching, CAD, Sketch-Based AI.

Mimari Tasarımda Eskiz ve Dijital Tasarım Araçları

Nurcan Yıldızoğlu¹

ORCID NO: 0000-0002-4072-0366¹

¹ Antalya Belek Üniversitesi, Mimari Restorasyon, MYO, Antalya, Türkiye

Eskiz, mimari tasarımın ilk örneklerinden beri kullanılan, sezgisel ve açık uçlu olduğu düşünülen bir tasarım aracıdır. Eskiz, mimarların yaratıcılıklarını ve sezgilerini serbest bırakmaları için bir fırsat yaratır, kendiliğinden fikir ve kavramların organik ve doğal bir şekilde ortaya çıkmasına neden olur. Dijital tasarım yöntemlerinin gelişmesiyle birlikte, manuel eskizlerin artık tasarım sürecinde kullanılan tek yöntem olmadığı kabul edilmiş ve yeni yöntemlerin kullanılmasına yönelik eğilim ortaya çıkmıştır. Mimari tasarımda kullanılan araçların çeşitliliği ve gelişimi, bilgisayar destekli tasarım (CAD), yapay zeka (AI) kullanımının tasarım süreçlerine entegrasyonu ile birlikte, mimari tasarımın gelişimine katkıda bulunmuştur. Bahsedilen her yöntemin kendine has olumlu ya da olumsuz yönlerinin olduğu bilinse de mimari tasarım süreçlerinde hiçbirinin tek başına kullanıldığını söylemek mümkün değildir. Bu noktada tasarım sürecini CAD ve yapay zeka destekli tasarım araçlarının yanı sıra mimarideki geleneksel manuel eskizlerle birleştirmek, tasarımda çeşitli ve uyarlanabilir bir beceri seti geliştirmeye yardımcı olur. Dijital tasarım araçlarının mimari alana entegre edilmesi, geleneksel eskizlerin özellikle mimari tasarımda ilham ve kavramsallaştırma açısından kalıcı önemini vurgularken aynı zamanda tasarım sürecini de güncelliyor. Bu makale, mimari tasarım süreci boyunca geleneksel eskiz, CAD ve yapay zeka odaklı tasarım araçları gibi çeşitli tasarım araçlarının kullanılmasındaki ilerlemeyi keşfetmeyi amaçlamaktadır. Bu makale, günümüz tasarım süreçlerinde hala güncelliğini koruyan geleneksel eskiz yerine hesaplamalı tasarım araçlarının kullanılmasının karşılaştırmalı bir analizini üstlenmekte ve bunların faydalarını ve dezavantajlarını yan yana getirmeyi amaçlamaktadır. Sonuç olarak, her ne kadar bir yöntemin diğerine üstünlüğünü ileri sürmek henüz mümkün olmasa da, geleneksel eskizin uzun süreli kullanımına rağmen tasarım sürecinde önemli bir yer tutmaya ve etkili olmaya devam ettiği açıktır.

Teslim Tarihi: 25.06.2024

Kabul Tarihi: 27.08.2024

Sorumlu Yazar:

nurcanyildizoglu@belek.edu.tr

Yıldızoğlu, N. (2024). Mimari Tasarımda Eskiz ve Dijital Tasarım Araçları. *JCoDe: Journal of Computational Design*, 5(2), 301-316. <https://doi.org/10.53710/jcode.1504947>

Anahtar Kelimeler: Tasarım Süreçleri, Geleneksel Eskiz, CAD, Eskiz Tabanlı Yapay Zeka.

1. INTRODUCTION

Sketching is a powerful and oftused design tool that gives a feeling of freedom with its subjective interpretation capacity. It is rough and lacking in detail in nature, and designers use it to express and develop their concepts in the design process. Due to the opportunities it provides to designers, traditional sketching has been used since the first designers as a design tool that enables the abstract ideas of designs to become a reality by drawing ideas on paper with the help of a pencil. In addition, while drawing techniques may differ, numerous designers recognize the utilization of sketches as a crucial component within their design process (Do, 2002). With the increasing prevalence of digital design tools like Computer-Aided Design (CAD) and Artificial Intelligence (AI) in architectural design process, traditional sketching is no longer a standalone design tool. So, the architectural design processes are undergoing a transformation, shifting from conventional paper-and-pencil approaches to utilizing digital design techniques. In light of these developments, the emergence of digital design tools and their acceptance and widespread use in architectural design processes have enabled significant revolutionary improvements and advances in architectural design processes. The evolution and transformation in architectural design processes have reshaped the way architectural design is approached and practiced, paving the way for the ongoing evolution and development of these tools.

