An experience-based interactive lighting design approach using BIM and VR: a case study

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Abstract. A lighting condition has a significant influence on humans’ concentration, performance, and eye comfort. A well-designed lighting environment is critical for work efficiency and human health. Lighting design is commonly based on designer’s previous experience and computational lighting simulation results. Although simulations can provide relatively accurate calculation results, several difficulties exist in terms of measuring actual users’ experience and reflecting their feedback into the design. In this traditional approach, users are unable to experience or feel realistic lighting effects until the installation phase. This lack of user experience in the design phase leads to increasing risk of redesign and revision, which are extremely time-consuming and reduce the efficiency of lighting design. Therefore, it is necessary to minimize the gap between the lighting design and users’ satisfaction. This research aims to enhance visualization of lighting design and thus improve the design efficiency by developing a real-time interactive lighting design approach using building information modeling (BIM) and virtual reality (VR) technologies. By integrating these technologies, the proposed approach is able to support user interactions, actual activities simulation, and personalized lighting design. In addition, the proposed approach can provide users with immersive and sensory experiences to evaluate their lighting design alternatives. The whole process of the approach includes 3D modeling in Revit, texture mapping in 3ds Max, simulation analysis in DIALux, and interactions development and VR realization in Unity. A case study was conducted to implement and validate the proposed approach. In this case study, users were able to experience realistic lighting effects and provide their feedback for improving the design in a sensory way while lighting simulation was automatically conducted simultaneously. The approach enables better user experience and provides a practical way to apply BIM and VR technologies to improve the efficiency of real-time interactive lighting design.

1. Introduction
Lighting can affect human performance on many aspects, such as cognitive performance and problem-solving ability by interfering with physiological factors such as circadian rhythms [1]. In particular, uncomfortable lighting conditions may cause visual discomfort and affect human emotions such as friendliness, alertness, and confidence, which further influence work productivity [1–3]. Current light design approaches often cannot satisfy this requirement and thus it is necessary to enhance visualization and users’ experience during lighting design processes. New technologies, such as building information modeling (BIM) and virtual reality (VR), can be of great help to address this problem. Bates and Meliani have mentioned that the visualization of building components provided by BIM model can help designers adjust their lighting system [4]. Heydarian et al. have collected
lighting-related user behaviors in virtual environment and integrated them with building performance simulation [5]. Moreover, several lighting design systems using BIM and VR, such as BIM-based lighting design feedback proposed by Natephra et al. and VRLight developed by Araújo, have already tried to explore the benefits of using these technologies when conducting lighting design [6,7].

This research aims to further propose an experience-based interactive lighting design approach by taking advantages of BIM and VR technologies. The proposed approach is designed to (1) enhance the visualization of lighting design and support users’ participation during the design phase; (2) provide sensory and immersive experience with VR technologies for personalized lighting design; (3) establish a real-time interactive design system to evaluate the design alternatives according to the space functions and users’ preference synchronously.

2. Methodology

In this research, the proposed lighting design approach is divided into the following steps described in figure 1. Then, a case study is conducted to implement and validate the proposed approach.

First of all, a lecture room at the University of Hong Kong was selected for the case study. The three-dimensional BIM model was then created using Autodesk Revit according to the measurement results of the lecture room. Indoor decoration and furniture layout were recorded and arranged in the BIM model in order to imitate the actual condition of the lecture room while the models of lighting fixtures were built separately so as to be interactable in accordance with the users’ requirements. After all revisions were done, the BIM model was exported as an FBX file and an IFC file respectively for texture mapping in 3ds Max and lighting calculation in DIALux.

To improve the quality of rendering and the performance of immersive experience, the texture of model was mapped and refined in 3ds Max. The textures were acquired by taking photos of the corresponding components in the lecture room, and further adjusted to the realistic brightness and scale. In addition, a plugin called Universal Material Converter (UMC) was used to convert materials from Autodesk Materials to standard materials used in the Unity environment seamlessly. All components were then grouped together in order to prevent the placing errors from occurring in Unity due to the loss of geometric information. The model was then imported into Unity as an FBX file.

DIALux was used to conduct the preliminary illumination simulation of the lighting system. Two standards described in DIALux, DIN V 18599-10: 2007-02 and BS EN 12464-1:2011, were adopted to stipulate illuminance minimums for different space functions. The minimum illuminance level of the selected lecture room is 300 lux for the classroom (audience area) and 500 lux for the lecture hall (lecture area). Then, two layouts of lighting systems (double-row and single-row) were designed (figure 2) and two kinds of lights were selected to provide different lighting plans. These two types of lights were selected from PHILIPS database, and their properties are shown in table 1. To evaluate lighting design plans, the central area of lecture division and audience division, as well as the connection area between these two divisions, were selected as the calculation surfaces. The light system simulation results are shown in table 2. Particularly, light B cannot provide a satisfactory result in the single-row layout design plan.
Both the 3D model and the calculation results were then imported into Unity for interaction development and VR realization. The built-in functions in Unity, such as User Interface (UI) system and lighting system, were used and modified to develop interactions between users and the proposed system. In addition, a plugin called LumenLights was used to establish the conversion relation between the unit of light intensity in Unity and the real-world unit of luminous flux, which helps to provide more realistic sensory experience. Besides, the video projecting function, which is a common activity in a lecture room, was set in Unity to test the designed lighting environment.

