Digital Campus with Virtual Reality: from Immersive Visualization to Interactive Experience

Yue Li[1,2], Qilei Sun[1,2], Cheng Zhang[1,3], Eng Gee Lim[1,2], Hai-Ning Liang[1,2], and Yong Yue[1,2]
[1]Virtual Engineering Center, AI University Research Center
[2]School of Advanced Technology
[3]Department of Civil Engineering
Xi'an Jiaotong-Liverpool University, Suzhou, China
firstname.lastname@xjtlu.edu.cn

Abstract - Constructing a digital campus with virtual reality (VR) allows users to experience an immersive campus life, access campus services remotely, and have social interaction with others. However, most existing digital campus systems only present users with immersive visualizations of the digital campus scenes only. We argue that digital campus with VR should move a step forward from the immersive visualization to supporting users' interactive experience. Hence, we propose a framework of digital campus with VR and present three scenarios at Xi'an Jiaotong-Liverpool University, which include the building evacuation drills, the digital library system, and the VR experiential learning. Our research provides practical insights into the design and application of interactive experience of digital campus with VR.

Keywords: digital campus; virtual reality; virtual campus; visualization; interaction

1 Introduction

Virtual reality (VR) can support immersive roaming within a reconstructed virtual environment of campus scenes, but digital campus with VR is more than immersive visualizations. In addition to immersion, VR is also known for its interaction and imagination features [1]. During the past decade, many universities in China have explored digital campus with VR technologies, with extensive efforts on 3D modeling of campus buildings and the construction of campus scenes. Although interaction was often included in their development process, it usually referred to the roaming methods within the campus scenes. For example, Guangzhou University and Qingdao University built their digital campus from reconstructed 3D models of campus buildings and allowed users to have an immersive campus visiting experience using the HTC Vive [2], [3]. Similarly, the digital campus of Jinan University presented users with three different roaming approaches with the first-person perspective across the land, water, and air [4]. The digital campus of Guilin University of Electronic Technology allowed a bird's eye view, connecting to an external database to show different building introductions [5]. These systems are distinct from traditional digital campus systems with 2D displays in terms of the visualization experience, but few explored interactions other than navigation and roaming. Tianjin University presented a shooting game within the VR campus scene [6]. However, the motivation, purpose, and the consequent effects of using a shooting game for campus tours were not clearly stated. Most research on digital campus provided detailed descriptions of the modeling process, including the construction of building models, the integration of the models to the game engine, and the optimization of scenes. Nevertheless, most applications fell upon the non-interactive experience category of VR system proposed by Zhao [7], whereas we propose that digital campus should be at least a human-virtual environmental interactive experience, and ideally a group-virtual environmental interactive experience. The development and application of digital campus with VR can offer more than immersive visualizations and go beyond campus tours. Earlier work on digital campus identified that it can be an information management system that integrates various campus systems and services [8]–[10]. Current research on digital campus with VR with immersive visualization laid a foundation for its use as an information management system in terms of the overall environment construction. However, more efforts are needed to address the aspects pertaining to interactive experience, such as its combined use with existing campus services and the collaborative learning environments with VR. Therefore, addressing on the need of interactive experience for digital campus with VR, we propose a practical framework, highlighting the significance of its use in interactive experience by presenting three use case scenarios that we are working on at the Xi'an Jiaotong-Liverpool University.

2 The Framework of Digital Campus with Virtual Reality

We propose a framework of digital campus with virtual reality and provide detailed descriptions for each component, including data preparation, 3D modeling, visualization, interaction, system integration, and deployment (see Fig. 1). At the data preparation stage, information about the campus buildings is collected. It lays a foundation for the 3D modelling stage to construct 3D meshes and edit textures and materials. These two components contribute to the visualization of digital campus, including the 3D scenes and user capacities of navigations within the scenes. This framework illustrates that in addition to the basic workflow of visualization, information systems of the campus can be integrated and interactive experience should be supported. Data of additional services are incorporated at the data preparation stage and inform the 3D modelling stage if needed. More importantly, interactions within the virtual environments are built upon the visualizations and the system integration. The following sections will explain each component in detail.

