Enhancing Public Engagement in Architectural Design: A Comparative Analysis of Advanced Virtual Reality Approaches in Building Information Modeling and Gamification Techniques

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Citation:

ABDELSALAM, Ehab, BURNETT, Gary and HEATH, Tim (2023). Enhancing Public Engagement in Architectural Design: A Comparative Analysis of Advanced Virtual Reality Approaches in Building Information Modeling and Gamification Techniques. Buildings, 13 (5): 1262. [Article] *buildings*

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Article

Enhancing Public Engagement in Architectural Design: A Comparative Analysis of Advanced Virtual Reality Approaches in Building Information Modeling and Gamification Techniques

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Abstract: Purpose: This paper investigates the potential of virtual reality (VR) technologies—specifically, building information modeling (BIM) ("Autodesk Revit") and game engines ("Unreal Engine")—to enhance public involvement in the design and execution of architecture and urban projects. The main research question focuses on comparing the effectiveness of these two methods in creating an interactive design model for participatory design in public spaces. Methods: The study employed a VR exploratory experiment with 33 participants, followed by semi-structured interviews to analyze two recent developments in London: the Sky Garden, and Crossrail Place Roof Garden. Participants interacted with the design models and provided feedback on their experiences. Results: The findings demonstrate that integrating VR with BIM software using the Enscape plugin effectively enhances user involvement, enabling real-time generation and testing of design alternatives. While both methods were found to be beneficial, participants reported a preference for the direct implementation of VR in BIM software. Conclusions: This research highlights the potential of VR technologies—specifically, BIM and game engines—as a co-design approach for public and social spaces in urban environments. It also identifies limitations and future research opportunities in adopting these methods for participatory design.

Keywords: virtual reality; BIM; gamification; participatory design; public realm; interactive design model

Citation: Ehab, A.; Burnett, G.; Heath, T. Enhancing Public Engagement in Architectural Design: A Comparative Analysis of Advanced Virtual Reality Approaches in Building Information Modeling and Gamification Techniques. *Buildings* **2023**, *13*, 1262. https://doi.org/10.3390/buildings13051262

Academic Editor: Alban Kuriqi

Received: 12 April 2023
Revised: 27 April 2023
Accepted: 9 May 2023
Published: 11 May 2023

1. Introduction

In recent years, VR has emerged as a transformative technology in the realm of participatory design for architecture and urban design, enabling diverse stakeholders to actively engage in design and planning processes [1–3]. Participatory design, which involves end-users and stakeholders in the development of architectural and urban environments, has gained significant traction as a means to ensure that designs are more inclusive, sustainable, and responsive to user needs [4,5]. The integration of VR in participatory design processes facilitates immersive, interactive experiences that allow users to visualize, explore, and provide feedback on design proposals in a realistic and engaging manner [6,7].

VR, which has evolved significantly over the past few decades, is defined as a "computer-generated environment that closely resembles reality to the person experiencing it" [8,9]. Transcending conventional visual aids, VR offers an immersive sensation of being present in a three-dimensional world [10,11]. While sight is the primary sense for receiving information, VR also takes into account the complexity of human perception, encompassing a rich array of senses such as hearing, balance, smell, temperature, emotion, and fear [12–14]. By simulating these sensory experiences, VR provides a more authentic and engaging environment for users, allowing them to interact with and explore the virtual space in a manner closely resembling the real world [15,16].

Previous research on immersive interactive VR in participatory design has primarily focused on its potential to foster collaboration, communication, and decision-making among stakeholders, as well as its capacity to bridge the gap between professionals and non-professionals in the design process [2,17,18]. These studies have highlighted the benefits of VR, such as improved spatial understanding and a heightened sense of presence, whilst acknowledging the need for further investigation into the optimal use of VR technologies and their impact on design outcomes [19,20].

Advancements in VR technology have introduced various tools and platforms catering to the architectural and urban design fields. These tools, including game engines such as Unity and Unreal Engine, and VR plugins for BIM software such as Enscape and Twinmotion, provide immersive experiences that encompass realistic visual and auditory sensations, along with the capacity to move within the virtual environment, adding motion and balance to the experience [19,21,22]. As the adoption of VR in participatory design for architecture and urban design continues to expand, it is crucial to examine the effectiveness of different VR technologies—such as BIM and gamification—in promoting meaningful engagement and improving the overall design process.

1.1. Research Background

1.1.1. BIM and VR Plugins

Over the past 35 years, significant advancements in hardware and software technology have transformed the ways in which architecture is perceived and communicated to the public. In the 21st century, the concept of "virtual buildings" has evolved from being merely a part of the construction process to a comprehensive means of sharing architectural visions and spatial experiences [23]. This evolution culminated in the development and reconceptualization of BIM within the architectural engineering and construction (AEC) industry around the turn of the century [24,25].

BIM is a model-based process that connects professionals across AEC industries, enabling more efficient design, construction, and operation of building infrastructure [25,26]. Through BIM, architects can create 3D models that incorporate data relating to the physical and functional attributes of buildings, ultimately enhancing the design process and providing a better understanding of building operation and maintenance. "Interoperability" is the notion that all parties involved in the building process work from the same model [16,17]. However, despite BIM's potential to revolutionize the architecture industry, previous research indicates that it has not yet been fully utilized. Indeed, barriers to communication between design team members and clients are hindering BIM's ability to achieve its optimal level of interoperability [20,27].

The integration of VR plugins within BIM systems offers numerous advantages for architecture and urban design projects. These advantages include immersive and realistic visualizations, improved communication, and fostering collaboration among professionals and stakeholders [17,21,28]. However, despite these benefits, the implementation of VR plugins in BIM presents certain limitations that warrant further investigation, particularly with respect to user interaction and engagement within participatory design processes [13,19].

Enscape, a widely-used VR plugin for BIM, exemplifies this duality. While it provides enhanced visualization capabilities, questions remain regarding its full potential for creating interactive participatory models and fostering meaningful engagement [29,30]. The limited scope of user interaction in Enscape underscores the need for research into optimizing its implementation in participatory design, specifically with respect to stakeholder involvement and collaboration. Moreover, there is a significant gap in research relating to participant behavior and interactions within Enscape-based participatory design processes [19,22].

1.1.2. Integrating AI with BIM and VR

The advent of the "Internet of Things" (IoT) has ushered in a new era of technological advancements, harnessing smart technologies, cloud storage, and fifth-generation (5G) communications to revolutionize traditional development workflows [31,32]. This technological paradigm shift underscores the need for various industries to adopt intelligent systems that capitalize on IoT, artificial intelligence (AI), and big data [33]. Digital computational technologies encompass a wide range of topics, including BIM, computational graphic imagery (CGI), VR, and AI [34,35].

AI is a rapidly evolving field encompassing advanced computational techniques that enable machines to learn, reason, and adapt, emulating human-like cognitive capabilities [36]. The integration of AI with BIM and VR offers transformative potential for community engagement in architecture and urban design [37,38]. VERAS, an innovative AI-driven plugin for Autodesk Revit, revolutionizes the design process by intelligently suggesting design modifications based on user prompts [39]. These prompts function as text-to-image inputs, allowing users to describe desired changes or features, which are then translated into visual design alterations by the AI. By harnessing the power of AI, VERAS dynamically adapts the design captured from Revit and Enscape, enabling users to rapidly explore various design alternatives. By leveraging the synergies between BIM, VR, and AI, professionals can foster iterative design exploration and enhance community involvement and creativity [19,20,40]. However, further investigation is needed to build interactive design models that effectively capture users' and clients' needs, ultimately leading to more efficient and inclusive design solutions in architecture and urban design.

1.1.3. Gamification in Architecture

Gamification—the application of game design elements and principles in non-gaming contexts—has gained traction within the built environment professions for its potential to enhance user engagement and motivation [41,42]. This approach surpasses traditional architectural software capabilities by offering interactive and immersive experiences, fostering collaboration, improving spatial understanding, and promoting creativity within the design process [43–45]. Unreal Engine—a prominent game engine—plays a key role in merging gamification with architecture and urban design by enabling the development of realistic, interactive environments in which users can navigate and modify virtual spaces in real time [46,47]. However, research on the practical applications and implications of gamification in VR—particularly the use of Unreal Engine—for capturing user behavior and preferences in architecture and urban design remains limited.