Virtual Reality Toolkit and SteamVR Plugin were used for building VR solutions and working with the Helmet Mounted Display (HMD) so as to allow users to interact with UI and game objects. In addition, HTC VIVE was used to enable users to have immersive lighting design experience and interact with the model in real-time to design and revise their lighting plans.

3. Results
Interactions between users and the proposed system are designed to support the personalized lighting design as well as the immersive user experience. These interactions can be divided into the following categories: a) Lighting instantiation; b) Lighting parameter adjustment; c) Personalized lighting design; d) Video projecting; e) Energy consumption.

There are two types of lighting fixtures and two lighting layouts in the proposed system for users to instantiate the lighting system. LightA and LightB are used to represent the two lighting fixtures, while SingleRow and DoubleRow offer two different lighting layouts based on the previous DIALux calculations. By combining the two types of lighting fixtures with two different lighting layouts, four lighting design options in total are presented for users to make their decisions based on their requirements, preferences, and budgets.
Lighting parameters (i.e., intensity and color) can be adjusted after instantiating the lighting fixtures. Bright, Medium, Dim, and Close are used to present the full, half full, quarter full and empty status of lighting intensity (figure 3). In addition, an Intensity Slider enables users to adjust the illumination level. For the correlated color temperature (CCT) of lighting, users are allowed to change it to 3000K or 6000K by using Yellow or White. Therefore, the adjustment of lighting intensity and color helps users observe and change the setting of lighting design.

Personalized lighting design is also supported in the proposed system via AddLight, Save, ShowAuto, and ShowManu functions. AddLight adjusts the illumination level of a specific area, which allows users to manually install a light fixture in anywhere of the ceiling by grabbing the lighting game object and moving it to the specific position (figure 4). After modifying the layout of lighting system, Save stores the current lighting design plan, which can be regenerated again by using ShowAuto and ShowManu for users to compare different lighting design plans.
Play and Pause are used to control the current playing video of the video projecting function. By combining this interaction with the aforementioned functions, users are able to refine the lighting layout based on their feelings.

Finally, the energy consumption results of different lighting design plans are calculated from DIALux and stored in the proposed system. CostBar reflects the total power consumption of each plan for users to balance between their requirements and total budgets. Moreover, the calculation result is also showed in Context as a text with other information such as type and layout. Besides, a “Not Satisfied” warning text pops up on the UI if the illumination level does not satisfy the minimum requirement of the relevant standards. These descriptions aim to provide users with supplementary information of lighting design in a semantic way.

Overall, these functions enable users not only to design their lighting systems interactively, but also to present relevant information to refine and compare several lighting design plans.

4. Limitations
In contrast to traditional lighting design approaches, the case study has shown that the proposed approach enables users to develop and experience their lighting design interactively by using BIM and VR technologies. However, several challenges have also occurred and affected the serviceability of the proposed approach.

A feasible calculation method of lighting illumination in Unity is lacked. Both the unit of light intensity in Unity and its conversion relation with the real-world unit of luminous flux are not available in the official documentation. Consequently, this proposed approach cannot reflect the real lighting effect. To partly address this challenge, DIALux and LumenLights are adopted in this research. DIALux is used to pre-calculate and examine whether the lighting design plans satisfy the relevant standards while LumenLights provides an empirical formula between lumen and light intensity in Unity. As a result, the prototype system allows users to evaluate and experience different lighting design plans qualitatively.

Moreover, the lighting fidelity is seriously affected by the render mode. The fidelity is determined by the number of pixel lights, which reflects the corresponding intensity of illumination. However, the increasing number of pixel lights also slows down the immersive experience. Therefore, it is vital to determine the optimal number of pixel lights to balance between lighting fidelity and realistic user experience.

5. Conclusion
This research proposed an experience-based interactive lighting design approach by using BIM and VR technologies in order to supplement traditional approaches in terms of users’ participation and experience. A case study was then designed to implement the proposed approach. Interactions in the VR environment were also developed to support the personalized lighting design as well as the immersive user experience. The lighting instantiation function provides automatic lighting design while the lighting parameter adjustment and personalized lighting design functions allow users to refine their design manually according to their preference. Furthermore, the video projecting function can simulate the real-life activity and the energy consumption function can show the energy calculation results.

The case study has shown that the proposed approach allows users to directly experience their lighting design plans and further conduct their personalized revision, which can highly enhance the designers’ understanding and reduce the time cost of redesign. However, the preliminary preparation, such as DIALux-Unity conversion, has increased additionally. Besides, the proposed approach also requires high-performance devices to perform. Therefore, this proposed approach is recommended for venues where the lighting effect is significantly sensitive to the users, such as lecture theatre and stage.

To improve the practicability of the proposed approach, several problems need to be further addressed. First, the quantitative analysis in the proposed system cannot be conducted due to the lack of a feasible calculation method of lighting illumination in Unity. In addition, lighting fidelity and user
experience should be balanced in order to have the most realistic lighting design effect. All these challenges will be considered as future work of this research.

6. References

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