Architecting the Metaverse: a paradigm shift for co-design in architecture

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Abstract. Although already used since the last decade of the 20th century, the concept of metaverse has gained relevance in the last decade due to the advancements of virtual reality, the gaming industry and the uptake of big IT companies. Metaverse for architecture design has been increasingly mentioned and used in practice, education, and research. Metaverse and the Extended Reality (XR) technologies that compose it and the multiuser possibilities enable immersive 3D experiences and interactions that engage multiple senses, creating a strong sense of presence in virtual environments. This heightened presence facilitates a deep understanding of spatial surroundings, allowing designers and laypeople to explore the built environment thoroughly. This paper explores the metaverse's potential as a collaborative design tool in architecture, emphasising its real-time interactive capabilities and support for participatory design. We examine leading metaverse platforms, focusing on key features crucial for architectural design, namely, 3D modelling options, customisation tools, interaction features, and co-presence. Furthermore, we present three case studies using metaverse, illustrating its utility across different architectural research scenarios. These cases involve co-design, user studies evaluating the built environment quality, and simulations of construction processes.

Keywords: Metaverse, Extended-reality, Collaborative Platforms, Design Process, Co-Design, Simulation.

1 Introduction

This paper explores how the metaverse can serve as a collaborative design tool in architecture, emphasising its capacity for taking multiusers, facilitating real-time interaction, and facilitating participatory design. The paper aims to examine various metaverse platforms, analyse their features and discuss how they contribute to the architectural design process.

The integration of the metaverse into architecture design has garnered growing attention and application in practical settings, educational contexts, and scholarly research (e.g., (Eloy et al., 2022; Kinzler et al., 2022; Ng et al., 2024; Sopher & Lescop, 2023; Tang & Hou, 2022)). The metaverse brings several opportunities for Architecture, such as its global accessibility and adaptive, parametric malleability (Schumacher, 2022). Additionally, the metaverse offers possibilities to design and visualise architectural projects in immersive 3D environments and virtual prototyping creation and testing. Added values of metaverse compared to XR and virtual reality (VR) are the openness of these platforms, their ever-present characteristics, the real-time collaboration among many stakeholders, and the ease of customisation provided. The increased presence enabled in the metaverse also facilitates a more inclusive exploration of spatial contexts that, by the ease of use and clarity, is helpful to both designers and non-designers (Martins & Wolfe, 2023). As a social collaboration space, the metaverse empowers architectural design with an "unlimited number of interlinked social experiments taking place simultaneously" (ZHVR Group, n.d.).

Not only can the metaverse be used to explore digital twins of what will be built in the physical world, but this technology also opens up a new realm of possibilities to design spaces that will **only be used in their virtual form**. Such virtual spaces come with limitless possibilities where physical restrictions such as gravity, materiality and durability, privacy and publicity are reinterpreted (Çalışkan, 2023; Shakeri & Ornek, 2023). Although these features seem quite interesting to explore, other authors tend to focus on virtual worlds that should be subjected to the laws of physics to make them more real (Contreras et al., 2022). Contrary to physical architecture, virtual environments are **temporary** and do not need to be taken as buildings that must last for decades. Nevertheless, this is also not a unanimous way of looking at the metaverse since some authors still see the metaverse as a space that should always function and where the data generated by users should be saved and updated (Contreras et al., 2022).

Relevant aspects of the experience of the metaverse are embodiment, presence, interaction, and communication. With **embodiment,** we mean the experience of controlling our body remotely while in the metaverse. The feeling of embodiment often comes along with **the feeling of presence**. A successful user experience in virtual worlds occurs when the user navigates the virtual scene but feels like he/she is in the real world. Higher embodiment is achieved when users feel body ownership, can control their body, have tactile sensations, feel the real and the virtual body superimposed, have a look-alike avatar, and respond to the external stimuli that occur in the virtual world (Gonzalez-Franco & Peck, 2018). Therefore, the possibility to customise the avatar and use more photo-realist ones greatly affects the embodiment of the user as well as his/her feeling of presence (Etienne et al., 2023; Nagy & Koles, 2014; Waltemate et al., 2018).

