Intuitive and Effective Gestures for Conceptual Architectural Design

An Analysis Of User Elicited Hand Gestures For 3D CAD Modeling

ABSTRACT
Gesture-based natural interfaces necessitate research into gestures that are intuitive for designers and effective for natural interaction. Intuitive knowledge is significant for conceptual design as it reduces time taken to complete tasks and improves usability of products. In a previously conducted experiment, we elicited gestures for 3D CAD modeling tasks for conceptual architectural design. In this study, we present a preliminary analysis of intuitiveness scores of gestures and evaluators’ ratings to analyze which gestures were more intuitive and effective for CAD manipulation tasks. Results show that gestures with high intuitive scores were not necessarily rated as effective by evaluators and that bimanual symmetric gestures consistently scored high for both intuitiveness and effectiveness. Based on our findings we give recommendations for the design of gesture-based CAD modeling systems for single and multiple users.
INTRODUCTION

During the conceptual design stage, designers tackle ill-defined problems and try to translate abstract ideas into objects (Cross 1982). The conceptual design stage is known to be a creative one, when architects and designers want to express design ideas quickly (Lee, Hu, and Selker 2006). As ideas are fluid, designers want to proceed unhindered, focusing more on their ideas than on the interaction technique used to visualize them (Nielsen et al. 2003; Alcaide-Marzal et al. 2013).

Gestural interaction has similarities to the tactile techniques employed by architects and designers, such as sketching, clay modeling or sculpting wherein they use their hands for form exploration. Hand gestures are seen to play an important role in perceiving and describing spatial information (Alaçam 2014). Hence, gestural interaction offers architects and designers a powerful technique for creating conceptual 3D computer-aided design (CAD) models.

However, previous studies in gesture-based conceptual CAD modeling systems focus more on recognition techniques or overall system architecture (Nanjundaswamy et al. 2013; Teng and Johnson 2014), rather than the nature of the gestures employed by the system. Often, users are made to learn an arbitrary set of gestures that are conducive to gesture recognition (Vinayak et al. 2013). Such a strategy is deemed problematic, as designers are made to remember an artificial gestural vocabulary that may not necessarily be grounded in their individual movements (Zamborlin et al. 2014).

This gap necessitates greater inquiry into the development of gesture sets employed by 3D CAD modeling systems. For instance, would one-handed gestures be more natural for conceptual CAD modeling, or two-handed? What kind of gestures should be used if the gestural interface were to be used by one person? What kind of gestures should be employed if the interface was shared by a team? We consider the definition of gestures as mid-air movements of arms and hands that convey meaningful information (van den Hoven and Mazalek 2011).

We regard two aspects as significant for the development of gesture sets for interfaces for conceptual CAD modeling: (a) their intuitiveness, and (b) their effectiveness.

Intuition is a type of cognitive processing that is often non-conscious and utilizes stored experiential knowledge (Blackler, Popovic, and Mahar 2010). Intuitive knowledge aids in finishing tasks quickly and improving usability, whereas unfamiliar features that need to be learned are time consuming and effortful (Blackler, Popovic, and Mahar 2003). Intuitive interfaces have been associated with “feeling easy” or “natural” in their use, which can be used without the user having to go through a lengthy learning process (Mignonneau and Sommerer 2005).

Thus, intuitiveness has been measured as the ease of use of products (Blackler, Popovic, and Mahar 2003) and has been widely used as a concept in product and industrial design, as well as computer applications and user interface design (Tovey 1997; Hurtienne and Blessing 2007). Based on the above definitions of intuition, we define intuitive gestures as those which employ users’ previous experiential knowledge and are perceived as “easy” by users.

The second aspect that is of significance in the development of a gesture set for conceptual CAD modeling is the effectiveness of gestures. Gestures are effective when they successfully communicate the intended meaning, that is, when there is maximum correspondence between the gestural message coded by the coder and that which is interpreted by the decoder (Varshney 1998). Loss of meaning can occur during the transmission of gestures, as there could be errors in the relaying or interpretation of gestures. Effectiveness is especially relevant when the gestural system is shared by a team or when the team collaboratively develops designs (Morris et al. 2006). In shared system settings, gestures serve to provide information not just to the computer, but also to team members (van den Hoven and Mazalek 2011; Visser 2009).

Although there has been some research in intuitive gestures (Grandhi, Joue, and Mittelberg 2011; Nielsen et al. 2003), our approach is unique as it investigates both intuitiveness and effectiveness, specifically in the context of 3D CAD modeling for conceptual architectural design. In related studies, we presented details of our gesture elicitation experiment with a motion capture system, a compilation of gestures from the experiment, and an implementation of a prototype (Tuncer and Khan 2017; Khan and Tuncer forthcoming; Khan et al. forthcoming). In this paper, we investigate intuitiveness and effectiveness of gestures for three manipulation tasks used in CAD modeling. Throughout the study:

- We investigate gestures for CAD manipulation tasks that are considered intuitive by participants and effective by evaluators.
- We analyze the type of gestures (unimanual/bimanual) that are associated with higher ratings of intuitiveness and effectiveness.
- Based on the above, we give recommendations for the design of gesture-based CAD modeling systems for single and multiple users.
METHOD

We refer to the experiment described previously (Tuncer and Khan 2017; Khan and Tuncer forthcoming). We conducted a gesture elicitation experiment individually with 41 participants (52% female, 48% male) from architecture (49%) and engineering product development backgrounds (51%). Over 90% of the participants were familiar with one or more CAD programs. The aim of the experiment was to elicit mid-air hand gestures and speech commands for 3D CAD modeling for conceptual design.

