Developing a VR Research Instrument for Participatory Design of Educational Spaces

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Abstract
Virtual Reality has a proven track record of benefits in the AEC industry. Participation of end-users in the design process has been advocated as a means to improve spatial quality in design. There is limited evidence of application of VR to promote design participation. This becomes even more important when the end-users of space are from different backgrounds. Design of educational spaces is challenging and demanding due to a multitude of reasons. This makes participation of higher importance in the design of such spaces. Traditionally paper-based methods have been used to facilitate participatory design of educational spaces. However, with the fast pace of migration to virtual environment solutions, VR applications seem to be a viable solution. Despite this, there is limited evidence of previous research in this area. This paper uses games engines to develop a virtual interaction environment to facilitate participation in design of educational spaces. A critical review of literature was used to set the boundaries of this research, interrogate the principles of participatory design, define a set of variables, and investigate the areas where VR can be applied as well as design features and aspects which can be comprised in participatory design of educational spaces. To enrich the scops and application of the knowledge claim of this research, the last section was also investigated through primary data collected from an expert survey conducted with school teachers. The development of the VR experiment is explained in this paper which will be verified as a part of future research. This will help close the loop on User Experience (UX) research process which has been utilized in this study.

Keywords
Virtual Reality, Participatory Design, Design Collaboration, Educational Spaces, Classroom Design

1. Introduction
Virtual Reality (VR) offers several proven benefits and has numerous potential areas for further development in the AEC industry. While its contribution to THE? improvement of current practices in the AEC industries is manifold, one of the common denominators for justification of need for and necessity of wider adoption of VR technologies is their role in facilitating collaboration. The scholarship on design on the other hand, has advocated it as a task which can be enhanced through collaboration. Therefore, it will not be unfounded/uncompelling to assume that participation in design can benefit from VR capabilities. This explains some 'cookie cutter' software applications which have started to emerge recently. Such approaches to application of VR in design, although easy, affordable and sometimes even intuitive to use, quite understandably try to remain as generic as they can. They are not niche or tailored to the specifics of a project and often very difficult to calibrate, manipulate, adjust or tune to fit the specific purpose of a project. On the other hand, there is a major gap in research documenting particular yet customizable workflow development aspects of such applications. This is probably due to the diversity in context, content, aspiration as well as methodologies in different design approaches and schools of thought. Such research is important because it investigates how a participatory approach to design can be nurtured and institutionalized using VR technologies. The factors affecting the design process are numerous and their weighting, significance and occurrence are varied. It is however of paramount importance that limited scope research in this area is initiated to lay the foundation for further developments and more all-inclusive investigation of what VR technologies can offer to enhance participatory design research. As an attempt to do so, a research project has been designed to investigate how the process of participation of a space end-user stakeholder group (teaching staff) can be improved in the collaborative design practice of an

educational space (a classroom). The contribution of the research project is multifaceted, part of which is reported in the current paper. The paper contributes to the state-of-the-art VR research through outlining a procedural workflow in designing a VR experiment for participatory design. A critical review of literature helped set out the boundaries of this research, interrogate the principles of participatory design and design collaboration, define a set of variables (and constants) in designing a classroom, and investigate the areas in which VR was best situated to help achieve research aim and objectives. The main focus of this paper is the VR development process of the experiment. The design of the research, the data collected and collated for, and the areas, factors and variables used in the development of the experiment are all covered in our other paper within the same collection. The findings indicate that different generations of teaching staff with varied prior experience of, and exposure to, VR technologies welcomed a niche experiment in VR, designed to facilitate their collaboration in the design process of their classroom. The views about how they would have preferred to have control over or be able to manipulate or customize the design layouts of their classes were expectedly varied. Due to COVID restrictions we were not able to validate the designed instrument with teacher participants. Had this been possible, the research would have been a step closer to delivery of a VR tool which could have enhanced the design participation experience of an end-user stakeholder group.