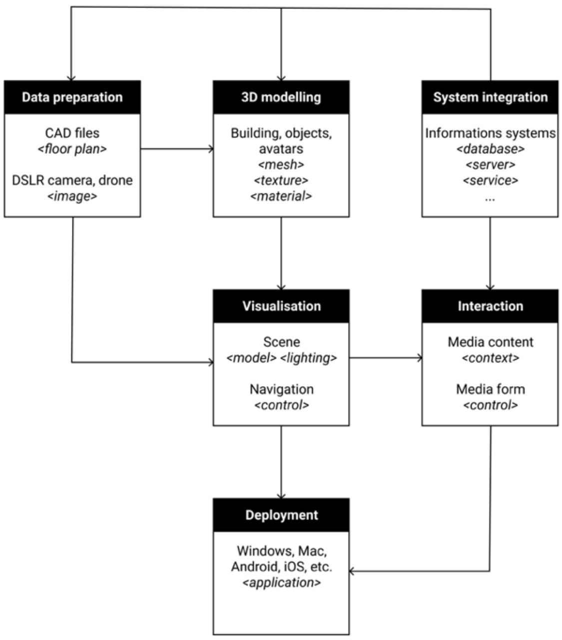

Fig. 1. The framework of digital campus with virtual reality.

2.1 Data Preparation

The digital constructions of a campus require two fundamental types of data: floor plan data from CAD software and image data from DSLR cameras. Floor plan data of campus buildings and landscape provides 2D information to refer to when constructing 3D models. CAD drawings contains information needed to construct the building's physical structure. Satellite images are useful references in modeling to obtain a top-down view of the campus terrain. Image data of campus buildings need to be captured to provide textures and materials to create realistic looks in the virtual environments. It is often easier to process the images of buildings in batch afterwards if they are taken under the same lighting conditions. These images are used to create building textures and as references in modeling. A more detailed and accurate digital reconstruction will also require geographical and topographical information to simulate the surface elevations and terrains of the campus. Overall, the floor plan data and image data contain essential information needed for a digital campus system and lay a foundation for the 3D modeling.

2.2 3D Modelling

3D modeling converts 2D information collected in data preparation to 3D models, including both the construction of shapes in meshes and the editing of the appearance with textures and materials. VR-driven 3D modeling should aim to produce models that are compatible with the following development in game engines, and scalable for system integrations. In addition to the modeling of campus buildings, many other virtual objects and virtual avatars are also needed in the integrations with other campus systems and services. In our practice, we explored the use of Revit and SketchUp. Revit is specifically designed for architecture and is widely adopted for building information modeling (BIM). It supports accurate constructions of building models with precise building information, including the building structures, room scales, and even the wall thickness (see Fig. 2). Although Revit produces models of industry standard, it is limited in terms of complex texture mapping. SketchUp is more light-weighted and handles modeling of architectures as well, but it is better fitted for quick modeling of the shape and look and less concerned on the preciseness (see Fig. 3).

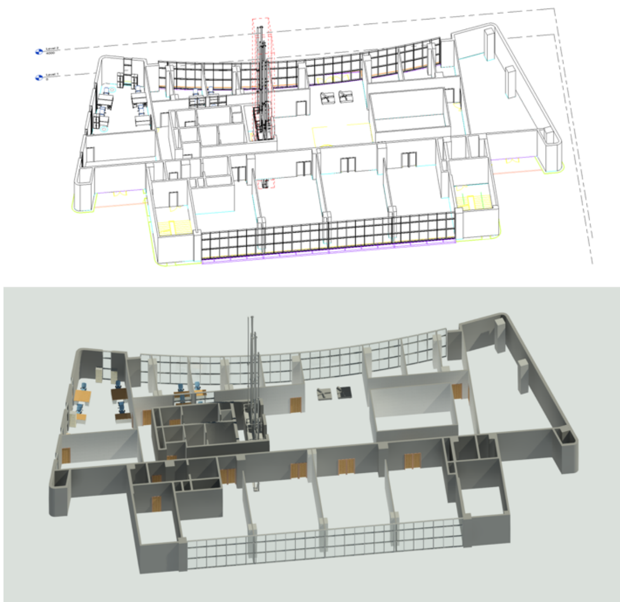

Fig. 2. Revit model in editing mode and render mode. 5th floor of the International Research Centre, Xi'an Jiaotong-Liverpool University.

