Enhancing User Experience through VR: Case of an Urban Agriculture Participatory Design Experiment

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Abstract

Virtual Reality has shown great potential when applied to the AEC industry. There are some less researched areas where VR can prove effective; among those are enhancing user experience and improving stakeholder participation. User participation in co-design of public and semi-public spaces has been advocated as a means to ensure wider community engagement and better project success. A series of different methodologies have been used to study urban agriculture. There is limited evidence of the application of VR to promote design participation in community projects and urban agriculture. With a wide range of proven capabilities and benefits, VR seems to be the next logical step to further progress community research for urban agriculture. This paper uses game engines to develop a Virtual Interaction Environment (VIE) to facilitate participation in urban agriculture beyond the existing boundaries of established methods. A critical review of literature was carried out to set the boundaries of this research, investigate the principles of participatory design and the user experience. The findings of the literature were used in combination with the outcomes of a "Map Walk" workshop with community participants to define a set of design variables to be incorporated in the design of the VR instrument for urban agriculture projects. The process of collecting the data in Map Walk, the development process of the VR experiment (the Alpha Build), the feedback loop from the VR experiment first run, the data verification and second stage of the VR experiment development (the Beta Build) and the second feedback loop are explained in this paper. The paper concludes with directions for future development in this area and for the use of VR in participatory community projects.

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

1. Introduction
Research on user experience through VR is well established. Community projects have benefited from an extended attention over the recent years. Urban agriculture has a long history which dates back to early human settlements. Analogue methodologies have been developed to systematically review, document, and utilize non-expert participants' input in community projects. There is however, a substantial gap in application of VR technologies in this area.

This study was funded through a Research England participatory research fund to investigate the role VR can play in enhancing the participants' experience in community garden projects. The research built upon an existing analogue methodology known as "Map Walk"[1] developed by researchers in University of Brighton back in 2014 and used for community urban garden projects to investigate what new and advanced technologies - in this case VR technologies - can offer to such projects. A three-staged qualitative research plan was developed to observe and comprehend the analogue methodology and to best develop an exclusive digital solution based on VR technologies to complement what was otherwise difficult if not impossible to achieve through analogue methodology. The design of this study, its development process and some of the preliminary findings of it have been explained in a separate paper

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[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.

in this conference. Detailed data collection and more in-depth qualitative text analysis of the user data during the analogue walk and two stages of the digital walks will be presented separately later on.

This paper concentrates on the development process of the novel research instrument developed specifically for this study based on the study of existing methodology and feedback received from the research participants. The research instrument was designed as an VR technology interactive digital walk through selected urban sites in Brighton city center, in South East UK. The development of the digital research instrument benefited from a two-stage development process known as the Alpha and the Beta Builds. The experiment was designed to help fulfill some of the objectives which were set out in this study including: 1) to develop an custom-built, customizable, easy-to-use, useful and flexible research instrument to facilitate co-participation; 2) to verify the instrument through user perception and attitudes towards the use of VR technology; 3) to establish areas for improvement; 4) to improve the VR experiment, rerun the user experience.

In addition to the above objectives of this study, this paper will also partially contribute to the last objective of the study that is: 5) to highlight the contribution and lay the foundation for future research in this area.

We start with a summary of the critical literature review to be used in conjunction with the goals set out to be achieved through the analogue map walks and the needs, wants and expectations of the participants which were collected through a focus group after the map walk experience to best devise the VR walks. It was deemed of paramount importance to keep the flexibility of what could have been offered through the Virtual Walks at maximum to be able to attend to the widest range of expectations expressed by the participants. Therefore, a generic game engine, although imposing a higher level of challenge, was the preferred route as opposed to an off-the-shelf application which would have been much easier to utilize but would have put more limitations on the width, breadth and depth of what could have been offered. An additional challenge was that many if not all of the research informants were from a background with very limited experience in VR beyond some limited gaming experience and most with no experience of or expertise in the Built Environment. Many of the participants however had some level of prior exposure to community or participatory projects which proved to be extremely helpful in the process of development of this study.

The Unity game engine was the engine of choice for its most relevant and direct benefits to this study above all the interface with GitHub which facilitated collaboration between developers in the development process of the virtual walks.