The design process is a subject that designers have been busy with for a long time. Nowadays, when the design process changes with the development of digital design tools, it is expected to accept that the design process exists based on traditional principles (Svetel et al., 2018). Digital design tools such as CAD and sketch-based AI tools are now widely used by designers in the architecture industry as accessibility has increased. Despite the evolution of these tools, their acceptance in the architectural industry, and their rapid integration into the design process, manual sketching remains an inseparable tool of the architectural design process. In the context of architectural design, although CAD and AI tools can fall under digital design tools, it is essential to distinguish between the roles of CAD and AI tools as independent techniques versus their integration into design processes. This study acknowledges the distinct characteristics of CAD and AI tools, which can vary significantly across different stages of the architectural

design process. To clarify the scope of this research, the focus is narrowed to the comparison and integration of traditional sketching, CAD environments, and sketching with AI tools. This refined focus aims to provide a clearer understanding of how these specific tools interact and influence the design process, and serves to enhance the coherence of the research findings within the context of the existing literature. In line with this information, the main focus of the research is on digital design methods such as CAD and AI and the impact of these digital design tools on factors that affect the design process, such as designers' creativity compared to traditional manual sketching. It is important to comprehend how digital design tools affect creativity in the design process and to have a deep understanding of how these tools are used in architectural practices. This understanding is crucial to ensure these technologies support and enhance designers' capacity to generate ideas and innovate rather than restrict them. The primary research question examines why designers continue to use traditional sketching methods by comparing digital design tools with traditional sketching methods. Additionally, the problem statement explores why the traditional sketching method remains popular among designers despite the increasing prevalence and accessibility of digital design tools.

2. LITERATURE REVIEW

2.1 Sketching Environment in the Design Process

Sketching is a fundamental human activity widely utilized to generate conceptual and creative ideas and overcome intricate design obstacles (Akin, 1978; Goldschmidt, 1991, 2017). Although drawing styles vary in architecture to help designers explore and embody their ideas, many designers consider traditional sketching an inherent part of the architectural design (Do, 2002). The process of sketching is often commonly considered an ill-defined design tool due to its open-ended nature, which inherently requires a definitive solution to the design problem (Goel, 1995). As a part of the creative process, sketching is a brainstorming tool, avoiding details and embodying roughness (Putra et al., 2022). It facilitates the translation of abstract ideas into concrete forms that effectively communicate design concepts. In other words, sketching has been a significant communication tool for creators, enabling them to articulate their ideas during the design process (Lawson, 2002; Lee, 2017). Sketching is one of the most well-known

methods in the architectural design process for abstract representation, which is traditional manual sketching via pen and pencil (Bryan, 2005; Goldschmidt, 1994).

Manual sketch acts make an essential contribution to architectural design stages because they have a crucial effect on sparking and evolving creative concepts in the initial design stage (Shih et al., 2015). They aid designers in visual reasoning and exploring spatial relationships between diagrams. Most architectural education includes utilizing traditional tools like pen and paper for crafting design and expressing designers ideas through drawing, with design thinking encompassing considerations of form and function, representing a mode of visual and spatial cognition (Do, 2002). Designers in architectural design still use manual sketching to generate new ideas, solve design problems, and express their concepts. Upon visiting previous sketches, including one's own and those of others, it is possible for new and unexpected ideas to emerge. Although designers mostly use manual sketching, especially during the initial design process in architecture, pen, and pencil are not the only tools for expressing ideas in designers' minds in tangible forms. With the evolution of computational design, different digital design tools, such as CAD and AI tools, have come to the forefront of the architectural profession and have become popular among designers.

2.2 Digital Design Tools Environment in the Design Process

The globalization of construction projects has compelled existing design tools to transition from individual design to the implosion of different design fields in order to enhance final products. Consequently, novel computational-aided design tools have emerged as a result of this shift (Goulding et al., 2014). In other words, there have been shifts in traditional sketching after the digital design era. These changes may affect the design process (Error! Reference source not found.). For example, some literature suggests that computer-aided design may negatively affect the creativity of designers (Robertson et al., 2007; Van Elsas & Vergeest, 1998; Verstijnen et al., 1998).

