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Challenges and Opportunities of Using Metaverse Tools for Participatory Architectural Design Processes

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Abstract: Participatory design emerges as a proactive approach involving different stakeholders in design and decision-making processes, addressing diverse values and ensuring outcomes align with users' needs. However, the inadequacy of engaging stakeholders with a spatial experience can result in uninformed and, consequently, unsuccessful design solutions in a built environment. This paper explores how metaverse tools can help enhance participatory design by providing new collaborative opportunities via networked 3D environments. A hybrid format (online and in situ) co-creation process was documented and analysed, targeting public space design in London, Hong Kong, and Lisbon. The participants collaborated to address a set of design requirements via a tailored metaverse space, following a six-step methodology (Tour, Discuss, Rate, Define, Action, and Show and Tell). The preliminary results indicated that non-immersive metaverse tools help strengthen spatial collaboration through user perspective simulations, introducing novel interaction possibilities within design processes. The technology's still-existing technical limitations may be tackled with careful engagement design, iterative reviews, and participants' feedback. The experience documented prompts a reflection on the role of architects in process design and mediating multi-stakeholder collaboration, contributing to more inclusive, intuitive, and informed co-creation.

Keywords: metaverse; participatory design; public space; virtual reality; co-creation

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1. Introduction

In the discipline of architecture, the renewed socio-economic landscapes have led to a call for more human-centric and collaborative approaches in designing living environments, especially in the face of a worldwide housing crisis [1]. Designing social housing estates can present several challenges, one of which is to create affordable, safe, and environmentally friendly living spaces that meet the needs of different communities [2]. Another challenge is to promote community spirit and social sustainability while ensuring that residents have enough shared and/or personal spaces [3]. Common design flaws can include a lack of community third places, like shops, pubs, and cafes, and bad connections to surrounding areas with few public transport links [4]. Also, insufficient green spaces and playgrounds can discourage cycling and walking, leading to the deteriorating physical well-being of residents in the long run [5].

Participatory design is a prospective approach to help deliver more responsive and sustainable spatial design by actively involving stakeholders throughout the design process, collecting users' input [6]. However, the lack of cooperative design tools and instant visualisation impedes how participants from diverse backgrounds can effectively communicate their varying spatial needs during the design process [7]. Although emerging technologies such as metaverse demonstrate new directions to collaborative virtual environments beyond physical constraints, the need for engagement methods in guiding reflective and creative processes within this new digital space limits our understanding of the power it can hold [8]. On the other hand, how such digital tools impact the way communities work together and accelerate or reproduce marginalisation is understudied [9]. This research aims to fill such gaps through first-hand experimentation with the latest metaverse technologies, organising an international co-creation event in a collaborative, networked virtual reality (VR) space.

The goal is to identify and analyse the benefits and limitations of metaverse tools in facilitating co-creation processes. Involving participants from diverse cultural and professional backgrounds, a co-creation workshop was organised within the CAAD Futures 2023 conference, enhancing public open spaces within social housing for social sustainability. In the co-creation process, a series of platform tools (Mozilla Hubs, Miro, and Zoom) and VR devices (Head-Mounted Display HMD) were used.

To the main research question—"*How can metaverse tools help enhance participatory architectural design?*"—the following sub-questions were added:

- What are the strengths and limitations of using metaverse technologies in co-creation processes?
- How did participants experience and perceive the collaborative process assisted by metaverse technologies?
- How did participants use or work with metaverse technologies to co-create spatial proposals?

2. Framework

While participatory design has been familiar to designers for decades, the application of metaverse tools to facilitate participation is relatively new and requires significant research [8,10,11]. Along these lines, this study operates within a theoretical framework formulated from a literature review on participatory design and public spaces, as well as the use of extended reality (XR) and metaverse to enhance participation.

2.1. Participatory Design, Co-Creation, and Public Spaces

Participatory design emerged in the 1960s–1970s, encompassing fields such as product development, architecture, and urban design [12]. The goal is to address conflicting values, ensuring the design outcome aligns with user interests [13,14]. Participatory methods range from consultation to co-creation, offering various levels of engagement, with co-creation being the most intensive [15]. During such a process, effectiveness is measured against the design objectives to be accomplished by asking simple but fundamental questions: what, when, where, how, and who are we designing for [16].

Within the realm of the built environment, participatory design can contribute to placemaking and community building, tackling broader social issues, while customising and structuring spaces to align with the specific needs of local communities, especially in supporting the four pillars of habitat design: sustainability, affordability, liveability, and community [17].

Frequently, the built environment is not satisfactory to its users due to failures in engaging all stakeholders. Studies like the one by Sanoff [16] have shown that people are more engaged when the design directly affects their daily lives. In that line of thinking, the role of public space in creating a sense of community is central. Francis et al. [18] stressed on creating conditions that can enhance a sense of community within residential neighbourhoods—a crucial undertaking by planners and researchers.

Scholars and local organisations have varying understanding on what helps to create successful public spaces, especially under different cultural and urban contexts. However, they share common indicators, including aesthetics, meaning, strategy, inclusivity, activity, sociability, comfort, safety, and efficiency [19–21]. These indicators can be used to guide participatory design processes, especially in ensuring that public space outcomes can satisfy qualities in future prospects, design, community, and utility.

Despite the opportunities that participatory design brings, it also comes with drawbacks and may reinforce or accelerate existing problems. Luck [22] argued that the use of the term 'we' is still a problematic issue, which may lead to a normative understanding of varied needs. However, Sanoff [16] mentioned how participatory design may be impacted by the prevailing participation of dominant persons, reducing its democratised purpose. All of these come down to how we tackle issues in equity and inclusivity within a co-creation process through engagement and tool designs.

2.2. Virtual Reality (VR) and Metaverse

According to Luck [23], participatory design has enabled participants to participate in design by developing several tools and techniques to support collective 'reflection-in-action'. This study is particularly interested in the concept of tools and techniques that, in practical situations, help participants to express needs and visions.

Metaverse refers to a network of connected 3D spaces, whereas VR is a term used to describe the immersive environments and devices [10]. Munster et al. [24] showed how participatory design can benefit from digital technologies. Specifically, VR and metaverse environments combined with 3D scanning and photogrammetry are the new realm for such collaborative participation. They can facilitate the inclusion of large numbers of participants while overcoming geographical restrictions. Additionally, the opportunities brought by metaverse enable diverse levels of immersive simulations (from non- to full-immersive), new collaboration, and interaction possibilities within the design process, providing users with new means to customise their habitats. The use of different levels of immersion in VR, from non-immersive to full-immersive VR, have been identified in studies as impacting the perception of users regarding the built environment. Eloy et al. [25] showed that immersive virtual reality devices give users a higher sense of presence than semi-immersive ones. In their study, Leggat et al. [26] showed that VR and its features provide potential for co-creation.

These arguments were widely tested in different design scenarios. In the European Commission project 'U_CODE Urban Collective Design Environment', digital tools were developed to facilitate massive participation in urban design and decision making [27]. Dorta et al. [28] presented a co-design approach based on social VR combined with physical mock-ups as boundary objects and concluded that the approach allows for obtaining, in a one-day workshop with non-designers, mature designs via 3D representations. Birrell et al. [29] used VR to assess the user experience in transport infrastructure, whereas Eloy et al. [30] used VR and AR as tools for the co-designing of housing transformations. On the other hand, White et al. [31] showed how digital twins can be used for urban planning, allowing users to interact and report feedback on planned changes in a city. According to Dzelme [10], digital twins can be redefined by metaverse's focus on users, gaming engines, and virtual experiences, making it more accessible and open to common users, which can be extremely useful for placemaking.

