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Comparison of CAD and manual sketching tools for teaching architectural design

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ABSTRACT

Communications for information synchronisation during the conceptual design phase usually require designers to employ more flexible and intuitive digital design tools. In developing such support tools, a case study research was initiated to first understand the current state of communication among novice design team members. The main purpose of the study is to understand the novice designers' collaboration culture when working on conceptual architectural design projects. The overall case study research involves 1) ethnography for data collection and 2) artefact and protocol analyses for data analysis. This paper presents the latter data analyses based on the earlier ethnography results about novice designers' conceptual design and technology design synthesis strategies. Data analyses on the characteristics of utilised external representation tools indicate that although conventional manual sketching is beneficial for providing rich intuitive design concepts, they have limitations when novice designers need to oversee complicated design problems. The study also found that although current conventional CAD tools are advantageous for detailed engineering design articulation, they do hinder novice designers' creativity due to their intuitive ideation limitation. Based on these results, this paper discusses the identified advantages and challenges of current design media and then proposes an alternative VR-based design interface for enhancing cognition and communication among designers during the conceptual design phase.

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1. Introduction

With progressive globalisation and specialisation trends in the building industry, collaboration among design stakeholders in distant locations becomes crucial [40,45]. Computer Supported Collaborative Works (CSCWs) [45] are currently no longer mere facilities but an integral part of comprehensive architecture, engineering and construction (AEC) firms. An earlier study [32] proposes the use of high-tech visualisation media for digitisation of the conceptual architectural design process. Furthermore, some studies (e.g. [16] and [19]) recommend integration of design and construction process to support collaboration among team members. Moreover, they argue that integration has major advantages in decreasing labour and material costs within current comprehensive production procedure models.

This integration is yet to happen smoothly since heterogeneous design media are being used during different design stages. For instance, conventional analogue format of design ideation tools, which are used during early conceptual design phase, are yet to be replaced with appropriate digital formats. This replacement is much desired for helping conceptual design stage outputs to better fit into the suc-

ceeding computerised engineering stages of the design process. We posit that the disintegration of the design parts is due to the limited efficiency of conventional Computer Aided Design (CAD) software during the intuitive conceptual design activities [25], causing designers to struggle in ensuring the transfer of information from the conceptual architectural design to rational engineering parts. Another reason is that the majority of existing geometric modelling software entail a high degree of specialisation from the users in order to achieve the final forms that designers desire. However, not all designers can and need to reach this distinctive degree of skills [27]. The problem is magnified when novice designers have limited expertise in using an external representation tool as a means for expressing and fortifying their design ideas. Consequently, such constricted approach hampers the capability of the design process and the collaboration that goes along [25] with it. Therefore, it can cause miscommunication for novice designers. An example is the case of architectural education where students and studio masters desire clear communication means during design studio tutoring.

It is our intent to use this study to formulate a theoretical foundation for developing an alternative digital design medium for better supporting the conceptual architectural design education. Our main aim is to understand the current state of communication among novice design team members. Therefore, we conducted a case study research to understand novice designers' collaboration culture when

working on conceptual architectural design projects. The overall case study research involves 1) ethnography for data collection and 2) artefact and protocol analyses for data analysis. This paper presents the latter empirical data analyses based on the earlier ethnography results about conceptual design and technology design strategies during the conceptual architectural design phase.

The purpose of the conducted artefact and protocol analyses was to objectively compare the design synthesis' characteristics when architectural students utilise external representation tools during the conceptual architectural design phase. In this paper, we summarise the earlier ethnography findings about conceptual design and technology strategies used by novice designers during conceptual architectural design, explain the artefact and protocol analyses part of the case study research methodology and present the resulting characteristics of utilised current external representation tools during collaborative design process. We conclude the paper by discussing the identified advantages and challenges of the current design media before proposing recommendations towards the development of a VR-based alternative design interface that would improve design representation, hence, enhancing cognition and communication among novice designers during the conceptual design phase.

2. Literature review

This paper presents a literature survey on two areas of design, which are design representations, and challenges and benefits of the current design tools. We focused on literature for teaching and learning design since design methodologies are usually transferred to novice designers by professional practitioners in design studios.

Many studies generally acknowledge design as a learning domain, in which past experiences and basic techniques are big contributors. However, most argue that the obtained skill is rarely explicit that even experienced designers have difficulties in articulating and understanding their own design proficiencies [42]. Our study has noted the diverse research agendas in design thinking. These include internal and external representations of designed objects [1], issues on design generation [8], knowledge bases of design thinking [44], formulation of design problems [2] and thought processes applied to learning [37].