Interaction within the metaverse for architecture design includes the options to interact with the environment via direct manipulation (e.g. adding, moving, editing objects) and with the other users through communication (e.g. talking, touching, making gestures). To use the metaverse as part of the design and decision-making process, interaction features that allow the **direct manipulation** of the environment and the visible objects, i.e. the built environment, are required in order to support design ideation (Ding et al., 2022; Yu et al., 2022). **Communication** may be verbal, by sound and writing, or nonverbal, by means that do not imply language. Nonverbal communication is often used in physical contact. Etienne et al. (2023) concluded that "photo-realistic avatars can increase confidence levels by making it easier for participants to associate the avatar's non-verbal behaviours with real-life experiences". These authors also show that although relevant, non-verbal cues and emotions are still complex of being interpreted in virtual environments. Nonetheless, Slater and Usoh (1994) stress that the face is the most powerful social symbol of self and that facial expressions are paramount for communication making us believe that this feature in metaverse will face significant improvements in the coming years.

This paper is structured in **five sections**. After the 'Introduction', in section 2, we analyse leading metaverse platforms, focusing on essential features for architectural design such as 3D modelling, customisation tools, interaction capabilities, immersion, and co-presence. Nine metaverse platforms were selected with higher dissemination - Frame VR[1], Mozilla Hubs[2], Decentraland[3], Second Life[4], VR Chat[5], Prospect[6], Meta workrooms[7], Spatial[8], and Arkio[9] – based on the research by Mystakidis (2022). Experiences were performed on all the platforms to test their functionalities. Section 3 synthesises the most relevant metaverse aspects needed for architectural design. In section 4, we present three case studies demonstrating the metaverse's usefulness in diverse architectural research scenarios. The paper ends with a 'Discussion and Conclusions' section.

2 Metaverse features

Table 1. Features present in selected Metaverse platforms.

	Frame VR	Mozilla Hubs	Decentraland	Second Life	VR Chat	Prospect	Meta workrooms	Spatial	Arkio

[1] https://learn.framevr.io/
[2] https://hubs.mozilla.com/
[3] https://decentraland.org/
[4] https://secondlife.com/
[5] https://hello.vrchat.com/
[6] https://irisvr.com/prospect/
[7] https://forwork.meta.com/be/en/horizon-workrooms/
[8] https://www.spatial.io/
[9] https://www.arkio.is/

Functionalities									
Create/edit 3D environments and objects		•	•	•	•				•
Import 3D environments and objects	•	•	•	•	•	•	•	•	•
Control lighting, shadows, materials		•	•	•		•			•
Control camera (both first and third person)	•		•	•	•			•	
Make meetings and presentations	•	•	•	•	•	•	•	•	•
Use with AR						•		•	•
Avatar Customisation									
Use default avatar	•	•	•	•	•	•		•	•
Customise/Import human avatar	•	•	•	•	•		•	•	•
Use camera as avatar		•							
Create avatar from camera								•	
Verbal Communication									
Megaphone (all in the room can listen)	•								
Microphone (spatial audio)	•	•	•	•	•		•	•	
Microphone (traditional audio)						•			•
Text	•	•	•	•			•	•	•
Non-verbal communication									
Emojis / emotes	•	•		•	•			•	
Gestures	•		•	•				•	
Gestures if using VR HMD					•	•	•	•	•
Facial expressions	•				•		•		•
Point at an object so that others see it					•	•	•	•	•
Direct manipulation									
Draw, annotate		•	•	•	•	•	•	•	•
Interact with objects (grab, seat, scale, etc)	•	•	•	•	•	•		•	•
Take a screenshot, video		•	•			•	•		•
Take measurements						•			•

The metaverse platforms Frame VR, Mozilla Hubs, Decentraland, Second Life, VR Chat, Prospect, Meta workrooms, Spatial, and Arkio are described in this section. For such description, we used five categories, 'functionalities', 'avatar customisation', 'verbal communication', 'non-verbal communication' and 'direct manipulation' as presented in Table 1, based on classifications developed in other studies (Çalışkan, 2023; Etienne et al., 2023; Shakeri & Ornek, 2023). In this paper, we are mainly concerned with the possibilities of metaverse as a tool for co-creation within the architecture design process and will emphasise the relevant aspects of metaverse for this process.

All platforms allow **multiusers** although the number of users is often lower in non-paid access and differs between the videoconference and the live scenes. E.g. meetings in Meta Workrooms support up to 50 participants simultaneously, but only 16 can join from VR.