In contrast, Madrazo (1999) argued that digital design tools enhance comprehension of form, aiding visual cognition. Marx (2000) corroborated this notion, suggesting that immersive visualization and feedback in computer-based tools prompt designers to engage in

mental imaging more frequently than traditional sketching tools. In addition, Won (2001) found that the cognitive behaviors of designers while using traditional sketching methods mirror those when using digital design tools. In addition, Bilda and Demirkan (2003), in their study on understanding the perceptual frequency of actions shown during the architectural design process, concluded that the actions shown during traditional sketching require more frequent attention changes with increasing actions compared to digital design tools and create more exploration opportunities. Likewise, Tang et al. (2011) found that digital design tools commonly used in drafting processes are very similar to the key features of traditional sketching tools in the architectural design. In addition, the mentioned study suggested that digital design did not affect the duration of explorative ideation relative to problem definition. In this regard, the use of digital design tools instead of manual sketching in architectural design has led to extensive discussions in the professional field. The utilization of traditional manual sketching methods entails inherent advantages; however, incorporating diverse digital design tools into the field of architecture has emerged as a pivotal and contemporary concern.

	Differences	Similarities
Traditional Sketching	<ul style="list-style-type: none"> *Creating more exploration opportunities (Bilda and Demirkan 2003) *Requiring more frequent attention changes (Bilda and Demirkan 2003) 	<ul style="list-style-type: none"> *Cognitive behaviors of designers during use of them (Won 2001) *Commonly used in drafting processes (Tang et al. 2011) *Did not affect the duration of explorative ideation relative to problem definition (Tang et al. 2011)
Digital Design Tools	<ul style="list-style-type: none"> *May negatively affect the creativity of designers (Robertson et al., 2007; Van Elsas & Vergeest, 1998) *Enhancing comprehension of form, aiding visual cognition (Madrado 1999) 	

Table 1: Differences and similarities of the traditional sketching and digital design tools.

2.2.1 CAD Environment in Design Process

Using geometry and expression capabilities, CAD helps designers immerse themselves in the design process and achieve final results practically from start to finish. In this respect, it attempts to substitute traditional techniques such as sketching, which can be called a digital design methodology (Shih et al., 2015). When attempting to depict

complex 3D objects, it is often challenging for 2D representations to accurately convey their intricacies. In a CAD modeling design environment, 3D objects can also be used to create 3D geometry or make changes to the model. Moreover, CAD modeling can significantly assist in design problem-solving (Shih et al., 2015). While traditional methods rely on sketching to convey essential concepts, they often fall short when dealing with complex issues, as noted by Lin (2003). Moreover, with the increasing efficiency and user-friendliness of CAD modeling programs, they are supplanting conventional paper and pencil methods, particularly within the realm of architectural conceptual design (Veisz et al., 2012). In the initial phases of the architectural design process, numerous designers, engineers, and educators use CAD tools.

On the one hand, several empirical studies show that current CAD tools can be as influential as sketching (Buchal, 2002; Hanna & Barber, 2001). Egli et al. (1997) invented the pen-based "Quick Sketch," with a 3D modeling system now available in CAD systems, and claimed that modeling the design interactively with this system at a concept stage was slightly faster than traditional sketching. Hanna and Barber (2001), in their study of architecture students who exclusively used CAD as a design tool, concluded that the students preferred using CAD over the traditional sketching method alone.

On the other hand, some studies suggest that CAD tools negatively affect the stages of the design process (Robertson et al., 2007). The main effects are restricting the designer's thinking and fixing the designer in the design phase as the design gains detail. Continuous and excessive use of CAD can dull the designer's creative abilities. CAD often draws criticism for shifting the designer's focus toward details instead of fundamental principles during the design phase (Utterback et al., 2006). During traditional sketching, designers can quickly capture ideas and focus on the essentials. On the other hand, a CAD system needs to examine some information to create a representation of an object, and by supporting this information, the final result can be produced, which can change the focus of the designer.

