Synopsis

of the Ph.D. thesis entitled

Investigating use of CAD during Idea generation stage of Product Design

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Doctor of Philosophy

by

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Introduction

The design process for new product development has seen enormous changes since the introduction of CAD (Aldoy 2011). CAD is an important innovation of this era that has changed the face of the design industry and has influenced the ways designers work today (Brown 2009; Robertson and Radcliffe 2009). However, its introduction and adaptation into the design process have brought in various views and concerns from the researchers. CAD is a very powerful tool for designing. However, it can be beneficial only by understanding and comprehending the limitations and advantages of the tool and being aware and willing to adapt the way it operates.

Many researchers (Stappers and Hennessey 1999, Tovey and Owen 2000, Robertson et al. 2007, Ibrahim et al. 2010, Won 2001) have argued the suitability of CAD when the ideas are crystallized and not for idea generation stage. CAD is well accepted as the drafting, visualization, and detailing tool but not as an exploration tool. Earlier studies (Lawson 2002, Jonson 2005, Won 2001, Abdelhameed 2007, Wojtczuk et al. 2011, Ibrahim et al. 2010, Tovey and Owen 2000) related to CAD compare it with sketching and physical modeling as these are the most established and well-accepted tools for the early phase of design. However, it is crucial to understand that today CAD is used along with sketching and physical modeling and not in isolation. CAD is considered as a new age tool to enhance the designer's ability to design better. The literature review illustrates a shift in the CAD-related research from comparing CAD tools with manual methods to a mixed-medium design environment. This makes it necessary to investigate the barriers and enablers offered by CAD and its effect on creative explorations in today's mixed-media environment.

This study is an attempt to understand ways in which product designers adopt CAD in their design process and how it affects their approach during the idea generation stage. The focus of this study is the exploratory phase of the design stage in the

process of new product development. The exploratory phase is defined as the phase where designers are exploring initial ideas for the given problem and ideas have not been fully defined or evolved into a concept.

Research aim and research question

The research aims to investigate the implications of using CAD during the idea generation stage of product design. It attempts to understand how does CAD position itself as a tool in the mixed-media environment and is used while generating ideas. How does it affect the process and the idea exploration?

Thus the **main research question** is:
How does use of CAD affect creative exploration during idea generation stage of product design?

The main question is further broken into **sub-questions** in order to answer the larger question -

RQ1: How does CAD position itself in the idea exploration stage of design process?
RQ2: What advantages CAD offers to the designer, if used in early phase of design?
RQ3: What limitations CAD impose on the designer's way of thinking?
RQ4: Does using CAD during idea generation results in more vertical exploration and hinders lateral exploration?
RQ5: How does CAD affect the design outcome because of its intervention?

Research scope and limitations

- The focus of the study is the idea generation phase and not the later stages of the design process, where concepts are finalized and tested.

- Research does not aim to compare CAD with other design tools like sketching and physical model making. It focuses only on the domain of product design in the mixed media environment.
- CAD tools in the study are defined as 3D solid modeling tools that are commonly available and used and do not include computer-aided sketching, haptic devices, and virtual reality.

Research design

The research methodology is based on qualitative research. The qualitative approach can be employed to determine the causes that influence the outcomes in a given context and scenario (Creswell 2011). The qualitative research can be intuitive and holistic and aim at achieving the depth of understanding, not breadth (O' Leary 2011). This makes qualitative research a suitable approach for the research context.

The thesis consists of eight chapters to achieve the objective of this research. The summary of each chapter and how it systematically weaves into the next is explained below and illustrated in figure-1 to provide an overview. Further, figure-2 illustrates the various research methods used for the studies.

Chapter 1 introduces the research background and context. It also explains the motivation behind conducting this research. Further, it briefly explains the structure of the thesis.

