VR as a Collaborative Design Tool for Urban Agriculture: An Alternative to Urban Map Walks Methodology

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Abstract
Urban agriculture has a long history in urban settlements. Once as a means of addressing food shortages mainly in the Global South, urban agriculture has now found a wider suite of purposes to fulfil, hence a greater momentum worldwide. Review of the existing literature indicated a growing body of research where different methodologies had been utilized to study the stakeholders' participation in urban community gardens. Despite the proven record of virtual reality (VR) technologies' role in facilitating design participation in other areas, no record of such research was found for urban agriculture. An analog methodology developed for urban agriculture, known as "Map Walks", was used as a basis to develop a VR-based digital walkthrough instrument aiming to concentrate on collaborative intervention in urban spaces, to add features and components associated with urban agriculture which were otherwise not achievable through the analog methodology. The two stage study opened up new horizons not only for the participants but also for the researchers as to how VR technologies can add more collaborative capacities in participatory design. The findings indicated that although it was found as an effective supplementary method to realize the impact of interventions in urban spaces, 1) proactive interaction with the application was key for all participants, 2) different users expected different things from the VR experiment, and 3) they responded to the use of technology diversely and not quite as per expectations.

Keywords
Virtual Reality, Urban Agriculture, Collaborative Design, User Experience, Map Walks

1. Introduction
Reculeau (2017) argues that agricultural activities in urban areas are as old as human settlements. However, the role of community stakeholder groups and their proactive participation have become more prominent in the success of public projects in recent years. Community garden (also referred to as urban gardening and urban agriculture) projects are classical examples where such participation has proven to be a substantial tool to document and make effective use of community level input thereby increasing the wider acceptance and long-term success of those projects. The research on participation in urban agriculture with VR and digital technologies is few and far between.

Building upon comparable methodologies in urban studies, Map Walk[1] has been developed by Tomkins, Viljoen and Bohn (2014) and used as a methodology to systematically yet informally facilitate community groups' participation process in gestation, promotion and consultation with a prospect to use the outcomes to influence policy- and decision-making processes for Urban Agriculture projects. As effective, easy-to-use, and user-friendly as this methodology is, it was felt that it can be complemented using additional means to capture emotional and cognitive responses using new technologies such as virtual reality (VR) interactive tours. A funded research project was therefore carried out to design and implement a VR-technology solution devised exclusively for this study as a complementary digital research instrument to investigate areas that are less likely to have been covered by the analog version of the research instrument (Urban Agriculture Map Walks). The prominence of VR in facilitation of

[1] Map Walk is a semi-structured guided tour using exclusively created orthographic maps of urban spaces with highlighted potential areas suitable for urban agriculture interventions, followed by a focus-group style meeting to discuss and document participants' views, opinions, and reflections on urban agriculture in the context specifics of the study cases.

participatory design which had been studied before (e.g. Piroozfar et al. (2022)) was one of, if not the most important capability that inspired the research team to choose the technology and develop a niche solution to best meet the intended aim and objectives of the project.

This project aims to investigate the role and impact of VR technologies in and the community stakeholder groups' perception of, and attitudes towards, the use of VR technology for urban agriculture community projects. To achieve this aim, following objectives have been pursued: 1) To critically review the latest research in the multi-disciplines involved in this research; 2) To learn the existing process of Urban Map Walks and its application to urban agriculture; 3) To develop an custom-built, customizable, easy-to-use, useful and flexible research instrument to facilitate co-participation; 4) To verify the instrument through user perception and attitudes towards the use of VR technology; 5) To establish areas for improvement; and (if possible): 6) To improve the VR experiment, rerun the user experience; 7) To highlight the contribution and lay the foundation for future research in this area.

Upon covering part of the in-depth literature review carried out for this study, this paper will explain the research design of the study including a brief overview of the development of the research instrument (which will be discussed in full detailed level in a separate paper), the data collection and analysis strategies, as well as the preliminary findings of the study with respect to development and improvement of the research instrument through Alpha and Beta Build stages. The full analysis of findings of the analog stage (map walk) and digital stages (Alpha and Beta Build) will be presented in separate publications later on.

2. Literature Review

2.1. Urban Agriculture

Agricultural activities moved to the city fringes and suburbia as a result of industrialization (Steel, 2013) and then back again to the urban areas when a revival of urban horticultural took place, predominantly in form of activities for food production (Appel and Spitthöver, 2011, Keshavarz et al., 2016). They have been used by the working class for an enhanced food security or the upper class as a place for self-realization, expression of individuality and a contemporary healthy lifestyle (Appel and Spitthöver, 2011).