Although all platforms include free features, several have **paid subscriptions** for enhanced features such as customisation (scene and avatar), number of participants and storage space. Examples are Mozilla Hub, in which the free subscription only allows a few customisations and with circa USA €79/month, all customisation is possible, 50 participants simultaneously and 25Gb of data for avatars and scenes (Mozilla Hubs shut down in May 2024). Another example is Frame VR, with subscriptions from USA $10, $50 and $200/month. For Decentraland, although the access is free, since the main goal is to buy and sell plots, the participants need to invest in buying the MANA cryptocurrency.

2.1 Functionalities

The analysed platforms have several common functionalities identified in Table 1. While all of them allow the **creation of a virtual scene** based on the platform's features and predefined scenarios, only some allow the **customisation of the entire environment** with personal imported objects. For architecture design, such a possibility is paramount, and Frame VR, Mozilla Hubs, Prospect, Spatial, and Arkio are the ones that performed better in this aspect. Formats such as glTF, OBJ and FBX are the most common ones used to import digital content modelled in other software. Prospect imports easily from Blender, Navisworks, Revit, Rhino and Sketchup in formats OBJ and FBX. Arkio imports easily from Revit, Rhino, Unity and SketchUp. Other platforms offer features that enable the import of 3D models, such as the VRChat SDK (Software Development Kit), which uses Unity as the 3D modelling software.

Additionally, most platforms commonly use and support spatial reconstruction through 3D scans if the final model is delivered in one of the accepted formats. The use of game engines (e.g. Unity and Unreal), especially the first-person shooter ones, as a complement to the traditional 3D modelling software used in architecture (e.g., 3Ds Max, Blender, Maya) bring other new domains as user interface content, character and game design and are supported by most of the platforms (Shakeri & Ornek, 2023). Parallel to creation, the option to **edit objects** is present in most platforms and includes deleting, moving, sectioning, changing the colour, changing the hour of the day (which can be used for solar studies), altering the scale, and rotation.

Besides creating the entire scene, these platforms also enable the **insertion** of different **objects** such as images, videos, photos, audio, text, shapes, 3D models, web browser screens, voice zones, spawn spots, and effects. These objects can be inserted as stand-alone objects or as part of panels (e.g. for the web browser and images). Several platforms have established limits that every scene must follow to improve performance, such as the size and number of files imported, shaders, and materials used.

Some platforms also include features for controlling the **lights, shadows**, and materials in the scene, which is very useful for architectural design. Additionally, the possibility of controlling diverse **cameras** that differ from the user view is helpful for design purposes. In Table 1, we identified the platforms that both control first and third person, enabling broader views of the objects.

Most platforms enable it to be used for **meetings and presentations,** allowing the user to, e.g. share his/her screen during such sessions. Meta workrooms is one of the platforms that is more focused on delivering options for meetings, offering several options for sharing content and creating queries to share among participants. Frame VR also enables the host of large events upon payment of more than $5K. Decentraland is mainly directed to games and includes features such as the ability to see the map/scene of the other gamers.

Using **HMDs (Head-Mounted Display)** to enhance the metaverse experience is relevant in most cases. Several platforms announce the compatible HMDs, which range often the most known ones such as HTC Vive, Oculus Rift/Quest, Windows Mixed Reality, as well as mobile devices that can be used with Google Cardboard. In cases like Arkio, interaction features increase, and the design experience is richer when using HDMs. All the listed platforms are web-based, allowing the use in desktops and mobiles. Also, all platforms permit **VR**, enabling a high feeling of immersiveness when using HMDs. Metaverses such as Arkio, Prospect and Spatial can also be used in **Augmented Reality** (AR) mode. Outside the confines of strictly digital realms, AR allows individuals to enhance the tangible world around them (Shakeri & Ornek, 2023). AR can be useful when the users are all in the same physical room working on a digital artefact placed e.g. on a real table.

2.2 Avatar customisation

Regarding the possibilities for avatar customisation, the analysed platforms have several options. The most common feature is the possibility of customising **a human avatar** using the options delivered by the platform or importing an avatar customised elsewhere. Among these popular features are customised gender, ethnicity, face (eyes, mouth, nose, hair), hair (colour, style), accessories (hat, glasses, earrings), and clothes. Additionally, few platforms include the option of creating an **avatar from the camera**, which adds to the participants' embodiment feeling. Also engaging is the option of using the camera as an avatar, such as the feature present in Mozilla Hubs.