Although several digital tools are helpful for design scenarios, there is ongoing discussion about the lack of truly efficient tools for the ideation stage of design [32]. Dorta [33] emphasised that computer representations and virtual reality are mainly used for presentation and validation rather than for design tasks. Dorta et al. [32] later developed and tested tools based on design flow and proved that it helps with enriching ideation processes through the attainment of a flow state of mind.

A significant issue in all online activities, including those in the metaverse, revolves around methods of gathering information through the internet [11]. Similarly, the use of

digital tools in co-creation can lead to ethical questions in data sharing, privacy, security, marginalisation, ownership, and authorship. Picon [34] mentioned the pervasive presence of code in design, the uniqueness and variation it supports as one of the key assets that can impact the notion of authorship.

All in all, XR and metaverse can facilitate real-time interactive collaboration and 3D multisensory and realistic experiences, together with multimodal interactions, providing a high level of presence in virtual environments. This can support a better understanding of spaces and sites, enabling the exploration of design in an environment augmented and empowered with more effective means of collaboration.

3. Co-Creation Workshop Design

Learning from the literature and case reviews, this study organised a co-creation experiment with a workshop-based approach, targeting three social housing sites. In this section, we start by introducing the sites and describe the experimental settings, explaining the technical aspects of the platforms used and the preparation of the metaverse environments. Afterwards, the participants' demographic information is detailed, as well as the workshop organisation and the six-step co-creation process.

3.1. Sites—Public Spaces in Social Housing

Three distinctive residential complexes in Lisbon, London, and Hong Kong were selected to provide workshop participants with hands-on exposure to unique architecture and urban spaces (Figure 1). These sites were chosen based on their architectural and social significance. All three cases were built in the 1970s, ranging from low to ultra-high density, housing hundreds to thousands of households (Table 1). The range of the chosen cases invites the participants to collectively learn about diverse approaches to social housing in terms of scale and density and to reflect on today's changing community needs.

The ***Prodac*** complex in Lisbon, Portugal, is a notable example of a small, low-density community established by the Prodac Association for Productivity in Self-Construction in the early 1970s. Its aim was to create affordable housing for residents previously in Bairro Chinês, an unauthorised housing area in Lisbon. Initially focused on single-storey houses, the second phase introduced a participatory process, allowing residents to choose from one to three stories, increasing their involvement in shaping their homes. Over four decades, these residents, currently circa 600 households, actively participated in constructing their homes and advocated for recognition as legitimate homeowners.

Figure 1. The three distinctive residential complexes selected: (**left**) Prodac, in Lisbon; (**middle**) Barbican, in London; and (**right**) Lok Wah Estate, in Hong Kong.

Table 1. The main characteristics of the three residential complexes selected.

	Prodac	Barbican	Lok Wah
Density	Low	High	Ultra-high
Scale	600 households	2000 households	10,000 households
Develop Period	1970s–1980s	1970s–1980s	1970s–1980s
Scheme	Housing to resettle slum or informal settlement	Initially affordable council housing for rent for middle-class professionals post-war	Affordable public rental housing for lower-income people
By	The Prodac Association for Productivity in Self-Construction	The City of London Corporation	Hong Kong Housing Authority
Amenity	Residents actively built their homes and sought recognition as legitimate homeowners	Includes the Barbican Centre, a performing arts cultural centre with various theatres and halls	Integrated podium with shops, markets, parks, playgrounds, and exercise equipment
Today	Residents actively built their homes and sought recognition as legitimate homeowners	Became an upmarket residential estate	Remains public rental housing

The ***Barbican Estate*** is an expansive residential complex encompassing three towers housing approximately 2000 households. The incorporation of spacious public areas is integral to both its architectural design and operational framework, creating a vibrant gathering spot in the heart of London. Notably, the complex includes the renowned Barbican Centre, serving as a cultural focal point equipped with various theatres and halls to salvage the heavily bombed site after WWII. Initially designed for middle-class professionals, it set out to be affordable, decent council housing at a sub-market rental rate owned and managed by them. Exemplifying British brutalist architecture, the Barbican today accommodates several notable institutions and has become one of the upmarket residential estates.

Lok Wah Estate is a public high-rise, high-density housing complex. Currently housing circa 10,000 households, it is known for its modernism design with Chinese-style decorative features and an efficient use of space. Designed and developed between the 1970s and 1980s, during the government's Ten-Year Plan that housed more than 1,800,000 residents in Hong Kong, Lok Wah Estate shares a layout with many other public houses built in the same period. Despite its repetitive design, Lok Wah encourages community interaction through its public spaces and integrated living amenities, including retail shops, wet markets, playgrounds, parks, and exercise equipment, within the podium complex, which is typical of Hong Kong public housing.

These residential complexes are one-of-a-kind in their architectural design and socio-economic approaches to affordable housing. They are excellent examples of diverse architectural efforts with public community spaces that can encourage participation and enhance the quality of life for their residents. However, they also face different challenges in accommodating today's changing community needs, which becomes an inspiration in the organisation of our participatory design workshops.

3.2. Metaverse Environment Creation

To facilitate an informed, spatial experience within our participatory design workshops, each chosen residential complex was transformed into a navigable 3D model in a metaverse environment for the participants to experience and work together in.

The Prodac (Figure 2) and Barbican (Figure 3) models were created using photogrammetry reconstruction processes. This involved taking a set of overlapping photographs, which were then uploaded on the software platforms Meshroom (www.alicevision.org, accessed on 1 March 2024) and Pix4D (www.pix4d.com, accessed on 1 March 2024). The software automatically analysed and detected coincident points on each photo, assembling

them and creating a full-scale 3D model complete with textures. Despite slight distortions, the end result was a closed recreation of the chosen urban space.

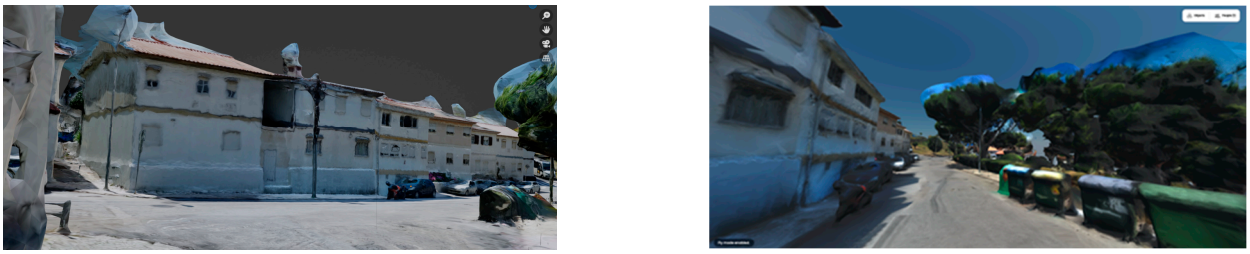

Figure 2. The metaverse scene where the collaborative process took place based on the Prodac complex in Lisbon.

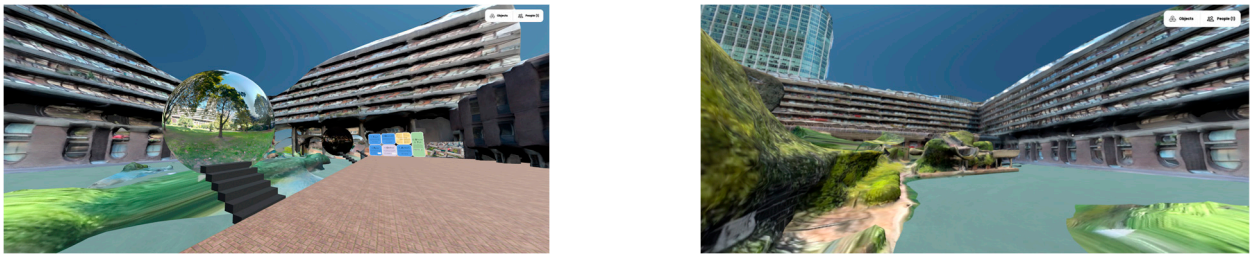

Figure 3. The metaverse scene based on the Barbican complex in London, with a simulation of the key water features.