In the realm of architectural visualization within the context of VR, numerous plugins, software, and engines are available for exploration. Nevertheless, for the purposes of this research, the focus was placed on Enscape and Unreal Engine, owing to their prominence and potential for crafting interactive VR platforms. Both tools exhibit exceptional capabilities in the generation of realistic, immersive environments, complete with a diverse array of simulation tools and interactive design features [22,30]. These aspects necessitate further investigation in order to comprehensively understand the potential of Enscape and Unreal Engine in fostering public participation within the design process. Moreover, it is imperative that the inherent limitations of employing these tools—such as the validity and legitimacy of information procured from VR simulations—are examined. It is also important that any potential biases that may emerge during the application of these technologies in architectural visualization are identified [7,10].

1.2. Purpose

The primary aim of the research presented in this paper is to investigate the potential of VR technologies—specifically, BIM software (Autodesk Revit + Enscape) and game engines (Unreal Engine)—to enhance public involvement in the design and execution of architecture and urban projects. The focus is on testing and comparing the efficiency of these two distinct methods and tools in creating interactive design models for participatory design in public spaces. The study assesses the impacts of these two VR methods in terms of collaboration, communication, and decision-making among stakeholders and end-users, while evaluating their benefits and limitations in the participatory design process.

Furthermore, the research investigates and compares users' engagement with the virtual environment, their interaction with various design tools, user behavior, and perceptions of space in terms of circulation, activities, design features, and teleportation methods when using both Autodesk Revit + Enscape and Unreal Engine. The main objective is to determine the most effective approach for enhancing user involvement and improving the overall design process.

2. Materials and Methods

In this study, a qualitative research approach was adopted with two main components: (i) a VR laboratory experiment, and (ii) semi-structured interviews. The VR experiment focused on testing and comparing two distinct methods for creating interactive design models for participatory design in public spaces: one method utilizing BIM software (Autodesk Revit + Enscape), and the other based on a game engine (Unreal Engine). Following the VR experiment, in-depth semi-structured interviews were conducted with participants to further explore and analyze their experiences and behaviors during the experiment, particularly in terms of their interaction with the virtual environment and design models. The interviews aimed to capture the participants' perspectives on their virtual experiences and behaviors. Each interview lasted approximately 30 min, was recorded and transcribed for analysis, and was conducted in accordance with approved research ethics guidelines.

2.1. Constructing an Interactive Design Model in VR

In the pursuit of evaluating the efficacy of the proposed interactive model, two contrasting case studies situated in London were selected for examination. These case studies represent the emerging trend of elevated roof gardens, which, despite being predominantly privately owned and managed, are increasingly promoted as "public" spaces [48,49]. This novel typology deviates from traditional public spaces, presenting unique design challenges related to accessibility, circulation, safety, security, and management [50,51]. These challenges necessitate further examination to develop an interactive participatory design that captures users' needs and behaviors.

The first case study focuses on the Sky Garden, located on the top three floors of the 20 Fenchurch Street skyscraper—commonly known as the "Walkie Talkie"—in the city's financial district [52]. The second case study examines Crossrail Place Roof Garden in North Dock, Canary Wharf. This 10,000-square-meter elevated green park, sheltered by a roof, is positioned above the Elizabeth Line—a significant component of London's integrated urban–suburban rail network [53].

The implementation of VR technology involved the use of both software and hardware tools. The first method used in the creation of the Sky Garden digital model involved the design and modeling of the project using 3DS Max software, followed by the importation of the model into Unreal Engine using the Data Smith exporter plugin [54]. This process facilitated the conversion of the scene elements into Unreal Engine assets. Subsequently, further visual coding was performed using "Blueprint" scripting in Unreal Engine, which enables the creation of interactive elements within the digital model (Figure 1). Blueprint in Unreal Engine is an advanced visual scripting system that enables users to create gameplay elements, interactive objects, and game logic, such as changing materials, moving objects, and annotations [54]. This method employs a node-based interface, allowing users to connect various nodes, which represent functions and operations, in order to create complex interactions and behaviors within the game engine.

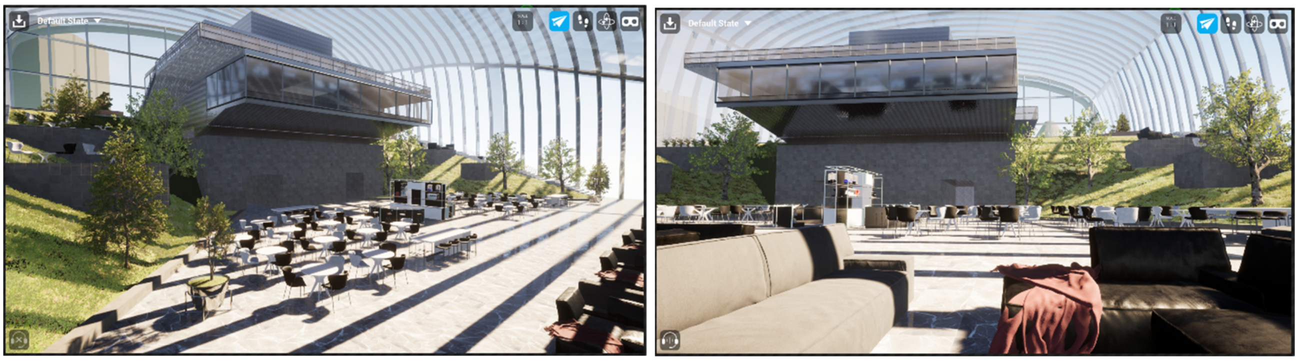


Figure 1. London Sky Garden model, Unreal Engine; source: author's model.

The second method used in the construction of the digital model of Crossrail Place was based on BIM using Autodesk Revit 2022.1.2 software. The use of the Enscape plugin, integrated directly into the BIM model, eliminated the need for data exchange and provided an integrated real-time visualization in VR [55]. This approach allowed for the investigator to make real-time design changes in VR based on user feedback and experience obtained during testing and evaluation of the VR model (Figure 2).

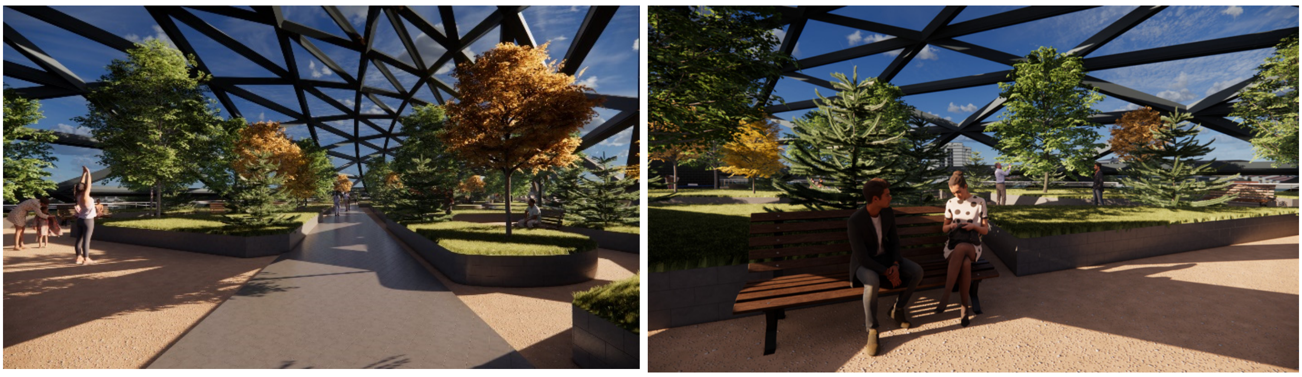


Figure 2. Crossrail Place Roof Garden model, Enscape plugin; source: author's model.

2.2. Environment and Safety Precautions

For the hardware component of this study, the Oculus Quest 2 was employed, which is a standalone VR headset developed by Facebook Technologies—a subsidiary of Meta [56]. The Quest 2 features four integrated cameras that monitor the real environment within the laboratory to ensure user safety. This headset enables the tracking of six degrees of movement, allowing users to navigate the virtual environment seamlessly. Additionally, a GoPro MAX 360-degree camera was utilized to record the participants' movements within the laboratory setting [57].