2.3 Verbal communication

The analysed platforms enable almost the same types of verbal communication. Most platforms enable **textual communication** by chat or notes. Several platforms enable chat, but in a few, e.g. Arkio, it is only possible to write on sticky notes. Regarding communication by **voice,** the available options are spatial audio, traditional audio, and megaphone. Spatial audio occurs when the sound level depends on the distance the user is from other users. Megaphone is when, although spatial audio is used, all users can listen independently of their location. Traditional audio is used through the microphone, as in a traditional video/audio conference.

2.4 Non-verbal communication

Several differences regarding non-verbal communication were noticed along the analysed platforms. Only some of the platforms allow users to communicate via **emojis** or emotes. In some cases, users can use **gestures** to express their feelings through the avatar's body expressions, and in others, gestures are possible only when using an HMD. Currently, only the platforms which enable the use of Meta VR with HMD enable the use of natural **facial expressions**, such as Meta, Arkio and VR Chat. Some platforms, such as Arkio and Prospect, identify where the users are pointing at. This possibility allows us to see what the other users are working on or pointing to specific scene objects during a verbal discussion.

2.5 Direct manipulation

Interaction within the virtual scene using direct manipulation is one of the main features of metaverse when used for architecture design and has a high impact on the feeling of satisfaction of users. Among the studied platforms, several options for interaction were found. Several platforms enable drawing and annotating scenes; others enable editing objects and scenes. Interacting with objects includes the possibilities of grabbing an object, sitting on a chair, and altering the visualisation of different layers of an object. Measuring the objects in the scene is a helpful feature for architectural studies present in Prospect and Arkio (Figure 1).

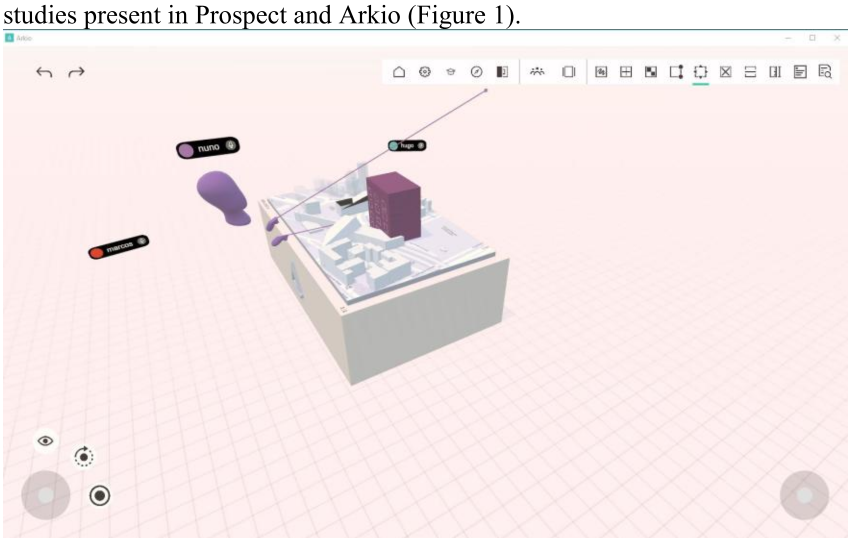

Fig. 1. Design test involving importing a 3D object, editing, and measuring among a multiuser collaboration delivered with Arkio.

3 Key features in Metaverse for Architecture design

Building on existing literature on the use of metaverse in architecture, we synthesise the most relevant aspects of metaverse that are essential for its application in architectural design processes (Çalışkan, 2023; Djerad & Kammoun, 2023; Ng et al., 2024; Shakeri & Ornek, 2023; Tang & Hou, 2022). The key dimensions we focus on include space, time, collaboration, interaction, avatars, communication, and movement:

SPACE:

i) The ability to **generate virtual scenes** and objects using various tools, such as 3D modeling, scanned assets, and the integration of external media (e.g., photos, videos, and audio elements).

ii) The utilisation of **fully immersive 3D spaces** where users can engage in exploratory and experiential design, moving beyond traditional 2D representations and actively "playing" within the 3D designed environment.

TIME:

i) Design teams and stakeholders can collaborate **synchronously**, allowing for immediate feedback, decision-making, and iterative design improvements.

ii) The virtual environment remains accessible across different time zones, enabling **asynchronous** participation where users can leave annotations, review changes, or contribute to the design process at scheduled intervals.

iii) The virtual environment is available during a **specific agreed time frame**.