CAD can replace conventional sketching tools in architectural design stages, especially in the initial conceptual design process. However, computational design methods are still in the transition and development phase (Buchal, 2002); this process is akin to the transition

from handwritten documents to ubiquitous word processing. In light of the literature, it is evident that the traditional sketching and CAD method has various opportunities and challenges for designers (Error! Reference source not found.). In particular, the literature argues that the opportunities offered by the traditional sketching method for creativity are at the forefront. In contrast, CAD methods are more prominent in terms of details and complex issues in design. Considering these points, arriving at a definitive conclusion regarding the comparative value of traditional sketches versus CAD representations within the architectural design process is challenging.

2.2.2 AI-driven Environment in the Design Process

Utilizing architectural design principles and processes in the context of artificial intelligence, particularly in sketching, is of great significance. AI tools exhibit promise in enhancing architectural sketches and concepts through various means. In recent years, the utilization of generative AI has gained significant traction for cultivating creativity within various domains (Zhang et al., 2023). Such capabilities could expedite the creation of diverse design options for architects to consider or facilitate the exploration of different design concepts without requiring additional visualization methods like 3D modeling and rendering tools (Hegazy & Saleh, 2023). In other words, AI tools provide users with a wide range of design ideas and help designers recognize potential strategies and approaches to overcome design challenges (Zhou, 2021). In this direction, many AI tools can provide a basis for designers' concept ideas. Different types of generative AI tools exist, such as text-based, image-based, and sketch-based. Generative AI tools that can be trained to complete incomplete sketches or create alternative designs based on existing sketches are called sketch-based AI.

In the conceptual design phase of architecture, sketch-based AI visual prompts can inspire architects to develop multiple design options. AI can provide conceptual sketches during the early design stage, serving as examples for design discussions (Zhou, 2021). In addition, it is very advantageous for designers that AI can introduce line changes in sketches and even better understand architects' sketches and complete unfinished sketch drawings. According to Zhang's (2023) findings, designers find great value in leveraging AI-generative image

design tools as they aid in generating alternative design options, sparking new creative directions, and refining existing sketches.

However, although AI-based design has positive aspects, such as producing inspiring results, studies also emphasize its negative aspects. In particular, Zhang's (2023) results showed that AI may not understand terms specific to the architectural field and can sometimes produce surreal images unsuitable for construction purposes. Sketch-based AI tools have been extensively researched in design and are increasingly advancing in interpreting hand drawings for various applications, a crucial development for designers. Baudoux et al. (2024) propose three critical features for upcoming and current sketch-based AI design tools. Integration is essential in both creating the sketch and storing features in memory. Symbolic and logical processes need to be integrated to manipulate various sources of recognition. Finally, the tools should be engaging, precise, and inspiring. To generate images, they must surpass simple geometric models.

2.3 Mixed Media Design Environment in the Design Process

Developments and studies in digital design tools have focused on integrating different design tools into various design processes to achieve final results, thereby enabling the increasing globalization of professional groups associated with construction projects, such as architecture and engineering (Shih et al., 2015). Römer et al. (2001) supported the idea that traditional sketching and CAD modeling are widely recognized and supported as the primary and most commonly utilized design tools by architects and educators in architecture. In addition, Shih et al. (2015) noted that the combination of manual sketching and CAD can be referred to as a mixed-media design environment. In addition, this article supports that the interplay between sketching and CAD modeling fosters a switching behavior that could potentially influence design processes.

Considering the challenges and opportunities of mixed media design, there is ongoing debate about applying the two methods combined in the process of design. On the one hand, during the design stages, designers are confronted with the additional responsibility of transitioning traditional sketches to CAD systems (Alvarado et al., 2002). This means that although sketching offers designers flexibility and practicality and is popular for designers to use in their early stages,

it can cut into the process of design fluently, especially when designs need to be transferred from sketch to CAD (Shih et al., 2015). This process is notably time-consuming and necessitates careful attention. Likewise, using both sketches and CAD tools underlines the importance of exploring the integration between mentioned tools to avoid wasting time and losing information during the transition from manual sketching to CAD tools (Römer et al., 2001). In light of this research, another research supports that streamlining the conversion of traditional sketches into CAD tools would offer designers several advantages (Lim et al., 2001). On the other hand, some researchers support the freedom of designers to switch between sketching and CAD modeling, ignoring the time loss when switching between tools (Do, 2005; Sachse et al., 2001). In addition, Evans (1997) provides a valuable perspective on the architectural design process with his concept of "translation," suggesting that architectural drawings act as translations of ideas and contexts into physical forms. In this context, it sheds light on the naturally switching behaviors observed during the design process because these translations are not merely technical practices but are deeply intertwined with interpretive and contextual dimensions. Thus, the switching behavior is intrinsically linked to the dynamics of transforming conceptual intentions through various modes of representation, enriching the understanding of how digital design tools and traditional sketching differ in their cognitive and representational approaches. As a result, when the sketching methods in architecture are examined, although each method has its advantages and disadvantages, their advantages and disadvantages also emerge when used together (Error! Reference source not found.).