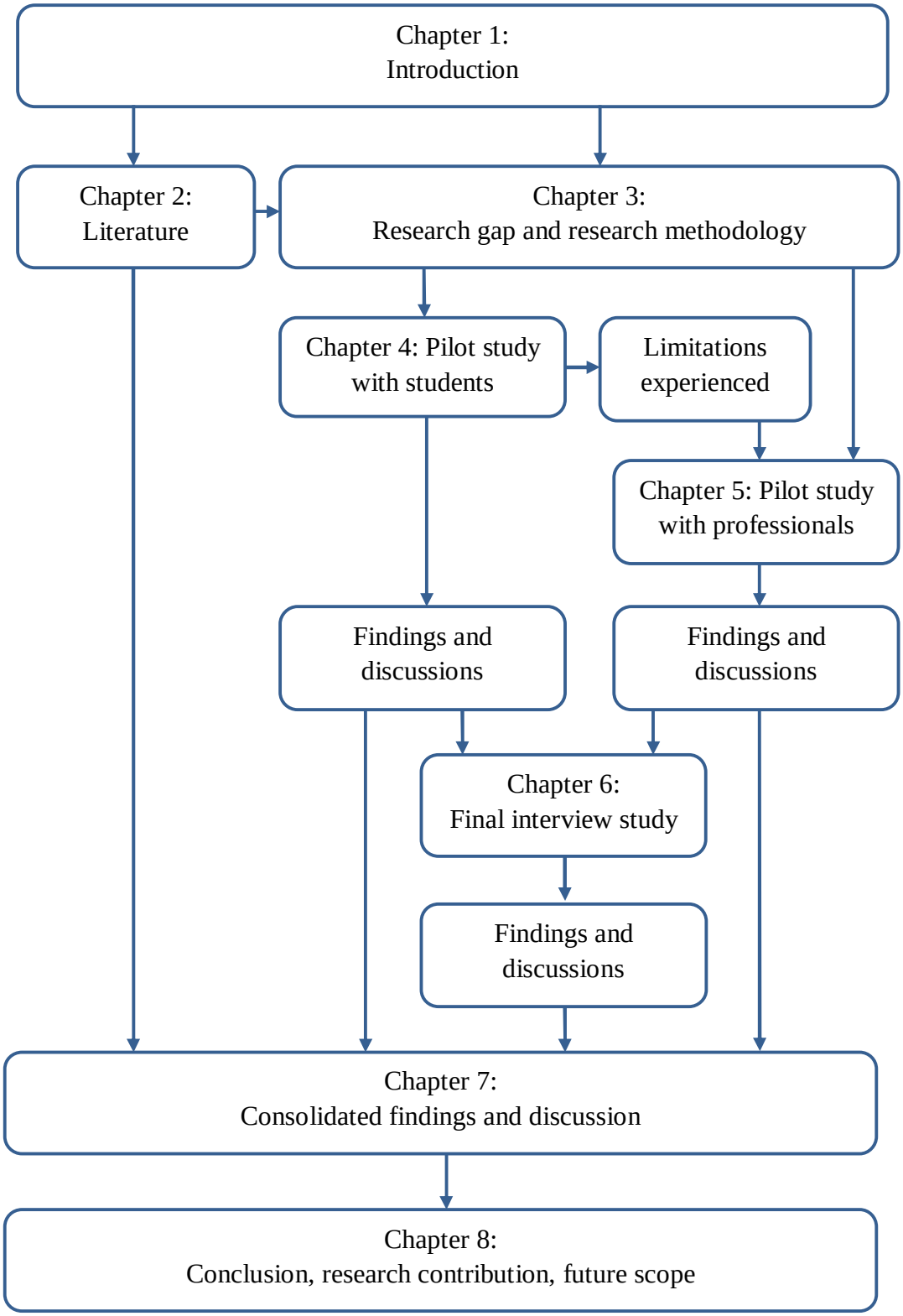

Figure 1: Thesis chapters and their interlinks

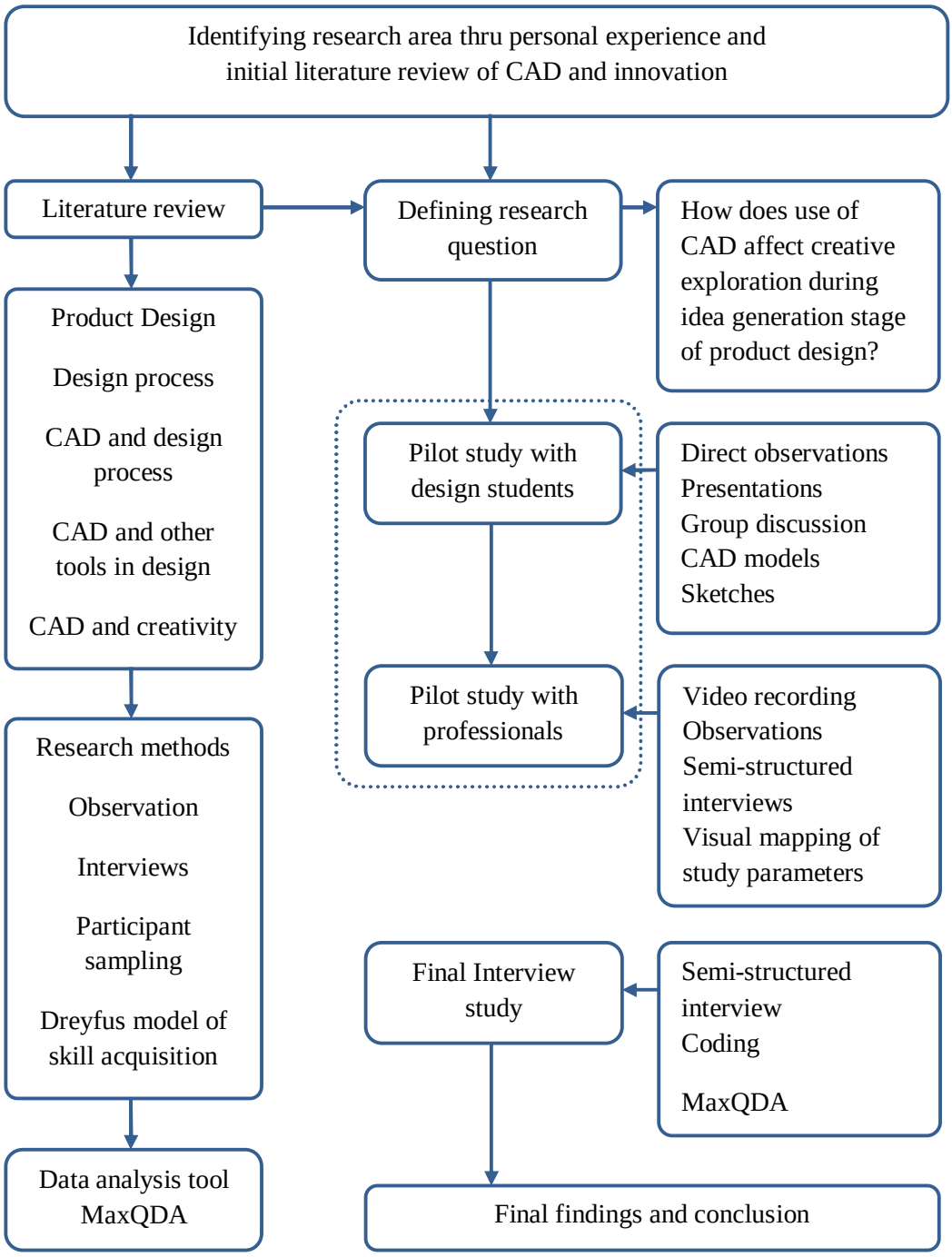

Figure 2: Research plan overview

Chapter 2 reviews the literature pertaining to the area of the research study. It enabled the researcher to identify the gap, define the research question, and formulate a plan for data collection and analysis. The literature review covers the product design process, early idea generation phase, creativity, and its relation to CAD. Literature that compares CAD with other established tool in the process of idea generation like sketching and physical modeling were also analyzed to understand the changing views on the inclusion of CAD in idea generation phase of product design over a period of time and mixed-media environment.

The literature review revealed that various researchers like Van Dijk (1995), Verstijnen (1998), Stappers and Hennessey (1999), Tovey (2000), and Won (2001) have argued that CAD systems are useful only at the design stages where ideas have been sufficiently crystallized. The reasons for this, Tovey (2000) mentioned, as CAD programs focus mainly on producing an end product or form and hence are not very helpful in the conceptualization stage. However, the introduction of digital media has introduced new design methods and processes and the design professionals today are moving beyond the traditional practices (Oxman 2006). Most of the literature reviewed was situated in the context of engineering, architecture and automotive styling. The literature related to CAD in idea generation stage within the context of product design was scarce. This helped identify the gap and focus the study in this direction.