The Lok Wah Estate (Figure 4) model was created based on an open-source 3D asset library Sketchfab (https://skfb.ly/oHGGo, accessed on 1 March 2024). The data source for the reconstruction came from the official Hong Kong CSDI Portal Common Spatial Data Infrastructure with the textures added from photographs of the building towers. This approach was chosen due to the high-density, high-rise context, which made it difficult to conduct photogrammetry on the ground. It resulted in a less distorted model with orthogonal geometries.

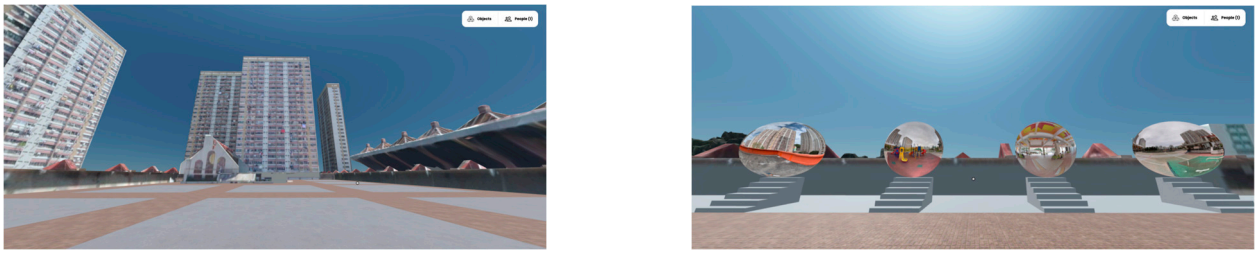

Figure 4. The metaverse scene based on Lok Wah Estate in Hong Kong, with a spherical projection of the 360° photos for the participants to get a better sense of the real site.

All the models were optimised in Blender (www.blender.org, accessed on 1 March 2024) through a decimation process, which reduced the number of polygons and downsized the 3D files within 50 megabytes for a smooth virtual experience.

Each file was transformed into connected metaverse spaces by publishing them online using a web-based VR platform, Mozilla Hubs (www.hubs.mozilla.com/spoke, accessed on 1 March 2024). The treatments on the collidability and walkability were performed in Hubs, especially to enhance the navigation on the irregular geometries and bounds where the participants can reach using custom nav mesh.

To make the VR experience more realistic and enhance spatial understanding, high-resolution 360° photos were integrated into the metaverse scenes using spherical projections

of images, with the skybox and lighting adjusted for better visibility. These panoramas enabled participants to explore the real site with immersive detail, providing a comprehensive view of the environment from every angle.

Finally, co-creation instructions were provided, animated water features or trees were added where necessary in each metaverse scene, and the web links were shared with the participants, which were multi-accessible using any mobile, computer, or HMD with internet.

3.3. Participants Background and Workshop Organisation

The participants were recruited through the CAAD Futures 2023conference and social media. They registered through an online form that simultaneously collected baseline information and shared research and data ethics details. The workshop counted participants from 10 different countries. One-third were physically at the conference venue at TUDelft, and the rest participated online.

The participants were separated into groups based on their site interests, with eight participants in Barbican, nine in Lok Wah, and seven in Prodac. Their ages ranged from 22 to 53 years old, with 50% men, 47.6% women, and 2.4% non-binary. Regarding the education level, 100% of participants had higher education (bachelor, master, PhD or equivalent) and were design professionals (44.4%); researchers (38.8%); students (11.1%); members of public organisations, NGOs, or social enterprises (14.3%); artists (5%); and from the technological industry (2.4%).

The workshop goal was to, through a co-creation process, enhance the quality of public open spaces in social housing for social sustainability and understand how metaverse may benefit/limit the process. The workshop was held on three platforms: Zoom, Miro, and Mozilla Hubs. Zoom was the platform where all the participants first came together for introduction. On Miro, each team discussed and ideated the design interventions. Mozilla Hubs hosted the metaverse scenes where the spatial proposals were created collectively (Figure 5). In this workshop, VR was used through the Mozilla Hubs platform that hosted the metaverse scenes for each residential complex. Most participants participated by a non-immersive experience of Mozilla Hubs through a computer screen. Immersive VR was addressed with the use of HMD devices, Oculus Rift 2, and occasionally used by the participants from the Prodac team at the conference venue. Such devices aimed to provide a higher immersion in the respective scene during the co-creation process. For each metaverse scene, at least two members from the organising team joined to facilitate the co-creation process following the six-step protocol detailed in the following section.

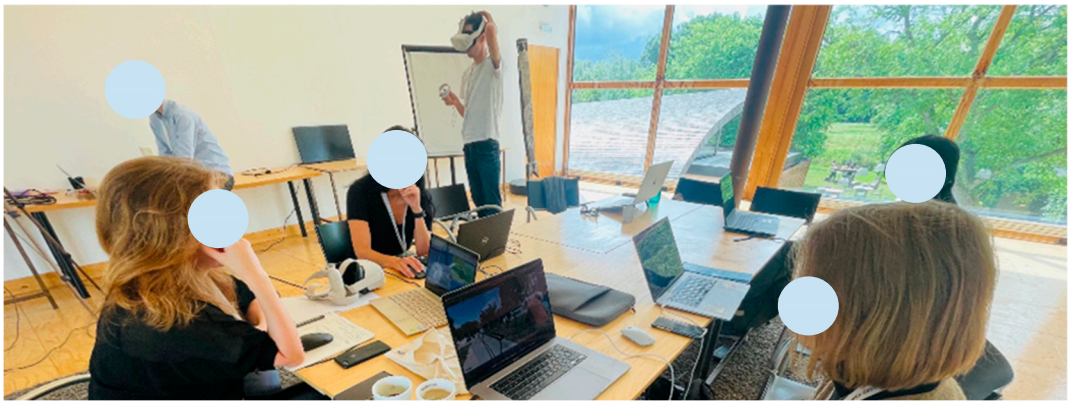

Figure 5. Team of Prodac during co-creation Step 5 'Action'. One participant is using an HMD (Oculus Rift 2) to access the metaverse spaces.

3.4. Co-Creation Process and Protocol

The workshop lasted approx. three hours, with the co-creation process divided into six-steps, preceded by 'prep' and succeeded by the 'reflect' and 'end' protocols.

Prep (20 min)—This introduction section was delivered to detail the workshop objectives and guiding questions, as well as the three targeted housing sites. Due to the hybrid mode (online and in situ), this Zoom section was critical to facilitate a warm-up and for the participants to choose their desired site and split into teams. Otherwise, the introduction could have been delivered directly in the metaverse environment.

STEP 1 'Tour' (15 min)—In their teams, the participants jumped into metaverse and navigated around their chosen site through Mozilla Hubs. For each scene, a member of the organising team introduced the neighbourhood by sharing a brief history and the original design intentions of the place while the participants practised the navigation and controls.

STEP 2 'Discuss' (15 min)—The participants discussed the pros and cons of the social housing design. The organising team defined twelve evaluation criteria (see the section Methods) to guide and foster the discussion.