It has been argued that although distinction can be drawn between urban agriculture and community gardens (and community food gardens as an extended concept), there could be benefits across the different concepts and that they have been used interchangeably (Tomkins, 2014). According to Kirby et al. (2021), food production in urban spaces can offer four potential categories of social benefits: health and wellbeing, economic opportunities, social cohesion, and education (Dubová and Macháč, 2019, Olivier and Heinecken, 2017, Reynolds and Cohen, 2016). As an environment "productive in economical, sociological and environmental terms", Continuous Productive Urban Landscapes (CPULs) have been proposed by Viljoen et al. (2005).

When first used by the UNDP in 1996 (Smit et al., 1996), urban agriculture was mainly concerned about the Global South – Africa, Asia and Latin America – but it has since prevailed in the United States (Balmer et al., 2005, McClintock, 2008), Canada (Kaethler, 2006), and the UK (Viljoen et al., 2005, Cullen, 2008, Tomkins, 2014) as well as other Global North economies such as Switzerland (Jahrl et al., 2021), Japan (Yuan et al., 2022), France and Germany (Kirby et al., 2021, Pölling et al., 2016) to name but a few. Kirby et al. (2021) studied differences in motivations and social impacts of urban agriculture types across case studies in Europe and the US. Political-administrative program (PAP) developed by Knoepfel et al. (2007) has been used for analysis of city policies to study the role of food gardening in addressing urban sustainability by Jahrl et al. (2021). Including social, health and well-being, disaster risk reduction, and environmental perspectives, Yuan et al. (2022) reviewed technological, socio-economic, and policy aspects of urban agriculture to highlight its value beyond mere profitability. Motivations for investing in allotment gardening have been scrutinized in the context of the city of Dublin by Kettle (2014). The role of community gardening has also been looked into for the purpose of place-making in social housing (Truong et al., 2022).

2.2. VR for Participatory Design

The Coronavirus pandemic exacerbated the move into virtual interaction environments (VIEs) which had already begun due to prevalence of game industry, wider availability of and accessibility to VR technologies and the proven benefits of VR in the AEC industry (Piroozfar et al., 2022). Cognitive mapping is essential for full spatial cognition (Briggs et al., 1973 in Walmsley et al., 1990) which can be characterized by three inter-connected features: "space itself, containing immovable structures and landmarks; objects within the space, which move or change state under certain conditions; and actors whose actions cause changes within the environment" (Dalgarno, 2002: p.154). MIT Nano Immersion Lab defines virtual reality as "a computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way". VR has been studied as a collaboration tool in children's design processes (Ryokai et al., 2022), for participatory evaluation of sound environments in urban spaces (Jiang et al., 2018), in experience design (Sherman and Craig, 2003), for participatory design experimentation with the elderly (Kopeć et al., 2019), as an interaction design tool in healthcare training (Matthews et al., 2020), to study novice designers' spatial cognition in collaborative design (Rahimian and Ibrahim, 2011), for semantic-based taxonomy in product design (Makris et al., 2012), in group debriefing in safety education (Luo et al., 2021), to investigate how immersion and interactivity drive VR learning (Petersen et al., 2022) and with reference to its effects in training simulators (Menin et al., 2022). A review of VR/AR (Augmented Reality) in human-robot collaboration (Dianatfar et al., 2021) classifies different areas of focus of publications in this area into: operator support, simulation, instruction (training) and manipulation (operation and control). However, apart from a comparative study of in-situ and VR walk-along interviews for auditing an urban park deck (Jaalama et al., 2022), there is very limited, if any other evidence, of previous work on participatory design for community projects, in general, and urban agriculture, in particular.