This paper will explain the development process of the VR experiment for virtual urban walks in depth with a special focus on the feeding back and forward process between the participants' attitudes towards and perceptions of VR and how those collected feedbacks were used to develop and subsequently to enhance the VR experiment during the two-staged process of development.

2. Literature Review
2.1 Urban Agriculture
Urban agriculture was mainly addressing Africa, Asia, and Latin America – the Global South – when first utilized by the UNDP in 1996 (Smit et al., 1996). Ever since, it has permeated into developed economies such as the United States (Balmer et al., 2005, McClintock, 2008), the United Kingdom (Viljoen et al., 2005, Cullen, 2008, Tomkins, 2014), Canada (Kaethler, 2006), Switzerland (Jahrl et al., 2021), France and Germany (Kirby et al., 2021, Pölling et al., 2016) and Japan (Yuan et al., 2022). Motivations for, and social impacts of different types of urban agriculture have been studied using case studies in Europe and the States and Europe (Kirby et al., 2021). Jahrl et al. (2021) have used Knoepfel et al.'s Political-administrative programme (PAP) (2007) to analyze city policies on food gardening with reference to urban sustainability.

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). Nonetheless, agricultural activities in cities are as old as human settlements (Reculeau, 2017). Agricultural activities have swayed back and forth between inner-city spaces and city fringes and suburbia as a result of industrialization (Steel, 2013) and revival of urban horticulture (Appel and Spitthöver, 2011, Keshavarz et al., 2016).

Referring to the works of Dubová and Macháč (2019), Olivier and Heinecken (2017), Reynolds and Cohen (2016), Kirby et al. (2021) argue that food production in urban spaces offer four social benefits namely health and wellbeing, economic opportunities, social cohesion, and education. While working classes have used it as a way of enhancing food security, the upper classes turned to it as a means of self-realization, expression of individuality and/or

a healthy lifestyle (Appel and Spitthöver, 2011). CPULs (Continuous Productive Urban Landscapes) have been proposed as an environment "productive in economical, sociological and environmental terms" (Viljoen et al., 2005). The value of urban agriculture is believed to extend beyond mere profitability and include social, health and well-being, disaster risk reduction, and other environmental perspectives (Yuan et al., 2022). Kettle (2014) have looked into motivations for investing in allotment gardening in city of Dublin and community gardening has been studied as a means of place-making in social housing (Truong et al., 2022).

2.2 User Participation and VR User Experience

Virtual environments can be alternatives to real environments for user experience studies, when a high presence is achieved (Busch et al., 2014). User experience is a determining factor in user participation for XR (eXtended Reality) technologies. User experience in immersive environments has been measured through different aspects or concepts directly or indirectly associated with it including engagement (Boyle et al., 2012) which, in a web application context, consists of cognitive, emotional and behavioral engagement according to Attfield et al. (2011), presence (Hein et al., 2018, Cummings and Bailenson, 2016) defined as "the propensity of people to respond to virtually generated sensory data as if they were real" (Slater et al., 2009, p.194), and enjoyment (Dey et al., 2018). It has been suggested that although VR and AR user experience research has recently benefited from an ever-growing level of attention, a direct comparison between different immersive technologies' user experiences is few and far between (Verhulst et al., 2021). Researchers who have carried out comparative studies between AR and VR in the AEC industry have suggested that 3D modeling is not a complication which can easily be ignored or avoided, VR can facilitate an earlier detection of problems at design stages (significantly more than AR can do), VR is capable of reducing the reliance on cognitive functions for the tasks (again significantly more than AR can do), and recorded higher level of feeling dizziness and motion sickness in VR than AR while AR was reported less fit-for-purpose than VR in their then state of development (Piroozfar et al., 2017).

3. Research Design and Methodology

This paper focuses on the development of the research instrument which was used for data collection and analysis in two stages of a study carried out to gauge the community stakeholder groups' perception of, and attitudes towards, the use of VR technology for urban agriculture community projects. The design of the study and preliminary findings have been presented in a separate paper.