Table 2: Opportunities and challenges of the design tools.

Design Tools	Opportunities	Challenges
Traditional Sketching	<ul style="list-style-type: none"> *Aiding creativity and intuition (Robertson et al., 2007; Van Elsas & Vergeest, 1998; Verstijnen et al., 1998) *Ease of quickly capturing ideas and focusing on the essentials (Utterback et al., 2006) 	<ul style="list-style-type: none"> *Falling short when dealing with complex issues (Lin, 2003).
CAD	<ul style="list-style-type: none"> *Assisting in design problem-solving (Shih et al., 2015) *Increasing efficiency and user-friendliness (Veisz et al., 2012) 	<ul style="list-style-type: none"> *Restricting the designer's thinking and fixing the designer (Robertson et al., 2007) *Dulling the designer's creative abilities when excessive use (Robertson et al., 2007)
AI-driven tools	<ul style="list-style-type: none"> *Providing users with a wide range of design ideas (Zhou, 2021) *Helping designers recognize potential strategies (Zhang, 2023) *Providing conceptual sketches during the early design stage (Zhou, 2021) 	<ul style="list-style-type: none"> *May not understand specific terms (Zhang's 2023) *Can sometimes produce surreal images (Zhang, 2023)
Mixed-Media Design Environment	<ul style="list-style-type: none"> *Switching behavior could potentially influence design processes (Shih et al. 2015). *Flexibility and practicality (Shih et al., 2015) *Supporting the freedom of designers to switch (Do, 2005; Sachse et al., 2001). 	<ul style="list-style-type: none"> *Confronting additional responsibility of transitioning (Alvarado et al., 2002) *Can cause losing amount of time and information during transition (Römer et al., 2001)

3. CONCLUSION

Traditional sketching is a fundamental and vital tool in architectural design, especially in the initial conceptual phases. It allows architects to reflect intensely on and interpret their design intentions, paving the way for a more expansive exploration of potential solution ideas. In architectural design, conceptual design methods need a predominantly human-centered approach, emphasizing the power of creativity and human ingenuity. Design development predominantly relies on computer-aided methods, enabling precision and efficiency in executing intricate designs. Consequently, traditional sketching techniques continue to be prevalent in the field of architecture.

Stones and Cassidy's (2010) found compelling results when they compared students' sketching work using traditional and computational media for reinterpreting design ideas during conceptual thinking. They discovered that traditional sketches were significantly more effective in facilitating reinterpretation and the generation of design ideas. These results underscore the importance of traditional sketching methods in the design process. In the context of ongoing discussions, a group of researchers argues that traditional sketching should remain unchanged and that it is a design tool that can be used in the conceptual design stages. Another group of researchers argues that using CAD tools developed to support, extend, or change sketches can contribute to obtaining more effective results in the design stages. On the other hand, researchers looking at newer developments argue that sketch-based artificial intelligence can contribute to achieving inspiring design results. In this context, sketch-based AI design produces content through hand-drawn sketches, a combination of two tools. In addition, some advocate the mixed-media method, where traditional sketching methods are used together with computational design methods. In conclusion, it is evident that with the development of digital design tools such as CAD, in pursuit of AI, the tools used in architecture also develop and change. Although it is not yet possible to assert the superiority of one method over the other, it is evident that traditional sketching with paper and pencil continues to hold significant relevance and effectiveness in the design process despite its long-standing use.

The findings of this study, it is clear that the interaction between digital design tools and traditional sketching has significant potential in the

design process. While much of the analysis has focused on pairwise comparisons between these methods, the value of using them in tandem should not be overlooked. This study focuses on a third scenario, where integrating digital design tools and traditional sketching facilitates a fluid "switching behavior" that enhances creative exploration and problem-solving. The mixed-media approach enables designers to utilize the strengths of both mediums, resulting in a more dynamic and adaptable design process. Furthermore, this research introduces a novel perspective to the existing body of literature by providing a comprehensive and intricate evaluation of how the integration of hybrid practices can elevate and enrich the design environment. This nuanced analysis offers an in-depth framework for comprehending the dynamic and evolving role of mixed media in contemporary design practice.