The study parameters identified through literature covered visualization, communication, fixation, bounded ideation, and circumscribed thinking (Robertson and Radcliffe 2009). CAD can help designers visualize their ideas in 3-dimensions and communicate the same across various platforms. However, the proficiency of the designer has a significant impact on the ideas produced. Circumscribed thinking occurs when a designer limits his thinking process and compromise on the design features due to the limitations of what s/he can create in CAD. Fixation can occur due to reluctance to make changes or commitment to a particular idea. Whereas,

bounded ideation can happen due to the boredom caused by the process of modeling (Robertson and Radcliffe 2009).

Chapter 3 clearly defines the gap from the literature and establishes the context of research. The research question evolved through the gap in the literature. The research question is further broken into five sub-questions to help focus the study.

Based on the research question, the chapter argues the qualitative versus quantitive approach. Since the research aims to understand the change in the process and approaches of the designer and not to prove or disapprove a hypothesis, the qualitative approach was chosen for the research. Interviews and observations were selected and studied as the primary study methods. Further, it was essential to understand how participants can be classified based on their proficiency levels. Dreyfus model of skill acquisition (Hunt 2008) was studied and deciphered to define the CAD proficiency levels of the participants.

Chapter 4 elaborates on the pilot study conducted with students of the postgraduate course of product design. Ten design students participated in the study and were given a time-bound design task to design a kettle. This study aimed to understand how participants incorporate CAD in their design process. It also probed into what advantages and limitations they face while using CAD. Participants used sketching and modeling during the task and finally presented their ideas to the class. Direct observation notes were taken during the task and their presentation. After the task, a group discussion was conducted to understand their views on CAD modeling in the design process and their experiences. Notes taken during the discussion, design task and presentation along with their sketches and models were used for drawing the inferences. An overview of the study method is illustrated in figure 3.

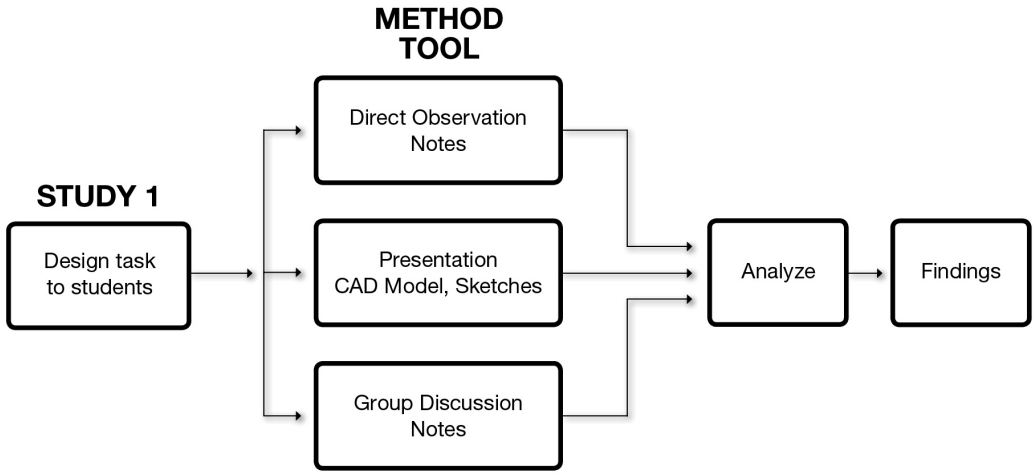

Figure 3: Methods and tools used in pilot study with students

An apparent effect of their proficiency levels was visible in the study. However, many participants felt more confident in presenting their ideas through CAD representations than through sketches. CAD helped them overcome their sketching skill limitations, and they felt that through CAD representations, their ideas get judged instead of their representation skills. An interesting observation showed how one participant visualized his idea in terms of CAD commands. This illustrated how their thinking process is getting influenced by the CAD modeling.