The development of the VR-technology research instrument was carried out following an in-depth literature review of urban agriculture, user participation and VR user experience, VR for participatory design and map walks for urban agriculture. We used the map walk methodology developed by Tomkins et al. (2014) and applied to several projects before, to walk the participants in the center of City of Brighton and Hove, in South East England, UK to visit a series of potential sites for urban community gardening, to discuss possibilities, potentials and restrictions around those sites and listen to concerns of different stakeholder groups' representatives who participated in the walk. This followed by a focus group discussion in the Community Kitchen Center in Brighton. The participants (N=16) were divided into smaller groups of 4-5 and participated in a semi-structured discussion. Each group was led by a member of the research team. The findings were collected and together with the findings of the literature review and in consultation with the Map Walk team were used to develop the main research instrument of this study in the form of a VR experiment, developed exclusively for this study using Unity game engine. The development of VR was conducted in two stages each followed by a data collection/analysis exercise; these are called the Alpha Build and the Beta Build. The Alpha Build was used as a testbed whose data collection/analysis outcomes were utilized for verification and improvement of the application and to develop the Beta Build. Together with the in-depth qualitative analysis of the participants' feedback in all three stages of this study, the final prototype of the VR application will be used to further develop research applications to investigate areas that were pointed out by participants in different stages of this study. This paper explains, in detail, the process of the development and improvement of this application during the Alpha and Beta Build stages.

4. VR Experiment Development (Alpha Build)

4.1. Spawn in place

In order to allow users to visualize the elements of urban agriculture in context of the given environment, a 'spawn in place' system was developed. This system allowed users to add and remove urban agriculture elements during runtime. In order to enable this, two distinct tools were developed, a spawn tool and a delete tool. The spawn tool was separated into three statuses; inactive, active and placeable, and active and unplaceable. When inactive, the tool was simply disabled, meaning that the tool neither rendered or functioned when an input was passed. This status was controlled via the UI menu, whereas the tool only became active when the spawn object menu was also active. The spawn tool

utilized raycasting, in which a ray would shoot from the user's controller to the colliders within the virtual environment. At the point that the raycast hits the 'Ground' collider, a hologram reticle was presented, acting as a visual cue for the participant to understand the rotation and proportions of the object they are spawning. In order to determine the status of placeable/unplaceable, the collider attached to the hologram was utilized to detect when this may be clashing with other objects within the scene. In the case that the hologram collides with a pre-existing object, the spawn tool would render red and any input passed would not invoke the spawn method. Once clear of the object, this would render green and the spawn method can be invoked when an input is passed. The spawn in place tool also needed functionality to be able to remove elements currently in the scene. Utilizing similar principles derived from the spawn tool, raycasting was employed to detect collisions with spawned object colliders. In the instance that a collision is detected and an input passed, a delete method would run, utilizing Unity's built in 'Destroy()' function. This however did not work as expected; the 'destroy' function required a transform (XYZ Position) to be passed in order to find the object to remove. However, as colliders would operate on local positions as opposed to world positions, the delete method returned a transform at identity (0,0,0). Subsequently, when one object was 'deleted', all objects from the scene were removed at the same time, as they all shared the same local position. To overcome this issue, the raycast instead detected the collision before iterating through a list of the currently spawned objects using the Unity 'FindWithTag()' function, allowing the tool to determine the correct object to delete. This was not ideal for the application as the function consumes a great deal of performance, however due to the limited number of objects that would feasibly spawn in the scene, this was opted for as an immediate solution.

4.2. OSM Modelling
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. Lighting & Baking
During the development of the alpha build, focus was placed on achieving the correct shape and form of the 3D models, and subsequently the lighting was implemented towards the end of the build. In turn, some visual artifacts created by poor UV map exports from Sketchup meant that many of the objects were patchy, with significant color bleeding. Due to the timescales for this build, this was not corrected in time, however, it was important to include these artifacts during the feedback stage so that they could be highlighted and addressed.

4.4. Audio
Pre-recorded audio sound effect files were obtained and modified using audio editing software (Adobe Audition etc.) to achieve the desired effect. Inside the Unity game engine, these sounds are delivered through an 'Audio Source', to be applied for diegetic or non-diegetic purposes. This would be determined by how the audio is enabled and the variables applied. Diegetic audio was implemented through a location (world position) based approach, whereby 'loop' and 'on awake' variables ensure the audio remained a constant from the beginning of the scene - these included sounds such as bird, car and wind noises. Non-diegetic audio was implemented through a trigger-based mechanism within the user interface. These included short duration sound effects in response to user input (i.e. User Interface buttons).