The researchers implemented various safety measures to minimize the risk of VR-induced discomfort. Adequate ventilation within the laboratory was maintained, and participants were given the option to wear anti-nausea travel sickness wristbands during the experiment. Furthermore, the laboratory was organized to provide a safe and obstruction-free environment for users before donning the headset. The Oculus Guardian—a built-in safety feature—was employed to establish room-scale mesh boundaries in the virtual environment. These boundaries would appear when participants approached the edge of the designated safe experimental area, preventing accidental contact with walls or furniture. The VR experience was introduced incrementally, limiting user sessions to 20 min with breaks provided in between. During these breaks, the participants were asked to complete a personal comfort checklist to monitor any symptoms that they may have experienced [58,59].

2.3. Participants

The study engaged 33 participants from diverse age groups and backgrounds, including architects, urban designers, interior designers, computer engineers, academics, and general users. Snowball sampling was employed to recruit participants through various international networks. Invitations containing detailed information about the study were then sent via email. To maximize the generalizability of the results and ensure that the findings were representative, targeted sampling methods were implemented. These methods aimed to (i) include participants from different architectural and urban design sectors, such as large and small firms; (ii) invite academics and experts in VR, design, and public engagement to provide their perspectives; and (iii) ensure that the public participants represented a variety of age groups and genders.

2.4. Procedure

The VR laboratory experiment, with a duration of approximately one hour, allowed the participants to engage with VR models of the Sky Garden and Crossrail Place. These models provided an immersive, real-time experience, enabling participants to examine and modify aspects of the environment such as materials, objects, design features, lighting, and time of day, as well as to capture virtual photographs.

After signing a consent form, the participants were informed that they could withdraw from the study at any time without providing a reason. The experiment was divided into three stages: (1) a 15-min presentation and induction, (2) an initial survey addressing participant demographics and prior VR experience, and (3) a 20-min exploration of the VR models (Table 1).

Table 1. Experimental procedures.

Activity	Duration
Induction (health and safety and consent)	15 min
Survey	10 min
Sickness questionnaire	5 min
London Sky Garden (VR experiment)	10 min
Break (sickness questionnaire)	10 min
Crossrail Place Roof Garden (VR experiment)	10 min
Break (sickness questionnaire)	10 min
Semi-structured interview	30 min

In the Sky Garden experiment, the participants adhered to a one-way circulation system, ascending the stairs in an anticlockwise direction, in compliance with COVID-19 regulations at the actual site. They were instructed to interact with the space by customizing the materials of floors, walls, and furniture to create their preferred design theme. The participants subsequently utilized the X-ray and virtual annotation options to further modify the space, adjusting object placement and adding highlights or notes. Finally, they captured two snapshot images of their design using the virtual camera, selecting views that they would photograph if they were physically present at the Sky Garden (Figure 3).

During the Crossrail Place experiment, the participants navigated the space freely, without following a fixed circulation route. In the second stage, they determined whether to add or remove design elements and components within the roof garden, which they could subsequently test in real time. The researcher added the participants' chosen components using Autodesk Revit, allowing them to edit their selections. Additions included public art, fountains, benches, flowers, animals, or sound effects. Participants were prompted to interact with the incorporated features and elements, employing the light simulation tool and virtual camera to produce rendered images (Figure 3). Additionally, the AI VERAS plugin in Revit provided the participants with the opportunity to delve deeper into their camera shots by generating AI-based descriptions of their design changes, fostering a more comprehensive exploration of their design modifications.

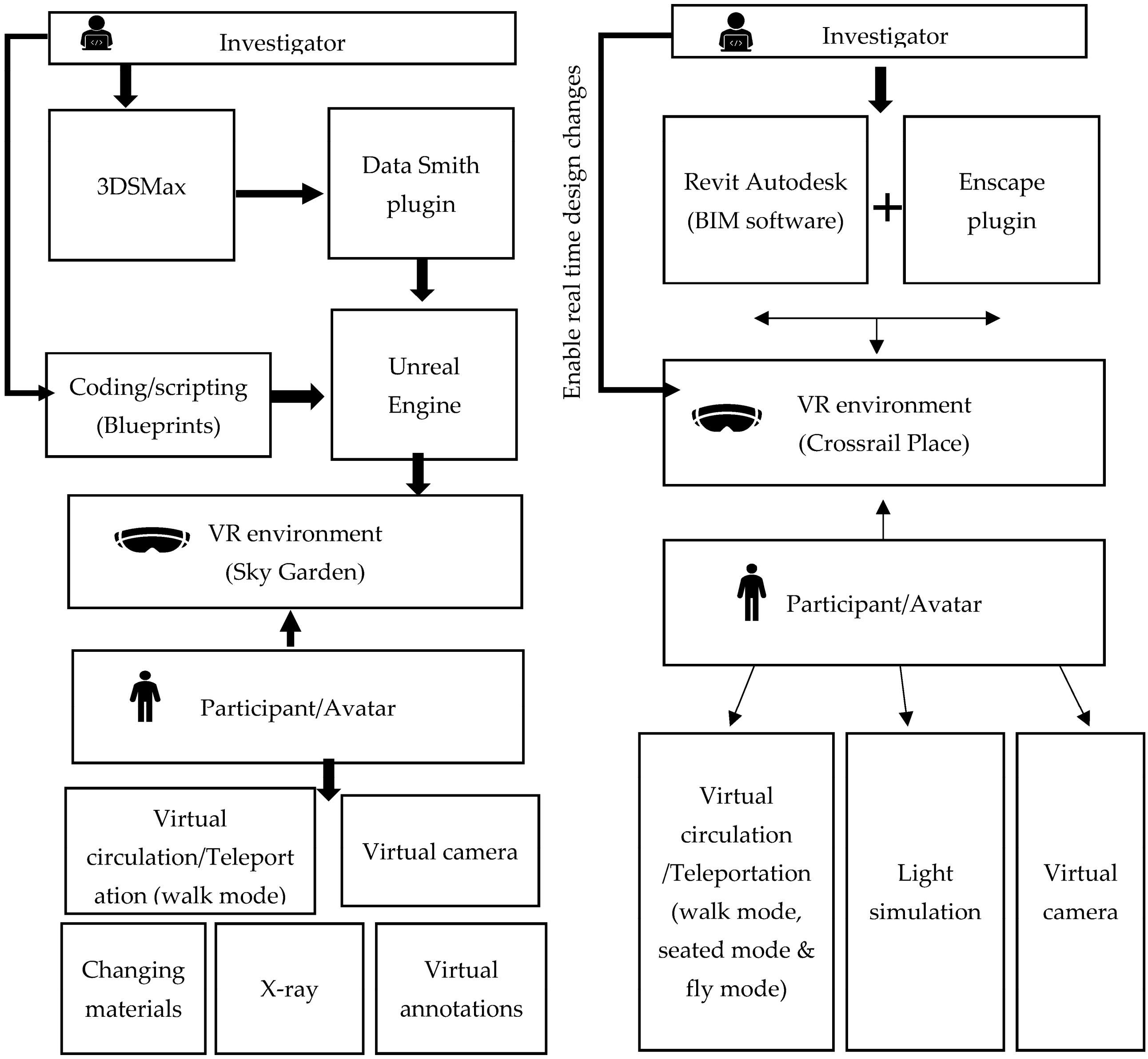


Figure 3. A schematic representation comparing the methodologies and processes involved in the creation of interactive VR models and participant engagement with interactive design features. Source: authors.

2.5. Demographic Data Analysis

All 33 participants were documented and categorized into distinct groups. Group A comprised the 36% (n = 12) of participants who had visited the London Sky Garden and Crossrail Place prior to the VR experiment, while the remaining 64% (n = 21) experienced both gardens exclusively through VR during the experiment. Group B constituted 55% (n = 18) public users and 45% (n = 15) experts in fields such as architecture, urban design, interior design, game design, and academia. Group C consisted of 52% (n = 17) first-time VR users, 42% (n = 14) occasional VR users, and 6% (n = 2) regular VR users (Table 2). The subset of participants (n = 16) with prior VR experience had encountered the technology in various domains, including gaming (the most prevalent), social networking, mental health, architectural design, urban design, education, and product design, demonstrating the diverse background and experience of the study participants.

Table 2. Demographic survey results for VR participants.