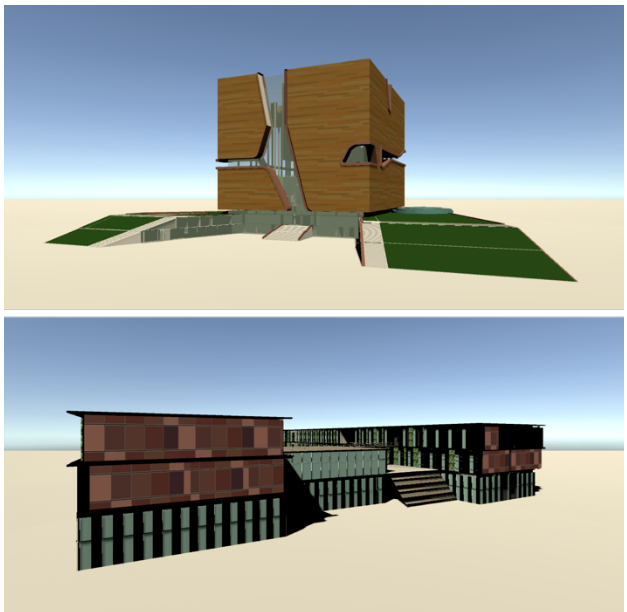

Fig. 3. SketchUp models of the Central Building and the Engineering Building, Xi'an Jiaotong-Liverpool University.

We also evaluated several other commercial software for 3D modeling. For example, 3DS Max is designed for general modeling and texturing. It is used for architecture modeling, but the models are usually constructed from free form, which makes it more complex to model and more difficult to ensure the accuracy of building information in 3DS Max than in Revit. However, models can be exported from Revit to 3DS Max to obtain more photo-realistic looks. Maya, on the other hand, works better in animation and rigging, which makes it a better option for virtual avatars. Blender as a free modeling software supports the modeling of virtual objects. In addition to the modeling of model meshes, mapping textures and applying materials are equally significant to simulate the look of the buildings. Building images taken with digital cameras are used to create model textures, but often need to be edited on the brightness, contrast, and color balance, etc. Texture mapping applies pixel details in a bitmap to the 3D surfaces of a model, whereas materials enhance the realistic look of the model by simulating the materials in real life. It includes references to textures and defines how the model should be rendered, for example, whether it is dull or shiny. As a result, the models are exported to FBX as a preferred format because it keeps metadata and geometry information of building models.

Other than constructing models from scratch, recent advances in aerial photography with drones also support collection of building data with camera positions, which can be used to generate 3D models directly using photogrammetry techniques. Software to do this includes RealityCapture and Meshroom. Although it provides a quick visualization with photo-realistic looks, it has several limitations. First, it requires both techniques in operation of drones and high-end workstations to process the large amount of data. Second, the fidelity and accuracy of building information with this approach cannot be guaranteed. Third, it often produces a model in one-piece, which means it will require significant post-processing efforts to segment the models and generate modularized components that are compatible to the development software. This can be a good option for quick visualizations with immersive experience, but not the ideal approach for scalable digital campus system development at the current stage. The industry is working hard to facilitate the VR-driven modeling and development in architecture, engineering, and construction (AEC) with immersive view and interactive experience. For example, Unity Reflect [1] supports the real-time 3D visualisation of Revit's BIM models in Unity. NVIDIA announced vMaterials [2] with real-world materials to use in modelling and VRWorks [3] to enhance development of the VR environments.

To summarize, most modeling software and the aerial photography with photogrammetry techniques support the 3D modeling of the campus buildings. However, in order to make the digital campus a scalable project with the implementation of interactions and integrations of other campus systems, it is better to carefully construct models with precise information with Revit or 3DS Max. In addition, for buildings which are more likely to be visited, such as main teaching buildings, it is better to preserve building information and details at a high level. Buildings and areas that are less likely to be visited can be modeled with quick and rough sketch models in order to speed up the development process. The choice of tools to use is dependent on the desired outcomes, but it is important to evaluate the project scale, prioritize features and functions to develop, stick to the selected tools, and use version control to track changes and manage the project.

