Frontiers of Architectural Research (2014) 3, 28–35

Higher Education Press

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/foar

Frontiers of Architectural Research

RESEARCH ARTICLE

Differences in spatial understanding between physical and virtual models

Lei Sun, Tomohiro Fukuda*, Toshiki Tokuhara, Nobuyoshi Yabuki

Graduate School of Engineering, Osaka University, Osaka 565-0871, Japan

Received 10 September 2013; received in revised form 26 November 2013; accepted 28 November 2013

KEYWORDS
Spatial understanding;
Scale perception;
Physical model;
Virtual model;
Virtual reality

Abstract
In the digital age, physical models are still used as major tools in architectural and urban design processes. The reason why designers still use physical models remains unclear. In addition, physical and 3D virtual models have yet to be differentiated. The answers to these questions are too complex to account for in all aspects. Thus, this study only focuses on the differences in spatial understanding between physical and virtual models. In particular, it emphasizes on the perception of scale. For our experiment, respondents were shown a physical model and a virtual model consecutively. A questionnaire was then used to ask the respondents to evaluate these models objectively and to establish which model was more accurate in conveying object size. Compared with the virtual model, the physical model tended to enable quicker and more accurate comparisons of building heights.

1. Introduction

In architectural and urban design processes, a consensus building process among various stakeholders, such as project executors, designers, neighborhood residents, users, and the general citizen, is required. Supporting technologies that provide 3D images to study and share future spatial designs have been subjected to research. Despite the digital age, physical models are still used as major tools. Arguing whether a virtual model can substitute for a physical model is an important theme in the field of computer-aided architectural design. In recent years, physical models have been built from 3D virtual models created by 3D computer-aided design (CAD) and building information modeling via a 3D printer or through traditional methods of handcrafting. Numerous studies on tangible user interface and augmented reality (AR) have combined physical and virtual models (Seichter, 2007; Kim and Maher, 2008; Tokuhara et al., 2010; Wang et al., 2013). The reason why designers still use physical models remains unclear. In addition, physical and 3D virtual models have yet to

*Corresponding author. Tel: +81 6 6879 7661; fax: +81 6 6879 7661.
E-mail addresses: sonrai@it.see.eng.osaka-u.ac.jp (L. Sun), fukuda@see.eng.osaka-u.ac.jp (T. Fukuda), tokuhara.t@gmail.com (T. Tokuhara), yabuki@see.eng.osaka-u.ac.jp (N. Yabuki).
Peer review under responsibility of Southeast University.

ELSEVIER Production and hosting by Elsevier

2095-2635 © 2014. Higher Education Press Limited Company. Production and hosting by Elsevier B.V. Open access under CC BY-NC-ND license.
http://dx.doi.org/10.1016/j.foar.2013.11.005

be differentiated. The answers to these questions are too complex to account for in all aspects. Meanwhile, differences based on a physical-medium model and a virtual-medium model may also be regarded as factors. Thus, this study only focuses on the differences in spatial understanding between physical and virtual models. In particular, it emphasizes on the perception of scale.

1.1. Background

Aside from text and diagrams, 3D visualization media, such as physical and virtual models, are used to confirm space or volume in design and presentation in the architectural and urban planning fields (Dorta and LaLande, 1998; Belcher and Brian, 2008; Fukuda et al., 2009). Physical and virtual models, such as virtual reality (VR), can display at an arbitrary viewpoint, and thus, they are effective for discussion and examination. A physical model can be observed from any viewpoint and can show the complete image of a depicted city simultaneously. However, difficulties persist if the pedestrian viewpoint and representation limitations caused by the small scale are considered. VR employs a virtual environment (VE), and thus, providing an eye-level viewpoint of pedestrians and drivers, as well as of other people and vehicles, becomes easy. Moreover, VR can dynamically simulate various effects, such as solar radiation. Nevertheless, problems such as intangibility remain. In addition, possible viewpoints are normally limited to a single place. Physical and virtual models are used together in construction sites, as well as in planning or design, because of their distinct characteristics. For example, during the planning and design stage, a physical model is used in the first conceptual expansion phase, and then VR is applied in the convergent design phase (Koga et al., 2008).

Combining physical and virtual models has several advantages, including ease of fabrication, user manipulation, low cost, and labor. Meanwhile, differences in physical and virtual models may also be regarded as factors. Spatial reasoning refers to the ability to understand the shape, size, location, and texture of an object or space. People have to use numerous clues and to think carefully to apply spatial reasoning. Moreover, how such clues are used remains unclear because of the complexities caused by distances to an object and observation conditions.

1.2. Previous studies

Siitonen (1995) used and compared a walk-through VR and an endoscope-photographing model method. He verified which technique is better in terms of manipulating objects, lighting, and spatial reasoning ability through visual observations of outcomes as well as interviews with participants. However, the verification results of his study lacked objectivity because they had not been quantified. Focusing on spatial reasoning ability by using medium systems, Witmer and Singer (1998) distributed a questionnaire on control, sensory, distraction, and realism factors that contribute to a sense of presence in VR. Furthermore, Lessiter and Freeman (2001) created a new questionnaire that addressed the sense of physical space, engagement, ecological validity, and negative effects. Spatial reasoning ability was compared with the results from IMAX 2D, IMAX 3D, computer games, and videos. Calibrated principal component analysis was also performed. According to these previous studies, the respondents could still experience the sense of "being there" that was elicited by VR even in another scene, but could hardly do so with a real-medium model.

Schnabel and Kvan (2003) examined the perception and understanding of spatial volumes within immersive and non-immersive VEs through comparisons with representations by using conventional media, such as 2D plans. They employed VEs successfully to study, communicate, and present architectural designs. However, VEs are seldom used in actual creation, form-finding, and collaboration in architecture. Seichter (2007) gauged the differences between two AR interfaces through user evaluation in an urban design studio. Although the targets examined were different, these studies would still be helpful in our study, such as in suggesting research methods.

1.3. Purpose of the study

The present study focuses on differences in spatial reasoning ability observed by using physical and virtual models. In particular, it emphasizes on the perception of scale. We explored issues in accuracy and response time through a series of design experiments. Physical and virtual models were shown to respondents. Then, a questionnaire was used to ask the respondents to evaluate these models objectively and to establish which one was more accurate in conveying object size.

2. Experiment

During the experiment, the same object depicted alternatively by physical and virtual models was shown to the respondents. Three categories were required. The first category was height comparison of relative sizes, the second was the actual size of a building, and the third

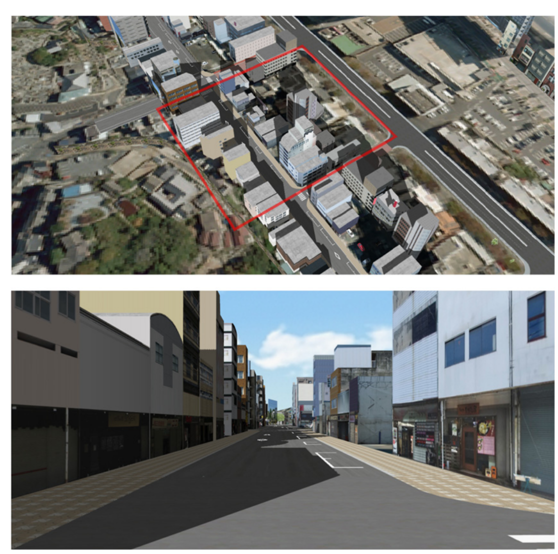

Figure 1 Virtual model by realistic representation of the target city in the experiment (up: bird's-eye view and down: pedestrian view).