2.3. Map Walk Methodology for Urban Agriculture

A map walk methodology was exclusively developed to study food gardening and urban agriculture by Tomkins, Viljoen and Bohn (Tomkins, 2014) and used ever since by Tomkins in urban agriculture community projects. The methodology involves marking an urban area with spaces deemed suitable for urban agriculture, producing an illustrative map of the area, design a walk path, guide a group of voluntary participants study the map, visit the urban spaces and discuss the potentials of changing the use of the predetermined urban spaces to incorporate urban gardens. The group will then participate in a focus group discussion of their experience using the maps and their walking experience of the selected urban spaces. The results will be added to the maps and used to produce reports to feedback to decision making processes if and where applicable. Walkable MR (Mixed Reality) map has been used as an interaction interface for cultural heritage (Bekele, 2019). Geospatial information and AR have been combined in previous research in different cognate fields including urban planning and design (St-Aubin et al., 2010, St-Aubin et al., 2012), to combine walkable maps and orthoimages in museums and public spaces (Wüest and Nebiker, 2018), for training operators in urban utility infrastructure networks (Piroozfar et al., 2019a, Piroozfar et al., 2019b) and in urban history (Maiwald et al., 2019). There are no precedents of using VR technologies for urban agriculture community projects. We have developed a VR-based technology solution to supplement and potentially enhance the participants' physical map walk experience.

3. Research Design and Methodology

This research seeks to investigate different community stakeholder groups' perception of, and attitude towards, urban agriculture through VR. In order to measure the participants' attitudes and perceptions, multi-staged research with a qualitative methodology was designed. Prior to commencing these stages, and to help establish the knowledge gaps, shape the research design, and scaffold the findings of this study at later stages, a review of urban agriculture, VR for participatory design and 'map walk' methodology was carried out through secondary research. Upon establishing an existing knowledge-base, a series of primary research stages were conducted, developing on the previous stage.

These stages were divided into one analog site walk followed by two digital VR developments (alpha and beta builds) and their corresponding data collection/analysis processes. The researchers observed the participants in the analog stage - also referred to as the 'map walk' - and interrogated the data collected during this stage to be able to understand the nature and process of these urban agriculture studies and to subsequently assist in shaping the research instrument in the form of a VR application, through discussion and exploration.

The second stage of the study commenced with development of the alpha build of the VR application, followed by the second stage of data collection in the study (and the first for the digital stage). Following action research principles, this stage utilized a focus group method. This was achieved in 3 parts. The first part of this stage focused on presenting the VR application to the participants in several smaller working groups and giving them the opportunity to play with the developed VR application, whereby users could provide informal responses as they were observing the application. These responses allowed the researchers to shape the second part of this stage by validating/confirming these perspectives through further investigation. The second part of this stage consisted of a semi-structured interview, formed of a series of open-ended questions, maintaining a qualitative nature while addressing the experience presented to the participants in smaller working groups. A semi-structured interview was deemed suitable as it allowed the researchers to address the informal discussions made during the first part of this study, thereby providing a level of flexibility in the study while at the same time capturing specific concerns, needs and preferences of the members of each working group. Finally, in order to create a feedback loop among the participant groups, each cluster was brought back together in a larger group to participate in an open discussion amongst all the participants led by the researchers to highlight any key observations, concerns or opinions that other groups may have not highlighted in their individual clusters, reflect on other groups' feedback and conclude the data collection.

The findings of this stage were used to improve the VR application and develop the beta build. The beta build was then used for another round of focus group experiment. The methodology developed in alpha build and explained above, was replicated for the beta build of the VR application data collection through focus groups to allow for consistency and a level of comparability between the two stages (see Fig 1).

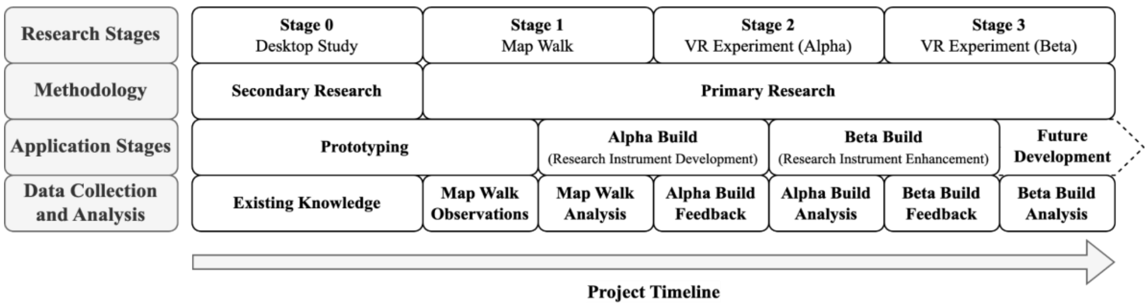


Fig 1: Research Design and Methodology

4. Preliminary VR Experiment Development

4. 1 Spawn in Place

The urban agriculture map walk is intended to provoke the imaginations of the participants, whereby individuals would utilize the map legend to understand what elements of urban agriculture could be placed in a given location. The users would then attempt to visualize these urban agriculture elements within the context of the location before discussing with their peers on elements such as its feasibility and sustainability.