2. Literature Review

2. 1 Design Collaboration and Participatory Design

Reviewing 94 articles published on design collaboration between 1986 and 2018, Azmi et al. (2018) identified four themes: teamwork, BIM, evidence-based design (EBD) practice, and modality supported collaboration design (MSCD). They suggest that digitally-supported collaboration is associated with improving the efficiency of the design process but has not been critically reviewed and integrated, specifically in terms of different complex issues, such as group cognitive action, reasoning, and sharing of tacit knowledge. Their review indicates very limited attempts on extended reality (XR) as a digital tool to support design collaboration. Sharing of tacit knowledge in collaborative design facilitated through VR is what this paper aims to contribute to/address. Design collaboration is a deep-rooted concept in different design disciplines and in the AEC industry. Several terms are either associated with or interchangeably used together with collaborative design such as participatory design, cooperative design, multi-disciplinary design, concurrent engineering, co-design, co-creation, simultaneous engineering, and integrated design, to name but a few. Collaborative design is concerned with how different parties work together and/or with clients or end-users. It helps satisfy the design intents, enhance the design process, and improve the quality of the final product. It has been suggested that some of the practical, political, and theoretical challenges of participatory design might be relevant to contemporary design thinking (Bjögvinsson et al., 2012). Issues pertaining to design collaboration might imbue highly differentiated types of approach among designers in search of a common design goal (Idi & Khaidzir, 2018). While some researchers believe that the key to a successful collaboration across multiple teams each with a different attitude towards the project is structure and organization (Chiu, 2002), others argue that unstructured collaboration can be more effective (Latch Craig & Zimring, 2000). While engaging ordinary people in creative design through participation in the design of their local communities has been advocated (DiSalvo et al., 2012), it has been noted that participants that lack some basic understanding of the project may shy away from collaboration (Hussain, 2010), and inability of technical members to communicate in a non-technical fashion may disrupt the participatory design process (Godjo et al., 2015). Moreover, logistic complications can make participatory design inefficient (Bodker, 1996). Hagen and Robertson (2012) examine how social technologies are characterized by being designed through use, which in turn lead into new forms of participation.

2. 2 Virtual Reality

The body of VR scholarship has enjoyed a substantial growth over the last few years due to prevailing game industry trends, wider availability of and accessibility to VR technology, proving VR's major benefits in the AEC industry and last but not least for the necessity to move into virtual interaction environments (VIE) as a result of Coronavirus international pandemic. VR has been used to study novice designers' spatial cognition in collaborative design (Rahimian & Ibrahim, 2011), as an interaction design tool in healthcare training (Matthews et al., 2020), for collaboration in children's design processes (Ryokai et al., 2022), experience design (Sherman & Craig, 2003), participatory design experimentation with the elderly (Kopeć et al., 2019), semantic-based taxonomy in product design (Makris et al., 2012), group debriefing in safety education (Luo et al., 2021) and to investigate how immersion and interactivity drive VR learning (Petersen et al., 2022). However, there is very limited, if any evidence, of previous work on participatory design of educational spaces in general or a classroom in particular.

2. 3 Classroom Design
It has been argued that 'space' has a special 'language' of its own (Lawson, 2001). Canter (1977, p.158) argues that "a place is the result of relationships between actions, conceptions, and physical attributes". Malaguzzi explores the idea of space as a means of promoting social relationships between people, choices, and activities, as well as influencing organization and cognitive learning. He asserts that users echo their ideas, values, and cultures through the space, creating a territory of characteristics and traits (Edwards et al., 1993). Referring to Piaget's idea that children require a cognitive style of learning to develop all the skills necessary to become a fully developed adult, this study focuses on the concrete operational stage – the third in Piaget's theory of cognitive development. Child-centered classrooms and 'open education' are direct applications of Piaget's views.