STEP 3 'Rate' (5 min)—Individually, the participants rated the sites in silence, to take time and reflect on their own and avoid groupthink, according to the criteria provided and through a google form.

STEP 4 'Define' (20 min)—The participants used Miro (Figure 6) to tabulate the characteristics of the sites they considered important for sustainable social housing and then divided them into aspects they liked and disliked about the space, considering the evaluation criteria defined. These pros and cons were then translated into two actions of design to improve the public space for residents.

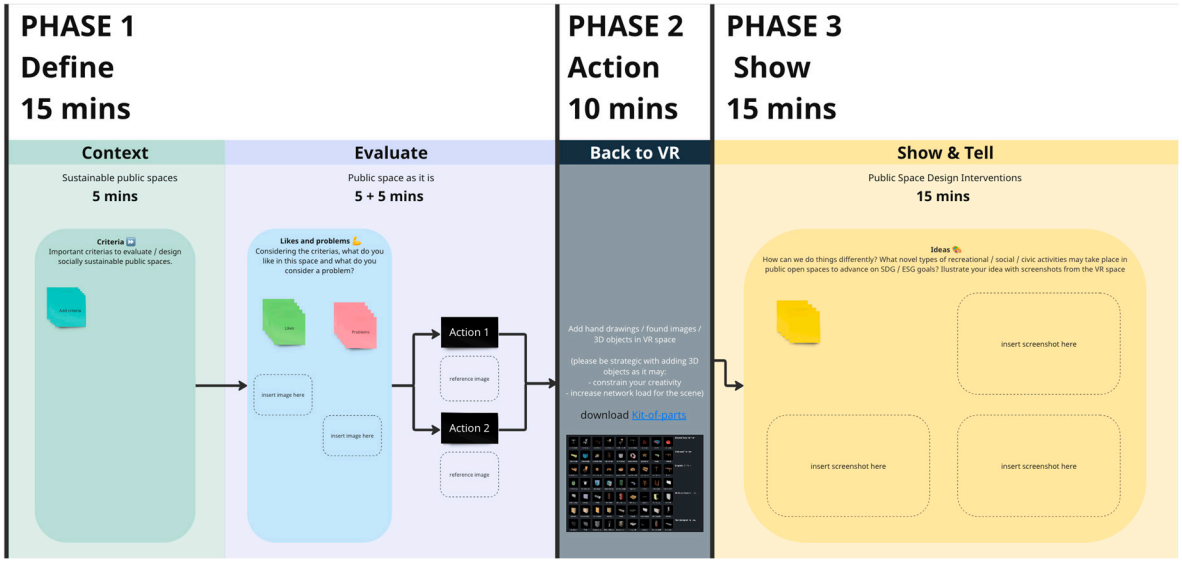

Figure 6. The Miro board used during the co-creation process.

STEP 5 'Action' (45 min)—The participants returned to Mozilla Hubs and carried out their design actions by adding 3D assets to the metaverse scene. The participants were provided with a kit of parts that included different types of amenities. Furthermore, they could add virtual sketches, reference images, or models found on the internet to illustrate their ideas.

STEP 6 'Show and Tell' (45 min)—The participants took screenshots of the interventions in the metaverse space and pasted on the Miro board; all the teams were back on Zoom to present their design interventions to the others.

Reflect (20 min)—Finally, everyone dedicated an overall discussion to the following:

- What innovative third place activities can happen in public open spaces of social housing; accordingly, what are the criteria to evaluate design of spaces?
- What are the challenges in co-creation projects, especially in scalability problems, and what are the real-world consequences?

- What are the strengths/limitations of metaverse and how to best utilise them during co-creation processes to create a paradigm shift in our modes of architectural production?
- How can we find design solutions that are environmentally beneficial, economically feasible, and simultaneously socially responsible?

End (5 min)—Each participant responded to an endline questionnaire to provide feedback on their experience and satisfaction on the workshop.

4. Methods

This section details the research data collection and analysis methods used to assess the project. The approach invited the participants to provide feedback and evaluate the success and limitation of the metaverse co-creation experiment to help improve the study iteratively. The key methods comprise three parts.

The first part was dedicated to a survey on the workshop experience and site evaluation. Here, two types of e-questionnaires, baseline and endline, were utilised to gauge the participants' engagement with the co-creation workshop. Additionally, a midline e-questionnaire was employed to assess the participants' contentment with the current site design. The data analysis involved the use of comparative–descriptive statistics to discern the similarities and disparities in the feedback provided by the various participant groups.

The second part comprehended the design documentation and discussion. Here, the proposals for public space co-created by the participants were documented using Miro and the metaverse scenes. Subsequently, the analysis of the design outputs and processes entailed an examination and reflection of the organisers' field notes from the group discussions that transpired during the co-creation process.

Finally, the third part was dedicated to the participants' feedback. In the context of gathering participant feedback, an open-ended question was incorporated into the e-survey to encourage the participants to share their insights and comments. The subsequent data analysis involved scrutinising the texts through a content analysis to discern the emerging themes.

4.1. Site Evaluation Criteria

To guide and foster the participants' discussion and evaluation, a set of spatial design criteria was identified by the organising team based on the literature review [19–21]. These criteria were grouped under four themes and sub-themes as follows:

1. Prospect
    - Sustainability—the design has sustainable features with Sustainable Development Goals (SDG).
    - Innovation—the design is innovative and expands the horizon of recreational, social, and/or civic activities.
    - Responsive—the design is adaptive and future-proof for changes in spatial function and technology.
2. Design
    - Aesthetics—the space is beautiful and attractive.
    - Meaning—the design tells the story of and symbolises the local context and community.
    - Strategy—the design has personalised and focused strategy, considers local problems, and is designed to tackle these problems and bring societal benefits.
3. Utility
    - Comfort—the design provides environmental comfort (e.g., walking, sitting, meeting, and playing, in sunlight or shade).
    - Safety—the design promotes 'eyes on the street', enough visibility, and a sense of safety.
    - Efficiency—different activities can share spaces to aid spatial efficiency.

4. Community
    - Inclusivity—the design takes special consideration of the needs of different genders, ages, and differently-able.
    - Activity—users may engage in diverse intergenerational activities with different social groups within the space.
    - Sociability—the design can stimulate spontaneous conversations and interaction between users and neighbours.

These themes and sub-themes identify the characteristics that should be present in public space design within social housing projects and were used as a benchmark against which each site was evaluated. Based on the observation of the sites, the participants scored the sites using 1 (present) or 0 (not present); the results are presented in Section 5.1.

4.2. Co-Creation Experience Evaluation Criteria

To evaluate the co-creation process, 16 criteria were adopted from the study [35] to guide the workshop and survey designs:

How the participants perceived the potentials of the metaverse design enabled by the used platforms.

- **Motivation**—I was motivated to engage (with agency, fun and rewarding).
- **Expression**—The metaverse co-creation process facilitated for me to express myself and my needs.
- **Ease-of-use**—The tools were easy to understand, interact and control.
- **Space**—I was able to better grasp site qualities because of the spatial experience provided by VR.

How the participants perceived the possibilities of participation that are enabled by the presented co-creation process.

- **Aspiration**—I am aspired to continue the participatory effort (work with local communities/ co-design) after this experience.
- **Reflexion**—I was stimulated to reflect on existing circumstances and search for improvement.
- **Creativity**—The experience helped me to think outside the box and be creative.
- **Sustainability**—I think I would be able and willing to help others in the future in similar processes.

How the participants perceived the quality of the learning that occurred during the design process.

- **Context**—I developed a deeper and more comprehensive understanding of the site context.
- **Design**—My understanding of the complexity of design/planning problems increased.
- **Community**—I have learnt something about the community that I did not know before.
- **Confidence**—My confidence in my ability/knowledge/skill has increased.

