Using virtual and augmented reality to study architectural lighting

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This paper presents industry stakeholder insights from the implementation of a dual modality intervention using virtual and augmented reality simulation to study complex lighting theory in architecture design. Using a design based research method the aim is to evaluate these insights and inform a pilot study to educate first year architectural design students on the complexities of lighting the built environment and methods to improve architectural workflow. The aim is to enable learners to experience natural and artificial lighting methods comparatively in real-time through multiple comparative visualisation methods. This is important to make informed evaluations regarding architectural designs in terms of spatial quality, character, performance, and user-comfort levels. This in turn allows architects to rapidly modify their designs to accommodate or mitigate the environmental effects. Outcomes from the initial usability test highlight the ability to switch back and forth between the virtual and augmented reality simulation technology, and between lighting visualisation modes as a huge step forward by the industry stakeholders. Additionally, the idea of representing the physical building where the simulation took place virtually using a detailed mapping gave a real-world anchor that made the simulations easy to navigate, leading to improved satisfaction and engagement. However, the study also highlighted improvements in the delivery of the simulation is required to improve simulation learnability and efficiency.

Introduction

The subject of lighting is considered fundamental in built environment education yet remains a complex learning topic (Webb, 2006). This can be attributed to the fact that light, and its effects, are better expressed experientially rather than theoretically. It is also difficult to teach about light before first educating about the effects of light (e.g. luminance or light intensity). In architectural education, the conventional way of teaching novice students about lighting effects is through a series of static 2D renders, photographs, and in-situ examinations (Descottes & Ramos, 2013). However, this pedagogical method lacks navigation, manipulation and visualisation at human scale (Birt, Horvoka & Nelson, 2015). This aligns with the learner view of Jones, Ramanau, Cross, and Healing (2010), who report that learners expect to be engaged with participatory, interactive, sensory-rich, experimental activities (either physical or virtual) and opportunities for input. These learners are more oriented to visual media than previous generations and they prefer to learn visually by doing rather than by telling or reading. Mayer (2014) and Bernard at al. (2014) also advocate the use of dual modality (multiple modes of presentation) delivery and content as this improves learner outcomes and recall leading to deeper learning. Therefore, this paper presents a rationale for a pilot study to answer the question, “How do learners perceive the multiple modes of presentation delivery of virtual and augmented reality technology to support learning of complex lighting theory?”.

Background literature

As educators, we are increasingly surrounded by a new breed of individual that tackles problems in new and different ways through technology (Corrin, Bennett, & Lockyer, 2013). This has led to much discussion about the potential of digital technologies in higher education to influence teaching culture (Lai, 2011) and enhance (Kirkwood & Price, 2014) classroom pedagogy. Kirkwood & Prince (2014), explain that technology has significant and interrelated impacts upon student learning and potential to transform learning practice but most studies focus only on reproducing or reinforcing existing practice and not transforming learning. This aligns with Ayres (2015), who indicates that most prior work in multimedia learning (Mayer, 2014) and blended learning (Bernard at al., 2014) has been formed around explanatory words and pictures with less attention to complex learning environments such as interactive visualisations, games and simulations. Connolly et al. (2012), also indicates games and the underlying technology as emerging and significant tools to enhance classroom pedagogy, to assist in transforming learning and improving learner motivation.

Architectural education has seen increased pedagogical use of video game technology (game engines) to study specific learning outcomes such as building information modelling workflow (Yan, Culp & Graf, 2011), spatial understanding (Valls, Redondo, Garcia-Almirall & Subirós, 2016) and environmental experience design (Kosmadoudi et al., 2013). Kosmadoudi et al. (2013), explains that the game technology offers immersion, curiosity, communication strategies to explain complex information, and relationship with the instruction content being presented which is novel and links back to the core outcomes as highlighted by Connolly et al. (2012). More recently, this use of game technology has been used to develop multisensory evaluations of urban spaces (Luigi et al., 2015) using virtual reality (VR) simulations which allow navigation and spatial understanding at human scale, this has also been highlighted in Birt, Horvoka & Nelson (2015) who explored the fundamental perceptions of learners and the use of virtual reality in spatial navigation of built environments. Augmented reality (AR) simulations have also been used to understand whole scale building sites on architectural plans (Lee at al., 2012) which allows for the whole system to be evaluated within the physical environment space under examination. This allows for a whole system view and conceptual understanding that is often missing in the human scale approaches.

Prior research in the use of interactive visualisation and game technology (Birt, Horvoka & Nelson, 2015) has revealed strengths and weaknesses in the impact of any single modality on learning, and those learners themselves have different styles (Mayer, 2014), needs and capabilities (Höffler, 2010). Additionally, architectural pedagogy benefits from visualisations allowing navigation of complex scenes, multiple perspectives and the ability to experience space at both a system level (whole model) (Lee at al., 2012) and at human scale (Birt, Horvoka & Nelson, 2015). To date most studies in the use of visualisations or game technology have focused on a single *silver bullet* method to visualise the learning artefact and have not embraced multiple visual modes of modality. The fundamental assumption(s) of the proposed simulation are: no technology offers a silver bullet for students to grasp specific concepts; multiple visual representations must take advantage of the differences between the technology representations and students learn through a variety of approaches. This reflects the general proponents of blended learning (Bernard et al., 2014) and multimedia learning (Mayer, 2014) that long appreciated and advocated for multiple modes of presentation, delivery and content.