A comprehensive literature review on the impact of school environments carried out for the Design Council points out 'temperature/air quality', 'noise', 'light', 'color' and 'other school build features' under 'The school built environment'. The research then carries on to also add 'furniture and equipment', 'arrangement and layout', 'display and storage' and 'ICT' more specific to the classroom under 'The physical environment of the classroom' (Higgins et al., 2005, pp.14-28). They suggests that: i) There is strong, consistent evidence for the effect of basic physical variables (air quality, temperature, noise) on learning; ii) Once minimal standards are attained, evidence of the effect of changing basic physical variables is less significant; iii) There is conflicting evidence, but forceful opinions, on the effects of lighting and color; iv) Other physical characteristics affect student perceptions and behavior, but it is difficult to draw definite, general conclusions; v) The interactions of different elements are as important as the consideration of single elements; vi) Much of what is known about student comfort, particularly in terms of furniture, has yet to be translated into actual school environments; vii) Since different room arrangements serve different purposes, it is necessary for classrooms to have some degree of flexibility; iix) Some improvements to environment may save time, which is then available for learning; ix) 'Ownership' of space and equipment by both teachers and students is important; x) Ownership and engagement are ongoing elements, so there has to be a balance (in display of student work, for example), between permanent and fresh elements; xi) Some physical elements in the classroom improve comfort, well-being and probably attitude - and so, perhaps, improve achievement (Higgins et al., 2005, pp.22, 28).

3. Research Design and Methodology

This paper presents the developmental workflow of a VR experiment for participatory design of educational spaces (classrooms) for teaching staff. A critical review of the literature on participatory design, application of VR technologies, and the design of educational spaces (classrooms) was used to address the latest development in the three areas that this research aims to triangulate. While the main study has used a mixed methodology, this paper is concerned with how the findings of the literature review, combined with findings of the expert users' survey were utilized to construct the VR experiment. All data collection procedures where human participants were involved were designed and conducted following GDPR requirements. The research project was vetted and approved by the University of Brighton's Tier 1 Research Ethics Committee. This paper focuses on the development of the experiment, building upon project collaboration and data synchronization principles, through 3D object modeling, texturing and hierarchy, data transfer, variant sets, locomotion, and user experience (UX). The research instrument designed in this study uses two stage of data collection – secondary, through the review of literature and primary through the survey carried out with school teachers and aims to facilitate the UX through interactive VR technologies. Classical UX process in software development was adopted but had to be limited to the development of the tool due to COVID restrictions. Closing the loop in the UX research process which would involve testing the UI with selected group of users, collecting feedback on the tool, focus group discussion to investigate users' needs, wants and preferences further and deeper will need to be explored as a part of the future development of this research once the pandemic restrictions are all over.

4. Experiment Development

4. 1 Introduction
The higher-level mechanics were established through conceptualization of how the VR application, or Virtual Interaction Environment (VIE), would function for the user. In discussion of VIE requirements it was apparent that there were two aspects to classroom layout arrangement: Large and/or multifaceted, groups of objects and furnishings

requiring pre-set layout which otherwise would be time consuming in manual placement; and the variable placement of singular one-off objects, independent from overarching layout organization. The approach to this was led by the concept of 'static and dynamic objects', informing several aspects of experiment development including but not limited to: organization and handling of 3D objects, user locomotion, user experience (UX).

Static objects consisting of non-moveable components such as desk and chair layouts, ceiling lighting, windows, and doors etc., were handled through 'placement by selection' or 'Variant Sets'. Although to some extent this approach is 'immersion breaking' and contrary to some VR UX principles, alternative approaches other than pre-set selections were not viable due to over-complexity of interaction.

Dynamic objects on the other hand consisted of items such as bins, specialized lighting, mobile whiteboards and screens, storage and other class/subject specific items. A 'Drag and Drop' system was developed to provide such functionality of manual placement and readjustment, although not fully implemented in the final build of the VIE, such a system was deemed fitting. Dynamic interaction contributes towards a greater sense of immersion (Dalgarno et al., 2002). Moreover, dynamic interaction's advantages over a static approach include more life-like control and sensory feedback (visual, haptic, auditory).

