The Impact of the Use of Computer-Assisted Drawing Tools on the Productivity of Architectural Design Process

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CHAPTER V

This empirical study delves into the architectural design process, focusing on the influence of computer-aided drawing tools (CAD tools) during the initial design stages. The primary objective is to assess quantitatively how the adoption of CAD tools affects design productivity. The research employs the protocol analysis method, conducted in two distinct phases. In the first, third-year architecture students were tasked with two design assignments. The first assignment required traditional freehand sketches, while the second involved CAD tools. The Concurrent verbalization technique was employed to capture design actions and thoughts.

In the subsequent phase, the research involved a detailed description and comparison of the two sets of design protocols. The analysis yielded intriguing findings. Contrary to conventional assumptions, our study reveals that the utilization of CAD tools during early design phases can have unintended consequences. While these tools offer digital precision and convenience, they may inadvertently hinder cognitive productivity. Designers using CAD tools exhibited hesitation and indecision, resulting in extended design timelines, and reduced ideational productivity. These findings have significant implications for architectural education and practice. They underscore the need for a balanced approach to CAD tools integration into design processes. Educators and professionals should consider the potential impact of these tools on the creative process, leading to a reevaluation of their role in architectural design curricula and workflows. Future research could explore strategies to optimize CAD tool usage, aiming to mitigate their disruptive effects on early-stage architectural design. Additionally, investigations into the role of training and interface design in enhancing the synergy between designers and digital tools offer promising research directions.

In summary, this study highlights the complex relationship between CAD tools and cognitive productivity in architectural design, prompting a reexamination of their role in shaping the design landscape.

Introduction

The Impact of the Use of Computer-Assisted Drawing Tools on the Productivity of Architectural Design Process

Every day, new technological tools are created to assist architects in their work, and these tools are revolutionizing the way architects approach design. In the midst of this transformative wave, a spirited debate has arisen within the community of architects, designers, and design teachers. This debate pits the time-honored practice of hand-drawing against the innovative power of Computer-Aided Design (CAD) tools. One camp ardently champions the enduring significance of hand-drawing, asserting that sketching by hand remains not only a cherished tradition but also an indispensable tool, especially in the early stages of design work. They argue that drawing nurtures creativity, allows tactile exploration, and establishes a profound connection between the architect and the design. On the opposing front are advocates of CAD tools who, with equal fervor, contend that digital technologies offer unmatched speed and early visualization capabilities. CAD tools, they assert, streamline the design process, enhance efficiency, and facilitate rapid exploration of design possibilities. This ongoing debate raises fundamental questions about the role of drawing and CAD tools in contemporary architectural practice and education, questions that our study seeks to address through empirical research.

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The architectural design process is currently a focal point of extensive research, driven by the proliferation and diversity of publications dedicated to this dynamic field. These works collectively underscore a profound transformation in architectural work techniques, spurred by the integration of cutting-edge technologies. Among these technologies, the adoption of CAD tools stands out as a game-changer, fundamentally reshaping how architects approach their craft. In this era, traditional tools like tracing paper and pencils have gracefully made way for CAD tools, while drawing boards have yielded to digital screens. Even the concept of archiving architectural plans has transitioned into the digital realm. These technological strides not only substitute traditional tools but also provoke a fundamental reconsideration of timeless design practices, such as drawing, casting a spotlight on their profound influence on the architectural design process itself.

In response to this paradigm shift, researchers have embarked on a mission to scrutinize the role CAD tools play during the conceptual design phase. Their mission is to provide empirical evidence that deciphers the intricate links between CAD tools and architectural design (Putra, A. M. & al., 2022; Fakhry, M. & al., 2021; Heidari, P., & Polatoglu, Ç., 2019; Al-Matarneh & Fethi, 2017; Bilda, Z. & Gero, JS., 2005; Montès, F. & De Biasi, P.M., 2000).

Amidst this vibrant discourse, four pivotal questions emerge. The two first are thematic and the two last are methodologic.

1. Does the introduction of CAD tools during the early stages of the architectural design process affect its cognitive productivity?
2. If yes, in what manners?
3. How would it be possible to quantify this impact?
4. Which method should we use to grasp all the aspects of the design activity?

These questions form the bedrock of our study, signifying its profound importance in the ongoing dialogue about the future of architectural design. They induce two main hypotheses.

1. The introduction of CAD tools during the early stages of the architectural design process affects its cognitive productivity.
2. The impact of CAD tools on the cognitive productivity of the early stages of architectural design process is quantifiable notably through the efficiency measure introduced by Goldshmidt (1995).

Our study is poised to answer these pressing questions and to measure the validity of these hypotheses. It holds immense significance for several reasons. Firstly, as the architectural community increasingly embraces CAD tools, there is a critical need to understand their impact on the cognitive dimensions of architectural design. Architects and designers grapple with the integration of these tools into their creative processes, and our research aims to provide empirical evidence to inform these critical decisions.

Moreover, our findings bear direct implications for architectural design teaching. As design pedagogy evolves in response to technological advancements, our study equips educators with evidence-based insights to refine curricula and instructional methods. By shedding light on the impact of CAD tools on design efficiency and cognitive processes, we contribute to the enhancement of architectural design education. Our research empowers instructors to prepare students for the evolving landscape of architectural practice, ensuring that emerging architects possess the skills and knowledge necessary to harness the potential of technology while preserving the essence of creative design.

