Change Detection in 3D Parametric Systems : Human-Centered Interfaces for Change Visualization

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Abstract. Research on current parametric modeling systems is mainly concerned with the underlying computational technology and designs produced, with less emphasis on human factors and design tasks. In these systems, users' attention is divided on system-imposed actions such as tool selection and set-up, managing obscured views, frequent view manipulation, and switching between different types of representations. In essence, control of the system can become more demanding than the design task itself. Thus, we argue that this unbalanced emphasis inhibits one of the most important functions of parametric design : agility in exploration of design alternatives by applying frequent user-introduced or system-generated changes on the parametric design models. This, compounded by growing complexity of the models and the effect of cognitive limitations such as change blindness, hinders change control and imposes an unnecessary cognitive load in design. In this paper, we made a first step in investigating users' visual cognitive challenges in the context of parametric design. The main research question is to understand if change blindness significantly influences designers' performance to detect and localize changes on a variety of models with different placement of change visualization on interfaces. Quantitative and well as qualitative results suggests that change blindness indeed occurs in this scenario and likely reduces designers' performance by making change detection highly challenging, slow and confusing. Hence, change blindness should be considered as an important factor in designing user interfaces that more effectively support the human designer to focus on the design task, while offloading other tasks to the system and getting adequate support from the computer.

CAAD Futures 2011 : Designing Together, ULg, 2011

1. Introduction

In the current rapid development of parametric design tools the underlying computational technology outpaces interface design, and little research has been done in this field [1]. Interaction with these tools is becoming cognitively more demanding : designers must switch between different views, manipulate views to adjust working context in relation to the model, select operations with complex parameters, and differentiate reference geometry from design geometry [1]. The complexity of 3D parametric systems can be easily observed from their interfaces (Figure 1).

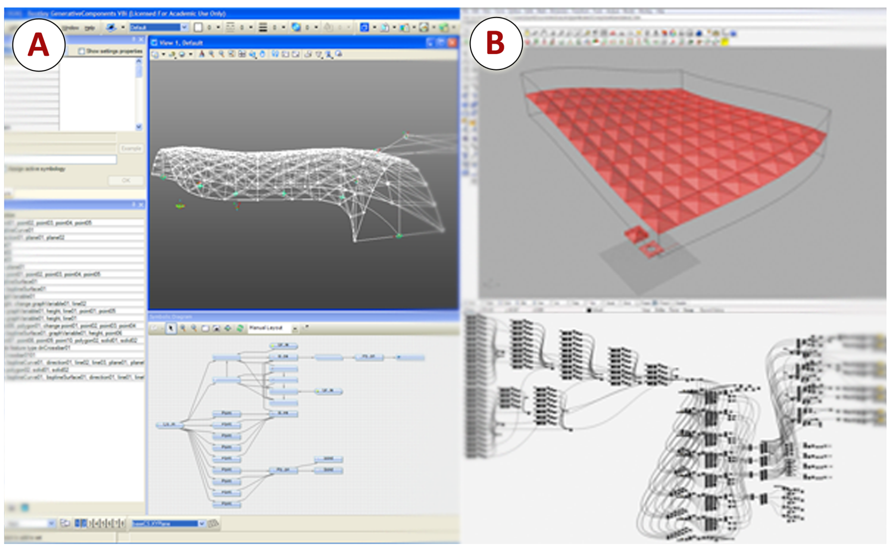


Fig. 1. A curve-based model built in (A) GenerativeComponents™ [7] and (B) Rhino Grasshopper® [8].

During the design process, parametric models change partially or completely. Typically, designers must detect the location of change, its source, magnitude, and propagation path, in order to make informed choices [5, 17]. In 3D parametric modeling, change can be either initiated by the designer or invoked by a script, and will then subsequently propagate to the rest of the model through parametric dependencies [25]. Although the change can be part of the design logic, the results may not be always obvious to the designer. In this paper, we argue that this difficulty in detecting change is exacerbated not only by the increasing complexity of the system interfaces and design models, but also by human perceptual limitations such as change blindness [18, 19].

The goal of this study is to investigate users' visual cognitive challenges in the context of parametric design, so that we can use this knowledge to develop more natural and effective parametric design interfaces. By interfaces, we mean both "user interfaces" that come as part of the system and "custom-interfaces" that can be developed and used by the designer for a particular purpose. We bring attention specifically to the importance of change control and detection in 3D parametric design. The term "change detection" here refers to noticing, identifying, and localizing a change in a visuospatial context [14]. Failure to properly detect changes may easily lead to frustration with modeling in 3D parametric systems and decrease designers' productivity and motivation regardless of powerful features provided. Moreover, such perceptual issue may lead to design failures. Novel interfaces are required to reduce if not eliminate these effects.