How the participants perceived the quality of the cooperation that occurred during the design process.

- **Satisfaction**—I am happy with the co-creation result.
- **Inclusivity**—I have found most others wanted similar things as me.
- **Outcome**—I think the co-creation outcome can better provide for inhabitants' everyday needs.
- **Consensus**—I was able to reach consensus with others without having to make a lot of compromises.

Each criterion was assessed by the participants using a Likert scale from 1 (disagree) to 5 (agree), with the results presented in Section 5.3. Besides the closed questions, the survey also included one open question to provide feedback about the overall experience, which is analysed in Section 5.4.

5. Results

5.1. Participants Evaluation on Spatial Quality of targeted Sites

Based on the participants' evaluation, Barbican received the highest score, while Lok Wah received the lowest; the difference is significant as we can observe in Table 2. Comparing all three sites, the evaluation results show that most participants felt all the sites lacked 'inclusivity', whereas all three sites scored high when it came to 'safety'.

Table 2. Midline questionnaire result—participants evaluated existing spatial quality of targeted sites. Each column represents feedback from one participant; highest and lowest values highlighted in green and red, respectively. If a criterion is present = 1; if it is absent = 0.

Quality/Site	Barbican					Lok Wah					Prodac							
	Participants				Mean	Participants				Mean	Participants							Mean
Aesthetics	1	1	1	1	**1.00**	0	0	0	0	**0.00**	1	0	0	0	1	1	1	**0.57**
Strategy	1	1	1	1	**1.00**	0	0	1	1	**0.50**	1	0	1	0	0	0	0	**0.29**
Inclusivity	0	0	0	0	**0.00**	0	0	1	1	**0.50**	0	1	0	0	0	0	0	**0.14**
Activity	1	1	1	0	**0.75**	0	0	0	0	**0.00**	1	1	0	0	1	0	0	**0.43**
Meaning	1	1	1	1	**1.00**	0	0	0	1	**0.25**	0	0	0	1	1	0	1	**0.43**
Sociability	1	1	1	0	**0.75**	0	0	0	1	**0.25**	1	1	1	1	0	1	1	**0.86**
Comfort	1	1	1	1	**1.00**	0	0	1	0	**0.25**	1	0	1	1	0	1	0	**0.57**
Safety	1	1	1	1	**1.00**	1	1	1	0	**0.75**	1	1	1	1	0	1	1	**0.86**
Efficiency	1	1	1	0	**0.75**	0	0	0	1	**0.25**	1	0	0	0	0	0	0	**0.14**
Innovation	1	1	1	1	**1.00**	0	0	0	1	**0.25**	0	0	0	0	0	0	0	**0.00**
Sustainability	1	1	1	0	**0.75**	0	0	1	1	**0.50**	1	1	0	1	0	0	0	**0.43**
Overall	**9**	**8**	**8**	**8**	**8.25**	**2**	**2**	**5**	**5**	**3.50**	**6**	**6**	**7**	**3**	**4**	**4**	**6**	**5.14**

Barbican scored an overall average of 8.25. All the participants noted the presence of 'aesthetics', 'strategy', 'meaning', 'comfort', 'safety', and 'innovation'. Three out of four participants felt the site also had 'activity', 'sociability', 'efficiency', and 'sustainability'. However, it performed the worst in 'inclusivity'. Overall, the Barbican scored relatively well. The result is in line with the initial discussions during co-creation; the participants pinpointed the strength of several spatial qualities, emphasising aesthetics, strategy, meaning, and innovation, with potential downfalls in inclusivity and activity that could empower community engagement.

Prodac scored an overall mean of 5.14. All the participants were of the opinion that the Prodac site lacked 'innovation'. Prodac scored the lowest in 'inclusivity' and 'efficiency' and highest in 'sociability' and 'safety'. These results are in line with the in situ discussion among the participants where they noticed that the low density promotes safety and has the potential to also promote sociability. The participants mentioned as potential downfalls the lack of people on the street that could be caused by the lack of inclusive space.

Lok Wah scored an overall average of 3.50. Three out of four participants felt the site had 'safety' and all the participants felt it lacked 'aesthetics' and 'activity', whereas half the participants felt the site had 'inclusivity', 'strategy', and 'sustainability', and one participant felt the site had 'meaning', 'sociability', 'comfort', 'efficiency', and 'innovation'. This is in line with the participants' discussion, pinpointing the strength of the spatial quality as safe, spacious, and central, with potential downfalls in generic and barren design, unshaded areas, and the lack of facility to accommodate community activity.

The results are shown in Table 2. The average of each criterion is shared at the end of each row, and the overall score given to the site by the participants is indicated at the end of each column. This allows us to compare three sites, along with the most commonly present or absent criteria for each site. In Prodac, all seven participants responded. However, not all participants completed the questionnaire in Barbican and Lok Wah, with only four responses each.

5.2. Participants Co-Created Spatial Design Proposal

Regarding the ***Barbican*** estate in London, the participants' proposals emerged from reflective thinking on how to make the space more engaging to a broad audience, reinforcing social cohesion among different stakeholders. As the space is surrounded by high-rise buildings, the central square was the area where the co-creators concentrated their efforts (Figure 7). One aim of the design was to create spaces and activities that would bring people together to share narratives about the space.

Figure 7. Proposal for a central place to meet and improve accessibility and inclusivity for Barbican in London.

The co-creation process identified some problems regarding the accessibility among areas of the neighbourhood and proposed new circulation options. For instance, the participants proposed a staircase to the rooftop of low-rise structures to fully utilise vacant public spaces and bridge areas segregated by buildings.

The participants gave the example of how one of them put a stove to signal a community kitchen. Another participant came in and swapped it with a firepit, transforming it into narrative events such as the ones of ancient times with the storytellers seated around a bonfire sharing stories, oral histories, drinks, and food, in a multicultural way.

Two of the participants from the Barbican experience physically knew the place and made comments. Although the geometries of the 3D models are crooked, this co-creation process introduced the possibility to perform meetings in a virtual environment created with photogrammetry of the targeted site, a new way to communicate with design teams or clients in real-world architectural projects.

There were notes considering the gentrification that is occurring in that area due to several reasons, especially a real estate valuation increase. The initial concept from such an open space, social cohesion, was not being achieved in current times.

It is worth noting that, in Barbican, the design process was entirely conducted online, and the participants used their own computers and internet connection to experience the metaverse; no HMDs were used. Although the team included text descriptions in Miro while discussing the design, the main outcomes were the metaverse scene.

The proposal for ***Lok Wah Estate*** in Hong Kong delved deeply into issues such as intergenerational relationships and the seamless integration of inhabitants and other users within the communal areas, bridging social segregation. The primary focus was an expansive rooftop square nestled between buildings (Figure 8).