Secondly, in an era where technology, including AI, is rapidly transforming various domains, comprehending its implications for creative fields like architecture becomes paramount. The architectural design process, with its blend of artistry and technical precision, serves as a compelling case study for exploring the transformative power of technology. By examining efficiency and cognitive aspects, our study offers a unique perspective on the evolving landscape of architectural design in the digital age.

In summary, our research is poised to illuminate the path forward for architectural design, where CAD tools and technology are becoming increasingly integral. We aim to offer insights that not only enhance the efficiency of architectural design but also foster a deeper understanding of the cognitive processes at play. Additionally, we contribute to the evolution of architectural design teaching, equipping educators with evidence to guide the next generation of architects in an increasingly technology-driven world.

2. Protocol analysis Method

Protocol analysis is an empirical and observational research method commonly used in design research. It has been widely used in design research since its introduction by Eastman in the late 1960s. (Eastman, C.M, 1969) It has proven to be a valuable method for understanding the cognitive aspects of the design process and exploring the influences of various factors on design activities (Craig, D.L, 2001; Jiang, H., &Yen, C. C, 2009; Cross, N., Christiaans, H. and Dorst, K.; 1996). Researchers use protocol analysis to gain insights into designers' thinking processes, problem-solving strategies, and the impact of different tools and techniques on design outcomes.

The process of protocol analysis typically consists of two phases. The first phase involves collecting empiric data through the recording of a designer's overt behaviors, such as verbalizations, sketches, and audio-visual manifestations (Newell, A., 1966), when achieving a design task. These records, known as design protocols, provide a detailed account of the designer's actions and thoughts during the design process. The second phase involves the analysis and interpretation of the collected data. During this phase researchers examine the protocols to describe and analyze the design process, identifying patterns, strategies, decision-making processes, and other relevant information.

By employing protocol analysis in this study, researchers aim to collect detailed data on the design processes with and without CAD tools, enabling a thorough analysis of the impact of CAD on the productivity and cognitive aspects of architectural design activity.

2.1. Verbalization Techniques

Within the framework of design research, the protocol analysis method employs two distinct verbalization techniques: the think-aloud and retrospective. The think-aloud technique involves the real-time verbalization of thoughts during the design process, whereas the retrospective one entails verbalization occurring subsequent to the completion of design work. In their comprehensive examination, Gero and Tang (2001) discerned that both techniques possess inherent advantages and address specific limitations.

Notably, simultaneous protocols, also called think-aloud method, offer a more expansive and nuanced perspective, particularly in the early phases of the design process. This comprehensive insight facilitates the sequential identification and analysis of the designer's thoughts as they naturally unfold. Considering these considerations, we have chosen to adopt the think-aloud technique as the preferred approach for our research study.

2.2. Approaches in Protocol Analysis for Data Collection

In the domain of protocol analysis, a notable dichotomy exists in the approaches employed for data collection and acquisition. These approaches are distinguished as the process-oriented approach and the content-oriented one.

The process-oriented approach is fundamentally oriented towards the comprehensive depiction and elucidation of the design process itself. This entails a meticulous examination of the sequential actions and decision-making procedures undertaken by designers during the course of their work. In contrast, the content-oriented approach directs its attention towards the substantive facets and intellectual content embedded within the design. It seeks to delve into the intrinsic essence of the design, encompassing its cognitive underpinnings.

Given the specific thematic focus of our research, which centrally revolves around the cognitive dimensions inherent in the design process, our methodological selection deliberately leans towards the content-oriented approach. This strategic alignment serves as the foundational framework that underpins our investigative endeavors.

2.3. Protocols Description

To access the extensive information contained within design observations or protocols, we adhere to the well-established protocol analysis methodology, which comprises two pivotal phases: segmentation and codification.

2.3.1. Segmentation

Segmentation, a pivotal facet of the analysis process, involves the dissection of the design protocol into smaller, coherent units or segments, guided by specific criteria. These criteria for segmentation may vary, contingent upon research objectives and the inherent characteristics of the design activity. Segmentation parameters encompass actions, decisions, shifts in focus, or other pertinent considerations. This process empowers researchers to discern and scrutinize distinct stages or phases within the design process, along with the transitions and transformations that occur therein.

The primary aim of segmentation is to break down the design protocol into manageable, discrete units, facilitating separate examination and coding. Each segment constitutes a discrete reservoir of information, amenable to evaluation in terms of its substance, contextual relevance, and interconnections with other segments. (Arrouf, 2012)

Within our context, each segment conveys a coherent assertion or declaration concerning a singular element, space, or subject within the design progression. These segments may vary in length, encompassing a solitary action or a sequence of actions. (Arrouf, 2006)

2.3.2. Codification

Following the segmentation phase, the subsequent step is codification, wherein each segmented unit undergoes individual processing. Codification entails the assignment of designated codes or labels to each segment based on pre-established categories or thematic frameworks. Segmentation and codification work in concert, serving as complementary stages within the protocol analysis methodology. Segmentation delineates the units of examination, while codification provides a structured framework for the categorization and analysis of the segmented elements.