4.5. LiDAR
During development a mobile phone with LiDAR camera with scanning applications were used to obtain point-cloud information of the associated real-world spaces. This information could then be exported into various point cloud formats (e.g. .PLY) and imported into 3D modeling software (SketchUp, Blender etc.). The large file sizes associated with point-cloud scans are not suitable for use in VR development environments due to computing load. As such, the scanned point-cloud was used as reference for modeling, as opposed to direct use, and exported to Unity game engine.

4.6. Locomotion and Scene Transitions
There was a need to develop a VR-based input system for locomotion to allow user navigation around 3D scenes. In particular, it was decided that teleportation-based locomotion (non-continuous motion) would be implemented rather than motion-based or any other type of locomotion, so as to avoid motion sickness and better ease of use. Locomotion capability was initiated through use of Unity's XR Interaction Toolkit which supports OpenXR controller input (for

wider compatibility across headsets). This provided the framework for interaction via components to build the locomotion system. Locomotion was built through the following: An 'XR Origin' representing the user's position within the 3D space; A Locomotion System script which controls access to the XR Origin (i.e. which Locomotion Provider controls the rig); And Locomotion Providers which physically move the XR Origin and consist of: Teleportation Provider, Snap Turn Provider, Continuous Turn Provider, Continuous Move Provider. As previously mentioned, continuous forms of movement were excluded from this application. The system was implemented by first setting up the XR Origin and applying input actions (via the Input Action Manager) to the headset controls, the default XRI Input Actions were used as these serve a good universal standard across headset controls. A Locomotion System and Teleportation Provider were added to the XR Origin component, along with a Snap Turn Provider with controller bindings set to left and right hand movements. To provide teleportation functionality, Teleportation Areas were set up to serve as collider planes for the XR Ray Interactor, of which is assigned to Left and Right Hand Controller game objects. The resulting line from the raycast was modified for aesthetic purposes by adding a 'XR Interactor Line Visual', allowing variables to adjust appearance and behavior. This also required the 'Line Renderer' component to function. Regarding scene transitions, a scene loader script was created which utilized 'on click' event commands linked with user interface buttons, the event tells the application to load a particular scene, the result of which would be that the user could navigate to different scenes once a UI button has been activated (pressed).

4.7. Modeling and UV Mapping

The process for developing 3D models, where not using pre-constructed assets, was done so within both SketchUp and Blender, the decision of which to use depending on the modeling requirements. Simpler 3D models were created within SketchUp which allows for rapid creation of flat-surfaced geometry such as buildings, furniture and some landscapes which do not require the level of detail of more complex objects which are otherwise best created within Blender; in some cases SketchUp objects were exported to blender to add further complexity and for UV mapping. Conversely, Blender offers advanced modeling tools, such as subdivision surfaces, NURBS, curve tools, Boolean operations, as well as custom shaders, materials and functionality.

4.8. User Interface

The UI system developed included elements such as buttons, text fields, drop-down menus, sliders, and other interactive elements allowing the user to interact with the software via activation of scripts or game engine components. These elements were hosted on UI pages, or 'Canvas' component, and triggered via VR control input with the left trigger button. UI pages were grouped under a parent 'menu' and, for ease-of-use and accessibility, tied to the left-hand control mechanism. The style of the UI design followed principles of skeuomorphism and was intended to reflect that of a binder, whereby information is contained within tabulated containers sorted by category.

5. Experiment Feedback (Alpha Build)

5.1. Spawn in place

The feedback received from the spawn in place system tended to focus on the rigidity and linearity of the spawning system. Comments were particularly related to polytunnels and planters, suggesting that these should be able to snap together and offer different module styles, including instances that can be stretched/extended. As well as snapping object to object, the participants also proposed that the objects snap to a fixed world grid, allowing for better space planning while also providing a clear visual indication of where the objects could be spawned. To address the principles of urban agriculture, participants also suggested that the tool be developed further to be able to spawn different types of plants/vegetation within the spawnable planters/polytunnels, as well as single entities on the ground. Furthermore, if the user was able to design their own spawnable objects before placing them, this allowed for a deeper level of communication and ideas can be shared more forthcomingly. Participants provided little feedback on the delete tool, suggesting that this was robust in fulfilling its purpose, however, users did enquire as to whether the delete tool could be used to remove elements already in the environment such as paths and buildings, otherwise referred to as terrain editing.