This study will include windows, shading devices, lighting (natural and artificial), color and storage and display areas as well as furniture layout as essential and common factors in classroom design for the design of a VR experiment as a participatory design tool for school teaching staff.

4. 2 Project Collaboration & Data Synchronization

A key aspect of development and collaboration was that it be carried out via remote working, something which evidently has become increasingly necessary and convenient with the onset of a global pandemic. GitHub (GH), the cloud-based version control development software, was used for this purpose to allow for file sharing and backup of data. Furthermore, GH has built-in source control for Unreal Engine (UE): The game engine used to create the VR application.

4. 3 3D Object Modeling, Texturing and Hierarchy

Although UE has such capabilities, dedicated 3D modeling software Trimble SketchUp (TSU) was used for the creation of 3D components (architecture, furnishings & objects). Although not deeply complex in functionality when compared to most of its competitors, it is nonetheless an industry standard application.

In order to facilitate efficient management of 3D components at a later stage, it was important that an object hierarchy be established. Parametric manipulation of these components benefitting from such systematic grouping typically involves object modification (scale, texture, location) or forms of scripting/programming (VR interaction, design variations etc.). Such tasks are streamlined when a centralized approach is taken to the organization of components and their parent components. These hierarchies implemented in TSU (Fig. 1) are maintained via use of the Datasmith (DS) plugin for UE, which acts as a cross-platform bridge for these assets to UE.

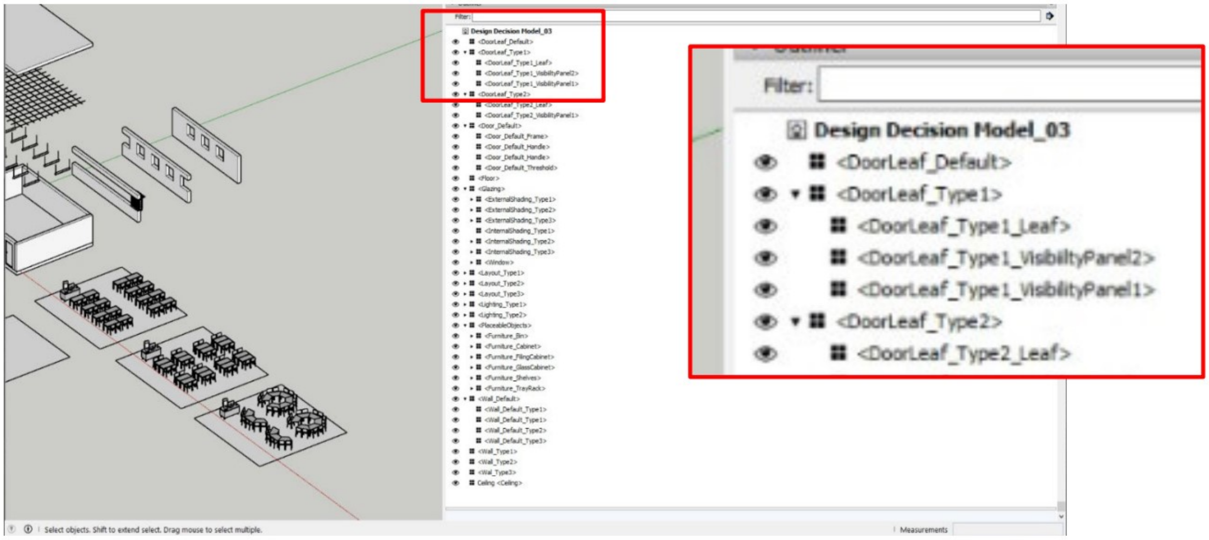

Fig. 1. Example of hierarchies generated within Trimble SketchUp

For texturing, object materials were left untextured (default white) in TSU to be fully textured in UE. Natively, UE allows for greater depth and realism, due to the advanced in-built renderer and set of tools. Although TSU has comparable tools and capability through utilization of 3rd party plugins/extensions such as VRay, this process was carried out inside UE so as to minimize potential data loss during bridging, which becomes a greater concern at later stages where larger file sizes are involved (e.g. high resolution textures). Dedicated material libraries such as ‘Megascans’ were used to facilitate quick application of Physically Based Rendering (PBR) textures which otherwise would have to be sourced and formatted layer by layer.