In this study, we focus on user interfaces controlling and visualizing changes taking place in the model on three different compositions in relation to the designer's locus of attention: on-model, peripheral and combined on-modal and peripheral visualization. Locus of attention refers to the "location" of the user's focus on the interface that may change unconsciously or consciously with the stimulus [13]. Our experimental study included three types of interface with different change visualization locations. The changes that should be observed or tracked depend on the design model at hand. Some examples of the changes are vector field direction, length or area, and number of elements in the structure. The interfaces in the study do not exhaust these changes, but rather question composition of interfaces that require improved change detection and control.

The next section briefly covers the foundations of this study, namely parametric design and cognitive issues designers experience, the importance of support for change detection in interface design, and approaches to parametric design interfaces. This is followed by the description of experiment design, results, and discussion sections. The conclusion section discusses the outcomes of this study.

2. Change detection challenges in 3D parametric design

The strength of parametric design systems is that they enable designers to create design representations that admit rapid change of design dimensions and structure [25]. That is, designers can use the same structure to rapidly explore better design alternatives. 3D parametric modeling, change can be initiated by designers or invoked by a script then propagated to the rest of the model through the parametric dependencies and dynamic relationships. Increasing complexity of models boosts dependencies and relationships between design elements. Therefore, designer's immediate control and full understanding of the changing model is not always possible, especially, when different designers compose the models.

The term "change detection" in general refers to the visual processes involved in noticing, identifying, and localizing a change in a given visuospatial context [14]. Change detection is important in 3D parametric modeling for agile analysis, informed choice and rapid design decision-making [17]. We believe that designers' change detection in the 3D modeling interfaces is limited due to incomplete or condensed visuospatial representations and continuous changes occurring in the model view. In addition, when working with large models on different interface components, there is usually a temporal gap or lag while the system updates the model before the user's attention moves back to the model again. Change detection during continuous morphing of design is challenging due to hidden parametric dependencies. Hence change detection is situated at the center of parametric modeling where design can be hindered by unbalanced delegation of design tasks and weak collaboration between the designer and the tool.

On models with large number of parts, the model is either displayed in its entirety with a small view-zoom factor or viewed locally by focusing on a specific part. This obliges designers to frequently manipulate views, requiring rapid shift in locus of attention and intense visual search [6]. Thus, the challenge of working with these systems becomes more obvious.

The first significant challenge is called "change blindness" which is a failure of the human to detect changes to information that occur within his or her visual field [12]. Due to this, it is highly possible that designers miss to observe changes on parametric models. Environment for change blindness is boundless and conditions can be almost anything that occludes the change or makes it less salient for a very short period of time [22]. For example, occlusion by any external window, zoom-factor, shift in view and locus of attention, and even simple and usual actions necessary for vision, such as saccadic eye movements and blinking [12, 19, 22].

The second challenge is related to the resources in visual memory : when external visualization is not capable of clearly representing the difference between pre- and post-change model, designers rely on their memory. However, visuospatial working-memory is not necessarily accurate and subject to the limitations in both the amount of information it can handle and the time it stays in working memory [10]. Additionally, the human visual perception system can track 3-4 objects at a time in a dynamically changing scene [24]. This becomes another limitation tracking dynamically changing models as opposed to "intermittent" changes. This can impede recognizing important changes on a large model where structure changes on multiple locations simultaneously. The designers need to maintain the continuity of the location and time of the elements being changed, which require proper support for effectiveness [5].

The third challenge is related to physical invisibility of changes to the human perception system. In parametric modeling, "changes" may or may not result in a directly observable outcome due to the magnitude or location of the change. Here magnitude refers to the relative size of a geometric element with respect to the zoom-factor of the view.

All these challenges and failure to detect changes may easily lead to frustration with modeling in 3D parametric systems and decrease designers' productivity and motivation regardless of the powerful features they provide. In the worst-case scenario, they may lead to fail-prone design outcomes. Thus, it is essential to consider these factors in developing interfaces for these systems.