Group	Description	Percentage	Number of Participants
A	Visited gardens before VR experiment	36%	12
	Exposed to the gardens only through VR	64%	21
B	Public users	55%	18
	Experts	45%	15
C	First-time VR users	52%	17
	Occasional VR users	42%	14
	Regular VR users	6%	2

2.6. Qualitative Data Analysis

The authors employed a theme-based analysis approach to examine various qualitative datasets. Content analysis—a proven method for addressing descriptive objectives [60]—was utilized, guided by a summative approach [61]. This strategy facilitated the exploration of the concepts comprising the themes and subthemes, as well as their interconnections. The final stage involved investigating the evidence of relationships between the overarching themes and identifying quotes that were initially difficult to categorize and integrate into the themes and subthemes. Subthemes were situated under the primary themes in the analysis of the research outcomes.

The interview analysis revealed three overarching themes: virtual circulation, participant interaction, and interactive design. Nine main subthemes (Figure 4) were identified under these primary themes, providing an initial structure for an interactive participatory design framework.

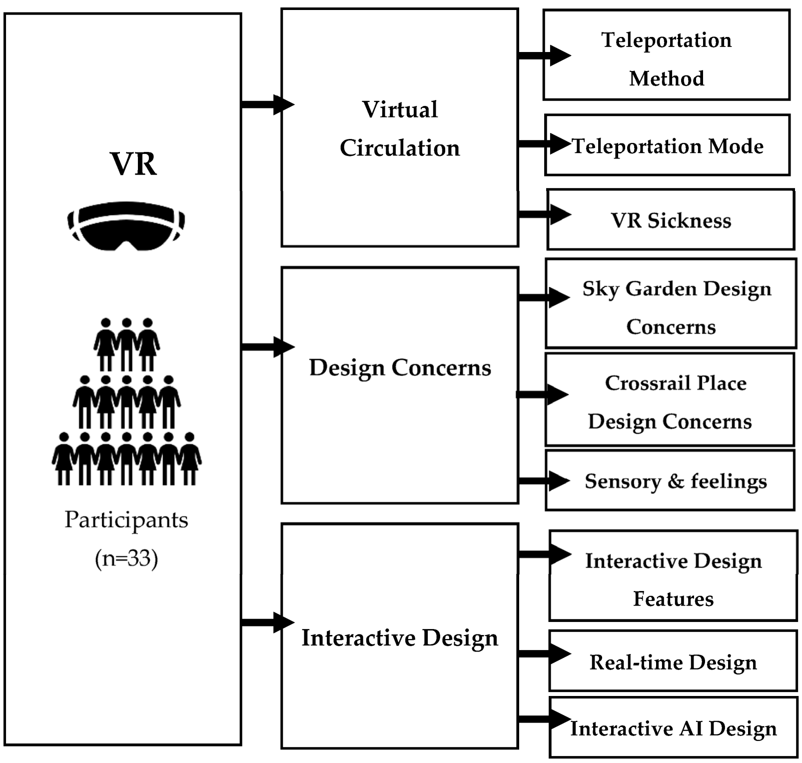


Figure 4. Framework displaying the main themes and subthemes for the VR experiment.

3. Results

3.1. Virtual Circulation and Teleportation

The teleportation method, which enables participants to navigate within the virtual environment, emerged as a significant theme during the VR experiment. The participants explored two distinct teleportation methods for virtual circulation. They employed the Unreal Engine teleportation system for the Sky Garden's one-way virtual circulation route, requiring them to physically navigate the safe "guardian" area and utilize the B and Y controller buttons for teleportation. Conversely, in Crossrail Place, participants tested the Enscape plugin teleportation method, which allowed them to physically traverse the safe "guardian" area and teleport using the upper trigger button whilst maneuvering with the left-hand controller's trackpad.

> *"The virtual circulation was straightforward and user-friendly, although it's a 3D model, it provides the same sense of scale and a degree of realism akin to the physical environment"*.
>
> (Architect participant)

The study's analysis revealed that each teleportation method possesses distinct potential benefits and limitations. The results indicated that 63.6% of the participants (n = 21) favored Enscape's teleportation, attributing their preference to its user-friendly interface, flexibility, smooth movement, and the availability of various motion modes, including "walk mode", "seated mode", and "flying mode" (Figure 5). The majority of the participants reported enjoying the flying mode as a novel experience, although some identified disorientation as a potential drawback. Notably, a considerable proportion of participants (n = 9) experienced slight dizziness while moving via the trackpad, particularly during the initiation of flight.

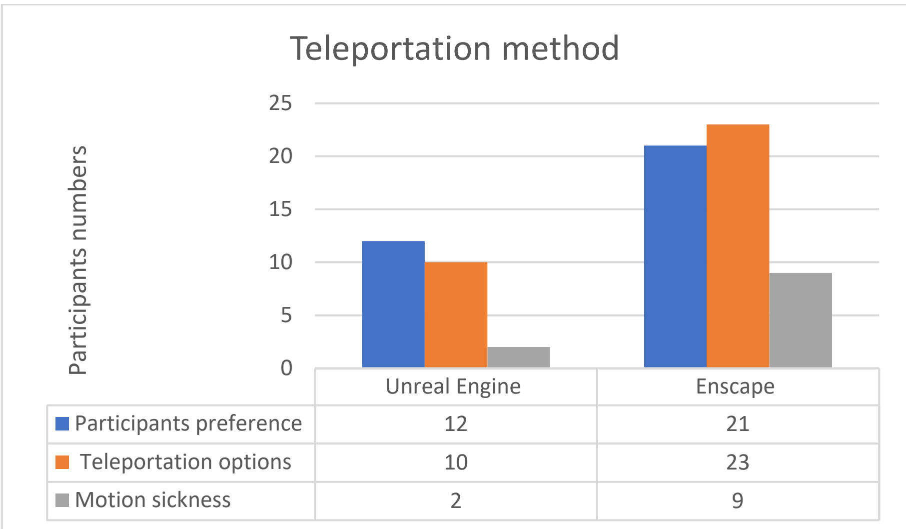


Figure 5. Graph chart for participants' responses about the different teleportation methods used in the study. Source: authors.

> *"Both methods have their merits; it is pleasant to walk around the space at eye level and use the controllers to position oneself in different locations. The creative aspect of the flying mode, offering unique perspectives unattainable in real life, was also enjoyable. While both methods are advantageous, I prefer Enscape's teleportation due to its broader range of options"*.
>
> (Academic participant)

In spite of the restricted teleportation options offered by the Unreal Engine, 12 participants favored this method, characterizing it as a superior approach for simulating a walking experience (Figure 5). The majority of the participants (n = 31) reported no motion sickness while testing this method, as it relies more on physical walking during teleportation. However, they expressed dissatisfaction with the necessity of using the B and Y controllers for teleportation, which seemed to disrupt the authentic walking experience. As highlighted by most of the participants, a significant constraint of this method is the physical space requirements within the laboratory setting; a vast, unobstructed walkable area would be necessary to achieve a fully immersive walking experience.

> *"I believe the Unreal Engine method was quite realistic when I began walking and looking around; however, the experience was not continuous, as I had to repeatedly press the buttons, causing it to skip intermittently. Thus, it did not provide a genuine walking experience unless a vast space was available"*.
>
> (Landscape designer participant)

3.1.1. Preferred Navigation Mode in Virtual Environments

The favored VR mode indicated by the participants (n = 16) was walking, owing to the human-scale, consistent pace of movement that facilitated environmental exploration. Walking was linked to tangible benefits for both mental and physical health in real life, while teleporting, though convenient and enjoyable, was disconnected from authentic human experiences (Figure 6). During the interviews, a considerable number of participants (n = 9) pondered the idea that when physical space is limited, a treadmill could serve as a practical means of navigating within VR. Omnidirectional treadmills are currently available and could offer an intriguing experience for participants; however, the primary barriers include the significant expense and the requisite training to operate the equipment effectively (Figure 7).

Figure 6. Participants testing different VR modes. Source: authors.

> *"I would rather be moving than merely sitting. I think a VR treadmill sounds appealing, as it will be beneficial for actual physical health and also help to reduce VR sickness symptoms"*.
>
> (Game designer participant)

Elderly participants generally preferred the seated VR experience, describing it as the "safest" and "most convenient" method for exploring virtual environments (Figure 6).