4. 4 Transferring Data

Datasmith (DS) is a collection of tools and plugins that bring entire pre-constructed scenes and complex assets created in a variety of industry-standard design applications into UE (Unreal Engine, 2022). DS was utilized to facilitate the import of the 3D modeling, texturing and hierarchy into the VIE (Fig. 2). It was found that materials applied in TSU using 3rd party software such as VRay, may not be imported. This is likely due to the system file locations for the 3rd party software being disjointed from DS’s targeted default location. In light of this, the decision to import textures separately within UE to create materials, was preferred due to UE’s inherent optimization capabilities that would help improve runtime performance, especially where stereoscopic rendering is utilized.

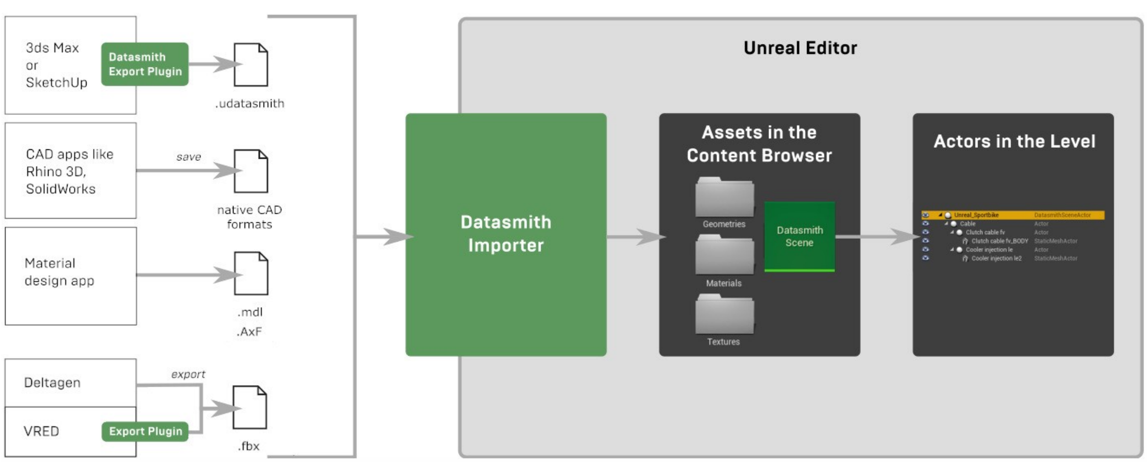

Fig. 2. Overview of Datasmith Import Process (Unreal Engine, 2022)

4. 5 Variant Sets
The VIE had various design categories, each with item variations. These item variations were established within TSU as children of a parent component. Following a DS import, which retained this hierarchy, a script in UE was procured to enable the user to cycle through variations and allow for only one instance per hierarchy to be visible at any particular point in time. The script was facilitated by UE's Variant Set capabilities which streamlines this process by associating an instance(s) with a visual status, established using a predefined Boolean value. These variant sets were then subsequently served by the widgets as part of the UX design, allowing the user to operate the variant sets at runtime.

4. 6 Locomotion
To enable users to move around the VIE, a parabolic raycast teleportation system was implemented; this was the preferred option to joystick controlled continuous movement as it can reduce symptoms of motion sickness caused by the use of head mounted displays (HMD) (Nisha et al. 2019) and is described closer to the 'comfortable' rating from 'Oculus comfort rating' (Oculus, 2021). The teleport system utilizes a reticle to identify where the user will be teleported to. They are constrained to an area using a navigation mesh parameter, 'bouncing back' the user from the boundary they are aiming at.

It was important to consider the navigation as the application runtime progresses, as there will be more obtrusive objects i.e., classroom desks and storage cupboards. A system providing predetermined teleport snap points was explored, however it was concluded that it would not give the teachers the full immersive experience of design elements required for collaborative understanding.