2.3 Visualization

Visualization in digital campus includes the construction of the campus scene and the implementation of navigation. Scene construction is the process to create a virtual environment with objects constructed in the 3D modeling process, often carried out in game engines such as Unity and Unreal (see Fig. 4). The construction of virtual environment includes a series of work activities, including terrain modeling and editing, adjusting the scene lightings, and optimizing the scene rendering. Organic modeling of plants, flowers, and rock are relatively complex in 3D modeling, whereas Unity supports the terrain modeling with enough details of a landscape at large scale. In addition, because the texture mappings generated in the 3D modeling process are not always supported in the game engines as expected, it often requires reapplying the model textures and materials during the scene construction. Lightings of the scene are often placed with considerations of the scene optimization. Since global illumination is computationally expensive, the calculations were handled beforehand and to avoid extensive and complex global illumination at runtime, often with baked global illumination lighting or precomputing real-time global illumination lighting. Real-time lightings are then overlaid to the lightmapped scene at runtime to increase the performance. In addition to the optimizations of lighting, we also optimized the scene by reducing of complexity of 3D models in the environment to decrease the computing workload. This was achieved in multiple ways, including decreasing the number of edges and vertices of the models, removing objects beyond the user' viewpoint, and compressing the textures. Optimization of the scenes is needed to make it suit for different platform needs and to ensure a smooth experience.

[1] https://unity.com/products/reflect

[2] https://developer.nvidia.com/vmaterials

[3] https://developer.nvidia.com/vrworks

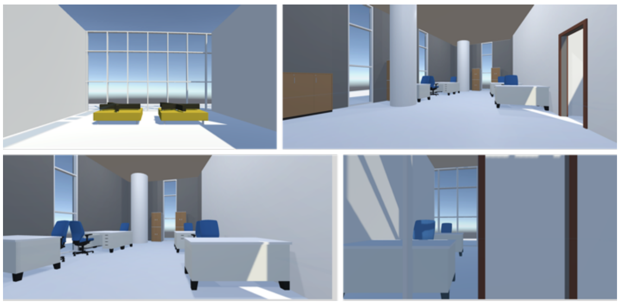

Fig. 4. Immersive visualizations in Unity. 5th floor of the International Research Center, Xi'an Jiaotong-Liverpool University.

As indicated in previous works, the initial user experience of digital campus with VR is seeing the visualization display of the constructed virtual environment. Such visualization can be achieved with various approaches and devices, including large projection screens, immersive head-mounted displays (HMD), and mobile-based displays with VR goggles. We consider navigation as part of visualization instead of interaction, because viewpoint tracking is a core capability of VR [11], and being able to see the virtual environment is a basic function for the visualization of digital campus with VR. Otherwise, there is no point to consider it as a VR system at all.

2.4 Interaction

Design of interactions within a virtual environment depends on both the context of applications and the available control over the objects, namely the media content to present and the media form used to present the content. We use three scenarios to describe some possible interactions for a digital campus system with VR: 1) BIM-based building evacuation, 2) digital library, and 3) VR experiential learning. The aim of the building evacuation in VR is to present users with the best path to escape in the event of fire or other emergencies. For this scenario, the media content consists of building models and graphics information, augmenting visual aid to inform users of the path to follow and providing responsive feedback to users if they are on the right path or going off the suggested path. Similarly, the path-finding interaction with visual aids were used in the digital library as well for book-finding. In the meantime, the digital library project requires the integration of existing databases, such as book and shelf catalogs. This adds to the media content to present. As such, interactions in this context is also linked with the system integration, such as the retrieval of book information from online databases. While the previous two scenarios reflect mostly single-user experience, collaborative learning is a multiuser experience. Interactions within a multiuser environment are no longer based around virtual objects only, but with other co-located users as well. Students can collaborate in the system and learn about design theories and construction process through interactions with the system, such as measuring distances, creating new objects, modifying surfaces, and add comments. These interactions within VR bring new forms of experiential learning in a collaborative environment. Details of the projects will be discussed in Section 3.