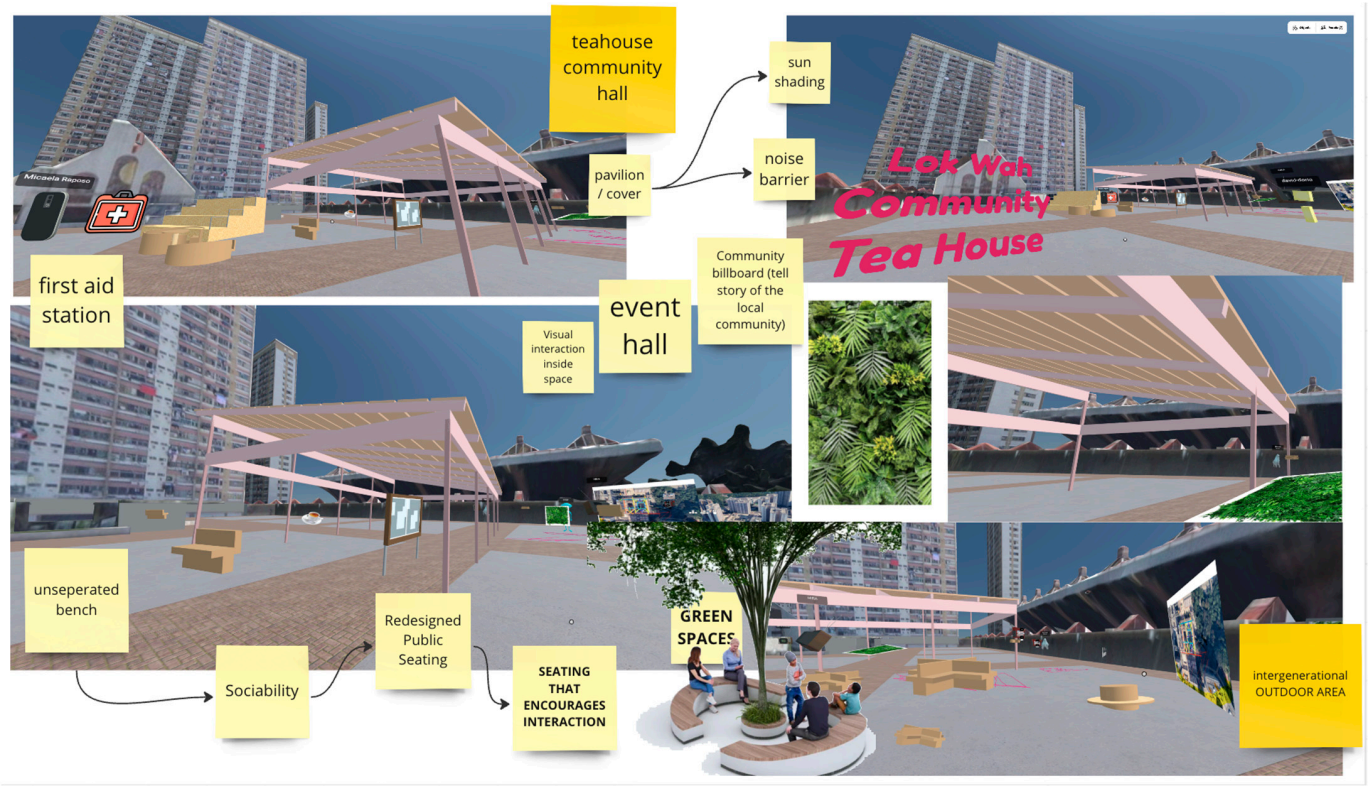

Figure 8. Proposals of an outdoor area for community-building activities with facilities and vegetation, for Lok Wah Estate in Hong Kong.

The proposed interventions comprised urban furniture, with a set of strategically placed public seating that would encourage interactions among residents and visitors through unseparated bench design. A participant contributed a detailed sketch of re-designed circulations between the amenities and vegetation.

To extend the duration of outdoor activities, the proposal featured a substantial canopy, serving not only as a shade from extreme sunlight and rain protection but also as a noise barrier to adjacent residential towers. The proposal also included essential facilities like a first aid station, safeguarding children and older adults.

There was a discussion on how to tell the story of local communities. The canopy was then replaced with a community teahouse, which a participant 3D-modelled on the spot, with the same colour scheme as the housing estate. Another participant immediately designed a signage board for the teahouse, following Hong Kong traditions.

To support both active and passive community-building activities, some integrated the teahouse with an event hall, while others integrated the playground with shaded grass lawn, enhancing family time. The collaboration was smooth as the participants reacted to each other's creation, giving rise to subsequent ideas like community gardens and graffiti walls, facilitating intergenerational areas. As there was a wealth of ideas but not enough time to build all the proposed facilities, the participants made collages with reference visuals on Miro to demonstrate their collective vision.

The design process was entirely conducted online and requested the inclusion of additional textual information within the design discussion. Each participant used their own equipment and internet connection.

The team that worked with the neighbourhood ***Prodac*** in Lisbon decided to design a proposal that would meet what they anticipated as being the expectations of the local communities.

The team assessed the place as too empty, missing green areas and activities. The emptiness of the public space was interpreted as a consequence of the absence of community activities in public collective areas. For that purpose, they conceptualised community urban gardens, providing a space for planting a variety of vegetables, fruits, and other crops.

Additionally, a second proposal emerged, featuring an outdoor cinema and cafes. This second proposal aimed to transform the existing park at the heart of the neighbourhood into a vibrant hub, currently devoid of any distinctive attractions.

Because these proposals were discussed face to face, the discussion was mainly in the physical room, and in Miro, only the photomontages were added (Figure 9).

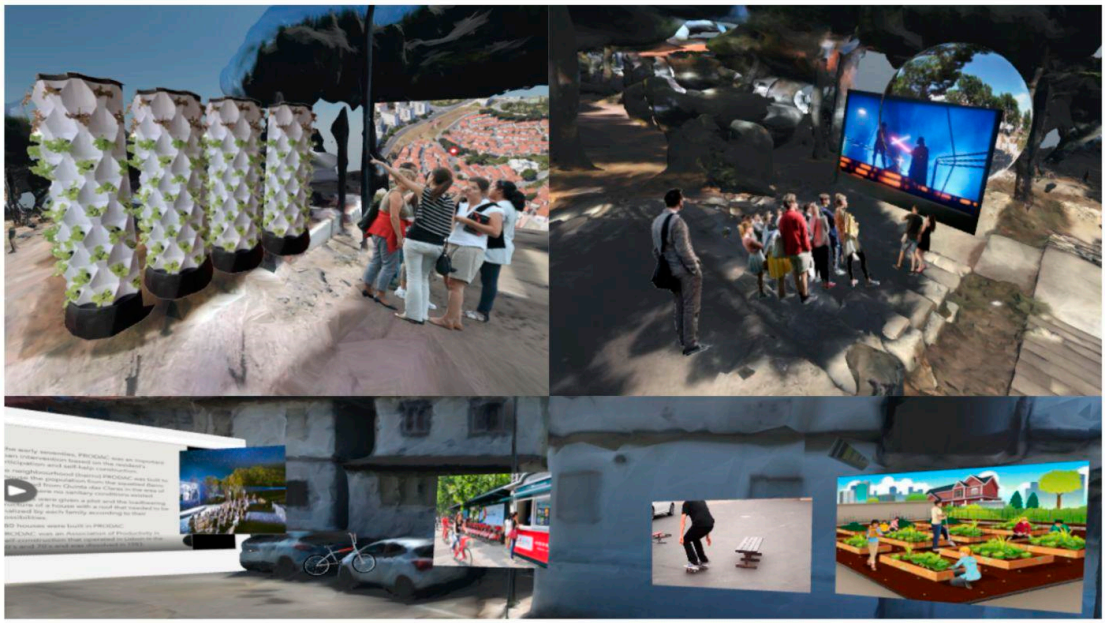

Figure 9. Proposal of an outside cinema and community urban gardens for Prodac in Lisbon.

This team was the only one which occasionally used HMDs. The use of HMDs provided a higher immersion to the ones using it but, according to the users' report, did not represent a benefit during the co-creation session because all the other members were in the same room and the use of HMDs therefore created a feeling of exclusion.

5.3. Participants' Evaluation on the Co-Creation Experience

The endline questionnaire results provided insightful feedback on the participant experience and satisfaction regarding the co-creation process (Table 3).