3. Approaches to parametric design interfaces

Even though, as Aish and Woodbury state, "[t]he interface appears to be the principal technical obstacle to further practical use" for 3D parametric design systems, to the best of our knowledge, little research has been done in this field [1]. In order to engage in growing complexity of design and cognitive challenges Erhan et al. have proposed Visual Sensitivity Analysis Method (ViSA) [5] [17]. They propose use of control features to change input parameters to the model. These changes are visualized on user-defined or selected visualization features that interface with model to calculate change and display the results before change is committed. Although they suggested change control and visualization' features to be located on different parts of the interface such as on the model, on a fixed view, or on floating views, they did not concerned with if and how visual perception system should be considered in designing interfaces for better change detection.

Figure 2 presents an example of a ViSA model with both on-model and peripheral change visualizations. On-model visualization displays changes on the model itself, at the expected designers' locus of attention, where change control features are located and designers are using it to modify a model. Displaying changes on a peripheral view — information visualized away from the locus of attention — can be an alternative. Some researchers tested the effectiveness of peripheral views to present secondary (peripheral) information that is not central to the primary task at hand [11, 20].

The results demonstrated that "peripheral" information displayed on peripheral view could be helpful in performing primary tasks in a "dual-task" environment. However, in parametric modeling, visualization features such as proposed by Erhan et al. [5] show changes as primary information. Therefore the findings of the existing research do not directly apply to our case. In other words, we don't know much about the effectiveness of using peripheral visualizations for 3D parametric design systems for displaying primary information but off the locus of attention. It is imperative to test whether they undergo the same cognitive challenges as the ones located on the central view.

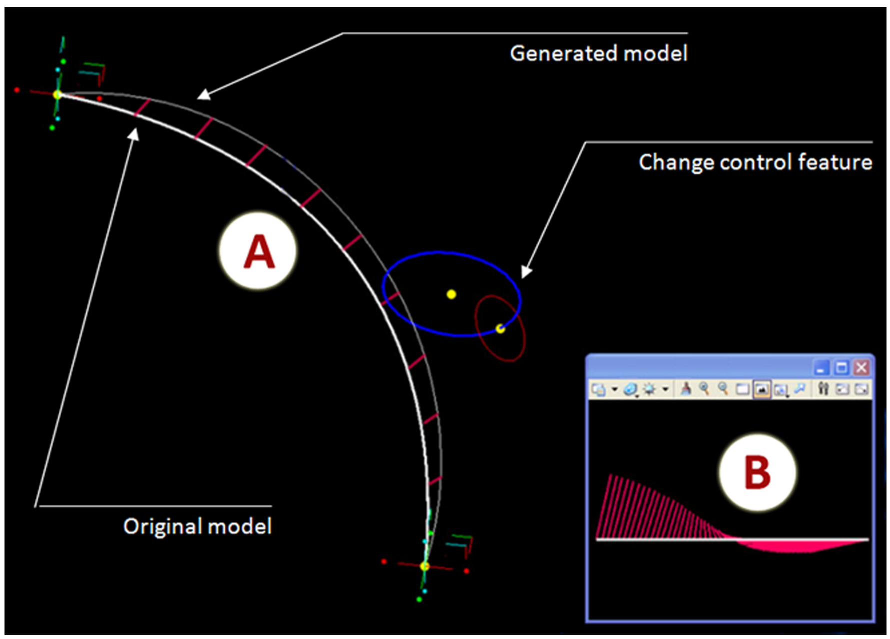


Fig. 2. An example ViSA model showing Bezier Curve as design, control feature for changing the design, and two different change visualizations as vector fields : on-model view (A) and peripheral view (B).

4. Methods

4.1. Research question and hypothesis

The key motivation of this experiment is to improve user interfaces for 3D parametric design systems by applying our current understanding of visual perception and in particular the phenomenon of change blindness. For this study, the main research question is to understand if change blindness significantly influences designers' performance to detect and localize changes on a variety of models with different placement of change visualization on interfaces.

4.2. Participants

There were 21 participants, all university students, nine of them male, with one whose data was disqualified, leaving 20. They entered into a draw to win one of the ten $20 gift certificates for a local café. Those who came through an experiment management system (71 %) gained 1 point of credit toward their course. One of the participants said that s/he was familiar with parametric design, four were not sure, and the rest were new to it. Seven had experience with 3D modeling, varying from one month to three years.

4.3. Equipment

We ran the study on four computers with 2GB of RAM, Intel Core 2 Duo, 14.10 inches WXGA LCD monitor, and 144.4MBits wireless network connection. All participants used an optic mouse for input. The experiment room had two tables, one for experimenters and one for participants and a whiteboard. The experiment instruction were written on the whiteboard as well as in each participant's experiment package, along with a sample filled questionnaire to assist understanding and flow.