> *"I prefer a hybrid mode; I enjoy physically walking around while also having the opportunity and freedom to use the controllers for teleportation.*".
>
> (A participant who had previously visited both gardens in person)

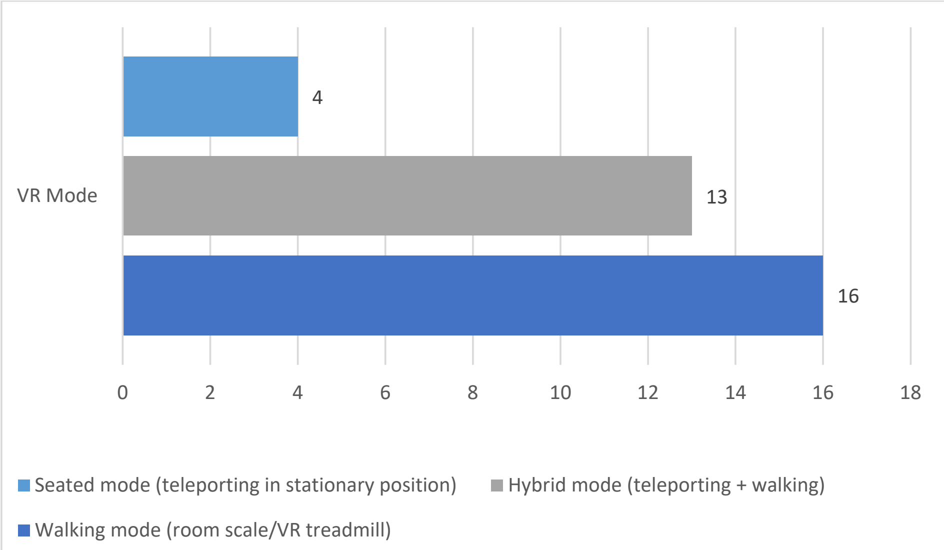
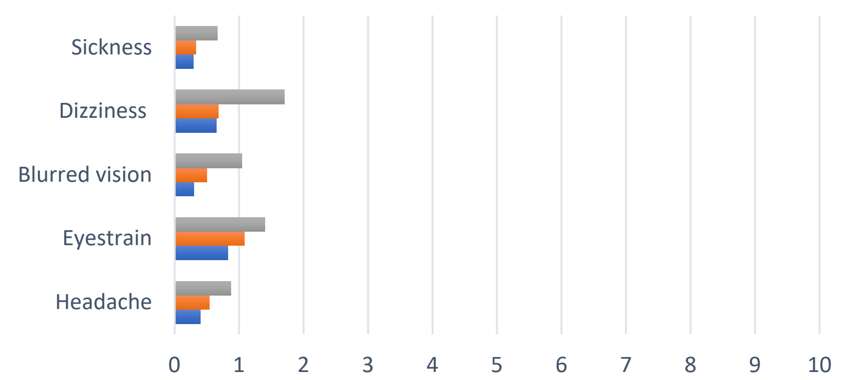


Figure 7. Graph chart for participants' VR mode preferences. Source: authors.

3.1.2. VR Sickness

This study showed that motion sickness can be reduced by limiting the time of users in VR to 20 min and allowing breaks during the exercise. Moreover, a hybrid teleportation method can encourage participants to walk in a safe environment. The results of the experiment showed a slight increase in the discomfort symptoms such as headache, eyestrain, blurred vision, dizziness, and sickness when testing both teleportation systems. This was documented and illustrated as shown in the following diagram (Figure 8), with most of the symptoms marginally increasing during the first experiment of the Sky Garden. They continued their gradual increase during the second experiment of Crossrail Place. However, the Crossrail Place experiment recorded the most significant increase in the dizziness effect, due to excessive use of the flying mode available in Enscape that was used by some of the participants.



	Headache	Eyestrain	Blurred vision	Dizziness	Sickness
After the Crossrail Place experiment	0.87	1.4	1.04	1.7	0.66
After the Sky Garden experiment	0.54	1.08	0.5	0.68	0.33
Before the experiment	0.4	0.83	0.3	0.65	0.29

Figure 8. Graph chart for the participants' average personal comfort before and after the study. Source: authors.

3.2. Design Concerns

In this study, most of the participants (n = 30) frequently highlighted the significant role of immersive virtual circulation methods, available in both Unreal Engine and Enscape, in elucidating design considerations related to both garden spaces. The incorporation of teleportation and virtual ambulation offered participants a detailed understanding of various design components, such as scale, lighting, materials, and furniture arrangement.

Notably, these VR platforms empowered a diverse group of participants, including those without formal training in architecture or urban design, to articulate their design constraints and actively engage in real-time editing and testing of their ideas (Figures 9 and 10). Furthermore, the inclusion of the Enscape library, which enabled the integration of numerous human models into the Crossrail Place VR model, significantly enhanced the participants' ability to interact with the space, allowing them to consider potential usage and activities that could transpire within the physical environment. The utilization of both platforms facilitated the identification of participants' needs and design apprehensions within the spatial environments, providing valuable insights into the strengths and limitations of each VR platform's capabilities to interact with the virtual environment. A more comprehensive analysis of these interactions is presented in the interactive design section.

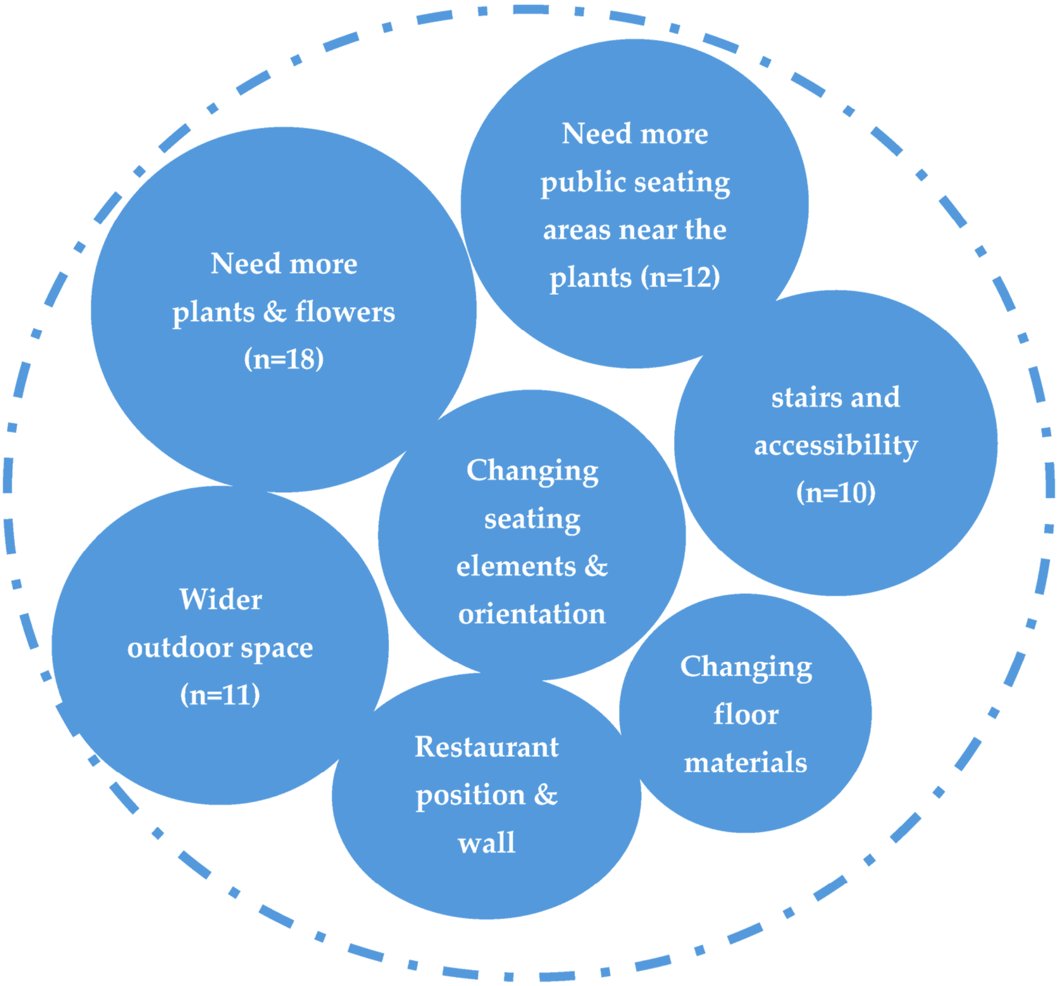


Figure 9. Bubble diagram illustrating the participants' design concerns after teleporting in the Sky Garden model. Source: authors.