Virtual Reality provides an additional dimension to the visualization of these urban agriculture elements, in which users would be able to place virtual objects in the scene as opposed to imagining their scale and proportions in context of the environment. In order to enable this visualization, a 'spawn in place' system was developed. This system allowed users to select an object from a UI (User Interface) menu before then placing the selected item onto the ground using a laser pointer.

4. 2 OpenStreetMap (OSM) Model

In order to provide context to the site, a 3D model of the city was desirable to include within the VR application. To facilitate the development of the 3D city, an open-source tool called 'Blender OSM' was utilized. This tool allowed the generation of 3D models within a given area; utilizing open-source data, elements such as building heights, building footprint, road paths, terrain levels and other geographical features were amalgamated to form a comprehensive 3D model within the modeling software Blender.

In order to efficiently represent the map generated by the research team, some edits were made to the generated model. The blender software aided in this as it provided the flexibility to edit any aspect of the imported data from the OSM plugin. In turn, the study area was highlighted in orange so that context could be derived from the surrounding buildings shown in white when viewed in context with the study map. This model was subsequently exported and imported into the game engine software.

4. 3 Drawing Tool

During the development of the application, participants highlighted the need to create their own placeable objects while also being able to manipulate existing site features. This, however, in practice, proved challenging due to time limitations and the extents that the UI provided for. To be able to address these queries, a drawing tool was implemented. Despite the different steer to what was set out, the drawing tool allowed users to draw in 3D space, be that written text or 3D objects, and be able to vision their imaginations more easily.

4. 4 Lighting and Baking

The urban agriculture walks are conducted at different times of the year at different times of the day to provoke a variety of responses to how the space might be used given the variance in climate and lighting. Therefore, it was important to capture how the scene may be lit within the VR application to communicate this variance to the user.

This was achieved by implementing an adjustable sun path that allowed the user to experience the site at different times of the day. The sun path followed real azimuth and altitude data at certain points in the day, and as the sun moved along this path, shadows and general scene lighting was updated. This meant that the user could understand which areas of the site would have more or less sun than others, allowing them to make informed decisions about where they might place the objects they are spawning into the scene.

4. 5 Audio

The use of audio was necessary in order to convey ambience, effect, and information to the user in order to improve their immersive experience. Towards this, a multisensory approach can be taken to use as many senses as possible (kinetic, visual, auditory). A variety of audio experiences can be created by combining interactive and adaptive audio techniques. Both diegetic sounds - which are heard as part of the environment such as dialogue, sound effects, and background noise - and non-diegetic sounds - that are related to the application menus and not part of the 3D world - such as feedback and user interfaces were used to help improve the user experience; the former to improve the sense of immersion and the latter to deliver or emphasize on the (background) information.

4. 6 LiDAR

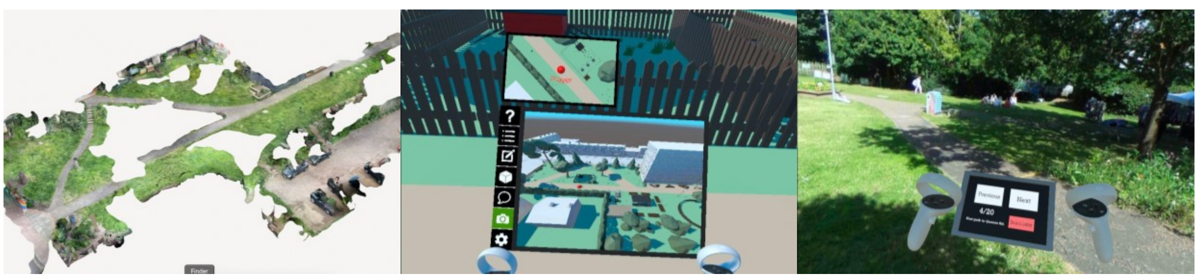
LiDAR was used as an approach to scanning and accurately digitally recreating the urban agriculture site. Although not as accurate as laser scanning stations, this technological approach was chosen to avoid risk of damage to expensive equipment exposed in public spaces. Furthermore, large file sizes from the high-fidelity output of laser scanning would not be necessary for this use case.

