Computers, Environment and Urban Systems xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

journal homepage: www.elsevier.com/locate/ceus

Virtual reality as an empirical research tool — Exploring user experience in a real building and a corresponding virtual model

S.F. Kuliga [a,*], T. Thrash [b], R.C. Dalton [c], C. Hölscher [a,b]

[a] Institute of Computer Science and Social Research, Center for Cognitive Science, University of Freiburg, Freiburg, Germany
[b] Department of Humanities, Social and Political Science, Swiss Federal Institute of Technology Zurich (ETH), Zurich, Switzerland
[c] Faculty of Engineering and Environment, Northumbria University, Newcastle upon Tyne, United Kingdom

ARTICLE INFO

Article history:
Received 18 June 2014
Received in revised form 22 August 2015
Accepted 10 September 2015
Available online xxxx

Keywords:
Virtual reality (VR)
User experience
Pre-occupancy evaluation
Real building
Research tool
Building usability

ABSTRACT

Virtual reality (VR) allows for highly-detailed observations, accurate behavior measurements, and systematic environmental manipulations under controlled laboratory circumstances. It therefore has the potential to be a valuable research tool for studies in human–environment interaction, such as building usability studies and post- as well as pre-occupancy building evaluation in architectural research and practice.

In order to fully understand VR as a valid environmental representation, it is essential to examine to what extent not only user cognition and behavior, but also users' experiences are analogous in real and virtual environments. This work presents a multi-method approach with two studies that investigated the correspondence of building users' experience in a real conference center and a highly-detailed virtual model of the same building as well as a third study that virtually implemented systematic redesigns to the existing building layout.

In the context of reporting users' experiential building evaluations, this article discusses the potential, prerequisites and opportunities for the implementation of virtual environments as an empirical research tool in the field of human–environment interaction. Based on quantitative data, few statistically significant differences between ratings of the real and the virtual building were found; however analyses based on qualitative data revealed differences relating to atmospherics. The main conclusion of this article is that VR has a strong potential to be used as an empirical research tool in psychological and architectural research and that future studies could supplement behavioral validation.

1. Introduction

The use of virtual reality (VR) is well-established in many domains. VR has been implemented as a research tool, e.g., for navigation and spatial cognition research, simulated medical treatment and skill training (Cliburn & Winlock, 2002; Dalton, 2001; Loomis, Blascovich, & Beall, 1999; Ruddle, Payne, & Jones, 1997, Darken & Sibert, 1996; Tanja-Dijkstra et al., 2014; Larsen, Oestergaard, Ottesen, & Soerensen, 2012). Research focused on *direct* comparisons between real and virtual environments investigated how cognitive and affective environmental appraisal and human movement patterns correspond in both environments (e.g., Westerdahl et al., 2006; De Kort, Ijsselsteijn, Kooijman, & Schuurmans, 2003; Bishop & Rohrmann, 2003; Skorupka, 2009; Haq, Hill, & Pramanik, 2005; Dalton, 2003; Witmer, Bailey, Knerr & Parsons, 1996). In addition, the use of VR could also be relevant for pre- and post-occupancy building evaluation, which could pave the way towards enhancing the usability of architectural environments.

The main purpose of this article is twofold: first, to reinvestigate environmental comparability, by comparing how users experience a real, extant and a corresponding, virtually simulated building (Study 1 + 2). Second, to extend previous research towards assessing how users respond to major redesigns of the existing building in VR (Study 3).

1.1. VR in the architectural domain

Virtual environments (VEs) lend themselves to building evaluation. They allow systematic environmental manipulations that cannot (or not effectively) be implemented in real environments (REs) once these are occupied. While it would be challenging to substantially alter spatial configuration in an existing building, the effect of several redesigns on users' behavior can efficiently be simulated in VR without interrupting ongoing building usage. In spatial cognition research VR has already been implemented for this purpose, e.g., to study wayfinding performance and spatial memory after systematically rearranging major circulation areas (Werner & Schindler, 2004). Similarly, virtual reality can support 'pre-occupancy evaluation,' an environmental evaluation from the users' perspective prior to the occupation of a building (Guski & Schuemer, 2008). However, only a few studies have investigated this potential so far; e.g., Palmon, Sahar, Wiess, and Oxman (2006)

* Corresponding author at: University of Freiburg, Institute of Computer Science and Social Research, Center for Cognitive Science, Friedrichstrasse 50, 79098 Freiburg, Germany.
E-mail address: saskia.kuliga@uni-weimar.de (S.F. Kuliga).

http://dx.doi.org/10.1016/j.compenvurbsys.2015.09.006
0198-9715/

assessed how people with disabilities perceived the accessibility of a planned building.

Current application scenarios for VR focus mostly on domain-specific architectural experts and less on the experiences of future or current building users. Drettakis, Roussou, Reche, and Tsingos (2007) asked a small sample of experts to rearrange environmental objects in a virtual urban square and to collaboratively discuss their design solutions. Others aimed at integrating simulated agent movement based on quantitative spatial theory, such as space syntax, into these applications (e.g., Broll et al., 2004); or understood VR as a collaboration tool for supporting stakeholders who work at physically separated locations (e.g., Argelaguet, Kulik, Kunert, Andujar, & Froehlich, 2011). Recent research investigated the potential of using VR for architectural education with the aim of providing architecture students with a user-perspective experience of their own building designs during an early design stage (Schneider et al., 2013).