COLLABORATION:

i) The ability to **create virtual events**, such as design charrettes, project reviews, where participants can interact with digital models.

ii) **Multi-user collaboration** within a shared space, where architects, clients, and engineers can collectively explore and refine design concepts.

INTERACTION:

i) Users can **directly manipulate objects** within the scene, e.g. adjusting scale, materials, and spatial configurations dynamically.

ii) Interaction is enhanced through **natural movements**, such as grabbing, pointing, and gesturing, which contributes to a more intuitive and immersive user experience.

iii) The use of **head-mounted displays (HMDs)** instead of traditional 2D screens offers a deeper sense of presence, allowing users to perceive spatial qualities and design elements with greater accuracy.

AVATARS:

i) **Higher fidelity avatars**, particularly those that incorporate facial expressions and body tracking (e.g., through camera-to-avatar mapping), improve user engagement and facilitate more effective user studies on spatial perception and behaviour.

COMMUNICATION:

i) The metaverse supports both **verbal** (voice chat) and **nonverbal** (gestures, text chat, emojis) communication, enabling nuanced discussions and interactions.

ii) **Interactive feedback** mechanisms, such as live commenting, digital annotations, and AI-driven suggestions, help streamline the decision-making process and refine design iterations.

MOVEMENT:

i) The availability of **diverse movement options** - such as teleportation, free navigation, and guided pathways - allows users to explore virtual spaces from different perspectives and scales, simulating real-world circulation patterns.

4 The Metaverse potentials as a collaborative design tool – Cases

In this section, we exemplify how using a metaverse for three different architectural purposes might be beneficial compared to other more traditional processes in the field, namely VR. The three presented cases are selected from the authors' ongoing research in ISTAR-Iscte in Lisbon. The three cases have in common the fact that they use VR, AR, metaverse, space simulations and multiusers, for research in the field of architecture.

4.1 Co-creation of housing design

In the scope of a PhD thesis about housing customisation through co-design processes, we are studying the potential of using a digital tool for the inhabitants to co-design their own houses (Raposo et al., 2024). A user-centred approach was used to define, prototype and test a graphical user interface for such a purpose.

Such an interface could benefit from the metaverse potentials since simulation, visualisation and interaction with the environment and users are intrinsic characteristics of the design process (see Figure 2). Most of the **functionalities** in Table 1 are potential benefits for a co-design process of architecture in the metaverse. Creating customised 3D environments is paramount since the scene simulates the environment being designed. When such scene customisation is impossible, a common workroom for a collaborative design process can be simulated. In this scenario, importing and editing **objects** is very useful for users, e.g., to walk around a 3D model and discuss the design. Also, reference images, such as samples of finishing materials, could be inserted as part of a panel. **Controlling lighting** and **camera controls** are essential in architectural design as the users need to explore the space immersively to have a sense of scale. A **multiuser** experience is also beneficial in involving different stakeholders, specifically in housing design, and engaging the household inhabitants in the discussion and decision-making process.

Regarding avatar customisation, the collaborative process would benefit from discussions among participants who are represented within the VR environment. **Creating an avatar from the camera** is an appropriate way to create a realistic representation of users. This realistic representation enhances the presence and feeling of collaborating with other users. The **verbal communication** is essential when the participants are discussing the design. In situations where users can walk around and explore the environment that is being designed, **spatial audio** can be used as the users talk about the specific place they are located. In situations with an object, e.g., a 3D model in front of them, the megaphone can be used for everyone in the room to discuss the same subject. In such cases, emojis can also be used to easily express users' satisfaction about the decisions made. **Non-verbal communication** is also important in co-design processes and should complement verbal communication. **Gestures** that show the users' reactions through the avatar's body expressions and seeing where the others are pointing are examples of how non-verbal communication can be used in collaborative scenarios. Regarding **interaction**, **drawing, annotating**, and **editing objects** are crucial for co-design. **Taking measurements** is also relevant.

Fig. 2. Test of the Housing Co-design tool in Spatial.

The use of metaverse for co-design in the presented case is beneficial compared to other VR approaches and traditional in-person collaborative meetings. Using the metaverse allows different participants to join a co-design process, overcoming spatial-temporal barriers. Also, creating interactive VR scenes allows us to simulate and explore design solutions that would be very time-consuming if using e.g. 3D physical models. Another benefit of the metaverse for co-design processes is the immersiveness and the possibility of navigating through the space, providing a better understanding of space for non-experts in architecture.