5.2. OSM Model

The feedback received on the 3D city model stemmed from providing geo-referenced context. Participants felt that the city model provided little context to streets, landmark features, orientation and site location when viewed in isolation, i.e. separate from the map presented digitally behind it. Users suggested highlighting features using tags/colors to be able to derive context to the site. In contrast to this, participants expressed that the city model helped provide a macro view of the project and helped guide them into the experience. This was also true of the 1:50 model (not developed using OSM).

5.3. Drawing Tool

Following the demonstration of the alpha build, users had expressed the need to develop their own 3D objects, alluding to different sizes of the currently implemented objects as well as further object types, such as plants and trees. Users also wished to manipulate the existing site, such as changing site levels. Due to time and feasible UI limitations, an interim solution was developed to address this concern. The solution formed two approaches. Firstly, additional items were added to the 'place object' list and of these additional items, some took form of varying sizes of already implemented objects. Secondly, a drawing tool that allowed users to sketch in 3D space was implemented.

5.4. Lighting & Baking
Users found concern with the visual artifacts created by the baked lighting, as anticipated during the build phase. Users also highlighted that the location of the sun was incorrect in context of the site; calling attention to its incorrect northerly position. Subsequently, further discussion into the sun's position suggested that a dynamic sun path would be beneficial, proposing that the ability to transpose the position of the sun in VR provides a benefit that the original map walk could not. Users addressed that visual elements such as shadows are greatly important in advising where plants and urban agriculture elements should be placed, due to principles such as frost pockets.

5.5. Audio
Feedback and testing revealed that some sounds needed tweaking/improvement/optimization, for example, due to delayed or inconsistent sounds. It was also identified that the spawn object function repeated

5.6. Locomotion and Scene Transitions
Following the first round of feedback, some limitations and difficulties were highlighted in regards to the locomotion system. As discussed, users suggested the following - The locomotion system needed to contain a 'step back' function, to accommodate for ease of use, allowing the user to back out of areas that are challenging to navigate. - "I preferred to walk through the site instead" - Many users found it difficult to learn the controls for moving around in VR, suggesting that some form of tutorial, interactive or otherwise, might assist learning. Users also commented that it would be good to be able to change the elevation (height) of the user to be able to see the site in its entirety from above (bird's eye perspective).

5.7. Modeling and UV Mapping
Due to time constraints, UV mapping was not carried out on objects during the first development build. Consequently, this resulted in a lack of consistency across models in regards to color, lighting, and shadows; a deficiency which was frequently highlighted by feedback from users, with the general consensus being that improvement was needed to create a more realistic and immersive experience. Feedback also commented that environmental details were missing and could be added "There's a lot of iconic street art not captured in the scene". It was also discussed that there was a lack of social spaces, and that social spaces could be integrated into the layout in addition to gardening elements.

5.8. User Interface
Feedback commented that wayfinding needed to be improved to better understand relative position for the setting of the site, in particular in regards to the introductory scene and 3D map…"Where is the station, beach, and where am I now?". This could be addressed via UI text elements placed on the site to provide context to the user.

6. VR Experiment Development (Beta Build)
6.1. Spawn in Place
Due to the timescale of the project, redeveloping the spawn in place system to incorporate the ability to snap to an in game grid was not feasible, thereby in order to address these participant comments, certain refinements were made to the objects and the pre-existing spawn in place system. Additional sizes of planters were introduced to address the varying types of modules, allowing for greater variety while maintaining a limit on options for the sizes available. Subsequently, the fixed 45 degree rotations were reconfigured to be adjustable within the UI menu, down to increments of 11.25 degrees (1/8th of 90 degrees); providing a greater degree of accuracy with their rotational position. Similarly, due to timescales of the project, providing a custom mesh builder and a terrain editing tool was also not possible. In order to address the ability to spawn plants/vegetation and custom objects, a drawing tool was implemented so that the participant could overlay their imaginations in 3D onto the polytunnels/planters/ground. This also helped keep the spawn in place menu short without significantly overwhelming the user with choices. Finally, to aid the conversation regarding objects currently within the scene, an options menu was developed to be able to load pre-configured layouts so that participants could edit/amend as required.