A snap rotation was deemed the most suitable option for user rotation as it would reduce the risk of motion sickness whilst also creating a more logical navigation. This was facilitated by moving the joystick along the X axis which will rotate the user by 22.5 degrees in the direction it is pressed.

4. 7 User Experience (Data Collection and Input stages only)
Most teachers surveyed (8/10) stated that they were aware of VR; however most had second-hand experience with it. Considering this, it was deemed appropriate to create a visual tutorial explaining the User Interface (UI) items. In addition to this, by using the Oculus Quest (OQ) controllers for the in-game hand models, it allowed users to visually acknowledge the actions associated with the buttons on the controls.

When initially planning the UI for applying design changes within the application, three options were explored: 1. Wrist widget, 2. Prompted object widget 3. Radial widget. The wrist widget, allocated on one hand, contains a singular design element and the associated variations on one slide; the following design element is accessible by clicking the next arrow. It was concluded that users are less likely to become overwhelmed and feel tedious of the application if they were aware of their progress, which is challenging to communicate using a radial or prompted object widget. This also acts as a navigation tool and assists users, should they need to go back to a previous design element to make changes.

The secondary option was to create widgets located by the design element to help guide the user through the VIE. To ensure users are able to locate the widget menu, a tracking arrow would prompt users in the correct direction. However, it was concluded that, through the perspective of the users, it would shift the purpose of the experiment from understanding the design changes to a sequential progression through the space.

In review of the design element: Lighting Intensity, it was found that the initial decision to have 3 options 1. Low, 2. Medium, 3. High; each with associated Kelvin levels was unrealistic. Considering this, the lighting intensity widget slide was changed from three options to a slider that increases/decreases when the slider is shifted along its axis.

5. Concluding Comments

This paper reports on the development process of a VR experiment which was devised to help the design participation experience of a non-design-expert end-user stakeholder group. The literature was used to designate the areas which could have been addressed and benefitted from the development of the VR experiment for design collaboration. While there were other potential design areas or variables, they were not deemed directly relevant, hence excluded. This was because they were pertaining to other different design decision levels which require more specialized expert decisions, are bound to meet other technical requirements or supposed to fulfill regulatory or obligatory requirements. The use of UE for development of the VIE in this study, although more challenging compared to some off-the-shelf VR solutions, was proved beneficial as it offered a higher level of flexibility and allowed for customization of the VIE to the specific research design in this study. Some of the preferences highlighted by the participants conform with the findings of the literature review although sometimes with a different level of priority or importance, while some others showed a different pattern to the contrary of the findings of the literature review. This could have been due to the direct or indirect implications of the COVID restrictions or due to specific participant samples used in this study. This is very hard, if possible, at all, to substantiate at this stage. Practical steps were taken in the development of the VR experiment to ensure that the UX would be as intuitive and smooth as possible. However, this was not reviewed, tested or fed back by the participants in this research due to COVID access restriction and was hence considered as future research. This was developed chiefly based on previous experience of the team in development of VR experiments using game engines and supported by the various resources provided by developer communities and evidenced in previous research.

6. Future Research

Future research includes, but is not limited to, testing the experiment with a focus group of teaching staff and collecting feedback to improve the application with respect to its construct, system hierarchy and the graphic/visual appearance. This can also potentially help develop the application further in some of the areas already covered and/or add some other design features that may have been overlooked. Building upon the findings of this research, a more comprehensive VR experiment can be developed to include other teaching facilities in a typical school such as computer labs, science labs, libraries, multi-functional spaces, and staff rooms. In case the developed application is applied to a broader range of stakeholders (both teaching staff and pupils), the collected data can be used to feed into a (semi-) automated self-enhancing design engine using principles of machine learning (ML) to improve the participatory design experience of teaching staff. To facilitate this, scripting may be required to enable data capture and extraction to feed the data into subsequent research.

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