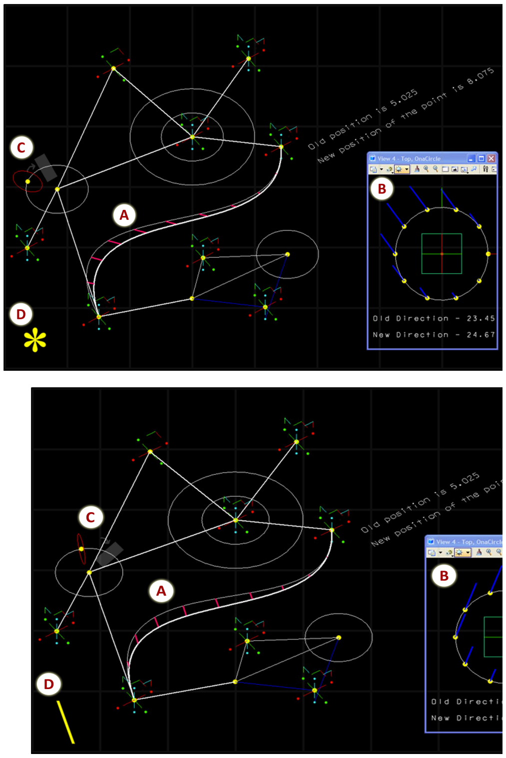
4.4. Simulated parametric system and task definition

We developed a simulated 3D parametric modeling system using Adobe Flash to be able to include participants without specific experience with parametric modeling. The system was based on screenshots taken from the models used in a recent ViSA study [5]. The interface included a geometric model and a peripheral window that was fixed at the right bottom corner. That allowed us to have three interface compositions to compare: changes visualized on-model, peripheral and combined on both locations. Some examples of the change visualizations are vector field direction, length or area and number of elements in the structure.

Figure 3 presents the two states of one of the compositions used in the experiment (with changes visualized on both locations). The difference between the two states is the displacement vectors [17] in the on-model visualization (Figure 3, A) and peripheral visualization (Figure 3, B).

The task for participants was to stimulate changes in the model, by clicking on the control point (Figure 3, C) and observe and identify the changes in the interface by clicking on each detected change using the computer mouse. Each model had four alternations (five different states) and participants could have repeated each task up to six times or until all changes were detected.

Continuously changing attention-demanding symbols on the lower left corner were added in order to increase the cognitive load (Figure 3, D). The appearance of the question mark symbol ("?") required participants to click on the area where they notice a change as fast and accurate as possible. There were two to four different changes per model. These steps of the task were completed with each composition.



a) State-1:
A. On-model visualization
B. Peripheral visualization
C. Trigger and control point
D. Element for cognitive load

b) State-2:
A blank screen was shown between State 1 and 2 for retinal transient.

Fig. 3. Two sample screenshots of the experiment system. After clicking on a control feature (C) in order to trigger a design change, participants' task was to detect all the resulting visual changes on both peripheral and model view.

4.5. Models Used in the Experiment

In total, we had six different models with changes on the models themselves (Figure 4, A) and on the visualization features located on the models and/or on the peripheral (view) window (Figure 4, B). By a "model" we mean a geometric structure comprised of basic features such as lines, curves, ellipses and text with parametric relations. The models also adapted different change visualization techniques showing vector-based displacement, magnitude (length and area), and number of changing elements. All models were based on the ViSA study and had similar interface structure including a peripheral window with geometric features visualizing changes. Although it is hard to claim absolute equivalence of the models, we tried our best to have relatively equal models. We attempted to balance the models in terms of the information they present by locating approximately same number of non-changing distracting elements and alternating number of changes and change visualization techniques.

Figure 4 presents abstract sketches of the six models used in the experiment (Figure 3 is an example of actual model used). The six models had different change visualization compositions: Two models with on-model visualization; three models with peripheral visualization and one with visualization combined on both locations. We intentionally kept the models simple and context-free to avoid "design" confound by having the participants focus on the task of detecting changes rather than the design.