Lighting simulation

Based on the literature review in particular the fundamental lighting theory of Webb (2006) and Descottes & Remas (2013), and the considerations of mixed reality (Birt, Horvoka & Nelson, 2015) and multimodal multimedia learning (Ayres, 2015; Bernard et al., 2014; Mayer, 2014) a simulation was developed to help answer the research question about "How do learners perceive the multiple modes of presentation delivery of virtual and augmented reality technology to support learning of complex lighting theory". The simulation was built using Rhino (rhino3d.com), Maya (autodesk.com/products/maya/) and Unity3D (unity3d.com) (see Figure 1) and is representative of an existing built environment space on the authors university campus (shown in Figure 1 left hand side). The intended thought of the authors is that in using the physical building as an anchor this would lead to improved understanding of the simulation and situate the user within the simulation environment. It was therefore important to have the virtual VR and AR representation(s) be as close too accurate as possible, to ground the learners within the familiar context.

Figure 1: Images of lighting simulation used in the physical building on the authors campus during industry and academic stakeholder critique. Shown are images from the VR (top row) using the HTC VIVE and AR (bottom row) using the Microsoft HoloLens

The intent is the VR simulation would provide a human scale representation allowing for spatial understanding as per the work of Birt, Horvoka & Nelson (2015); Kosmadoudi et al., 2013; Valls, Redondo, Garcia-Almirall & Subirós, 2016; and Yan, Culp & Graf, 2011. The AR simulation would allow for orientation at scale situated within the backdrop of the physical building as seen through the augmented overlay as per the work of Lee at al. (2012). The conditions chosen for this simulation can be loosely described as a sunny morning in the summer. For accuracy, the actual coordinates (28.073S, 153.416E), orientation (5^0W), and date (20 Dec, 2016) were used to gather the proper altitude and azimuth of the sun along its path. The real-time simulation covers all 24 hours in the day, and can be sped up or slowed down to allow users to vary their experience. The simulation also allows learners to switch between natural light conditions (shown in Figure 1 centre), and luminance (light intensity) mapping overlays (shown in Figure 1 right hand side). By visualising the effects of sun through simulated natural light and luminance mapping to visualise light intensity transfer, the simulation enables learners to experience this important comparison in real time in both the human and whole system scale. This in turn allows informed evaluation regarding the design in terms of spatial disposition, function and user-comfort levels. This is further enhanced by allowing users to spatially navigate (move around) both the virtual and physical building to experience all aspects of the built environment.

Research method

The theoretical framework underpinning this work is design-based research (DBR) methodology. Specifically, Reeves (2006, p. 59) four step model for planning design-based research will be followed through two-three feedback loops, with the first loop beginning with analysis of the problem, development of the solutions informed by existing design principles and technological innovations as discussed in the presented literature review, followed by an evaluation by three independent industry critics (presented in this paper). This first loop will then be followed by the proposed second loop pilot study that will involve an iterative implementation of the new solution using the feedback from the first loop experts (presented in this paper). This will be delivered into the classroom by a discipline expert practitioner positioned to evaluate the effectiveness of the solution who will provide detailed feedback on the re-design from the student stakeholder perspective. This will then result in a loop back for design refinement and further iterative testing and evaluation if required.

For the first loop, three industry critics were recruited as part of a final semester masters by coursework thesis presentation where the simulation was presented for evaluation and grading. Categories were developed for both the observation as well as the data collection for surveys. These are based on previous work of Birt, Horvoka & Nelson, (2015). For the proposed second loop pilot study, an undergraduate class at the lead authors institution will be recruited as per the studies ethics to perform the testing. Specifically, a small sample of students (*n <= 30*) will be selected for this initial student usability test in line with common first phase software usability testing practice (Nielsen, 2012), so that it would be possible for a single research assistant to interact with these students in depth and collect rich feedback on their use of the tool. Participants will be given a primer on the skills to be covered, and then asked to complete three survey instruments on the applicability of the lighting method using traditional 2D methods, VR and AR. Students will be given access to the simulation tools before completing the survey on the use of the mixed reality interventions. Details of the results of data collection for the first loop are included below.

Results and discussions

The first loop DBR testing of the intervention was conducted using three independent industry stakeholders and data was collected and analysed through a research assistant. The results of the quantitative survey with the industry critics are presented in (Table 1), with each item ranked on a Likert Scale of 0 to 5, where 0 is not relevant and 5 is very relevant. During the intervention, a video recording was taken of the industry stakeholders including technology use, questions and answers.

