Virtual Reality-Based Immersive Digital Learning Resources: Initial Study of the Design Features Perception from Future Architects

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***Abstract*—Increasing demands and needs of utilizing Virtual Reality (VR) technologies have pushed many commercial and non-commercial industries and institutions to innovate, including in the education sector. This paper presents a preliminary study of understanding the perception of undergraduate Architecture students in the first Sino-Foreign University in China of various design features. These features were selected on the basis of their functionalities in the VR environment development context, *e.g.* a VR scene or site that can be visited as part of the learning process within the discipline. Hence, the participants were asked to evaluate the importance of each design feature, after experiencing a VR scene created under a university-scale project, namely V-ROOM. Results obtained from this study are hoped to provide future recommendations for numerous stakeholders working in or pursuing the architecture field, including students, educators, and architects. It is interesting to find that amongst fourteen design features investigated in this work, collaborative real-time editing, object/model scaling, and texture modification appeared to receive the highest ratings from the participants, and hence are the most crucial features to be considered in the design process. Furthermore, correlation matrix is also produced to investigate the relationship between these features.**

***Keywords*—virtual reality, design features, VR for architecture, correlation matrix**

I. INTRODUCTION

Virtual Reality (VR) technologies have existed for many years in the gaming industries; however, its potential has also been recently recognized in several sectors, including in the areas of architecture and engineering design in Higher Education (HE) as an immersive digital learning tool. While the conventional design process requires three execution steps – sketching, CAD modelling, and rendering – VR allows designers to directly manipulate design the 3D models in an immersive virtual environment [1] and project these models into the environment.

A. Immersive Technologies in Higher Education

Immersive technology is defined as a piece of technology which acts as a bridge to connect people with virtual realms – allowing users to sense, interact, and explore a digital world generated by computer graphics [2]. In this era, immersive technologies are used in different subjects taught in Higher Education including medicine; science, technology, engineering, and mathematics (STEM); as well as in the social sciences and humanities. Various studies have investigated the use of VR in these subjects, and how it impacts teaching and learning in HE institutions. Findings suggested that VR technologies could influence students' learning experience in a positive way, such as increasing their motivation, engagement and attention [3, 4, 5]. VR also plays a significant role in STEM-based education, especially to support a variety of hands-on engineering learning activities. The main motivations of using VR in engineering education are twofold; they are the availability and viability of VR technologies in representing complex real world situations. The benefits include supporting engineering design activities as well as training activities for both teachers and students before they can utilize the instruments employed in the physical labs [6, 7].

B. VR in Architecture

VR technology has been used in various fields in the industry, and architecture is no exception. VR can be defined as a type of technology which allows its users to interact and explore the reality in a different form – often as a three dimensional virtual space [8]. With the rapid advancement of VR technology and design methods, VR and architecture are becoming closely linked and are often integrated in numerous architectural simulations and projects.

Researchers have argued that VR could potentially assist architects, designers, and other professions to show their design mock-ups to the clients [8]. One such example is in the engineering field, where VR is used as a tool to facilitate engineers in the stages of product design and development [9]. From design perspectives, it is crucial to consider the relationship between design visualizations and notions of experience [10]. This is where VR comes across and fill in the gap by providing the design representations in the virtual realm.

In addition to visualising the architectural design, VR creates the experience of being inside the design; going so far as to be able to navigate from one room to another room, open doors, and windows, interact with other individuals, and move objects around. The use of VR technologies allows clients to explore and interact with the design [11] – thus enabling them to give more specific (and direct) feedback to enhance design iteration quickly [12]. This interaction is also possible in a real-time environment, such as when two architects access the created VR scene at the same time. Traditionally, architects relied on pencil-and-paper drawings, digitalized, and rendered images to visualize clients' requirements. This method is not sufficient for customers to envision the true space and perform interactions with the model, such as measuring the scale of rooms and objects [13]. Nonetheless, by utilising VR to convert architectural practices into the virtual world, architects can communicate their ideas in a more convincing and understandable way.

A previous study on the built environment curriculum in an architecture study programme analysed the feasibility of integrating 3D modelling and VR in their teaching and learning [14]. Instructors reflected that the use of VR enabled easier delivery of information and improved students' understanding of built environment components. Although drawbacks of using VR exist, such as instructors and/or students possibly not being familiar with VR usage, the study provided clearer motivations of the efficacy of the implementation of such technology in this particular area.