2.5 System Integration

The ultimate goal of digital campus with VR is to establish an information management system that integrates various campus systems and services. The fundamental infrastructure and resources of a digital campus include campus network, host server, storage devices, security devices, database system, and other supporting systems [9]. Based on the infrastructure and resources, a unified authentication platform and data exchange platform are established to provide basic supporting services, on top of which information systems are established. A comprehensive digital campus system with VR should aim to integrate these information systems, such as human resource, education management, office automation, mail system, data collection system, and report system, to create a unified information portal of campus. With this regard, the system integration is closely connected to the interaction design. Meanwhile, because additional functions are required with system integration, it also involves preparation of supplementary data preparation and 3D modeling in an iterative process.

2.6 Deployment

Current VR display devices are based on different platforms, from mobile-based goggles, desktop-tethered HMD, to room-scale immersive display. Cross-platform application deployments are supported by Unity and Unreal game engines. Windows and MacOS are often used for desktop-based VR, whereas Android and iOS applications are built for mobile-based VR. Projects can be exported to allow both simple immersive visualizations and interactive experience.

3 Interactive Experience

3.1 BIM-Based Building Evacuation and Shortest Path Finding

Evacuation drills are significant safety training for students because injuries and deaths are likely to occur under critical threat situations and simulations of such circumstances to get students prepared can save their lives. However, such simulations of fire in practice are often unrealistic and can be ineffective if students are not engaged and do not take them seriously. In addition, the drills can be expensive to perform in terms of the management of time and people. Digital campus with VR can perform building evacuation drills with immersive visualizations and engage students with interactive experience. Therefore, this project tries to address the safety problem during building evacuation and can be used for evacuation training in VR. BIM provides the 3D geometric data of a building, which is the fundamental spatial aspect for evacuation. Moreover, attributes of components stored in BIM models provide other essential data for the endurable time for the structures under disaster.

These data preserved in digital campus models allowed us to investigate additional criteria for a safe and efficient evacuation in buildings.

Our project explored the safest path for evacuations with considerations of the shortest path and simulations of fire based on the building structures and fire time. Algorithms of finding a shortest path are available based on geometrical shortest length. However, in the case of disaster, safety should be taken into consideration and given a priority. For example, when the fire lasts for 5 minutes, the fire actually takes little impact on the evacuation. Therefore, people can choose the shortest path to escape (see Fig. 5a). However, when the fire lasts 40 minutes, the previous corridor becomes risky and inaccessible with increasing temperature and carbon monoxide concentration based on our simulation [12]. Thus, another longer but safer path is selected as the optimized evacuation path (see Fig. 5b). Within the campus building in VR, we augmented visual aids including animated arrows to guide the evacuation process in real time (see Fig. 6). VR can support the visualization of the simulation of fires and evacuation paths under different circumstances.

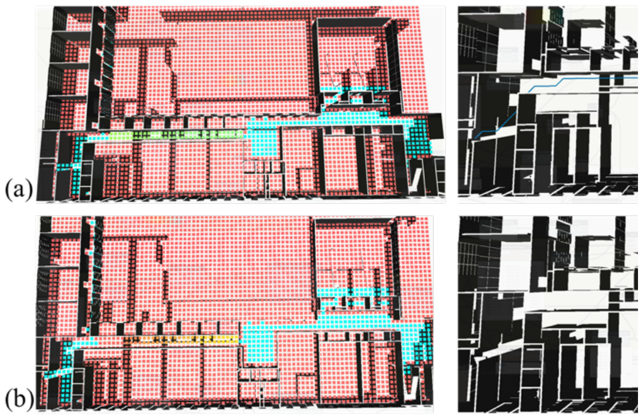

Fig. 5. System showing the evacuation paths for fire in (a) 5 minutes and (b) 40 minutes. Engineering Building, Xi'an Jiaotong-Liverpool University [12].