Despite these multiple varied studies, some studies (e.g. [39] and [42]) continue recommending the need for a design methodology for improving the design process and the quality of designed artefacts. Simultaneously, the early stages of problem finding and analysis during semantic design phase are of central importance to design results because 70% to 80% of production overheads are determined there [39]. Moreover, the characteristics of these stages are strongly affected by the tool that designers use when embodying their designed concepts [33]. Scholars (e.g. [6] and [43]) have suggested that among the design tools, external representations not only serve as memory aids, but also facilitate or constrain the inference, the problem-solving and the design stage understanding during idea generation process. Other researchers (e.g. [39] and [42]) believe that designers can benefit from abstract external representations (i.e. sketches) particularly when they are in the early conceptual design stages. However, despite the diversity of available external representation tools, we believe that there is a need for a design representation tool that could support conceptual design collaboration when designers need external representations the most.

Existing literature highlights sketching using pencils and papers as one of the most famous abstract representation methods. By the year 2000, its effectiveness—particularly during early conceptual design stages—was frequently appreciated (e.g. [6], [14], [17], [26], and [35]). This advocacy was at the highest level when some scholars (e.g. [38], and [4]) highlighted the importance of freehand sketches as an indispensable media for designers to make reflective

dialogues with their own ideas. Such gratitude to manual sketching methodologies started waning with improvements of Computer Aided Design (CAD) tools and their increasing utilisation in complex projects due to globalisation challenges. A more important reason for this tendency towards digitisation of a design process is the added value of digital representation for future analysis and process integration.

Our literature survey notes the increasing tendency for using CAD tools during early conceptual architectural design process commencing after the year 2000. Scholars were impressed with their excellent capabilities especially in their advanced photorealistic visualisation of projects (e.g. [29] and [30]). However, doubts about the effectiveness of CAD tools in handling early conceptual design stages started almost concurrently with their appreciation in literature. For instance, Lawson [26] ironically calls these tools "Computer Aided Drafting" rather than design. Other researches (e.g., [42]) doubt the usability of such tools stating that although the CAD media have had a huge impact on the effectiveness of design groups, there are still characteristics of designing which are exclusively related with freehand sketches. A study by Kwon et al. [25] attributes this inadequacy to the limitation of intuitive sketching capabilities of the CAD software. Therefore, they posit that conventional CAD tools might not be much desired during the conceptual phase.

Yet, due to increasing globalisation of design projects, designers are finding conventional sketching tools inadequate for handling engineering parts of the design process. For instance, a research highlighted in [9] describes an exemplary evidence of such global project in the design of a Boeing 777. Its design involves 10,000 designers in 238 teams scattered worldwide across 17 time zones. We hereby note the stark differences between technical engineering documentations versus the intuitive conceptual design documents. Therefore, the transitional and iterative conceptual phase is a potential knowledge-loss period [18,21] that is identified in a product development lifecycle process. This supports Fruchter's [16] earlier findings on the potential losses of tacit knowledge within transitions of interrupted design process. Hence, our study focuses on the conceptual design phase when designers would start integrating sketching with engineering considerations. Therefore, we posit that a deep understanding of design process and characteristics of currently used methodologies is needed to find a successful methodology for handling the conceptual design phase. Many researchers in this area have conducted experiments to evaluate different media during a short-term design activity in a laboratory condition involving design students (e.g. [4], [31], and [41]). A number of studies compared conventional CAD tools against the conventional sketching media and concluded that manual sketching tools are superior compared to conventional CAD media during the conceptual architectural design process. Nevertheless, such content-oriented studies have yet to study which aspects of the utilised media improve or hamper design activities' quality.

We report the results of the earlier part of our case study research by filling up the aforementioned theoretical gap. The study by [34] adopted an ethnographic approach on a long-term and real design studio project to obtain a better understanding on how design collaboration, design transactions and information flow characteristics between studio masters and their students are supported by available technologies in a design studio project. The mentioned study found three types of external representation modes used by designers: *fully manual*, *mixed* and *fully digital*. The study revealed the inflexibility of traditional geometric modelling tools within intuitive ideations. On the other hand, it also observed the shortcomings of conventional manual sketching tools in articulating design ideas and translating tacit knowledge into explicit knowledge in complex design problems. We include the challenges and benefits of each visualisation method (Table 1) during the conceptual architectural design phase as per summarised by the study.