Thus, this paper will investigate various VR design features that could be used for the development of digital learning resources in the architecture discipline from the perspective of Higher Education students. The elaboration of how the study was conducted will be presented in Section II, including the definition of fourteen design features included in the study. Section III will demonstrate results of this study, comprising analysis of the students' perception of using VR for their design thinking process and correlation matrix amongst these design features.

II. Methodology

In this study, undergraduate students from the architecture discipline were invited to visit a digital two-storey house environment. The virtual house is composed of a living room, a kitchen, a study-room, bathrooms, a veranda, a balcony, and a bedroom, which was developed by the V-ROOM project team. The models in this environment were built using SketchUp® 2020 – a common essential 3-Dimensional (3D) modelling tool used by students enrolled in the architecture degree. These models were then brought inside a virtual environment using the game engine, Unity®. The Unity platform, released in 2005, is a real-time game development program that supports both 2D and 3D platforms, where artists and designers can collaborate with developers to create fascinating immersive and interactive environments, including in VR [15].

Fig. 1 Participants experiencing the virtual house, courtesy of V-ROOM

The study participants were equipped with the same Desktop/Computer-based VR equipment. In this case, an HTC VIVE Pro® headset was used to provide a fully immersive experience, as illustrated in Figure 1. All participants were allocated the same amount of time to explore the virtual house. During the immersive virtual visit to the VR house, as shown in Figure 2, the students experienced a 3D exploration of a pre-prepared house model environment. This experience aimed to recreate a real-life scenario, for instance, when students visit a newly constructed house in a VR scene without the need to be physically on-site. Human models (avatars), as shown in Figure 3, were also incorporated in the virtual environment (also referred to as a 'scene') to allow the participants of the study to compare the aspects of object proportions and model scaling when designing one is required.

Fig. 2 Exploration of a house model VR scene, courtesy of V-ROOM

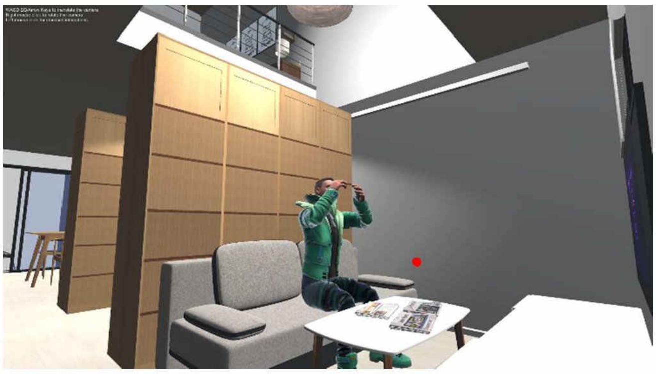

Fig. 3 VR house interior with human display, courtesy of V-ROOM

A. Data Collection

The participants of this study consisted of 14 undergraduate students from the School of Architecture and Built Environment (ABE) at the University of Nottingham Ningbo China. All participants registered to join the study on a voluntary basis and consent was received from the participants before the study was conducted. After the completion of their immersive exploration of the VR house scene, the participants were asked to complete a post-session questionnaire. Data collected in this paper focus on investigating the importance of a number of design features to be embedded in the VR scene, for the purpose of design thinking process. The results are also helpful to provide recommendations to future architects when designing digitalised teaching and learning resources using VR technologies, which could then be used in creating an immersive learning environment in both Higher Education and industry. One possible industrial application is that the VR scene can be used as training material, which mitigates the learning barrier between junior and senior staff.

It is expected that through the understanding of the importance of each design feature and implementing this knowledge into professional practice and applications, students' learning experience can be improved through experiencing a first-hand visit to an environment in VR. Projection of the VR scene is also expected to stimulate students' creativity and critical thinking, *e.g.* through a follow-up activity and/or discussion embedded in the classroom. The design features investigated in this study were defined and explained through text information as well as videos embedded in the questionnaire. Some of these features are already being used in and introduced to VR by commercial companies or industries to create innovative and performance-optimised products. However, they are not yet broadly integrated and used as digital learning resources in the school or any educational institution curricula where VR clearly excels, especially in the architecture discipline. In higher education, the most popular application of VR is in medicine which accounts for 78% of reviews [16]. Design features investigated in this study are presented as follows.