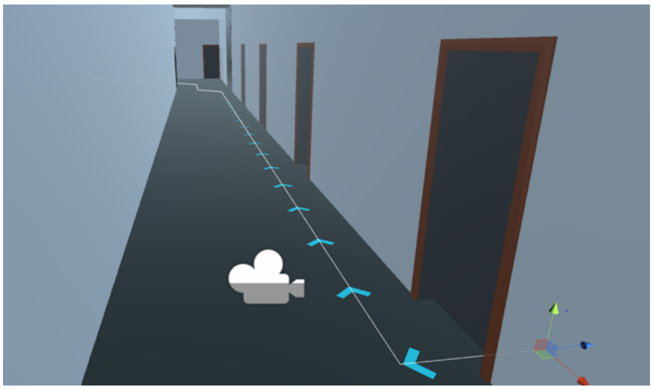

Fig. 6. Visual aids to guide the evacuation. Engineering Building, Xi'an Jiaotong-Liverpool University.

3.2 Digital Library System

The digital library project aims to develop an application that improve students' experience in the university library with booking finding and returning. Although we adopted a mobile Augmented Reality (AR) approach in this project, we found it linked closely with digital campus framework. In order to support accurate and stable in-door pathfinding for the navigation among bookshelves, we obtained the CAD files of the library (data preparation) and constructed the BIM models (3D modeling). With the building information in the BIM models, we applied a path-finding algorithm to calculate the fastest path. However, the visualization component for AR is different from the immersive VR. Considering users are physically based in the real world, we presented augmented visual aids to show the path and guide them to the target bookshelf (see Fig. 7). In addition, the interactions implemented in the digital library AR app was based on smartphone's touchscreen control. This system also incorporated the library database to retrieve information about a book's title, author, ISBN, and catalog number, etc.

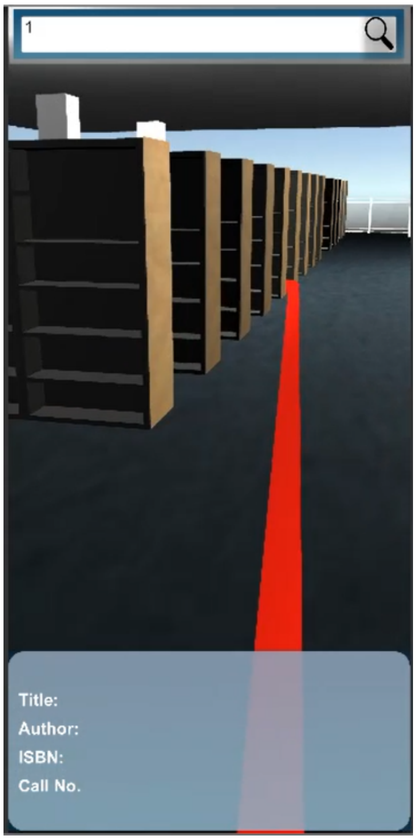

Fig. 7. Digital library system with augmented path. Central Building, Xi'an Jiaotong-Liverpool University.

Despite the use of a different technology, the project's workflow is consistent with the framework of digital campus with VR. Nevertheless, we encountered challenges to precisely locate the mobile device for indoor positioning and to accurately align the rendering model with the actual localized objects and space. At the current stage, we have evaluated different indoor positioning technologies in terms of the accuracy, efficiency and effectiveness, and identified advantages and disadvantages based on the results. We also explored the use of place markers at the entrance of each room to help locate the device. Further improvement will be proposed to address the challenges and to enhance the system performance. By the end of this project, it is expected to have a seamless AR navigation experience with localized 3D features of XJTLU library space to pinpoint the location of the books.

3.3 VR Experiential Learning

VR's richness in embodied interactions can contribute to the experiential learning process, which involves concrete experience, reflective observation, abstract conceptualization, and active experimentation [13], [14]. In the architectural engineering domain specifically, it is believed that the incorporation of information technologies, such as VR, can facilitate students' active learning and improve their communication, collaboration and productivity, leading to better coordination of design drawings, faster delivery, reduced costs, and safer construction sites [15]. Therefore, we developed a VR-based design and construction environment and used it as a teaching and learning tool to support students' experiential learning. We tried to enable the learning-by-doing approach with three teaching and learning objectives: 1) to support students' understandings of the design theories and schemes by investigating corresponding impact of different design scenarios, 2) to facilitate student learning of the construction process and the safety issued to be considered on site constructions, and 3) to investigate the effectiveness of such a learning and teaching tool in architectural engineering education. The implementations of the system and the research outcomes have been published in [16].