4.2 Testing robotic construction

As part of a PhD thesis focused on using drones for robotic construction, we explored the potential benefits of using autonomous drones in cooperation with human workers to assemble complex construction elements, specifically wall elements (Figure 3) (Pereira da Silva et al., 2022). We aim to highlight how this technology can shape the construction industry's future. To achieve this, we employed a virtual construction simulation approach to define, prototype, and test a robotic construction methodology that can later be applied in real-life construction processes.

Construction simulations can greatly benefit from the metaverse and its inherent potential. The design process of complex architectural elements, construction processes, and visualisation, as well as human-machine cooperation and the construction environment, are all intrinsic characteristics that can significantly benefit from most of the **functionalities** in Table 1. Although **creating custom 3D** environments for the experiment is unnecessary, a large empty default space is required where drones can build, and users can move around and cooperate to simulate the hybrid process. On the other hand, the ability to use specific architectonic elements and simulation/flight scripts is required, making it essential for users to import and edit objects to walk around the construction process and 3D model and cooperate in the defined tasks.

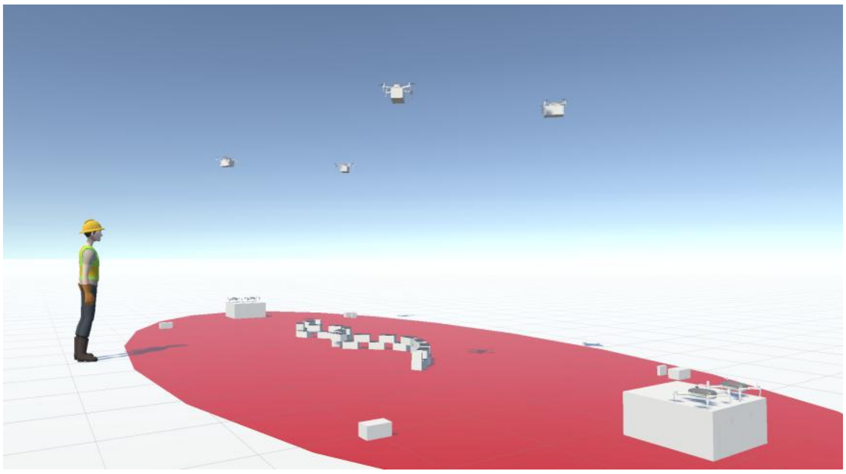

Fig. 3. Robotic construction environment developed in Unity and imported into Mozilla Hubs.

A **multiuser experience** is essential for numerous construction workers and stakeholders to actively participate in discussions, cooperation, and analyses of the robotic construction process, with effective **verbal communication** being paramount during these interactions. **Spatial audio** improves collaboration by facilitating communication in restricted locations and groups, enhancing the overall experience. When participants are spread out across a wide area, a **megaphone** option can efficiently address all users simultaneously, encouraging them to discuss the same topic. Although **emojis, non-verbal communication**, and **gestures** help express satisfaction and reactions through avatars, they may not be necessary for pre-programmed robotic processes. However, functionalities like **object interaction, drawing, annotating**, and collaborative **object editing** are essential for collaborative scenarios. Additionally, the ability to take **measurements** during construction and upon completion is a crucial feature.

In the scope of this research the metaverse presents great potential to explore the collaborative construction experimentation between humans and machines by allowing multiple participants to engage in collaborative construction while overcoming spatial and temporal limitations. It also enables the users to discuss and create other cooperative scenes between humans and drones, making it easier to simulate and explore different construction processes, robotics, and human tasks. The immersive nature of the metaverse makes it easier to understand complex 3D elements and construction processes, allowing architects, contractors and construction workers to analyse and test different construction processes. These advantages make the metaverse an invaluable tool for conducting comprehensive and efficient studies, particularly in robotic construction, where complex simulations and collaborations are essential.

4.3 Assessing the public space

Within the research project GreenCity4Aging (https://greencity4aging-iscte.hub.arcgis.com/), we study how green streets can promote walkability (i.e., walking competence) and the social integration of older people in the urban tissue.

Part of the research methodology is the development of user studies where older people are confronted with and evaluate diverse street designs.