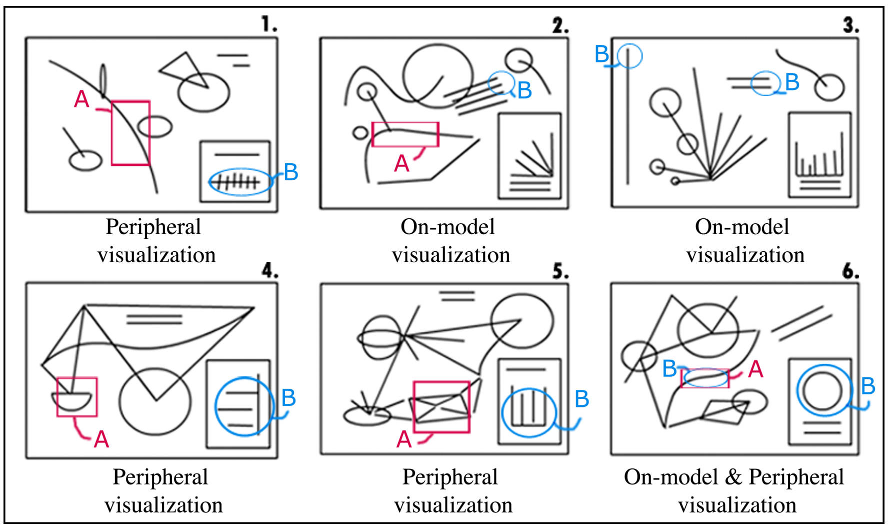


Fig. 4. Six models used in the experiment showing changes on the model (A) and changes on visualizations (B).

4.6. Procedure

The experiment had three main parts : a) brief introduction to the study and parametric design concept, b) demo and practice of the system, and c) participants interacting with six models shown above. After each interaction, for every model, the participants commented on location and nature of changes, by marking and describing them on the sketches of the models (Figure 4) provided on a separate paper.

The whole experiment lasted 30-45 minutes, and was run in parallel with up to four participants working on different computers and two experimenters in the room. Even though an introduction to the study was provided, the participants have remained naive to real purpose of the experiment. They have been actively searching for all kinds of changes (i.e. both model changes and visualization changes). Participants were not familiar with change blindness, the purpose of the "blank black screen" inserted very short of time (20ms + network latency) during change" and how it affects change detection.

4.7. Measures

As in other "flicker paradigm" based change blindness studies [15, 16], performance is quantified via response time [14], which in our experiment is measured as time and number of trials participants spent to complete each task. In order to let participants find all changes, participants could have interacted with each model up to six times.

The quantitative data was automatically collected by the system. It recorded when and who worked on which model. The logging systems required some rules for participants to follow, such as "no random clicking", "no double clicking" and "no dragging". Screen captures were used for further review.

5. Results and discussion

To assess how change blindness might have occurred for the different models and view, we analyzed participants' performance in terms of overall change detection time and number of trials to detect changes. Figure 5 presents mean scores for the different models and interfaces (on-model, peripheral and combined views).

Figure 5a shows mean of time participants have spent (in seconds) to complete the task for every model. Mean across all models is 98.9s with a standard deviation of 66.3s. Figure 5b shows mean number of trials participants used for each model. Mean across all models is 2.73 and standard deviation is 1.13. As mentioned earlier, each trial had 5 states of a model, thus, requiring an average of 10.92 alternations before being identified. Thus, participants were on average unable to detect all changes in the first trial, and had to repeatedly go through the changes until they were able to identify all resulting changes in the model. This suggests that there was change blindness did indeed occur, corroborating our initial hypothesis.

As can be seen from Figure 5, overall performance was varied between the different models and views, but did not show any clear trends between the three different viewing modes. This might indicate that on-screen, peripheral, and combined views are similarly (in)effective in presenting changes. As the experimental design was exploratory in nature and thus not balanced (i.e., all participants performed the tasks in the same order using the same sequence of models and views, such that learning/fatigue/practice effects are confounded with potential influences of the different views), we refrained from using inferential statistics to compare the different models and views. Instead, we compare in the following the quantitative data with the qualitative data from the questionnaires and from observing participants' behavior.

Participants' post-experimental comments supported the quantitative results and suggest that change blindness did indeed occur and likely reduced task performance: participants reported, for example, that : "It was really tricky to spot the changes; there is a lot to look at", "It took me quite a few times to find differences and I replayed to confirm what I saw" and "The overall test was very difficult and confusing. I constantly had to look at different locations to find the changes". One of the participants wrote : "I don't know if it is intentional, but the break between screens makes it harder to identify changes". Thus, the qualitative data form participants' verbal responses corroborate the quantitative data and suggest that change blindness did, in fact, occur in the 3D parametric modeling task used, and likely was a critical factor in reducing participants'' performance.