Feature (a): Object/Model Scaling

In this feature, the user can change the size of models using a variable scaling parameter controlled by a User Interface (UI) with typed text input or a slider. Scaling is important because models usually must be adjusted according to the size of the environment, the level of detail needed and client specifications. Architects can proportionate the model correctly to the size of the environment by giving a scale to the object after it is built [17].

Feature (b): Object/Model Slicing

This feature will enable: (i) elimination of unwanted surfaces created during the designing process; and (ii) analysis and optimisation of 3D printing, when combined with a cross-sectional analysis technique to larger models. In the latter context, detailed 3D printed architectural models of high quality are used to showcase ideas and impress clients. A previous study showed that stronger 3D models can be produced by editing the shape and adjusting the printing orientation of weaker components of the structure according to the structural analysis [18]. Hence, users are able to cut the model at any position and conduct specific cut-section analysis.

Feature (c): Object Creation (Assembly)

The current path to 3D modelling for VR is to first create the model in CAD (Computer Aided Design) and then bring it into VR through an engine [19]. Creating whole new non-uniform objects in VR is very difficult; however, creating new objects by combining pre- CAD designed parts, such as from an asset library, is possible. Hence, it allows the architects to create the final design of products more efficiently.

Feature (d): Texture Modification

The material chosen gives the design its characteristics [20]. Architects have to take into consideration sensorial aspects and experience to make a design aesthetically pleasing [21]. Through today's graphical revolution in real-time 3D Virtual Reality, they can visually experiment a variety of textures on their design and learn faster.

Feature (e): Collaborative Real-Time Editing

A BIM framework is now integrated in many projects. In this framework, information is shared with stakeholders who take part in decisions especially at the conceptual design stage [22]. This feature would allow multiple users to navigate through models and edit simultaneously.

Feature (f): Viewing the Outside Environment from Inside Models

When a design is carried out, the architect must take into consideration the targeted end-users' expectations, predicting how they will use the design [23]. This feature would allow users to view the outdoor environment from inside their design (*e.g.*: the landscape or another building from a room's windows).

Feature (g): Observing the Models in Different Environments

This feature would allow to view the model on its designated site and investigate how it interacts with the environment or its context. The user can identify which area does the model best integrates blend with the surrounding. Virtual Reality can be used to effectively inform on environmental threats and support environmental protection [24].

Feature (h): Analysing Thermal Imaging of Models

In architecture, thermography is used to analyse microclimates inside buildings, reinforcements in concrete, and how the outdoor environment affects the indoor temperature [25]. This feature will allow users to identify areas with certain temperatures and alter these according to the needs, *e.g.* when comparing outdoor and indoor temperatures.

Feature (i): Analysing Heating, Ventilation, and Air Conditioning (HVAC) System in Models

HVAC varies depending on the design. Architects must find the optimal HVAC system to minimise energy waste [26]. This feature would allow users to analyse their designed HVAC through simulations run in VR.

Feature (j): Observing Indoor Lighting

When designing indoor lighting, architects must ensure that lighting equipment can be easily installed and maintained [27]. Through this feature, they can experiment with different lighting systems in VR. It is worth noting that VR has also been used to test various lighting scenarios which is economically cheaper and more time-efficient compared to creating a test room [28].

Feature (k): Observing Outdoor Lighting

Daylight should be taken into consideration when designing. This feature would allow users to analyse the interaction between the model and outdoor light sources including shadows. The design should maximise the use of daylight as it is important for an individual's well-being and their interaction with the physical environment [27].

Feature (l): Weather Changing

This features provides model analysis under different climates or weather. For instance, designing while considering a specific climate condition, *e.g.* altering a building to be built in a snowy area.

Feature (m): Observing Models in 3D from Multiple Perspectives

Skilled architects can mentally create a spatial 3D representation of any 2D design that they see [29]. This feature will give students the opportunity to quickly have a 3D view of both internal and external parts of their design. This will help them develop the spatial visualisation skill for their career.

Feature (n): Walking through the Layout (Positioning in 3D Model)

Being able to navigate through models in VR would be beneficial to the architects and their clients [12]. Modifications can be implemented in designs without having to redo all drawings and models.