6.2. OSM Modelling
Continuing from the feedback obtained from the alpha build, some alterations were made to the 3D city model. Tags were added onto the model to highlight key landmarks, providing context to the site. The tags utilized the design

principles of 'billboarding' whereas the text would always face the in-game camera so that the participant could view the model from any angle and be able to understand the context. In addition, blender OSM was revisited to import a texture overlay onto the terrain. The previous model, which used lines to denote roads, gave little context to green areas and bodies of water. By implementing an open street map texture overlay, roads were clearly denoted as well as their corresponding names, and additionally, greenscape and bluescape were presented clearly which aided in the conversation surrounding urban agriculture.

6.3. Drawing Tool

The drawing tool utilized the tracking of the VR controllers to allow users to draw in the 3D environment. Much of this tracking data has been processed and made easily accessible using Unity's XR Toolkit. Using this data, two additional events were created; "Started()" and "Canceled()". Simply, these events are invoked when the trigger is pressed and the trigger is released respectively. When "Started", the following methods are executed. Firstly, the user interface menu is hidden so that the user can see what they are drawing. Secondly, a new 'line renderer' object is instantiated at the current position of the controller, this line renderer object is spawned with a numerical suffix to allow differentiation between the line objects. Beyond this, a loop is triggered so that a new point of the line renderer is added each frame, meaning that as the controller moves, the new position of the controller is added to the points list of the line renderer. When "Canceled", the loop is set to false so that the drawing mechanics do not continue to run. In addition, the UI menu reappears to allow the selection of other menus. Lastly, a box collider is formed around the extends of the newly created line so that the delete cool can register the collisions to allow the user to remove any drawing they have done. When tested, it was found that the original method of raycasting to delete objects meant that hitting the line object was very challenging, especially at a distance. To aid in the deletion of these drawings, the delete tool utilized 'spherecasting', utilizing similar principles to raycasting with the added benefit of capturing a larger scope of objects; returning the closest object to the user as the collision.

6.4. Lighting & Baking

In order to correct the visual artifacts created by the poor UV map exports, the models were re-mapped using Blender. Once remapped, these were reimported into Unity and re-baked. The lighting settings were altered to account for the implementation of dynamic lighting; 'Baked Indirect' lighting was utilized so that building depth was captured while allowing the direct lighting to move within the scene. In order to implement the sun path, data was taken from open source online tools to obtain the azimuth and altitude at certain points of the day during a specific time of the year. For this application, the position of the sun was captured every two hours from 6am to 6pm. This data was implemented onto the scene direct lighting object and made adjustable using a slider within the UI menu.

6.5. Audio

During the 2nd stage of development, sound performance was improved, including trigger-enabled sounds, such as the spawn object functionality. To reduce audio overlap caused by the spawn in place function, the frequency of the 'on-trigger' variable activation was reduced.

6.6. MiniMap

In feedback stage one, the need for a real-time bird's-eye perspective was highlighted. This led to the development of a Minimap system. This was created through implementing another scene camera and displaying it as a UI element that the user could enable on demand. Another camera was set up and applied to the XR Origin so that it would follow the position of the user. The view aspect was set directly above the player and angled down in bird's eye perspective, with the projection set to 'orthographic' to create a 2D view with no perspective. A new UI element, a 'Raw Image' was created which serves as a host that the camera image can be rendered onto as a texture rather than a sprite - as is typical with UI elements - and was applied under the UI controls of the left hand controller, to show up on activation. A Render Texture was created for this purpose to serve as the texture input on the Raw Image, the Render Texture is then applied as the output texture of the camera. The player's position relative to the surroundings would be difficult to see on the map, as only two controllers make up the 3D physical representation of the player, as such a large red sphere object was used and bound to the player's origin to better indicate this. The sphere was set to only be visible on the 2D Minimap display so as not to interfere with the main user viewport.

6.7. 360 Photograph Walkthrough

In response to feedback from participants after development stage 1, it was suggested that it would be beneficial to be able to conduct a map walk virtually, for those who cannot attend physically or as a reminder for participants. As such, a walkthrough tour was created using 360-degree photos. The process was carried out within Unity, whereby captured 360 photos were imported as textures and 'Cube' shape applied, turning the image into a cubemap, which is necessary to create a skybox later on. A new material is then created utilizing the texture and 'Cubemap' type shader applied

which can be allocated as a 'Skybox' overlay to the VR camera. Several scenes were set up, each with their own skybox (360 image) and navigation between which was handled using the aforementioned scene loading, here applied to user interface elements on an information stand (3d model).