Since the design task was performed by the participants simultaneously, their individual processes could not be observed in-depth. The inferences were drawn hugely from their presentations and group discussions.

Chapter 5 describes the next pilot study conducted with professional designers. To overcome the limitations faced in the previous pilot study, this study employed five professional product designers with 3-5 years of work experience. Three of these participants were also SolidWorks certified professionals, and the other two participants had been using this tool for the past five years and were competent users.

Three participants were given a design task of designing a bread toaster for visually impaired users, and the other 2 participants were given a brief to design a spoon for a 5-star restaurant. The toaster task involved functional thinking and required a problem-solving approach. Whereas, the spoon design task was based on formal exploration. This helped understand the role of CAD in different scenarios.

The task was conducted with one user at a time, and the whole session was video recorded with a digital camera. CAD activities were desktop recorded with *Webinaria* desktop recording software. The think-aloud process was intentionally avoided as the task required participants to explore ideas and involve CAD modeling. Thinking aloud could have made them conscious and increase cognitive load. After the session, a semi-structured interview was conducted with the designers where they reflected on their experience during the session, elaborated on their design ideas and shared their views.

The video recorded sessions were transcribed and study parameters were visually mapped on transcribe. Interview transcribe further helped as supporting data for analysis. Figure 4 illustrates the methodology used for this study.

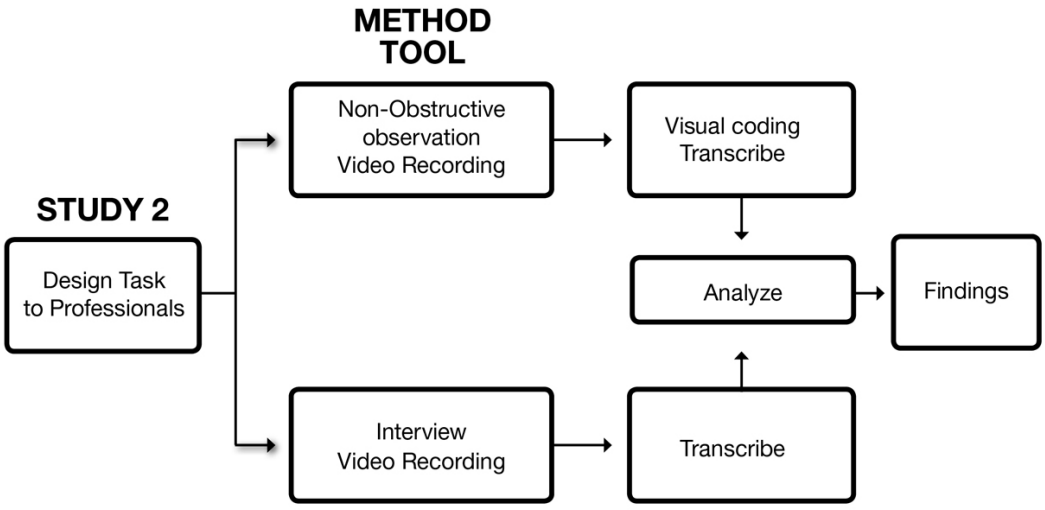

Figure 4: Methods and tools used in pilot study with professionals

Visualization was identified as the most significant enabler. Rough CAD modeling in practice and a limitation of perceiving the size on the screen was observed. Circumscribed thinking was evident in form exploration. During formal explorations, considerable time was spent on exploring how to model, leaving lesser time for design exploration and decision. During CAD modeling more time was spent on details and less on the overall design.

In a qualitative study, in-depth information and knowledge are obtained from a small number of cases or participants, but it lacks the potential for generalization (Patton 2002). In order to qualify the findings from the pilot studies, an in-depth interview study was conducted with 25 professional product designers. **Chapter 6** explains the interview guide, interview method, coding process, analysis, and findings of the final study. The researcher conducted semi-structured one-on-one interviews in informal settings. The interviews allowed participants to recall experiences from the past and share their views on their approaches and process. The interview guide was drawn from the findings of the pilot studies and clubbed to answer a specific research question. The two sets of codes were used for coding purposes. The first set was based on the question, and the second set was based on a study parameter. MaxQDA software was used for coding and analysis purpose of the data. Findings helped answer the research questions.