B. Data Analysis

The post-session questionnaire required the study participants to rate the perceived necessity for the design features in a VR environment that are listed in Section 2.1, from *'feature (a)'* to *'feature (n)'*. The participants were briefed prior to completing the questionnaire. The participants were made aware of the expectations, *i.e.* they were expected to rate these features from a range of 1 to 10, where 1 is 'not necessary' and 10 is 'very important'. The ratings were based on the participant's perception of the necessity and relevance of each feature to be considered and used in their career and study in the discipline, *e.g.* when designing an environment or a structure.

A correlation matrix of these features was then constructed from the results of the data analysis to identify which specific areas must be prioritised forward in the development of a VR environment, *e.g.,* a virtual environment of a building construction site as a digital learning resource for architecture students. The aim of this was to find the best approach to facilitate and ease the design thinking of the higher education students through the utilisation of VR technologies.

III. Results and Discussion

A. Design Features Perception

The architectural elements that are present in a VR environment would undoubtedly be expected to be one of the key 'pillars' for designing models that can be exported and used in a VR scene. Results that are obtained from this study can provide current and future architects with general technical suggestions for a priority list for when developing a VR-based environment that is strongly dependent on: (i) the physical design properties, such as functionality (how an object design can meet the required function or purpose) and innovations (identify how changes brought to a design based on innovative ideas can be actualized); (ii) the design learning process such as kinesthetic experience (learning through multi-sensory experience, which can provide in-depth engagement with the environment) and aesthetic evaluation (learning through visual interpretation of the beauty in the design context).

For example, when a VR scene is used to showcase a newly-developed building to potential buyers and/or investors who are unable to view it in person, it allows the user an immersive experience. Through this, the closer to reality a given VR environment developed is, the more reliable are the analyses given by users concerning *e.g.,* the proposed building. Another advantage of using this VR scene is it promotes cost-efficiency for the collaborative work between architects and engineers before making a decision about the final design of, for instance, a building. This is because the concept of VR is similar to an engineering system simulation, but with extra immersive 3D-view capabilities.

Hence, the fourteen design features (from ***a*** to ***n***, as listed and explained in Section II were presented for the participants of the study to rate based on how they perceive the cruciality of the given features with regards to the use of VR scenes for architecture-related contents. The results of the survey, shown in Figure 4, demonstrated that the mean value of 8.08 out of 10.00 was obtained for the overall participants' perception towards embedding these features in the VR scene that they would like to create, had they required one. This rating reflects a generally positive perception towards the proposed design features and towards how important these features are for their learning journey.

The top three design features, meanwhile, received the highest importance ratings from the study participants were: feature (e), collaborative real-time editing (8.86); feature (a), object/model scaling (8.64); and feature (d), texture modification (8.5). This suggests that these three features should be considered main priorities when designing a VR-based learning scene for Architecture students. Collaborative real-time editing allows architects to gain immediate feedback, which in turn facilitates rapid design iterations with potential for peer collaboration or student-tutor collaboration. Object/model scaling improves relations between an item and its surrounding. Texture modification facilitates important roles in developing any space. Materials manipulation allows viewers to imagine and understand a space better without touching it and it is highly related to lighting and shadows.

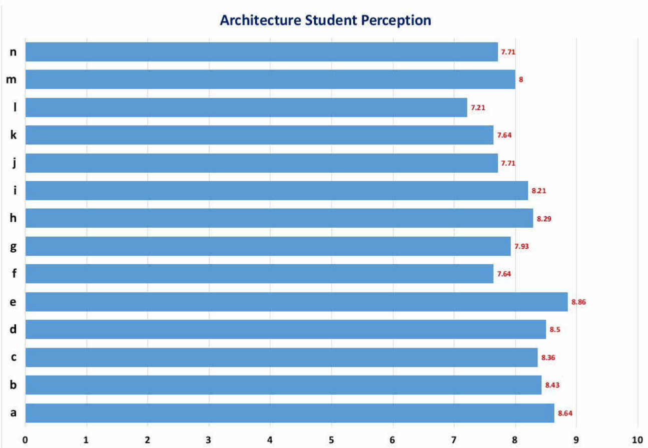

Fig. 4 VR Design Features Perception of the Architecture Students at the University of Nottingham Ningbo China

B. Correlation Matrix of the Design Features

Statistical Pearson's correlation coefficient was used to determine the correlation value amongst the proposed design features, as demonstrated in Fig. 5. Results show that all parameters have positive correlations to one another, with the three strongest correlations as follows:

i. 98.9%, correlation between the HVAC analysis (feature i) and thermal imaging analysis (feature ***h***).

ii. 97.2%, correlation between the outdoor lighting and indoor lighting observations (features ***k*** and ***j***, respectively); and

iii. 90.9%, correlation between collaborative real-time editing and texture modification (features ***e*** and ***d***, respectively).