The fundamental purpose of codification is to systematically categorize and structure the segments in alignment with their intrinsic content or distinctive attributes. This systematic codification process equips researchers with the means to methodically dissect the data, identify recurring patterns, establish correlations, and unveil overarching themes within the design process.

By adhering to the conventional protocol analysis methodology, researchers attain a systematic framework for structuring and dissecting the amassed observations. The meticulous segmentation and codification procedures serve as the linchpin for comprehending the data, extracting pertinent insights, and unravelling the intricate facets of design activities, strategies, and cognitive processes at play.

It is pertinent to acknowledge that variations of the standard protocol analysis methodology may be applied by researchers in accordance with the specific objectives and contextual nuances of their research. The paramount objective remains the structured organization and coding of data, thereby facilitating meaningful analysis and interpretation.

To code the collected protocols, researchers often employ a coding scheme that varies based on the research goals and objectives.

2.3.3. The coding scheme

To delineate the comprehensive observational compendia, Arrouf (2012) devised an intricate coding strategy, drawing from cognitive science insights into the perceptual and conceptual dimensions of human cognition. Inspired by the coding systems advanced by Suwa and Tversky (1997); Suwa, Gero & Purcell (1998), and McNeil et al. (1998), He constructed an elaborate coding scheme that encompasses eleven distinct informational categories, each associated with a specific cognitive level. This meticulously crafted scheme facilitates a thorough and nuanced codification of the cognitive intricacies inherent in the design process. Arrouf (2012) defined these categories as follows:

1. External Perception Category (PE)
It belongs to the cognitive level of perception. It records actions of perception of the design setting data and the designer's interpretations.

2. Internal Perception Category (PI)
It also belongs to the cognitive level of perception, but it focuses on the perception that takes place within the design process.

3. Sense figuration category (FS)
It records the actions of figuration of sense which produce abstract and ambiguous figures.

4. Morphic Figuration Category (FM)
It regroups the actions of figuration of the object under-design shape and the actions which allow the passage towards this shape figuration.

5. Prior Knowledge Reference Category (RE)
This category of actions, as its name suggests, calls on the prior external knowledge of the designer.

6. Internal Knowledge Reference Category (RI)
It allows the designer to create references and to use them, by constituting a reservoir of knowledge specific to the design situation.

7. Sense Production Action Category (CAS)
This category belongs to the semantic cognitive level. It serves to give and produce sense throughout the design process.

8. Abstract Design Actions Category (CA)
This category also belongs to the semantic level and records six types of actions, which are about strategies, relevancies, goals, and decisions.

9. Morphic Design Actions Category (CM)
It brings together actions like those of the abstract design category, but which are now of a morphic order.

10. Internal Knowledge Reuse Actions Category (RCI)
This category allows the designer to go back very far in the time of the process to reuse previously generated information or knowledge.

11. Evaluation Actions Category (CR)
The actions in this category evaluate the different morphic productions in relation to goals, strategies, and relevance previously produced.

3. Experience

The protocol analysis method encompasses a two-phase experiment, as elucidated by McNeill et al. (1998). The initial phase, known as the preliminary exercise, involves the experimenter acquainting the subjects with the verbalization technique. This phase includes addressing any inquiries to ensure a thorough comprehension of the process. Subsequently, in the second phase, referred to as the experiential phase, the subjects actively participate in a 45-minute design session.

3.1. Participants

The experiment engaged the voluntary participation of four third-year architecture students, comprising two male and two female individuals. The primary objective was to gather data through two distinct design sessions, each focusing on a specific design task.

3.2. Design task

The participants were asked to complete two design tasks: one employing freehand drawing and the other utilizing the ArchiCAD® drawing software. Each design session had a duration of 45 minutes, with separate sessions dedicated to each task on different days.

Throughout the experiment, participants were instructed to engage in verbal thinking aloud while designing, articulating their thoughts and actions. The experimenter consistently reminded them to vocalize their thought processes throughout the experiment.

For the freehand design task, participants were assigned the challenge of designing a house on a 300 m2 plot. Their design brief encompassed creating a two-level house that included specific elements, such as a small garden, a garage, three bedrooms, two bathrooms, two toilets, a kitchen, a dining room, a living room, and an office. To facilitate the task, participants were provided with a spacious table equipped with an array of drawing materials, including pencils, markers, colored pencils, and tracing paper ***(Fig. 1).***

Figure 1. *Photos taken during freehand work, by authors (2013)*

In contrast, when working with ArchiCAD®, participants exclusively relied on computer tools, completely replacing traditional drawing materials. For this particular assignment, students were instructed to design a prestigious restaurant in proximity to the university. The restaurant's design parameters encompassed various functional areas, including a reception area, a dining room, a pantry, a cloakroom, customer restroom facilities, a kitchen, storage areas, a manager's office, a staff area, restroom facilities for staff members, a service courtyard, and a terrace that served as an extension of the dining room ***(Fig. 2).***

Figure 2. *Photos taken during work with informatics tool, by authors (2013)*

3.3. Data collection technique

To document the design activities, a dual-camera setup was employed. During the freehand task, one camera was positioned in front of the subject, while the other was focused on the worktable, providing a clear view of the produced drawings ***(Fig. 3).***