The use of metaverse for developing such a study could take advantage of the potential of metaverse platforms (see Figure 4). Regarding **functionalities** such a study should be devised in a platform that allows the **creation** of customised **3D environments** since specific scenes need to be presented to participants. Such virtual scenes could be delivered for higher realism using 360º videos or an entire 3D-modelled environment. Also, controlling **the camera** is paramount since the participant's perspective using a first-person shooter is essential. Within such a study, using the metaverse would allow multiusers and the researcher to immerse in the same scene, observe the participant, or even interact with him/her and do a walking interview.

Regarding the **customisation of the avatar**, embodiment features are also essential to increase the participant's embodiment (Nagy and Koles 2014), so features that enable the **creation of an avatar from the camera** would be the most appropriate. If other users enter the same virtual scene, having them represented more realistically enhances the feeling of presence. Regarding **verbal communication** and depending on the study protocol, it could be relevant to have **spatial audio** to communicate with other avatars, e.g. the researcher, and the possibility to write or use emojis to express the emotions along the test. Regarding **non-verbal communication,** and again, depending on the study protocol, this feature would only be relevant if data collection from the participants depended on this communication. For the **interaction** features, such a study does not require that the participant interacts with the environment.

The use of metaverse for this study brings advantages related to other methods. Compared to local observations, simulations in the metaverse enable manipulation of the scene presented to participants and, therefore, use slightly different variables to test their impact on users. Compared to other simulations, e.g. photos, videos, and stand-alone VR, the metaverse enables tests to be developed in a geographically free environment and easily enables multi-users.

Fig. 4. Test of a simulation of an outdoor environment using photogrammetry and 360º images in Mozilla Hubs.

5 Discussion and Conclusions

This paper explores the use of metaverse in collaborative architectural design processes. To do so, we selected nine metaverse platforms and identified which of their main features are relevant to developing a collaborative design process.

Aspects such as the customisation of the scene and the objects used are paramount in architecture, so such platforms can be used as simulations of the design under development. Additionally, the feeling of presence in such an environment is seen by several authors as relevant for a successful user experience. Such a feeling of presence can be linked with the possibility of customising the avatar, the availability of interactive verbal and non-verbal communications, and the availability of options for the direct manipulation of objects in the scene. Additionally, overcoming spatial-temporal barriers and the possibility of multiusers navigating simultaneously are vital.

Finally, the three studies presented aimed to showcase the versatility of the metaverse across different stages of the design process and for diverse purposes. These cases cover collaborative design, evaluations of built environment quality through user studies, and simulations of construction processes. Using the metaverse potential, these cases offer an increased experience in architectural design, such as augmented services and digital twins. Our analysis identified Arkio and Prospect as the most promising platforms for collaborative design (Mozilla Hubs was equally promising, although shut down).

Besides the potentials of the metaverse highlighted in this paper, its use also comes with significant obstacles, such as level of realism, internet speed, and lack of advanced design features “such as those for analysing building performance, cost, and land use” (Ng et al., 2024; Yu et al., 2022, p. 20).

The shutdown of Mozilla Hubs, one of the most widely used metaverse platforms, brings the discussion of end-of-life software back into focus, including abandonware, plugins, and software that has never been updated. Authors such as Assad and Henein (2022) have discussed the consequences that may arise from the ‘throwaway culture’ and highlighted the gap in research and the lack of guidance on these practices and their consequences.

While this paper primarily explores the use of the metaverse in the pre-construction phases of physical buildings and its potential, our perspective extends beyond tangible reality. We advocate for developing the metaverse as a purely architectural domain, where virtual spaces exist independently from the physical world. As Schumacher (2022) highlighted, in such cases, architects - not graphic designers - will lead the design of immersive, three-dimensional virtual environments. In *Ready Player One* (Spielberg et al., 2018), the physical world is seamlessly augmented by virtual content, allowing people to engage in a simulated version of everyday life (Geraghty et al., 2022). Similar scenarios already exist today, with workers operating in virtual environments (Trickett, 2023) and audiences attending cultural events, virtual concerts, and digital art galleries. Trickett also highlights the benefits of the metaverse in his concept of *Building Less is More*, where constructing fewer physical buildings leads to a more fulfilling virtual existence while reducing CO_2 and GHG emissions (Trickett, 2023). Expanding on Schumacher’s view, a recent Goethe Institute report describes the metaverse as either a replica of reality or an entirely new, imagined space where people can "be anything" and exist anywhere, encouraging creativity and innovation (Bakk & Gschanes, 2024). In this scenario, architects play a vital role in shaping a holistic, immersive virtual world.

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