These significantly high correlation values indicate that any changes made to the first feature will significantly influence the second feature, *e.g.* the HVAC analysis feature is highly likely to affect the thermal imaging analysis feature, due to their strong relationship. In the context of the design features perception, the study participants believe that the two features have similar importance when it comes to design consideration for a VR-based environment.

The second highest correlation value, between outdoor lighting and indoor lighting observation, presents opportunity to include both indoor and outdoor environmental analysis as part of overall building performance analysis in future iterations of VR support for architects. The third highest correlation value shows texture modification is a pivotal feature in real-time editing. Material textures express peculiar qualities of a space, which is often modified during the editing stage.

It is also worth noting from Fig. 5 that features ***j*** to ***n***, which focus on the environmental design analysis, have relatively weaker correlations when compared against features ***a*** to ***f***, which are of the object/model-oriented design analysis. These results are expected as the two concepts differ from each other.

Design Features	a	b	c	d	e	f	g	h	i	j	k	l	m	n
a	1.000													
b	0.546	1.000												
c	0.657	0.675	1.000											
d	0.610	0.804	0.760	1.000										
e	0.588	0.857	0.695	0.909	1.000									
f	0.519	0.485	0.536	0.709	0.656	1.000								
g	0.650	0.792	0.604	0.664	0.696	0.707	1.000							
h	0.572	0.612	0.832	0.807	0.641	0.572	0.609	1.000						
i	0.552	0.586	0.853	0.778	0.625	0.580	0.621	0.989	1.000					
j	0.458	0.396	0.630	0.380	0.421	0.516	0.743	0.563	0.648	1.000				
k	0.497	0.358	0.692	0.439	0.408	0.573	0.707	0.653	0.733	0.972	1.000			
l	0.343	0.315	0.441	0.384	0.463	0.428	0.501	0.413	0.501	0.775	0.720	1.000		
m	0.438	0.434	0.459	0.476	0.620	0.658	0.742	0.490	0.544	0.842	0.778	0.811	1.000	
n	0.453	0.352	0.294	0.337	0.506	0.562	0.556	0.266	0.325	0.628	0.591	0.780	0.769	1.000

Correlation Heatmap
> 0.9
0.8-0.9
0.7-0.8
0.6-0.7
0.5-0.6
0.4-0.5
0.3-0.4
< 0.3

Fig. 5 Correlation Matrix of the VR Design Features

This correlation matrix is hoped to demonstrate whether there exists a causality amongst the design features, which would be useful in architectural design planning and implementation, whereby learners and educators can adopt the implications of this matrix into their teaching and learning activities.

IV. CONCLUSION AND FUTURE WORK

The study conducted in this paper investigated the importance of various design features for consideration of developing a VR-based environment and/or a VR-based learning scene, aimed at the following:

i. Suggesting insight towards each design feature in the architecture discipline from the perspective of undergraduate students, and how these features are statistically correlated to each other.

ii. Providing recommendation of the features that have a higher importance, and hence a higher priority, to future architects, learners, and educators for designing a VR-based environment.

iii. Presenting design thinking and design feature perception for utilising VR in the architecture discipline.

iv. Providing general guidelines for VR content developers when designing a virtual environment.

It is worth highlighting that, from the study, collaborative real-time editing, object/model scaling, and texture modification were found to be the most important features that need to be considered in designing a VR environment, which received the highest importance ratings amongst the features.

Future studies from this preliminary study would consider the expansion of the number of study participants and include a specific immersive learning context for the architecture students other than a virtual house by considering the obtained results from the current study in the design process of the VR scene. The authors will also investigate how using VR learning content for these students would impact their overall learning experience. It is also deemed necessary to look at the use of VR technologies in different stages of architecture design within the scope of HE and/or architectural practice (conceptual stage, design development, the final design stage and construction stage).

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