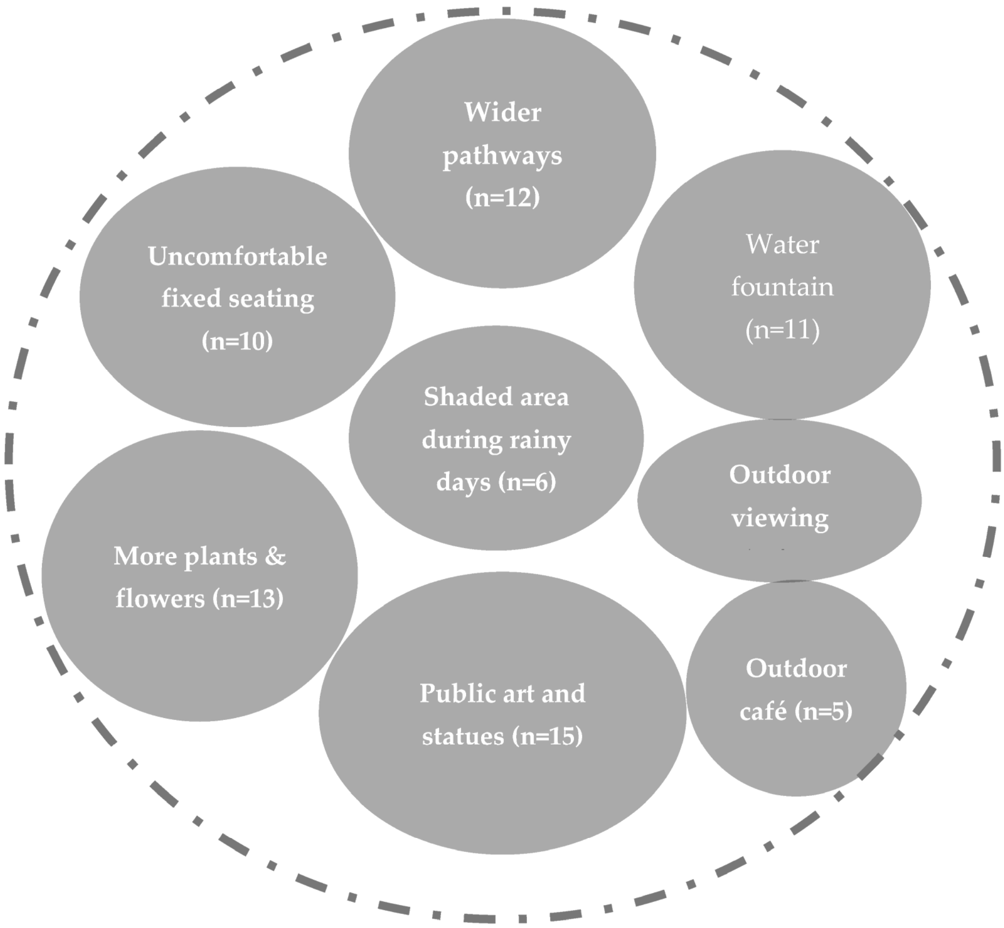


Figure 10. Bubble diagram illustrating the participants' design concerns after teleporting in the Crossrail Place model. Source: authors.

> *"I appreciate the static human models in the Crossrail Place model, as they help identify needs and activities in the space. Observing these virtual interactions, like a father with a child or friends taking pictures, evokes the experience of watching people in real-life urban settings".*
>
> (Academic participant)

The majority of the participants (n = 28) consistently observed that the VR experience, enabled by both Unreal Engine and Enscape, engaged their senses and fostered interaction with diverse design features and objects in the spatial environment (Figure 11). This immersive approach heightened their comprehension of needs and usage within the space, while also stimulating creativity and the investigation of alternative design scenarios. Nonetheless, the lack of specific sensory experiences—such as tactile sensations, air movement, olfactory stimuli, and footstep sounds—was recognized as a considerable obstacle to attaining a fully immersive VR experience.

> *"I wish there were tactile capabilities; experiencing material textures would greatly enhance the experience. For instance, with the leather chair, being able to feel the material would be beneficial. Sometimes, objects may appear visually appealing but lack comfort".*
>
> (A participant who has not physically visited either garden)

Figure 11. Participants' interactions within the virtual environment. Source: authors.

3.3. Interactive Design

The opportunity for interactive design emerged as the most salient and enjoyable theme among the participants. All participants (n = 33) concurred that employing these novel tools and features could substantially enhance their perception of design quality in both case studies. A significant proportion of participants (n = 28) posited that utilizing these tools in architectural design can effectively engage users in visualizing and refining intricate aspects of a project. Furthermore, such interaction allows users to comprehend specific design challenges, enabling them to modify the design and evaluate the space's utility based on their individual needs and preferred activities.

Utilizing the Unreal Engine platform, the researcher constructed interactive VR environments by employing the Blueprints visual scripting method. A range of interactive features, such as real-time material changes, were made possible through this approach, with numerous interactive materials integrated into the floors, bars, chairs, and walls of the Sky Garden for the participants to select and adapt. Additional interactive components facilitated by Unreal Engine include X-ray capabilities, object manipulation, virtual annotations, and virtual camera functionality. In contrast, Enscape provides features such as light simulation and screenshot rendering. However, the degree of participant control in terms of design alterations, encompassing objects and materials, is notably limited within this platform. Despite these constraints, the study investigator introduced and adjusted design elements, enabling participants to evaluate them in real time as they explored the virtual environment of Crossrail Place, in accordance with their individual preferences.

During the experiment, the interactive design process was categorized into two distinct subcategories: interactive design simulation, and real-time design. Interactive design simulation provided participants with the ability to control and assess various design scenarios within the space, encompassing aspects such as light simulation, which facilitated the real-time evaluation of lighting conditions at different times of day and seasons. Other elements included material alterations for design objects such as floors, walls, tables, and seating spaces; X-ray functionality that enabled participants to move and conceal specific design objects; virtual annotations that allowed for highlighting and sketching of desired changes and requirements within the space; and, ultimately, the use of a virtual camera for capturing rendered images and screenshots of real-time modifications and edits (Table 3).

Table 3. Displaying the differences between the main interactive design features tested by the participants on both VR platforms.