4. 7 Minimap

Taking from gaming principles and jargon, a minimap - a small map that displays an aerial view, giving an idea of location of the user in the environment, while also identifying points of interest - would serve this purpose.

4. 8 360 Photograph Walkthrough

The application incorporated 360-degree images into a 'walkthrough' format as a supplement to the physical walkthroughs, and complimented the annotated scale models of the site as contextual information. By using photos, context could be provided as to the existing urban agriculture site and more intricacies can be displayed than that of a digitally recreated VIE (e.g., due to hardware limitations, etc.). Furthermore, they provide a comparison between the existing and proposed uses of the site. Through the virtual experience, limitations and requirements associated with physical presence could be overcome (location, accessibility, mobility, weather and time, cost).



Figures 2: a) LIDAR Scan; b) Minimap and Overview Camera; c) 360 Photos used in application.

4. 9 Locomotion and Scene Transitions

A locomotion system in VR was required to enable users to move around the 3D environment to provide them with a seamless, intuitive, and immersive way to move within VIEs, and furthermore limit discomfort and sense of encumberment. In addition to the locomotion controls, a method for loading Unity scenes was required to enable user transition between them via U.I. control or through a 'portal', such as an interactive item within the scene itself (e.g. a door).

4. 10 Modeling and UV Mapping

Modelling of 3D objects was a necessary undertaking of constructing and forming the static (close, surrounding, or distant environment) and interactive elements (such as spawnable objects and other dynamic objects) within a given scene. In order to create a more aesthetically pleasing, immersive and believable environment for the users, care and attention was required during the modeling process to ensure correct detail, scale and texture of each object.

UV mapping techniques were involved as part of the modeling process, so that 3D objects could be clad with texture maps in order to appear more natural and realistic. This process is carried out in 3D software such as Blender.

4. 11 User Interface

A well designed User Interface (or U.I) was required to provide a graphical representation of elements allowing the user to interact with the application, serving as a bridge between user and software to input information, receive feedback, and access the features and functionality of the software.

The aim for the UI design was that it be intuitive and aesthetically pleasing, resulting in tasks being performed efficiently and effectively. This comprises overall design, layout, and organization of the UI which has an impact on the user experience, and should be designed in a way that is both aesthetically pleasing and functional.

5. Data Collection and Analysis

5. 1 Urban Agriculture Study Site

Prior to developing the application, geometric and contextual data was captured from the site of interest. This was achieved using a mix of 360 photographs, LIDAR scanning and open source mapping data. The LIDAR scan was achieved using the application 'Polycam' on an iPhone 13 Pro, whereby the development team walked around the perimeter of the site, capturing the bounds of the contextual geometry. This geometry provided a base measurement for the 3D model to be developed from, allowing accurate proportions to be reflected in 3D.

The 360 photographs, intended as reference images for the development of the 3D model, were subsequently used in the final build acting as a 'site walkthrough' for those unable to visit the site. These photographs were captured using a GoPro Max and Ricoh Theta 360, both of which utilized tripods set at eye level to reflect what the participants would visualize were they at the site.

Open Source mapping data was utilized later during the development stages as a means of capturing the cityscape. Data from 'open street map' was imported and 3D generated in Blender using the 'Blender OSM' plugin. This was then used comparatively with the LiDAR scans to generate an accurate site perimeter while maintaining an effective cityscape backdrop.

5. 2 Experiment

Following the development of the application, the VR study went on to present the software program to a group of participants. The presentation for both of the feedback stages was set up in the same fashion. The room where the experiment took place consisted of up to eight 'stations' consisting of a VR headset casting to a screen at the end of a table; participants could sit around the table and see the VR users' perspective cast onto the screen. The VR headset utilized for this experiment was an Oculus Quest 2, opted for due to its wide use case, ease of use, availability and untethered nature.

Each table consisted of up to 4 participants with 1 presenter. Participants took turns using the application for up to 5 minutes, while informally discussing aspects about the application with one another. Subsequently, the groups took a short break before returning to respond to a series of questions prompted by the presenter. The questions poised to the user groups focused on elements surmounting to Virtual Reality, Urban Agriculture and User Experience. Succeeding this, each of the tables combined into one large focus group to share their individual discussions and help highlight any potential conflicting or corresponding arguments poised by each table.