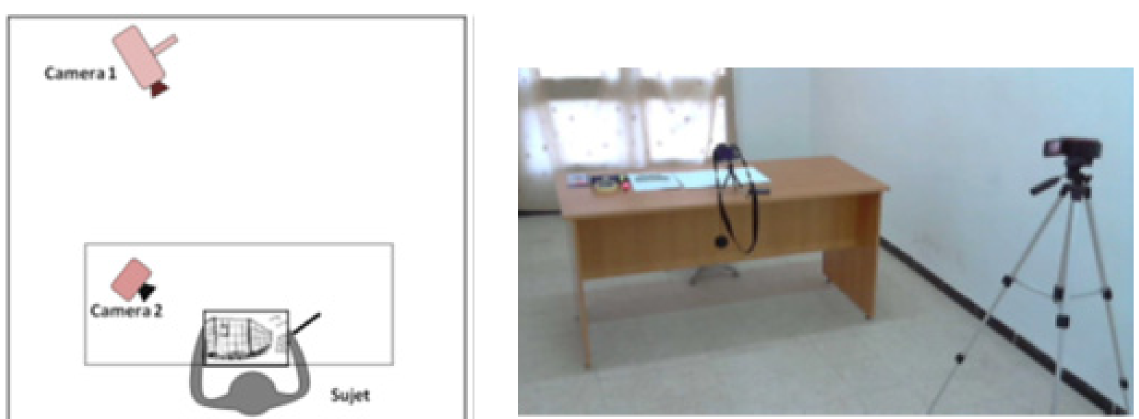


Figure 3. *The experimental setting for the free-hand session, by authors (2013)*

Conversely, during the software-based task, one camera was situated in front of the designer, while the second camera was positioned above the designer's shoulder to capture the screen and display the digital drawings ***(Fig. 4).***

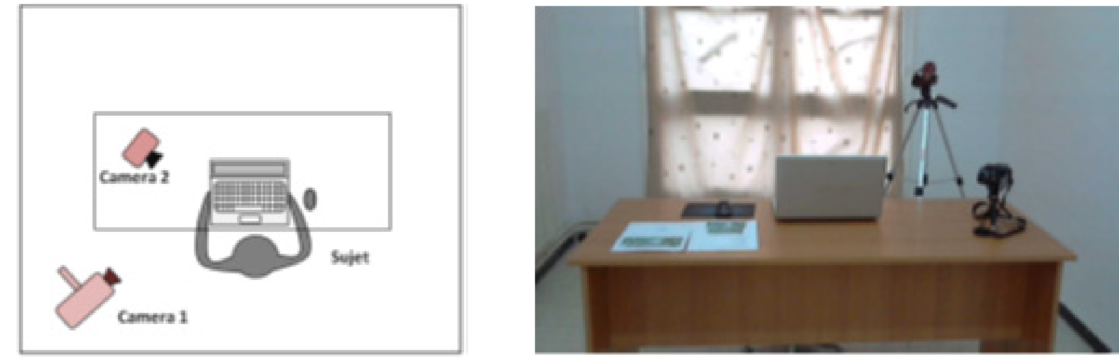


Figure 4. *The experimental setting with CAD tools, by authors (2013)*

3.4. Collected data

The experiment yielded two types of data. The first type comprised graphic productions collected on paper for the freehand session ***(Fig. 5)*** and digitally saved for the software-based session ***(Fig. 6).*** The second type encompassed verbalizations and gestures made by the designers, which were subsequently extracted from the video recordings by the experimenter.

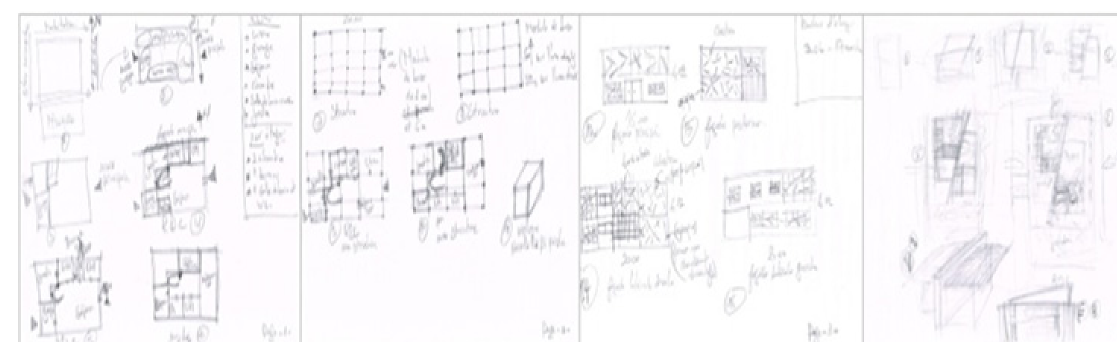


Figure 5. *Some collections from the first design task (individual house), (2013).*