The word “intuitive” was not used in the pre-experiment briefing. Participants were shown 3D-modeling referents on a screen in the form of short video clips, and were asked to articulate the referent. The experiment was conducted in two sessions, with the order of the sessions counterbalanced. In session A, participants could articulate the referents using only gestures, whereas in session B participants could use gestures and/or words, as desired. After every response, participants were asked to rate how easy they found the task on a 5-point scale.

Video data from the experiment was analyzed by three coders-cum-evaluators (subsequently referred to as “evaluators”), all from an architecture background and well-versed in CAD software. The coding scheme identified morphological themes, based on the movements of arms or hands, in the data. Training sessions were conducted prior to the coding wherein the evaluators were shown the referents and explained the coding scheme. Inter-rater reliability was found to be good (Krippendorf’s α>0.7) (Krippendorf 1980). The evaluators were also asked to rate the effectiveness of each gesture on a 5-point scale.

We considered three manipulation tasks from the experiment, namely Scale, Rotate and Move. Based on the definition of intuition as stored experiential knowledge that is not used consciously, and its relationship with ease, we computed intuitiveness scores for gestures based on two factors: (1) the participant’s rating of ease from session A; and (2) repetition of the gesture across sessions. Both factors were given equal weight in the scoring metric, which was calculated on a scale of 5. Hence, the gestures with high participant ratings, which were also repeated across sessions, got high intuitiveness scores. We analyzed the intuitiveness scores of gestures and the evaluators’ ratings of effectiveness from session A to determine the gestures that were most intuitive and effective.

RESULTS AND DISCUSSION

We refer to the categorization of gestures based on the number of hands used to articulate the gesture presented earlier (Tuncer and Khan 2017; Khan and Tuncer forthcoming).

- Unimanual: Gesture is performed by one hand.
- Bimanual symmetrical: Both hands are used symmetrically and simultaneously to articulate the gesture.
- Bimanual action reference: One hand performs the gesture, while the other hand serves to identify a reference point, plane or object.

We analyzed the intuitiveness scores and the evaluators’ ratings of effectiveness for each thematic category of gestures for the manipulation tasks (Figure 1). For the task Scale, the gesture themes “Arms open out in V shape” (Mdn = 4.5) and “Arms move in opposite directions” (Mdn = 4) got high intuitiveness scores, whereas only the former got a high effectiveness rating (Mdn = 4). The theme “Only hand motion” got a poor intuitiveness score (Mdn = 2) as well as a lower effectiveness rating (Mdn
Results from Spearman’s Rank Order correlation test. Median intuitiveness scores and evaluators’ ratings of effectiveness reveal a statistically significant correlation for the task Rotate only (Table 1).

We also analyzed intuitiveness scores and effectiveness ratings based on the number of hands used in gestures (Figure 2). For all three tasks, bimanual symmetric gestures got high median ratings for intuitiveness as well as effectiveness. For the task Move, although bimanual action reference gestures got high intuitiveness scores (Mdn = 4.5), the corresponding effectiveness ratings were lower (Mdn = 2).

We found that the gestures with high intuitiveness scores were not necessarily considered effective by evaluators. Subjective measures indicated a significant correlation between intuitiveness score and evaluators’ effectiveness rating only in the case of Rotate. This finding is significant for the design of gesture sets for CAD modeling applications for collaborative use. It suggests that while for single-user applications gesture sets for CAD modeling applications could have gestures considered intuitive by the individual users, for collaborative use, it is crucial to employ gestures that are considered intuitive as well as effective. For example, in a single user system, a particular user may favor and employ the “Trace path” theme for the Move task. However, for multiuser systems, it would be prudent to employ the “Push box theme,” which is both intuitive as well as effective.

Our research augments previous studies that found bimanual gestures to be most intuitive (Grandhi, Joue, and Mittelberg 2011). Additionally, we specify that bimanual symmetrical gestures—wherein both hands are used simultaneously and
symmetrically—were found to be most successful, both in terms of intuitiveness and effectiveness. Although other gesture types such as bimanual action reference were found to be intuitive by participants in the case of Move, bimanual symmetric gestures consistently scored highly for both aspects of intuitiveness and effectiveness in all three tasks. Hence, although intuitive bimanual action reference gestures could be employed in the case of single-user applications, we primarily recommend the use of bimanual symmetric gestures in case of collaborative gesture-based CAD applications. Figure 3 shows the bimanual symmetric gestures that were found to be both effective and intuitive for the manipulation tasks Scale, Rotate and Move.

As opposed to previous works that employ arbitrary author-defined gestures (Nanjundaswamy et al. 2013; Teng and Johnson 2014), our study developed user-generated gestures and conducted an analysis to determine intuitive and effective gestures. We believe that such an approach will lead to a more successful gesture interface for conceptual CAD modeling, as it is based on the way designers naturally use their hands to rationalize 3D forms.

Perceptions of intuitiveness and effectiveness of gestures are subject to numerous factors such as sociocultural conditioning, education and experience. In this paper, we analyzed intuitiveness and effectiveness based only on hand gestures for articulating CAD modeling tasks. A significant aspect that is central to human communication, and hugely impacts perceptions of ease and effectiveness is speech, which we have not investigated in this paper. Further research involves a greater investigation into the use of gestures along with speech and the intuitive interplay between speech and words.

CONCLUSION
In this study, we presented a preliminary analysis of intuitiveness scores and evaluators’ ratings to investigate which gestures, elicited from a previously conducted experiment, were more intuitive and effective for the CAD manipulation tasks Scale, Rotate and Move. An interface based on such an investigation of intuitiveness and effectiveness of gestures is especially relevant for creative applications such as conceptual architectural design, which require spontaneity and fluidity. This interdisciplinary research, taken further, promises to transform the way architects and designers conceptualize designs using CAD.

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**IMAGE CREDITS**

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