'Sustainability' emerged as the highest regarded criteria across all the participant groups, averaging 4.6, which may reflect the long-term relevance of the engagement experience. In contrast, 'expression' and 'space' received the lowest average score of 3.6, possibly indicating the limitations of communicating or understanding the tailored VR environment.

The Barbican and Lok Wah participants shared a higher overall satisfaction with an average score of 4.1. Barbican excelled in 'sustainability', 'aspiration', and 'context', suggesting the experience is seen as forward-thinking and well integrated into its intended setting. However, it fell short in 'space' and 'design', with the latter also being a weak point for Lok Wah. These might point to a need for more intuitive or user-friendly metaverse features that could enhance spatial orientation or interaction within the virtual space.

Prodac, with an overall mean score of 3.9, indicated a slightly less favourable experience, with lower ratings in 'expression' and 'design'.

Table 3. Endline questionnaire results. Each column = response from one participant; highest and lowest values highlighted in green and red, respectively.

	Criteria	BARBICAN						Sum	LOK WAH						Sum	PRODAC						Sum	Mean	Mean
Game design	Motivation	4	5	5	3	5	2	24	5	4	4	4	4	4	25	5	5	4	4	3	5	26	4.2	**3.8**
	Expression	3	5	5	3	5	3	24	4	4	3	3	4	4	22	3	4	2	3	2	5	19	3.6	
	Ease of use	3	5	3	3	5	4	23	3	3	4	4	5	3	22	5	5	2	4	2	5	23	3.8	
	Space	4	4	4	2	5	4	23	4	3	5	4	4	4	24	3	4	2	3	2	4	18	3.6	
Participatory experience	Aspiration	5	4	4	3	5	5	30	5	5	4	5	4	4	27	5	4	4	5	4	5	27	4.4	**4.4**
	Reflection	4	4	5	4	5	5	27	4	5	4	5	4	5	27	5	5	3	4	3	4	24	4.3	
	Creativity	4	4	5	5	5	4	27	5	4	3	4	5	5	26	4	5	3	4	3	5	24	4.3	
	Sustainability	5	5	5	5	5	3	28	5	5	4	5	3	5	27	5	5	4	5	3	5	27	4.6	
Learning outcome	Context	5	5	5	4	5	3	27	4	4	4	3	3	5	23	4	5	3	4	2	5	23	4.1	**4.0**
	Design	5	5	5	2	5	2	24	5	4	3	3	5	3	23	4	3	3	4	2	4	20	3.7	
	Community	5	5	4	2	5	4	25	5	3	4	4	4	5	25	4	4	4	4	4	4	24	4.1	
	Confidence	5	5	4	3	5	2	24	4	4	5	5	4	5	27	5	3	4	4	3	4	23	4.1	
Cooperative outcome	Satisfaction	5	5	5	3	5	2	25	5	3	5	4	5	4	26	3	4	4	4	3	5	23	4.1	
	Inclusivity	4	5	4	3	5	2	23	4	3	5	4	4	4	24	4	4	3	4	3	5	23	3.9	**4.1**
	Outcome	5	5	5	3	5	2	25	5	4	3	4	5	5	22	5	5	4	5	3	5	27	4.3	
	Consensus	4	5	3	3	5	2	22	4	5	5	4	4	4	26	5	5	4	4	3	4	25	4.1	
	Mean	4.4	4.8	4.4	3.2	5.0	3.1		4.4	3.9	4.1	4.1	4.2	4.3		4.3	4.4	3.3	4.1	2.8	4.6			
		4.1							**4.2**							**3.9**								

In analysing the general aspects of the metaverse participatory design experience, the vertical comparison highlights several key areas. 'Game design' averaged 3.8; while the overall structure and aesthetic of the VR design are satisfactory, there is a recognised need for enhancements in terms of the user interface, navigational ease, and interactive elements. The 'participatory experience' was rated highly, averaging 4.4, reflecting an appreciation for the engaging aspects, with metaverse conducive to involvement and a sense of agency and contribution to the process. With a mean score of 4.0, 'learning outcome' was also viewed positively, suggesting the experience imparts new skills and knowledge for participants, indicating the feeling of enrichment and informed post-interaction. Finally, 'cooperative outcome' averaged 4.1, revealing that the participants find the experience fosters teamwork and collaboration, facilitating collective input and cooperative outputs.

Not all the participants completed this questionnaire; six participants responded from each team, totalling 18 responses.

5.4. Participants' Feedback

All the participants of the workshop were invited to share feedback regarding their overall experience of the workshop through the endline survey. The themes that emerged are as follows:

Potential in innovative methods for co-creation. Generally, the participants were excited about using new and innovative digital co-creation methods. There was also an interest in using new platforms like Mozilla Hubs for engagement and discussions. The participants felt that the VR tools could be developed further to facilitate the co-creation process and make the experience more immersive.

Technical difficulties limited the sharing of ideas. Most, if not all, participants struggled to access the metaverse space at least once in the session. This was due to disruptions in the internet service during the workshop and increasing 3D objects during co-creation. This disruption sometimes made it difficult for ideas to flow between the participants.

Controlled environmental conditions required to create an immersive experience. The participants suggested the need to have dedicated environments and sufficient time that would allow participants to fully immerse in the experience with no distraction.

More information needed for participants to make informed decisions. Even though the participants felt they needed more information on the sites, they considered the open-

ended approach to have its benefits. They recommended using specific scenarios in future sessions to get detailed feedback from participants.

Participants were satisfied with and saw value in the experience. When being asked 'If there are similar events in the future I would participate again or recommend to others', the median was 5 out of 5. This helps us conclude that most participants saw value in the process explored during the workshop.

6. Findings and Discussion

6.1. Strength of VR Environments in Co-Creation

The experience proved successful both as a collaborative design process and as a way of using virtual environments to foster discussion, engagement, and immersion. Although some difficulties were identified, we see them as opportunities for improvement to make future experiments more intuitive for users and meaningful for participatory and collaborative processes. Although one interpretation could be the lack of immersiveness of our study, the study of Van Leeuwen et al. [35] shows that VR headsets are equally effective compared to non-immersive devices in informing participants.

There is a clear consistency between the participants' comments (5.4) and the scores (5.3) regarding the experience. Four main strengths were identified.

Firstly, the participants praised the VR experience as an innovative, engaging method, identifying playfulness as a strength. This finding is in line with other studies, such as the one by Dorta et al. [28]. Also, as found by Van Leeuwen et al. [36], viewing design by using immersive VR using headsets provides higher engagement than when using non-immersive displays. Although using the metaverse, the workshop was held for most of the participants using non-immersive devices (computer screens) and therefore the results of this study can only be directly applied to non-immersive VR-based platforms.

Secondly, the participatory experience was commented on as positive regarding the open-ended approach that fostered creativity. The findings from Dorta et al. [33] showing that a creativity flow occurs in a similar way in non-immersive and immersive environments is emphasised by our results. However, the participants expressed a desire for more base information to outline the goal and improve the discussion and decision making. Despite this, VR fosters collaboration, as realism provides a higher immersive experience that gives a sense of scale, allowing for the active contribution with imagination and radical interventions. The score reflected this, with the aspects related to the participatory experience being the highest rated in the endline questionnaire, especially 'sustainability'.

Thirdly, virtual reality is an enriching experience as it effectively educates its users, developing new skills and knowledge. In addition, it is inclusive for allowing one to go beyond spatial–temporal constraints.

Finally, VR and the use of metaverse involves marginal costs for the co-creation participants as no specific infrastructures need to be acquired.