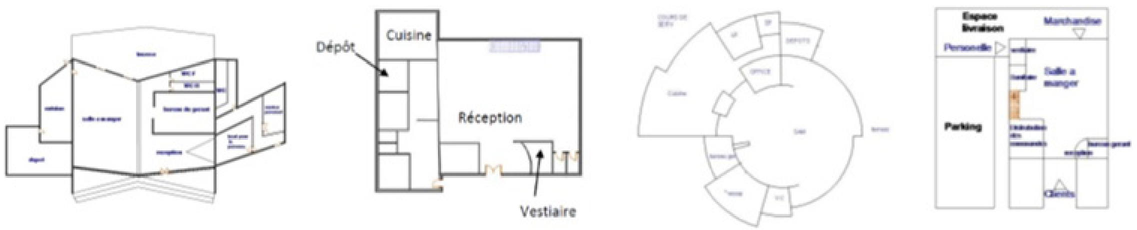


Figure 6. *Some collections from the second design task (a restaurant of high standing), (2013).*

3.5. Description of the collected data

Post-experiment, a comprehensive review of the recorded videos was conducted to transcribe the verbalizations of each participating designer. This transcription process culminated in a text corpus, which was subsequently segmented and codified in accordance with our predefined coding scheme ***(Table 1).***

4. Results

To measure cognitive productivity, we adopt concept of efficiency as echoed from Goldschmidt (1995).

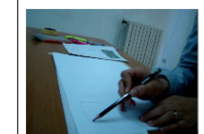
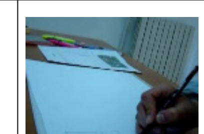
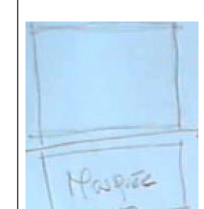
4.1. Efficiency Assessment

Goldschmidt's conceptualization of efficiency is rooted in the optimization of design actions and the minimization of the path length required to attain the intended outcome. In order to operationalize this concept, we undertook an assessment of efficiency within the design process at two distinct levels.

4.1.1. Efficiency at the Cognitive Path length Level

In the initial level of analysis, we conducted a comparative evaluation of the "cognitive paths" within each design process. To execute this assessment, we considered both the number of segments and the duration of the design activity. Specifically, we compared the lengths and durations of two key components: the global path, representing the entirety of the design process, and the elementary paths, corresponding to the individual segments, within each of the eight design processes.

Table 1. Description model (codification of the segments number 1 and 2, excerpt of subject 2 freehand work -SSO2-).

Time	N. Segments	Verbalizations and Actions	Graphic Production	Action Category	Explanation
2.09'	**1**	Depending on the plot of land the project can have 4 façades.	 	**PE** **CAS** **RI** **FM** **RE** **CA**	Interpretation Of project data «Land to Façades ». Introduction of a conceptual notion "façade". Creation of a reference Of conceptual notion. Represent and visualize the conformation of the land and the idea of the 4 façades. Refer to the substantive knowledge of the field. Identify an abstract relevance "know the number of façades"
2.11'	**2**	We note the presence of a mosque.	 	**CA** **RI** **FS** **FM** **PI** **RI**	Identify an abstract relevance « the existence of a mosque ». Creation of a relevance reference. Producing non morphic abstract figures «Writing: mosque» Represent the Conformation of the object. Visual perceptual interpretation of visual data. Use of internal references Previously generated

• The Length of Design Processes

Table 2. Number of segments and duration in time, of the processes of all subjects.

The Process	Number Of Segments	Duration	State of The Design Task
SSO-1-(Subject 1 without CAD)	53	28':47	Complete
SAO-1-(Subject 1 with CAD)	35	45':00	Incomplete
SSO-2-(Subject 2 without CAD)	113	41':07	Complete
SAO-2-(Subject 2 with CAD)	60	45':00	Incomplete
SSO-3-(Subject 3 without CAD)	112	34':12	Complete
SAO-3-(Subject 3 with CAD)	94	45':00	Incomplete
SSO-4-(Subject 4 without CAD)	98	44':51	Complete
SAO-4-(Subject 4 with CAD)	40	45':00	Incomplete

The table presented above delineates the process length data for the eight analysed collections, denoting the count of segments within a designated time frame. A comparative analysis of these eight processes reveals noteworthy distinctions. Notably, when CAD tools were employed, participants did not manage to conclude their designs within the allocated 45-minute time-frame, in contrast to the manual sketching sessions, which featured a higher number of segments ***(Table 2).***

These findings signify a palpable influence of CAD tool utilization on the temporal dimensions of the design activity. Specifically, CAD tools exhibited a propensity to diminish the number of segments while concurrently extending the duration of architectural design work. This phenomenon underscores the deleterious impact of CAD tools on the productivity of the architectural design process, primarily through the elongation of task completion times.

The observed effects on process length and completion time serve as a pertinent reminder of the imperative to consider the ramifications of CAD tool integration in architectural design practice. Design professionals must remain cognizant of potential work-flow disruptions associated with CAD tools and pro-actively institute measures to optimize their processes, thus mitigating any adverse effects on productivity.

• Average segment length analysis

As previously elucidated, the cognitive efficiency of the design process hinges on the intricate interplay between its duration and productivity. Efficiency, in this context, manifests in the ability to generate solutions and ideas within a compressed time-frame. In our study, we have adopted an intention-oriented segmentation approach, wherein each segment represents a novel intention, idea, or manipulated object within the design process. Consequently, the quantity of segments not only signifies the volume of ideas under the purview of the process but, when coupled with the average segment length, affords valuable insights into the efficiency and intensity of cognitive exertion.