Chapter 7 revisits the research questions and answers those by consolidating the findings from all the three studies and learnings from the literature review. The summary of key findings addressing research questions are shown in table 1.

Table 1: Summary of key findings with research questions

Research query	**Key findings**
How does CAD position itself in the design process?	• Keywords, notes and rough sketches are used to record the thoughts. • Rough sketching allows the ideas to be explored in segments or as a whole. When making a CAD model, the designer is more focused on the holistic view of the design and the focus keeps shifting between the modeling strategy and design decisions. • CAD is integrated with other tools to overcome the limitations of a single tool. The use of CAD models in the background for sketching or sketching directly in the CAD environment are some of the ways of combining different tools. • Rough CAD modeling is done in the initial exploration phase to get idea about volume and proportions and comprehend spatial relations between components. • Proficient users are more comfortable and confident about exploring ideas directly in CAD and may work on CAD and rough sketching in parallel. • Advance-beginners need some starting point and clarity before starting with CAD • The vastness of design brief influences the way CAD is used in process. • Another aspect influencing CAD's inclusion in ideation is whether the brief requires functional-thinking and problem-solving or it needs formal

Research query	Key findings
	exploration only.
What advantages CAD offers to the designer, if used in the early phase of design?	• Visualization is identified as the biggest advantage. • The instant visual feedback on the changes made helps designer to make design decisions • CAD can handle complexities and scales that may be difficult to handle through sketches and physical models. • CAD helps designers overcome the limitations of sketching skills and make them more confident about presenting their ideas. • CAD visualization help eliminate ambiguity and make representations more comprehensible. • It aids communication and help overcome the limitations of language of communication. • CAD help enhance the spatial visualization and spatial relations between various componenets. • CAD can aid in quick prototyping and can eliminate the need for prototyping in the initial phase. • CAD can help bridge the gap between design and engineering.
What limitations CAD impose on the designer's way of thinking?	• Circumscribed thinking was identified as the biggest limitation. • Designers with lower proficiency are led more easily to change the designs to suit their proficiency levels. • The pressure to deliver and time-limitation can also influence the design outcome.

Research query	Key findings
	• Most of the participants were found using two or more software to achieve the desired results. • CAD representations can cause a feeling of moving towards completion and can lead to fixation. • CAD representations can influence the design decisions and some designers make representations sketchy purposefully to communicate the initial phase of design. • Perceiving and finalising sizes looking at the screen is difficult.
Does using CAD during idea generation results in more vertical exploration and hinders lateral exploration?	• CAD is very supportive for vertical exploration irrespective of the proficiency level of the designer. • CAD is also beneficial for repetitive work like creating arrays and tessellations. • It is not found to be flexible enough to support lateral exploration. • The time required to create a CAD model leads to fewer alternatives.

Chapter 8 concludes the thesis and summarises the research contribution. It articulates the implications of the findings on design practice, design pedagogy and CAD software development. It further suggests the scope for future research.

Research contribution and scope

The study helped understand how designers accommodate CAD in their exploratory process in combination with other tools like sketching and physical modeling. It

strengthens the view that CAD has become an integral part of the design environment and is extensively used even in the idea generation phase of design. It helped identify the visualization and communication as the most prominent advantages, along with speeding up the design process and enhanced confidence. The barriers that designers need to be aware of and be cautious of are circumscribed thinking, fixation, limitations of size perception, and design decisions led by the realistic renders. The proficiency of the designer has a significant impact on their approaches, and it is essential to accommodate a system to work towards improving one's abilities consciously continuously.

The research can help design faculty develop and teach a design methodology that would inform students about the scopes of various tools they use and help them develop their design methods.

It can shed light on the way CAD is used by designers and help developers to align it more towards the needs of a designer. The study informs the current practices and various strategies adopted by the designers to overcome the limitations. It can make designers more aware of their processes and help them develop it further to maximize the results.

Similar research in the various fields of design like fashion, interior, communication, and craft can be undertaken to find the similarities and dissimilarities in the practices. This can further inform pedagogy and software development for such areas.

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