The experience was overall positive, as even the lowest scores were above average, and the participants reported they would repeat and recommend it.

6.2. Limitations of the Approach

This research successfully used VR to comprehend, study, and co-create public spaces, but it also identified five significant limitations.

Firstly, VR's immersive nature can be counterproductive as it can distract participants from the task and reduce their focus if the interface is not familiar or common. However, this may be a short-term limitation as the tool becomes more popular in the future and, therefore, people become more used to using it.

Secondly, the level of realism achieved in the VR environment needs to be improved to accurately portray the real-life climate, including lighting, textures, sound, and object interaction. A low level of realism can lead to inaccurate feedback or misinterpretations. Accordingly, there is a recognised need for enhancements in the 'game design' category, especially in the 'expression' and 'space' criteria which received the lowest score.

Thirdly, VR's novelty and technical interaction requirements can create obstacles to inclusivity by limiting accessibility and hindering participation from diverse, less technologically driven groups. There is a need to develop more user-friendly design features and improve the equipment to enhance the co-creation and interaction with the VR environment. Finally, the physical space where VR experiments occur needs careful consideration to provide adequate space for participants to move freely without encountering obstacles and balanced lighting.

Fourthly, VR demands robust infrastructure, including high-speed internet connections and powerful computers and VR headsets. The use of HMDs only occurred during the design of the Prodac neighbourhood. Although the experience was considered positive by the participants, the literature shows that the understanding of the space with immersive VR is better than with non-immersive [33]. Due to low Wi-Fi connectivity, the HMDs were not working properly, and the lack of good interaction during the experience made it not immersive enough to engage the users. Some difficulties were experienced by the participants, who commented especially regarding technical issues, such as slow internet and heavy 3D models. These difficulties hinder the participatory experience and sharing of ideas.

Finally, the fifth limitation is that several participants lacked knowledge regarding the site where they participated. In a real-life co-creation process, the involved stakeholders always have prior knowledge regarding the site they are discussing, and this was not the case here. We acknowledge that this limitation impaired the accuracy of the proposals but highlight that this was different from the workshop's aim.

Despite these limitations, VR offers valuable potential for participatory architectural design processes. By acknowledging and addressing these limitations, we can pave the way for a more inclusive, efficient, and effective use of VR in co-creation processes. These findings underscore the importance of a design that supports the functional sustainability of the VR experience and encourages user expression and comfort within the virtual space.

6.3. Next Steps

As described in the previous sections, the virtual experience within a collaborative design process has strengths and weaknesses. The workshop experience allowed us to spot opportunities for improvement, and some additional insights were brought to the discussion.

Regarding the realism versus the soft infrastructure, there is a need to find a balance between the polygon count and texture and the rendering capabilities of the equipment used. On the one hand, realistic visualisation is an added value as it allows for a better understanding of space, especially by non-designers, than more abstract representation. On the other hand, powerful equipment and a good internet connection must be guaranteed to support the collaborative design process that uses realistic virtual environments. When these conditions cannot be guaranteed, e.g., if the session is held fully online and the participants use their equipment, the organisers must streamline the 3D assets to find such balance. Also, the authors argue that using HMDs does not benefit the co-creation process if it is not used by all the participants in an in-person workshop, as it causes a feeling of exclusion.

Additionally, having more information about the site is crucial for the co-creation process. The workshop aimed to test the inclusion of metaverse tools in the process. Thus, the participants involved were not the real end-users or other stakeholders, as they were mainly design experts. In real co-creation scenarios, citizens and other stakeholders are the ones involved, as they are the ones who have the social experience of living in the place and know what its needs are. Also, involving non-experts in design requires having helpful and intuitive design tools to allow them to express their ideas. The design of a ready-to-use kit of parts can improve the design experience. However, other user-friendly design features need to be developed.

These findings also raised other insights, such as how the co-creation process is driven by space scoring, the VR environment quality, and professional or personal experience. In the Prodac case, geographical and cultural issues highly impacted the perception of space and its evaluation by people from different countries, as, e.g., some found it very green, while others felt green was absent. These different perspectives led to suggestions related to their cultural background. In the Hong Kong case, the process lacked verbal communication, but the workflow went very well in the creation of proposals. In the Barbican case, the professional background impacted the experience, as the iconic characteristics of the neighbourhood raised the 'can't touch this' position of the participants, who were mainly design experts.

During the workshop, some architects expressed that, although it is important to listen to end-users' needs, the design is their task. As stressed in the first sections of this paper, the end-users must be involved in the design of their living areas to satisfy their needs. There is therefore a need to rethink the role and perspective of the architects, as they should act as mediators and foster the stakeholders' collaboration with effective design tools.

Another insight was the amount of time needed to carry out a co-creation process using metaverse tools. The duration of the workshop was approximately three hours. The goal was to test the process, and the authors consider that for this purpose, the duration was adequate. However, a real co-creation scenario would need more time to discuss and create appropriate design solutions.

7. Conclusions

Metaverse can bring geographically far away people together and facilitate real-time interactive collaboration. Additionally, it enables the provision of several types of 2D and 3D information with the expected potential to combine them understandably. Although recognised as paramount to achieving social sustainability, co-creation processes in architectural design come with several challenges. Based on the results of data collection during the workshop, the findings addressed our research questions in aspects of the strengths and limitations of the metaverse technologies, the participants' experience of the collaborative process, and the ways in which the technologies were being used to co-create.

Firstly, we identified the strengths of metaverse in playfulness, creativity enhancement, expanding potential solution space, and accessibility for allowing for co-creation processes to go beyond spatial–temporal constraints. However, the main limitations identified were the need for robust infrastructure, including high-speed internet and the level of realism of the scene. Regarding inclusivity, metaverse segregated the less technologically driven, i.e., those who do not master the tools and those who do not possess the needed hardware and internet connectivity.

Secondly, based on the researchers' field notes, it raised insights on how participants experience and perceive the collaborative process assisted by metaverse technologies. We found that the participants regarded the VR experiences as innovative, providing an engaging experience, with features that fostered creativity. This was also reflected in the questionnaire results, showing that the participatory experience was the highest-rated criteria. The qualitative feedback from the participants further underlined the innovative and engaging approach. However, the participants reported that more background information should be provided, with the technical limitations hindering the creative processes.

Thirdly, we considered how participants use or work with metaverse technologies to co-create spatial proposals. Our observations during the co-creation process led us to conclude that cultural and professional background highly impacted the understanding and evaluation of space and, consequently, the design proposals. Despite such differences, metaverse tools can support multi-stakeholder collaboration through design visualisation balanced with streamlined 3D assets. However, the navigation controls should be intuitive so that participants can easily explore the scene and communicate.

In addition, the metaverse features should provide toolkits and allow for freedom in the addition of external content, such as reference images and open-source assets, to

demonstrate ideas. In our workshop, such strategies facilitated the ease of use to concentrate the participants' attention on the discussion and co-creation of spatial proposals. However, there was a recognised need for enhancements in terms of representation and options for expressiveness, as assessed by the participants through the questionnaire.

Finally, this study concluded that more intuitive design tools need to be developed to improve the quality of a metaverse co-creation process. This can help to ensure that participants are engaged and not distracted by technical challenges. Also, the participants discussed that the slow response and breaks of the metaverse scenes negatively influenced the co-creation.

For future research paths, the findings highlight the need to test the use of metaverse by involving public space users, as they are the ones who best know the place under discussion. As such, a longer and iterative experience should be outlined, with planners and designers being open to this innovative approach.

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Data Availability Statement: All the data from the surveys are in the paper. Due to the closure of Mozilla Hubs, the metaverse scenes are no longer available.

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