Figure 7 serves as an illustrative representation of our findings, spotlighting the disparities in average segment lengths between processes involving CAD tools and those executed in a hands-free manner. Several factors contribute to this disparity. Firstly, the proclivity for indecision and fluctuating intentions is conspicuous in CAD-driven processes, leading to frequent alterations in decisions and strategies without crystallizing a definitive idea. This vacillation invariably prolongs the segment lengths, as the design process grapples with the quest for a precise direction. Secondly, the temporal investment necessitated by CAD software operations, encompassing activities such as level adjustments, object creation, and drawing element selection, contributes substantially to the elongation of segment durations.

The integration of CAD tools, as evidenced by these findings, engenders inefficiencies within the design processes, accentuated by heightened hesitancy, fluctuation, and temporal demands. Consequently, the design workflows involving CAD tools tend to exhibit reduced fluidity and diminished intensity in comparison to hands-free processes. This accentuates the imperative of comprehending the implications of CAD tool utilization on cognitive efficiency and underscores the incumbent responsibility on designers and teachers to acknowledge these constraints, thereby augmenting their design processes and those of their students.

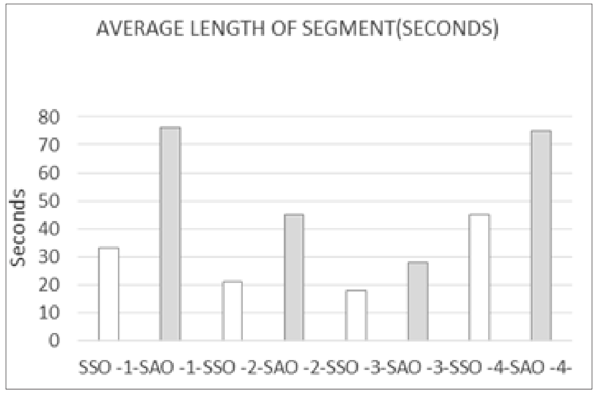


Figure 7. *The average length of segments (seconds), by authors (2013).*

• The average length of the first five segments analysis

Throughout our experimental endeavours, an intriguing pattern emerged concerning the generation of effective ideas within the design processes. We consistently observed that, irrespective of whether CAD tools or free-hand techniques were employed, the inception of effective idea generation uniformly commenced at the fifth segment. However, upon delving into the examination of the average length of these initial segments, a noteworthy divergence materialized—processes involving CAD tools exhibited considerably lengthier segments in comparison to their counterparts employing free-hand techniques, as delineated in ***Figure 8.***

This observation implies that design processes reliant on CAD tools grappled with a slower commencement. The prolonged segment durations signify that designers employing CAD tools invested more time in the cultivation and refinement of their ideas before embarking on the phase of generating effective solutions. This delay could be attributed to various factors, encompassing the learning curve associated with CAD software or the intricacies inherent to navigating through the multifaceted design features imposed by the tool.
In summation, our findings substantiate the notion that design processes involving CAD tools tend to experience a more sluggish initiation concerning the generation of effective ideas in comparison to their free-hand counterparts. Consequently, it becomes evident that if the primary objective of the initial five segments is to instigate the design activity, achieving this objective is notably more arduous in computer-based processes. Consequently, we can infer that CAD tools introduce inefficiencies at the outset of the design activity. This phenomenon may be attributed to the immediate freedom and flexibility afforded by free-hand techniques, enabling designers to manifest their ideas in a more intuitive and spontaneous manner.

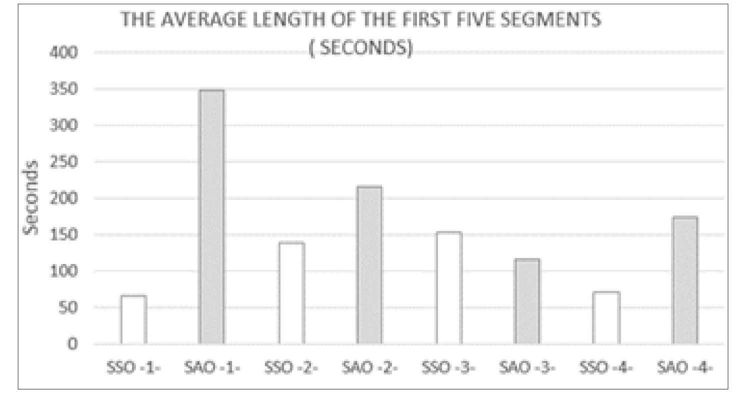


Figure 8. *The average length of the first five segments, by authors (2013).*

• Number and percentage of ideas in each process analysis

As previously noted, the juxtaposition of the number of segments in processes conducted without the use of CAD software (SSO1, SSO2, SSO3, and SSO4) and those employing CAD tools (SAO1, SAO2, SAO3, and SAO4) reveals a discernible dissimilarity, with the former exhibiting a greater abundance of segments. To delve further into the ramifications of software utilization on the character and content of these segments, we conducted a meticulous examination of the number and proportion of segments dedicated to design ideas, as depicted in ***Figure 9.***