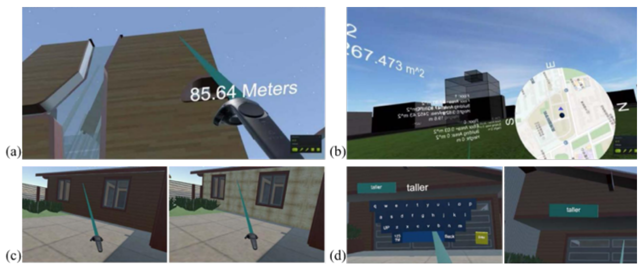

Fig. 8. Interactions implemented for VR experiential learning of architectural engineering: (a) measuring distances; (b) creating new objects (with FAR and 2D map); (c) modifying surfaces; (d) adding comments [16].

This project is an example of how digital campus system can be incorporated to facilitate students' experiential learning. The digital campus buildings can present students a spatial awareness in the virtual environment. Fig. 8 illustrates some interactions within the digital campus for VR experiential learning of architectural engineering. We developed a point-to-point distance measure interaction to provide instructions to students in building design with reasonable dimensions. We also designed system functions to allow student modifying building surfaces with pre-defined materials and adding real-time comments via a virtual keyboard. With the ray-casting and selection techniques, students can modify the target surface, type texts, and see the instant changes on building appearances. Students' understanding of the design theories and construction process is facilitated by their sketching interactions with the environment to create new objects and editing existing one. The system automatically calculates the Floor-Area-Ratio (FAR) when a new building is created and a 2D map is supplemented to help students understand the building location with the digital campus. Students can query the database for user and building information. These interactions supported our first objective to support students' understandings of design theories through active engagement with design activities in the virtual environment. Our second objective was fulfilled with the use of a virtual construction site, which was incorporated to the digital campus for VR experiential learning from an existing design (see Fig. 9) [17]. Regarding our third objective, we received positive feedback from 26 out of 31 students confirmed the positive effects of the use of VR on their learning of architectural design and more than half of the students found the tool impressive. Students ranked the sketching as the most useful function, followed by measuring, navigation, and material changing. The results from students supported our claims on the significance of interactive experience other than mere immersive visualizations with navigation within the virtual campus.

Fig. 9. Designed game for construction site exploration [17].

4 Conclusion and Discussion

In this article, we introduced a framework of digital campus with VR and highlighted that other than immersive visualizations, it is significant to develop and design for interactive experience and the potential integrations of existing systems and databases. Choices of 3D modeling software and techniques have been discussed with specific concerns to address in design for a scalable digital campus system. We argue that digital campus with VR should move a step forward from the immersive visualization to support users' interactive experience. The three scenarios about the completed and ongoing projects at the Xi'an Jiaotong-Liverpool University provide practical insights into the design and application of interactive experience of digital campus with VR. The evacuation drills within a campus building demonstrated a safety critical context. We incorporated the BIM information preserved in the 3D models to conduct simulations and calculate the safest evacuation path. Interactions in this project include the simulation of fires and the visual aids augmenting the evacuation path in real time. The digital library followed a similar workflow of data preparation, 3D modeling, and also used path-finding techniques for visualizations of indoor paths. Although we adopted an AR approach to visualize the path, it fits in our proposed framework and addresses the need for interactive experience. Regarding VR experiential learning, our user study has shown the benefit of having interactive experience over mere visualizations. We believed that there will be extensive use of VR for teaching and learning within the digital campus and it will be a group-virtual environmental interactive experience [7]. Future use of VR for experiential learning is likely to involve multiple users in a collaborative environment. Supporting users' sense of being in the virtual environment and being together with others is significant for computer-mediated communication and collaborative learning.

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