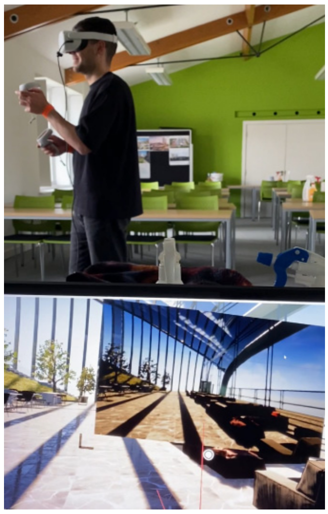
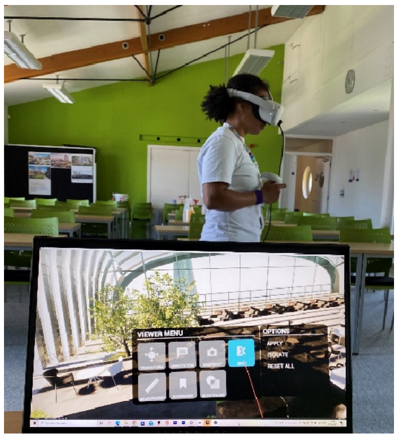
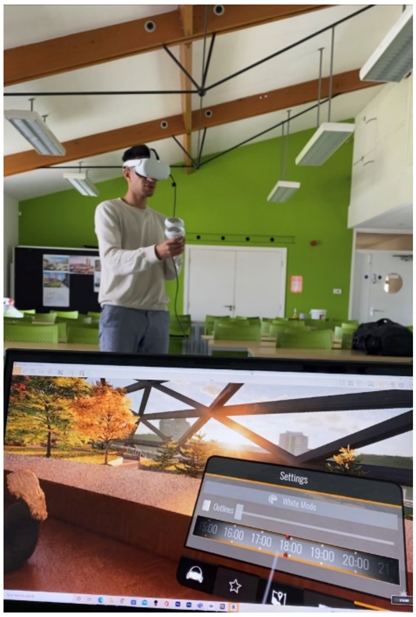
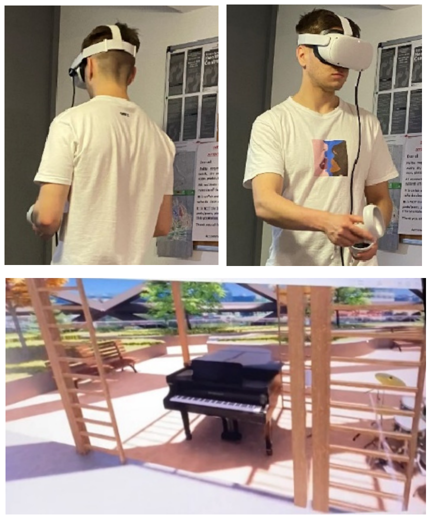
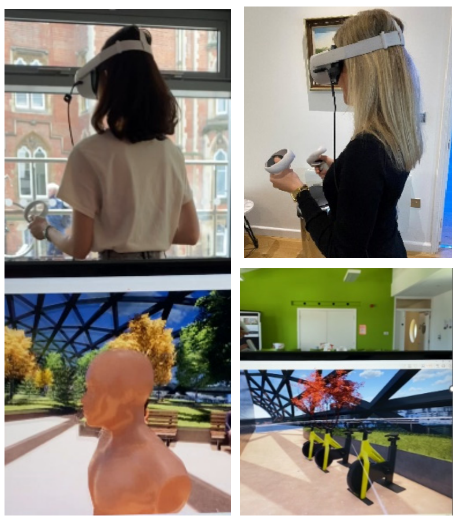
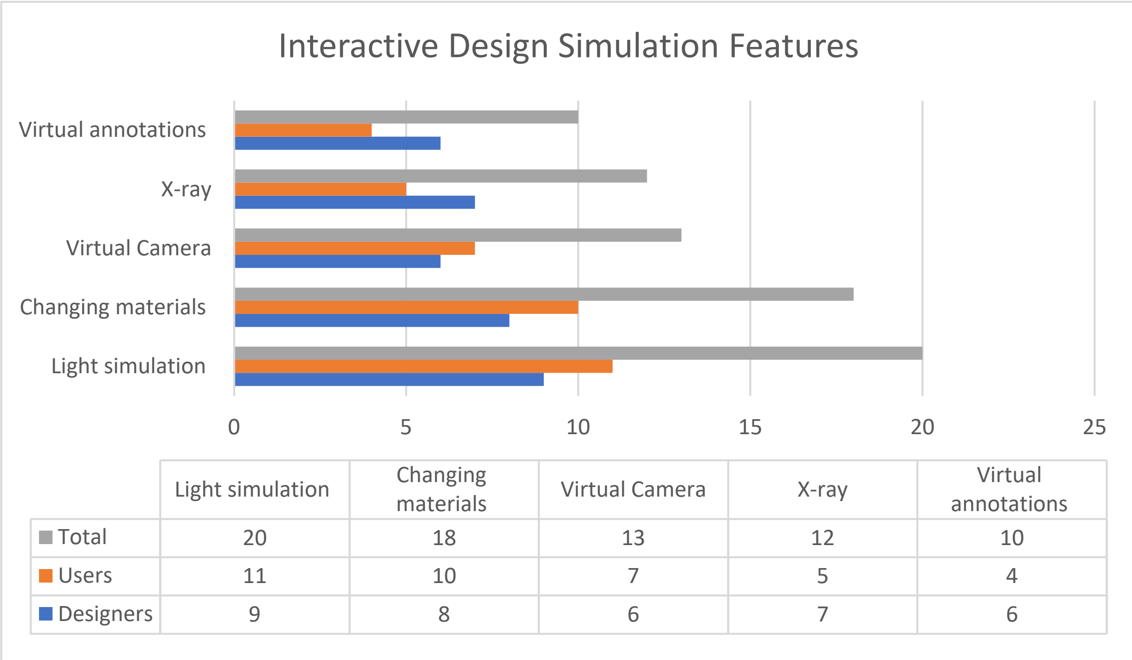
Design Feature	VR Platform	Participant Quotes	Image
Changing materials	Unreal Engine	*"I appreciated the ability to change materials and modify the design of elements. It's a potent interactive tool, particularly for visual learners."*	
Virtual camera	Unreal Engine and Enscape	*"I enjoyed using the virtual camera in VR; it was engaging and encouraged me to explore different design alternatives. Capturing these static images of the changes allowed me to compare them at my convenience."*	
X-ray and virtual annotations	Unreal Engine	*"The X-ray and annotation features are valuable for architects, enabling free line drawing and aiding in identifying design constraints. It's an excellent collaboration tool for design teams and clients during the design process."*	

Table 3. *Cont.*

Design Feature	VR Platform	Participant Quotes	Image
Light simulation	Enscape	*"Undoubtedly, the light simulation was an exceedingly effective tool and well-executed. I believe it holds the potential to significantly influence design changes, making it more sustainable."*	
Real-time design	Enscape	*"I would like to see the roof garden as an adaptable space having different activities and themes that could be changed regularly."*	
		"I think a Calisthenics park, or an outdoor gym would be good for people to exercise in this open environment."	

The findings revealed that the participants found light simulation and material alterations to be the most potent simulation tools, greatly enhancing their experience. Furthermore, the virtual camera was lauded for its enjoyability and effectiveness, as it offered flexibility in capturing real-time spatial alterations whilst serving as an efficient communication medium between users and designers. Finally, the majority of experts and designers underscored the significance of X-ray functionality and virtual annotations as interactive design instruments, invaluable for testing various design strategies and facilitating communication amongst project team members (Figure 12).



	Light simulation	Changing materials	Virtual Camera	X-ray	Virtual annotations
Total	20	18	13	12	10
Users	11	10	7	5	4
Designers	9	8	6	7	6

Figure 12. Graph chart for the participants' selection of the interactive design simulation features. Source: authors.

Capitalizing on the combination of Revit BIM software and the Enscape plugin, the study investigator facilitated a real-time design experience in VR that was not available in Unreal Engine. This was highlighted by the participants (n = 26) as a powerful, engaging feature for clients and architects during the early design stages, as it can save time and effort. This method was tested by the participants during the second experiment. As they completed their virtual circulation in Crossrail Place, they frequently mentioned their design concerns and identified elements that they would like to see added to the space. Many participants (n = 21) stated that the current design of Crossrail Place Roof Garden needed more interaction, and they suggested new design scenarios and activities to attract more visitors. The most common design themes suggested and tested by the participants, with real-time changes made by the study investigator through Revit, included water elements, exercise spaces, public art, comfortable seating areas, additional flora, open plazas for events, gaming areas, outdoor cafés, and outdoor spaces for animals such as birds and butterflies (Table 3).

Enhanced Design Exploration through VR and AI Integration

Within the scope of this study, it was discerned that a subset of participants (n = 8) demonstrated a keen interest in further exploring design changes for Crossrail Place, following their engagement in the VR experiment utilizing Enscape software. Despite the immersive experience facilitating a more comprehensive understanding of the site's design and prospective alterations, these participants aspired to investigate and assess additional design ideas that proved challenging to articulate. To surmount this challenge, the participants utilized Enscape-rendered images from the VR experiment in conjunction with the capabilities of VERAS an AI plugin for Autodesk Revit. By employing descriptive prompts, the participants successfully delineated their envisioned changes for Crossrail Place, encompassing the incorporation of materials such as mosaics and bamboo, the addition of cascading plants, and the installation of water fountains (Figure 13). This finding underscores the potential benefits of leveraging VR and AI technologies within the architectural design process, facilitating more refined and informed exploration of design possibilities.

Figure 13. AI-generated designs for Crossrail Place Roof Garden, created by participants using VERAS on Revit.