Figure 9 conspicuously illustrates that processes devoid of CAD tools manifest a significantly higher count of ideas. This observation underscores that the use of CAD tools appears to curtail the generation of ideas within the design process. To ensure that the upsurge in the number of ideas within software-free processes is not merely a consequence of their larger segment count, we calculated the percentage of ideas for each process.
The percentage of ideas corroborates the earlier observation that processes conducted without the aid of CAD tools engender a substantial quantity of ideas in contrast to those reliant on CAD tools. This substantiates the proposition that the incorporation of CAD tools exerts a dampening influence on ideation productivity throughout the design process.
These findings underscore the profound impact of CAD software on idea generation and intimate that its utilization may constrict the quantity of ideas generated during the design process. It is imperative to acknowledge that additional factors, such as the designers' familiarity and proficiency with CAD tools, may also contribute to the observed disparities. Nevertheless, the data depicted in Figure 9 lend credence to the assertion that the integration of CAD tools can impose a constraining effect on ideation within the design process.

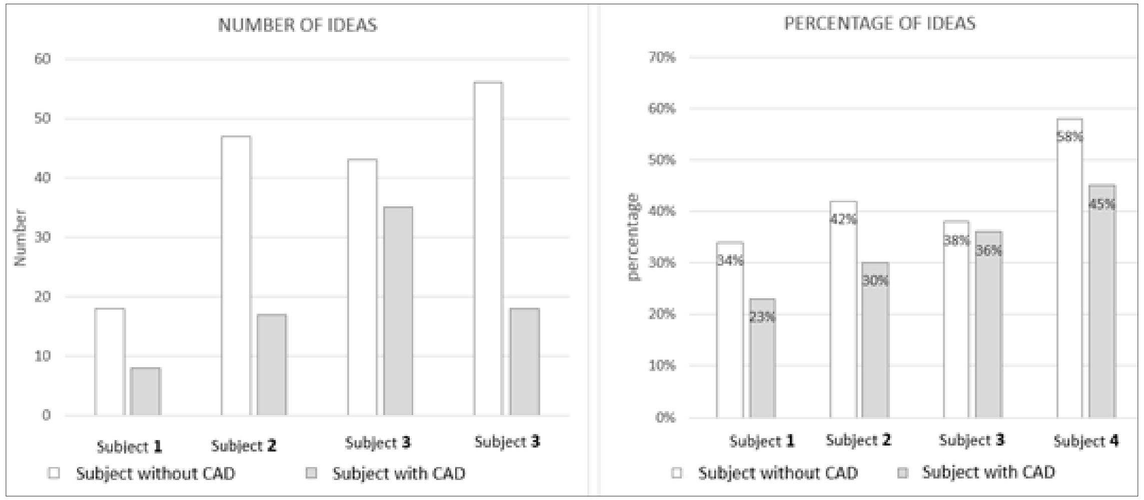


Figure 9. *Number and percentage of ideas for the eight analysed processes), by authors (2013).*

- **Number of actions and Number of actions by segment in each process**

Table 3 presents a comparative analysis of the number of actions expended in each process, both with and without the utilization of CAD tools. The table encompasses the total count of actions as well as the average number of actions per segment for the eight processes under scrutiny.

Consistently, it becomes evident that both indicators register higher values in the processes conducted without the aid of CAD tools in contrast to those incorporating them ***(Figure 10)***. This discernible trend underscores that the incorporation of drawing software effectively curtails the number of design actions across all categories.

It is worth noting that when considering the average length of segments in free-hand processes, which is typically less extensive than that of segments in processes employing software, the overall reduction in the number of actions points toward a decline in the intensity of cognitive activity within these processes.

These outcomes substantiate our prior findings and underscore that the utilization of drawing software leads to a reduction in the intensity of cognitive activity in the design process, consequently diminishing its cognitive productivity.

Table 3. Number of actions and Number of actions by segment for the eight analysed process

The Process	Number Of Actions	Number Of Actions/Segments
SSO-1-(Subject 1 without CAD)	254	4,79
SAO-1-(Subject 1 with CAD)	158	4,51
SSO-2-(Subject 2 without CAD)	647	5,72
SAO-2-(Subject 2 with CAD)	314	5,23
SSO-3-(Subject 3 without CAD)	554	4,94
SAO-3-(Subject 3 with CAD)	397	4,22
SSO-4-(Subject 4 without CAD)	513	5,23
SAO-4-(Subject 4 with CAD)	170	4,25