Figures 3: a) Researcher explaining controls; b) Participants using application; c) Group discussion

The feedback obtained by the users in these sessions was collected using audio recorders and note-taking. This data aided in the subsequent development stages wherein the software could be adjusted to align more closely to the comments provided by the participants.

5. 3 Data Analysis

The data collected at each of the respective feedback stages was categorized into two distinctive areas; feedback pertaining to the topic of Urban Agriculture and feedback on the VR application itself. Comments relating to the VR application were prioritized in order of importance, higher priority items being those that would cause significant disruption to the user's experience. In addition, any items that were insurmountable during the project time period, were detailed and excluded from the development stage, highlighted as areas to be addressed for future development of the application.

Data pertaining to the topic of urban agriculture was comparatively assessed against its frequency of occurrence during the focus group conversations. Those topics that occurred more frequently in discussion were prioritized as areas to address/develop tools for in subsequent builds of the application. Similarly, those that were discussed infrequently were noted and excluded from development. Upon creating a priority list, the development team divided the tasks and proceeded to add features and correct any application errors/bugs.

6. Concluding Comments and Future Research

In this paper, the design and preliminary findings of this research in this two-part study have been presented; those were used to inform the later development of a VR-based system providing a digital supplement to an analog methodology for urban agriculture to help community stakeholders experience new dimensions which are not otherwise accessible merely through the analog methodology. In combination with the findings of the analog map walks, prior literature was drawn upon to define the parameters of, and approaches to, the experiment, identifying the elements and factors that should be incorporated into the design of such a VR-technology solution.

The use of VR in developing the digital walkthroughs demonstrated not only how it complimented the traditional approach but highlighted several benefits over the analog map walks including: a more immersive experience for the participants, enhanced comprehension of the subject matter leading to improved outcomes, enabling accessibility, as well as promoting proactive user participation in the design process of associated community projects. Furthermore, it showed promise for use in aiding decision-making in community projects. User participation was set up to give users the freedom to choose how they engage with the application and to provide constructive feedback in order to maximize potential insights that could guide future development.

Given the unique requirements of the project, a tailored approach to application development was deemed necessary in order to unlock the full potential of the technology. This approach was more resource-intensive than simply relying on pre-defined solutions. However, the ability to include niche features made it the most suitable option as it was not bound to limitations - in terms of assets, software and/or hardware compatibility/interoperability - inherent in an “off-the-shelf” application. As such, Unity game engine was employed to build the application, and all other pre-existing software packages which were reviewed and tested were disregarded.

Besides the typical project challenges, namely short timeframe, limited resources (including hardware and finances), and complexity due to the tailored approach, the majority of issues encountered were related to programming bugs, glitches, or optimization issues within the game engine editor. Additionally, there were some minor issues with software-to-software and software-to-hardware interoperability, which, for the sake of brevity, will not be discussed in this paper.

This paper contributes to research in the field through exploring a unique and niche use of VR, including its capabilities and limitations, tailored towards use as a tool to facilitate participatory design with a specific focus on community projects in general and urban agriculture in particular. This adds to existing knowledge in the field which is currently few and far between. This research not only serves to promote and further establish 'Map Walks' as a methodology, but also aims to showcase the additional features that can only be enabled via VR-technology enabled interaction with existing settings and add, omit or amend desirable features or elements of urban agriculture to an existing urban space, explore, evaluate, and document alternative options and collect feedback from a wider range of community participants. This feature is what has effectively supplemented the existing map walk methodology.

Furthermore, this research provides scope for future research to explore greater complexity of features, including those that facilitate more advanced collection and storage of data digitally and to the cloud, as well as those that add to the depth and quality of user experience. Additionally, the potential of Augmented Reality (AR) as an alternative digital medium was considered and has promises to be explored, with future research comparing the effectiveness of both VR and AR for use in user feedback-led development of community projects, taking into consideration metrics such as capturing emotional and cognitive responses, as well as gauging ease of use and the level of user comprehension and engagement. The application of VR to garden design could also be extended into the design of public urban spaces. The expansion of VR (and also AR) for niche social applications is an area for further investigation to help enable people to contribute to participatory design processes (similar to garden/urban walks, museum virtual exhibitions, etc.) with an aim to encourage and/or facilitate the inclusion of disabled, less-abled and neurodiverse individuals' participation in society.

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