Thus, for environmental planners, VR offers numerous advantages, like visualizing, experimenting, experiencing, analyzing and collaboratively discussing planned designs and already constructed buildings. Nevertheless, information about how building users interpret, interact with and experience virtual, architectural (re)designs before construction is not yet widely integrated into applications — despite the availability of high-quality, affordable technology (e.g., Oculus Rift, HTC Vive, Google Cardboard, Samsung Gear VR, LeapMotion, Virtuix Omni). If the use of virtual simulations and user evaluations were more integrated into user-centered design, this could lead to improved usability of buildings. In the current work, building usability is conceptually defined by building functionality, along with a pleasant, satisfying environmental experience for building users. It is thus following conceptual approaches by Krukar, Dalton, and Hölscher (2016).

1.2. VR in the psychological-research domain

For behavioral researchers, VR offers the advantage of highly-detailed measurements (e.g., precise data indicating where participants navigate, pause and look) under controlled laboratory circumstances. Still, studies investigating the comparability of real and virtual environments remain to some extent inconclusive. Some findings suggest that people may use similar cues and similar wayfinding strategies and evaluate wayfinding difficulty similarly during real and virtual wayfinding (e.g., Skorupka, 2009); but others did not find comparable results (Haq et al., 2005). Similar discussions exist for distance estimations in VEs (e.g., underestimation, Witmer & Kline, 1998; inaccuracy, Wilson, Foreman, & Tlauka, 1997; or correspondence, Ruddle et al., 1997; Interrante, Ries, & Anderson, 2006). Differences in terms of cognitive, affective and esthetic user ratings include enhanced liking ("pleasure") of the real building (Westerdahl et al., 2006) or less positive ratings and the absence of psychological arousal in the virtual building (De Kort et al., 2003). These findings may be related to the level of realistic, visual fidelity of the virtual simulations used in these studies; the degree to which experiences in the VE resemble real-world experiences (De Kort et al., 2003). The order in which participants were exposed to either environment also appears to influence user responses in terms of environmental appraisal (e.g., Pals, Steg, Dontje, Siero, & van der Zee, 2014; Bishop & Rohrmann, 2003) and potentially distance estimations (Ziemer, Plumert, & Kearney, 2010).

1.3. Prerequisites for using VR as a research tool

For the question of environmental comparability it is central to accurately simulate 'naturalistic' experiences (Bell, Greene, Fisher, & Baum, 2001) in virtual as in real environments. Towards this end traditional simulation approaches in environmental psychology have included sketches, photographs and slide shows (Bateson & Hui, 1992). More recently, 'virtual laboratories' that translate the key aspects of a naturalistic setting to a simulated one in the research lab provide highly-controlled experimental environments with high realism and ecological validity (De Kort et al., 2003; Loomis et al., 1999).

The more an environmental representation comes to resemble the real-world environment it mimics, the more realistic users' responses are expected to be (Freeman et al., 2000, p. 151); at its extreme (hypothetically) leading to indistinguishable environments and thus equivalent responses (Loomis et al., 1999). Present day VR-technology is technologically capable of simulating highly realistic, highly detailed, and 'complex' (i.e., large-scale, multi-level) environments.[1] Common presentation devices include single or multiple connected desktop screens (e.g., Hochmair, Büchner, & Hölscher, 2008; Kalff & Strube, 2008) and large projection screens that partially or completely surround participants and that can be used for individual or group presentation (e.g., Schneider et al., 2013; Fröhlich & Wachsmuth, 2013). More immersive presentation devices, such as head-mounted displays use head-based tracking and rendering to allow highly realistic, real-time rotation of the head. Translation of body movements, such as walking, can be simulated by using either a joystick/joypad, or physically within a designated area/on a treadmill. Recently developed head-mounted displays that were originally designed for entertainment purposes, such as the *Oculus Rift* (Oculus VR, Inc, 2014), may over time become affordable and efficient research tools.

Current computer graphics are able to provide visual experiences which relate strongly to real visual experiences (visual realism). Some devices (e.g., head-mounted displays, CAVEs) can, in addition, represent perceptual and bodily experiences that relate to real-world user performance (behavioral realism); e.g., by providing feedback about changes in viewing directions, head and body rotations. The question then is which elements of users' experiences in real and virtual environments are directly transferable from more immersive technology to less immersive technology (e.g., video presentations). On the one hand, due to simulating both visual and behavioral realism, more immersive systems are believed to produce higher levels of experiential realism, such as presence (the subjective, psychological state of being in one place, while physically being in another; Witmer & Singer, 1998). Spatial learning, for example, is better supported when using highly-immersive technologies that provide active motion and bodily feedback rather than desktop devices (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). On the other hand, although desktop screens with high-quality computer-graphics do not offer as much behavioral realism (in terms of bodily feedback) as more immersive technologies do, they sufficiently achieve visual realism. In fact, it may be possible that more immersive systems at times lead to *less* behavioral realism; e.g., due to difficulty with controls.[2] The current study used a desktop VE[3] and predefined routes that did not involve any active wayfinding *tasks*. Experiential realism was thus approached via visual realism (in Studies 1 and 3), which was expected to be sufficient to assess users' experiences, and active movement was enabled for an approximation of behavioral realism in Study 2.

1.4. User experience

In order to better understand how users experience space (with the aim of potentially integrating this insight into post- and pre-occupancy building evaluations), it is necessary to find a common ground in the definition of 'user experience' as it relates to user-centered architectural design. In human–computer interaction, the term user experience has been

[1] For an example of current visual realism in games, see, e.g., *Alien:Isolation* by Creative Assembly (2014).

[2] A more detailed discussion about the relative influences of technological aspects (e.g., screen size, field of view, level of realism, stereoscopy, level of detail) on spatial comprehension and presence is outside the scope of the current work; but, Kalisperis, Muramoto, Balakrishnan, Nikolic, and Zidic (2006), for example, provide an overview.

[3] At the time of the studies VR-tools such as Oculus Rift were not yet available.