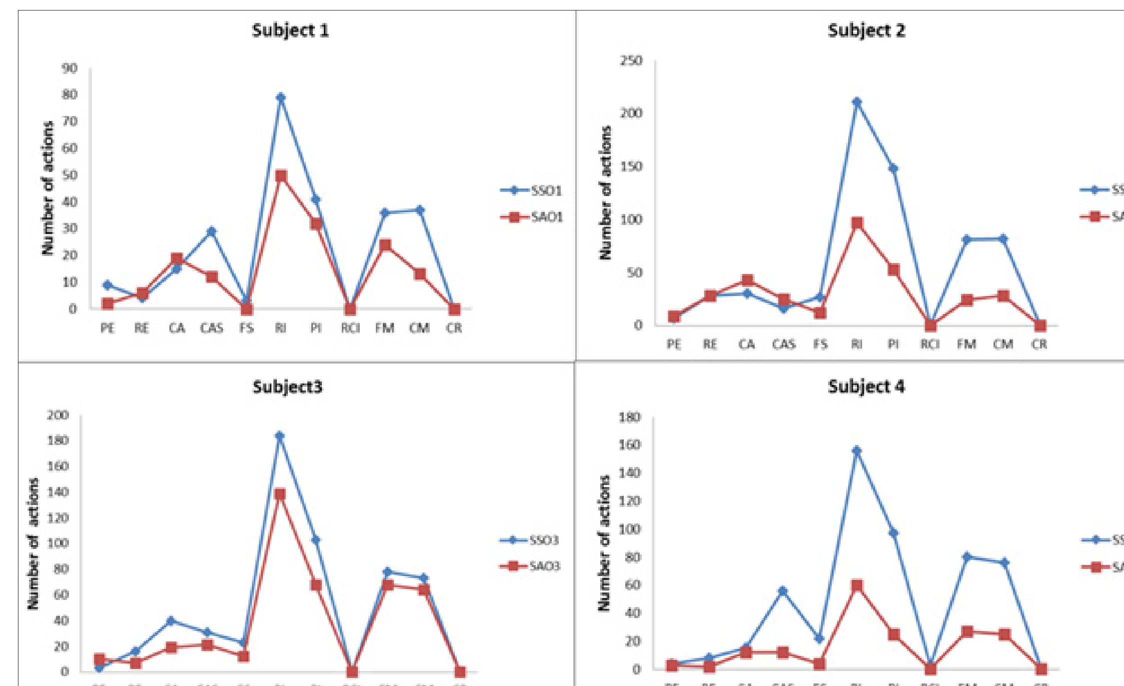


Figure 10. *Number of actions of the eight design processes without software (SSO1), (SSO2), (SSO3), (SSO4) in blue, and with software (SAO1), (SAO2), (SAO3) and (SAO4) in red, by authors (2013).*

5. Conclusion

The principal objective of this research was to assess the influence of computer-assisted drawing tools on design process productivity. The study employed the protocol analysis method, facilitating data collection and the examination of the work undertaken by four architecture students. Each student was tasked with completing two design assignments: one utilizing freehand sketches and the other employing CAD tools.

The investigation has divulged that the integration of CAD tools in the early stages of the architectural design process leads to decreased productivity. This decline can be ascribed to diminished efficiency, resulting in a protracted design process characterized by hesitancy and indecision. Furthermore, CAD tools negatively impact ideational productivity, culminating in a reduction in the intensity of cognitive activity.

These findings have brought to the forefront the challenges associated with CAD tool deployment, including heightened hesitancy, instability, and time consumption. Design processes involving CAD tools lack the fluidity and intensity observed in their freehand counterparts. It is imperative for designers to recognize these constraints and consider their implications for cognitive efficiency to optimize their design work-flow.

Additionally, the study underscores that design processes incorporating CAD tools experience a slower initiation and encounter greater difficulty in generating effective ideas. This disparity can be attributed to the immediate freedom and flexibility offered by freehand techniques, enabling designers to express their ideas intuitively and spontaneously. CAD tools, conversely, may introduce constraints and require additional time for familiarization, which can impact the initial ideation phase.

Considering these findings, we recommend architects and architecture students initiate their design work manually. Once ideas are sufficiently developed, designers can harness computer-assisted drawing tools to facilitate technical drawing, model visualization, and the execution of mechanical or repetitive tasks. By being cognizant of these challenges and making informed decisions regarding tool selection, designers can pro-actively address them and enhance their overall design process. It is equally advisable for architectural design educators to take note of these results and incorporate them into their teaching, emphasizing the value of beginning design work by hand and without CAD tools.

5.1. Limitations of the Study

As with any research endeavour, this study has its limitations. The primary constraint is the sample size, with the experimental work restricted to eight collections (four created manually and four with computer tools) due to practical considerations related to the research's time constraints. Expanding the dataset would undoubtedly strengthen and enhance the reliability of the results.

The study's second limitation pertains to the utilization of a single computer-aided drawing software, specifically ArchiCAD. Incorporating various CAD tools could potentially yield more comprehensive and nuanced results.

5.2. Future Perspectives

The methodology adopted in this study has proven effective in achieving our intended objectives, motivating us to explore several future research avenues to further our understanding of the impact of computer-assisted drawing tools on architectural design. Our forthcoming endeavour include:

1. **Expanding the Corpus:** Broadening the dataset to deepen our analysis and improve the generalizability of results.

2. **Varied CAD Tools:** Investigating the impact of various computer-aided drawing software programs to gain a more comprehensive perspective.

3. **Full Design Process Assessment:** Assessing the influence of computer tools throughout the entire architectural design process, from initial sketches to final projects, to pinpoint the stage at which computer tool usage becomes advantageous.

4. **Collaboration with Computer Scientists:** Collaborating with computer scientists to develop intuitive computer tools that align more closely with freehand work, particularly in the early design phases.

These future perspectives aim to provide a more comprehensive understanding of the intricate relationship between computer-assisted drawing tools and architectural design, ultimately contributing to improved design processes and outcomes.

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