Acknowledgements

I would like to thank Prof. Dr. Fehmi Dogan encouraged me to work in this paper.

References

- Akin, O. (1978). How do architects design. *Artificial Intelligence and Pattern Recognition in Computer Aided Design, IFIP*, 65–98.
- Alvarado, C., Oltmans, M., & Davis, R. (2002). A framework for multi-domain sketch recognition. *Proceedings of AAAI Spring Symposium on Sketch Understanding*, 1–8. <https://cdn.aaai.org/Symposia/Spring/2002/SS-02-08/SS02-08-001.pdf>
- Baudoux, G., & Goucher-Lambert, K. (2024). Understanding Complex Sketch Recognition Strategies For Intelligent Sketch-Based Design Tools. *IDETC-CIE International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*. <https://orbi.uliege.be/handle/2268/318801>
- Bilda, Z., & Demirkan, H. (2003). An insight on designers' sketching activities in traditional versus digital media. *Design Studies*, 24(1), 27–50.
- Bryan, L. (2005). How Designers Think: The design process demystified. *Architectural Preee and Elsevier*.
- Buchal, R. O. (2002). Sketching and computer-aided conceptual design. *The 7th International Conference on Computer Supported Cooperative Work in Design*, 112–119. <https://doi.org/10.1109/CSCWD.2002.1047659>

- Do, E. Y.-L. (2002). Drawing marks, acts, and reacts: Toward a computational sketching interface for architectural design. *AI EDAM*, 16(3), 149–171.
- Do, E. Y.-L. (2005). Design sketches and sketch design tools. *Knowledge-Based Systems*, 18(8), 383–405.
- Eggl, L., Hsu, C., Bruederlin, B. D., & Elber, G. (1997). Inferring 3D models from freehand sketches and constraints. *Computer-Aided Design*, 29(2), 101–112.
- Evans, R. (1997). *Translations from drawing to building*. <https://espace.library.uq.edu.au/view/UQ:7c76d56>
- Goel, V. (1995). *Sketches of thought*. MIT press.
- Goldschmidt, G. (1991). The dialectics of sketching. *Creativity Research Journal*, 4(2), 123–143. <https://doi.org/10.1080/10400419109534381>
- Goldschmidt, G. (1994). On visual design thinking: The vis kids of architecture. *Design Studies*, 15(2), 158–174.
- Goldschmidt, G. (2017). Manual Sketching: Why Is It Still Relevant? In S. Ammon & R. Capdevila-Werning (Eds.), *The Active Image* (Vol. 28, pp. 77–97). Springer International Publishing. https://doi.org/10.1007/978-3-319-56466-1_4
- Goulding, J. S., Rahimian, F. P., & Wang, X. (2014). Virtual reality-based cloud BIM platform for integrated AEC projects. *Journal of Information Technology in Construction*, 19, 308–325.
- Hanna, R., & Barber, T. (2001). An inquiry into computers in design: Attitudes before–attitudes after. *Design Studies*, 22(3), 255–281.
- Hegazy, M., & Saleh, A. (2023). Evolution of AI role in architectural design: Between parametric exploration and machine hallucination. *MSA Engineering Journal*, 2(2), 262–288.
- Lawson, B. (2002). CAD and creativity: Does the computer really help? *Leonardo*, 35(3), 327–331.
- Lee, H.-K. (2017). From Sketch to Screen, from Scratch to Competence. *International Journal of Art & Design Education*, 36(3), 303–314.
- Lim, S., Duffy, A. H., & Lee, B. (2001). *Intelligent computational sketching support for conceptual design*. <https://oro.open.ac.uk/37887/>
- Lin, C. (2003). Seeing Moving Seeing Model for Computer Media. *8th International Conference on Computer Aided Architectural Design Research in Asia, Bangkok*, 199–208.