Specifically, and in terms of the positive outcomes, the experts rated the dual modality simulations positively (*table 1 >= 4.00*), in regards to satisfaction 4.00(VR)/4.33(AR), memorability 4.33, manipulability 4.33(VR)/4.67(AR), navigability 4.33, real world 4.00(VR), communication 4.67, creativity 4.33(VR)/4.67(AR) and engagement 4.00. The ability to “switch back and forth between the AR and VR simulations, and between the natural lighting and luminance mapping simulations”, was commented on by the industry stakeholders as “a huge step forward in design”.

Table 1: Average industry stakeholder usability assessment survey results for the VR and AR simulation

Question	Average		StdDev	
	VR	AR	VR	AR
1. Accessibility: Visualisation is readily accessible	3.33	3.33	0.47	0.58
2. Learnability: Visualisation is easy to learn	2.67	2.67	0.47	0.58
3. Efficiency: Visualisation is efficient to use	3.67	3.33	0.47	0.58
4. Satisfaction: Visualisation provides (confidence) of the design	4.00	4.33	0.82	0.58
5. Memorability: Visualisation is memorable in support of the design	4.33	4.33	0.47	0.58
6. Error Free: Visualisation is free from visual and design errors	3.33	3.33	0.47	0.58
7. Manipulability: Visualisation variables can be manipulated	4.33	4.67	0.94	0.58
8. Navigability: Visualisation allows the user to change their viewpoint	4.33	4.33	0.94	1.15
9. Visibility: Visualisation provides clear detail to interpret the design	3.67	3.67	0.47	0.58

Question	Average VR	Average AR	StdDev VR	StdDev AR
10. Real world: Visualisation provides a match to the real world	4.00	3.67	0.00	0.58
11. Communication: Visualisation aids stakeholder communication	4.67	4.67	0.47	0.58
12. Creativity: Visualisation allows user creativity with the design	4.33	4.67	0.47	0.58
13. Engaging: Visualisation is meaningful	4.00	4.00	0.82	1.00
14. Motivating: Visualisation aids acceptance of the design	3.67	3.67	0.47	0.58

Additionally, "the idea of using a detailed and furnished space gave a real-world anchor that made the simulations easy to navigate through". Because of the increased level of immersion and interactivity, the stakeholders showed a higher level of curiosity and engagement. As such, they were active in their own pedagogical process. This is in line with results by Birt, Horvoka & Nelson (2015), Lee et al. (2012) and Luigi et al. (2015) and highlights the positive outcomes the technology provides especially in regards to users ability to manipulate variables within the simulation and the real world understanding imparted.

In terms of the mixed outcomes (*table 1 >= 3.00 < 4.00*), the experts noted that the current simulation implementation(s), "required expensive equipment and significant setup and space", which was also highlighted in the average accessibility response of 3.33, "time to use", which resulted in an efficiency response of 3.67(VR)/3.33(AR) and general "differences between the real world and simulation", which resulted in a visibility of 3.67, real world 3.67(AR) and error free of 3.33. The authors will address these by improving the simulation experience in terms of the real-world nature and exploring the use of cheaper more accessible mobile phones to capture the simulation pedagogy in both the VR and AR form. This will be compared to and contrasted with the HTC VIVE (VR) and Hololens (AR) simulations. This is in line with the study by Lee at al. (2012) that performed the building simulations using a mobile device and a simple image marker to improve accessibility to the simulation.

Finally, the area that needs most improvement (*table 1 < 3.00*) was learnability. The reviewers noted that "the technology takes time to get used to" and "requires assistance" which was highlighted in the average response of 2.67. This is not satisfactory and the authors will need to address this before student trials by firstly providing a picture in picture video tutorial to ground the learner and then scaffolding and supporting the learner through a guided tutorial within the simulation environment. This is in line with common game (Connolly et al., 2012), blended (Bernard et al., 2014) and multimedia (Mayer, 2014) learning design.

Conclusion

Students learn in different ways with evidence suggesting that multiple forms of media are useful tools of instruction for active learners. Combined with this is a push towards simulation and mixed reality to teach complex concepts in architectural design, including the concept of dynamic lighting, which is currently taught using static 2D renders. This paper presents results from a study looking at the use of multiple modes of visualisation methods to teach lighting concepts, using a combination of VR, AR, grounded within a real world physical representation. Using a design based research methodology, the first loop of a usability study was conducted with three industry experts and results provided.

Results showed that the experts valued the ability to switch between different modes, and gave a positive rating to the memorability, manipulability, navigability, real world aspects, communication, creativity and engagement of the multiple simulations. However, they also acknowledged that the system was expensive to set up and not very accessible, and that the learnability of multiple systems was difficult. From the perspective of the authors, much additional work is needed to simplify the currently cumbersome workflows between software platforms and discipline-specific methodologies toward these platforms. A simplified workflow will facilitate increased uptake in both educational and professional setting, further adding to the value of these mixed reality visualisation methods. It is intended that these issues will be addressed in future work.

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