> *"I envision incorporating a water feature in Crossrail Place as it could create a more dynamic atmosphere. The soothing sounds might offer a calming effect for those seated and reading, while simultaneously serving as an engaging distraction for passers-by".*
>
> (Landscape designer participant)

4. Discussion

This study aimed to explore the implications of two distinct VR platforms—Unreal Engine and Enscape—for architectural design and urban planning by comparing their respective advantages, limitations, and opportunities, thereby contributing to a broader understanding of how VR technologies can enhance the design process. The findings aligned with the existing literature [2,3,10], highlighting the transformative potential of immersive VR technology in decision-making and participatory design in architecture. In line with the experimental study conducted in the previous section, the results demonstrated significant potential for utilizing these novel methods as part of a collaborative approach for designing and refurbishing public spaces. Additionally, 87% of the participants (n = 29) stated that using VR in architecture and urban design has high potential as an effective design tool for communication between space users, clients, and designers. The results also revealed that most of the participants who had previously visited the gardens and those who had only experienced the gardens in VR shared the same design concerns, limitations, and suggested features, showcasing the high capabilities of the VR systems used to capture the real environment for users.

Numerous prior research investigations have explored the utilization of various VR systems' capabilities within the fields of architecture and urban design; however, they emphasized the knowledge gaps and the necessity for further examination of user behavior and interaction in the virtual world when employing the system's capabilities to construct an interactive participatory design approach [1,19,37]. This constitutes one of the initial research endeavors examining participants' interactions with two distinct methods for developing an interactive VR model, endeavoring to integrate AI and VR into BIM. This study's novelty resides in the comparative analysis of the Unreal Engine and Enscape platforms in architectural design, providing valuable insights for future research and development.

Unreal Engine excels in creating visually realistic, high-fidelity models, providing participants with an immersive experience that closely mimics the real world. This superior visual quality enables participants to thoroughly explore and assess design scenarios, gaining a deeper understanding of spatial configurations and aesthetics [16,62]. However, this platform necessitates exporting digital models from CAD software and requires proficiency in gaming engine software and programming languages such as C++ and Blueprints coding, which may pose limitations on its usability for architects and urban designers aiming to create an interactive VR platform that allows users to change materials, move objects, and create dynamic lighting [63–65]. Additionally, concerns were raised about Unreal Engine's limited teleportation VR method compared to Enscape.

In contrast, Enscape enables real-time design alterations due to its direct integration with Revit, making it more accessible to professionals lacking extensive programming knowledge [19,29]. Although its graphical quality does not quite rival that of Unreal Engine, Enscape offers users a user-friendly interface and simpler navigation, which may lead to increased motion sickness during the virtual experience as a result of different teleportation modes, such as the flying mode. Moreover, real-time interactivity allows users to effectively communicate and collaborate with other team members, streamlining the design process and promoting more efficient exploration of design scenarios [21,22]. The potential integration of emerging technologies such as AI and BIM with VR platforms presents intriguing possibilities for the future of architectural and urban design. Specifically, the combination of Enscape and VERAS provides an opportunity to harness real-time data analysis, predictive modeling, and automated design generation within the virtual environment. These advancements can facilitate more informed decision-making, improve collaboration among team members, and enable seamless communication throughout the project lifecycle [20,66].

The majority of the participants (n = 27) in this study identified the BIM method, employing the Enscape and VERAS plugins, as the most effective approach for constructing an interactive design model in VR. The direct connection between the Revit model and the associated plugins facilitated real-time design modifications. These findings indicate that the strength of utilizing this approach lies not solely in the exceptional level of detail within the virtual model and the immersive experience that it provides, but also in the direct interaction and communication that it fosters between the designer (investigator) and users (participants), as well as other project team members.

Although this study offers valuable insights, it is essential to acknowledge certain limitations. Firstly, the research focused exclusively on two VR platforms, which might limit the generalizability of the findings. Future studies could investigate additional platforms, examining their respective advantages, limitations, and opportunities. Additionally, such studies may benefit from including a larger and more diverse group of participants to better understand the potential impact and usability of these technologies in various contexts. Secondly, constructing a fully immersive and interactive VR using these methods presents several challenges that need addressing to make this technology more accessible to a wider range of designers and the general public. The participants in our study identified four primary areas for improvement: physical space restrictions, VR-induced sickness, social interaction, and sensory stimulation. Physical space constraints were highlighted as a significant obstacle to VR experiences [67,68], with participants favoring the exploration of open, expansive areas for a more authentic experience. Furthermore, our investigation indicated that limiting VR usage to 20-minute intervals and incorporating breaks during the activity could alleviate motion sickness [69,70], while a hybrid teleportation approach might facilitate participants' safe exploration of their surroundings [71,72].

The majority of the participants expressed an interest in sharing their virtual experiences via social VR applications [73,74], indicating that subsequent research should focus on establishing a direct connection between architectural design software and social VR applications to enhance collaborative design processes. Furthermore, the study participants displayed a propensity to interact with virtual objects through touch, grasping, and manipulation [75,76], suggesting that developing multimodal haptic devices capable of replicating the properties of virtual or remote objects and accommodating human gestures could augment the immersive VR experience. Consequently, further research should explore solutions to these limitations, including the implementation of omnidirectional treadmills [67], the development of strategies for minimizing VR-induced sickness [69,71], the establishment of direct connections between architectural design software and social VR applications [73], and the creation of multimodal haptic devices for sensory stimulation [75,76].

The impact of this study is evident in its potential to influence future research and the development of more accessible and integrated VR solutions for the architectural design and urban design community. By highlighting the areas for improvement and opportunities for each platform, this study provides a foundation for further exploration of VR technologies and their potential to transform the design process. Moreover, this research emphasizes the importance of considering user experience, social interaction, and sensory stimulation in the development of VR platforms for architectural design and urban planning. By addressing these aspects, future research could contribute to the development of more effective and engaging VR solutions that benefit both designers and end-users. Lastly, this research raises questions about the role of artificial intelligence (AI) in enhancing VR capabilities for real-time design and collaboration. Future studies could investigate the potential of AI-driven VR tools in enabling designers, clients, and end-users to seamlessly collaborate and contribute to the design process.

5. Conclusions

In conclusion, this study provides valuable insights into the implications of using two distinct VR platforms for architectural and urban design projects: a gamification-based method using Unreal Engine, and a BIM method utilizing the Enscape plugin for Revit. By comparing their respective advantages, limitations, and opportunities, this research contributes to the broader understanding of how VR technologies can enhance the design process, streamline decision-making, and facilitate participatory design. The experimental study that we conducted demonstrates the potential of employing these methods as collaborative approaches for designing and refurbishing public spaces. The majority of participants acknowledged the effectiveness of VR as a communications tool among space users, clients, and designers.

Despite the limitations related to the generalizability of the findings and the challenges of creating a fully immersive and interactive VR experience, this research lays a foundation for the future exploration of additional platforms, as well as solutions to the identified limitations. These include addressing physical space constraints, mitigating VR-induced sickness, enhancing social interaction, and stimulating the senses through multimodal haptic devices. Furthermore, this study emphasizes the importance of considering user experience, social interaction, and sensory stimulation in the development of VR platforms, which can lead to more effective and engaging solutions that benefit both designers and end-users.

In light of these findings, it is strongly recommended that future development of architectural software should focus on integrating VR into a more intuitive design system. Importantly, this new system should not necessitate designers acquiring additional programming skills or exporting digital models to other game engines. The implications of this research are apparent in its potential to guide future investigations and the development of accessible, integrated VR solutions for the architectural and urban design communities. Furthermore, this study raises questions concerning the role of artificial intelligence (AI) in enhancing VR capabilities for real-time design and collaboration, presenting a compelling area for future research. By addressing the limitations and capitalizing on the opportunities for improvement, this study can significantly contribute to the advancement of VR technology in architectural and urban design, ultimately revolutionizing the design process and fostering a more inclusive, collaborative, and innovative approach that benefits both the profession and the communities that they serve.

Author Contributions: Methodology, A.E. and G.B.; Software, A.E. and G.B.; Formal analysis, A.E.; Investigation, A.E. and T.H.; Writing—original draft, A.E.; Writing—review & editing, A.E. and T.H.; Supervision, G.B. and T.H. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the University of Nottingham, The Faculty of Engineering Research Excellence PhD Scholarship.

Data Availability Statement: The data presented in this study is unavailable due to privacy and ethical restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

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