https://papers.cumincad.org/data/works/att/caadria2003_a2-3.content.pdf

- Madrazo, L. (1999). Types and instances: A paradigm for teaching design with computers. *Design Studies*, 20(2), 177–193.
- Putra, A. M., Hardiman, G., Sardjono, A. B., Madyamadja, E., & Cahyandarirl, G. I. (2022). The effect of manual sketching on architectural design process in digital era. *Journal of Theoretical and Applied Information Technology*, 100(2). <http://www.jatit.org/volumes/Vol100No2/10Vol100No2.pdf>
- Robertson, B. F., Walther, J., & Radcliffe, D. F. (2007). *Creativity and the use of CAD tools: Lessons for engineering design education from industry*. https://asmedigitalcollection.asme.org/mechanicaldesign/article-abstract/129/7/753/462646?casa_token=SI6tzk1-2IUAAAAA:1mFqurZnXrl5cF3Zi1B_J074GctIR6NxcWB8AnBGj2Zwt_5pD0-kNuq6uiUOS_O0STonFZuV&casa_token=2PDBluc4X1wAAAAA:POx6RENDThA3UXcQAU5c2YxinRev7LluTD9AVkFgz7TODzGLvxjgismZizlnXwPMDZj-PdFy
- Römer, A., Pache, M., Weißhahn, G., Lindemann, U., & Hacker, W. (2001). Effort-saving product representations in design—Results of a questionnaire survey. *Design Studies*, 22(6), 473–491.
- Sachse, P., Leinert, S., & Hacker, W. (2001). Designing with computer and sketches. *Swiss Journal of Psychology/Schweizerische Zeitschrift Für Psychologie/Revue Suisse de Psychologie*, 60(2), 65.
- Shih, Y. T., Sher, W. D., & Taylor, M. (2015). Understanding creative design processes by integrating sketching and CAD modelling design environments: A preliminary protocol result from architectural designers. *ArchNet-IJAR: International Journal of Architectural Research*, 9(3), 76.
- Svetel, I., Kosić, T., & Pejanović, M. (2018). Digital Vs. Traditional design process. *Proceedings of 5th International Academic Conference on Places and Technologies, "Places and Technologies 2018—Keeping up with Technologies to Adapt Cities for Future Challenges,"* 453–460.
- Tang, H.-H., Lee, Y. Y., & Gero, J. S. (2011). Comparing collaborative co-located and distributed design processes in digital and traditional sketching environments: A protocol study using the function-behaviour-structure coding scheme. *Design Studies*, 32(1), 1–29.
- Utterback, J. M., Ekman, S., Sanderson, S. W., Vedin, B.-A., Verganti, R., Tether, B., & Alvarez, E. (2006). *Design-inspired innovation*. World Scientific. [https://books.google.com/books?hl=tr&lr=&id=_6PICgAAQBAJ&oi=fnd&pg=PR5&dq=Utterback,+J.M.+\(2006\).+Design+Inspired+Innovati](https://books.google.com/books?hl=tr&lr=&id=_6PICgAAQBAJ&oi=fnd&pg=PR5&dq=Utterback,+J.M.+(2006).+Design+Inspired+Innovati)

on.+New+York:+World+Scientific+Publishing+Co.&ots=EkXS3VYEy&sig=gg2V_78tNluaU6L3i96XifY0Kkc

- Van Elsas, P. A., & Vergeest, J. S. M. (1998). New functionality for computer-aided conceptual design: The displacement feature. *Design Studies*, 19(1), 81–102.
- Veisz, D., Namouz, E. Z., Joshi, S., & Summers, J. D. (2012). Computer-aided design versus sketching: An exploratory case study. *AI EDAM*, 26(3), 317–335.
- Verstijnen, I. M., van Leeuwen, C., Goldschmidt, G., Hamel, R., & Hennessey, J. M. (1998). Sketching and creative discovery. *Design Studies*, 19(4), 519–546.
- Won, P.-H. (2001). The comparison between visual thinking using computer and conventional media in the concept generation stages of design. *Automation in Construction*, 10(3), 319–325.
- Zhang, C., Wang, W., Pangaro, P., Martelaro, N., & Byrne, D. (2023). Generative Image AI Using Design Sketches as input: Opportunities and Challenges. *Creativity and Cognition*, 254–261. <https://doi.org/10.1145/3591196.3596820>
- Zhou, Y. (2021). *Sketch with Artificial Intelligence (AI): An Attempt to Integrate Artificial Intelligence in Architecture Conceptual Design* [PhD Thesis]. University of Hawai'i at Manoa.