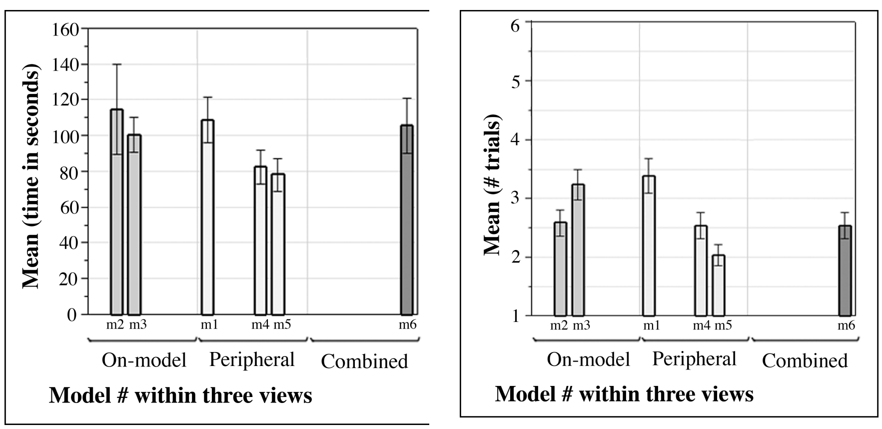


Fig. 5. (a) Mean number of time (in seconds) participants spent working on each model, and (b) Mean number of trials participants used to complete the task for every model.

As previously stated, we used a "flicker paradigm" in an first attempt to simulate visual disturbances, general distractions, and an overall high cognitive load that that is typical for normal 3D parametric design scenarios.

Further research is needed to investigate how change blindness occurs under more natural 3D parametric design modeling situations and if a flicker paradigm is the most suitable method to simulate these factors. In the current study, it enabled us to study change detection in a highly controlled experimental setting that allowed for reproducible conditions while reducing complexity to a manageable level.

5.1. Limitations and future work

The current study was designed as an exploratory study and will guide us in the design of the next study, which will use a fully balanced experimental design that allows for a quantitative comparison of different models and visualization conditions. In particular we aim to identify where on the user interface we could best visualize the changes taking place on the model such that they enable designers to control their design effectively. The current results also highlight the need to pretest the different models and change visualization methods for their equivalency if location of change visualization is to be tested.

In addition, we plan to collect data for change localization time as another measure to evaluate the best location for change visualization. In the current study, we asked participants to click on the area when and where they noticed a change following the "?" symbol shown on the screen. However, we discovered that only few participants followed this instruction, such that we will have to carefully revise our instructions and task to ensure compliance. If successful, this change localization time variable can separate change detection and localization into two distinct factors, which will be crucial in improving user interfaces. In addition, techniques such as eye tracking could help in the future to get a better estimate of the user's locus of attention during the different design tasks, and how it interacts with change detection and localization for different retinal eccentricities.

Finally, although if we didn't require participants to be experienced designers for this experiment, it will be useful to have a pool of experienced designers working on realistic design models in order to improve the ecological validity of the future experiment.

6. Conclusion

We have conducted a study using six different parametric models and three interfaces that provided on-model, peripheral or combined change visualizations. Manually triggered changes simulated changes and real 3D models generation. Quantitative and well as qualitative results suggests that change blindness did indeed occur in this scenario and likely reduced participant's performance by making change detection for 3D parametric design model highly challenging, slow and confusing. Hence, we argue that change blindness should be considered as an important factor in understanding and improving the effectiveness of 3D parametric systems. In particular, be careful re-design, experimentation, and applying what is known in cognitive psychology about perceptual/cognitive limitations in general and change blindness in particular, we hope to be able to iteratively improve and refine the 3D parametric design interfaces. This will help us to reduce user frustration and cognitive overload and thus improve the overall effectiveness of 3D parametric modelers. Ultimately, applying such an approach will enable us to design interfaces that more effectively support the human designer, by taking into account specific strengths and weaknesses of our perceptual and cognitive system, thus enabling the designer to more effectively focus on the actual design task while offloading other tasks to the computer and getting adequate support from the computer.

7. Acknowledgements

This work was partially supported through the Canadian Natural Science and Engineering Research Council Discovery Grants and Collaborative Research and Development Programs; Bentley Systems, Incorporated; the MITACS Accelerate program; and the Networks of Centres of Excellence program through the Graphics, Animation and New Media Network.

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