6.8. Locomotion and Scene Transitions
It was decided that a 'step back' function not be added to the controller functions as it would have made the controls too complicated for the users with an already extensive list of controls and functionality. Instead a UI-based explanatory tutorial was added to explain controls. Due to limitations with time, the interactive tutorial aspect was not investigated. Following testing of the elevation change functionality, it was decided that this be handled differently due to the potential exposure of the model boundary, as well as the potential loss of scale/proportions at ground level. Instead the Minimap approach was implemented to resolve this concern.

6.9. Modeling and UV Mapping
To address stage 1 feedback. all items were UV mapped in Blender before being exported to Unity. The surface faces of the 3D object are "unwrapped" and aligned with an assigned texture along defined edges to create a "seamless" look across separate surfaces. In turn, this allowed the baked lightmap textures to render correctly on the 3D objects within the scene.
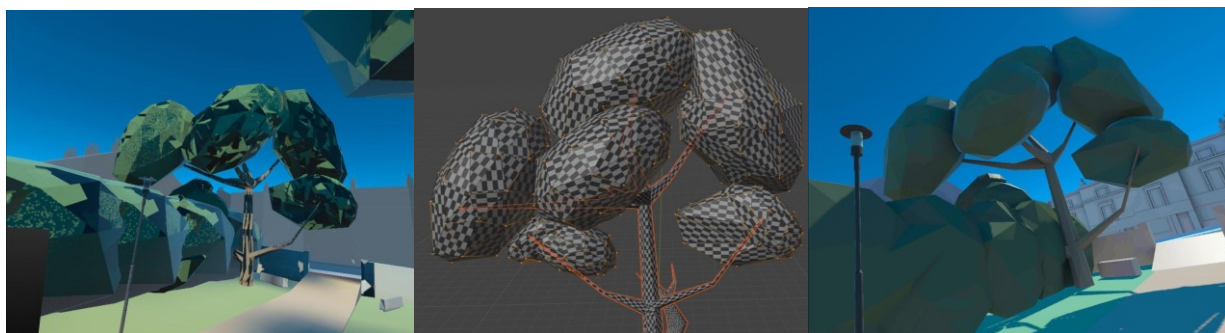
Figures 1: a) Tree model with texture & lighting issues; b)UV map scaling check; c) Post mapping & re-lighting

6.10. User Interface
In addressing lack of wayfinding, 'Billboard' UI text was attached to key locations on the 3D map. The billboard effect is applied to text within Unity by rotating the text object so that its forward direction always points towards the camera, this is achieved through scripting or built-in components such as the Billboard Renderer. This made it useful for indicating or labeling items, creating head-up displays (HUDs), speech bubbles, and other types of on-screen text that should always be visible to the player.

7. Experiment Feedback (Beta Build)
7.1. Spawn in Place
Following the presentation of the beta build, the feedback reflected similar themes to the previously obtained feedback from the alpha build. Participants suggested that having a grid/snap system was very desirable and perhaps should have taken a greater priority in the development. Furthermore, the participants went on to discuss expanding this grid to vertical planes, introducing the principles of vertical urban agriculture. Additionally, by having pre-existing objects within the scene, participants provided comments on developing an 'edit' tool, albeit neither a spawn or delete tool, but the ability to manipulate existing objects in place, be that position or rotation. Lastly, some users felt that icons were not representative of what was being spawned and would have preferred 3D representations of these spawnable objects rather than a 2D icon.

7.2. OSM Modelling
The participant comments on the beta build came across as promising, with many suggesting that the billboarding text applied to the 3D city model helped provide a lot of context to what they were visualizing and they could easily navigate to the site in question. In light of this, little feedback was suggested for the city model, suggesting that this was developed to a suitable level of detail. Despite this, when in the 1:1 model, some participants alluded to providing context for the site utilities, whereby water and other underground assets could be used for the purposes of urban agriculture. Previous research has suggested that despite local authorities making their utility data more accessible, there is still a lack of digital formats (Piroozfar et al., 2019) thereby making this difficult to implement into such a model.

7.3. Drawing Tool

The feedback obtained from the drawing tool was generally positive and users found that they were able to communicate their intentions better with a drawing tool implemented. Some responses suggested that the indication that the drawing would originate from the controller was unclear, and that this should be made more obvious, perhaps by means of a visual tutorial or larger more prominent indicator. Some participants also suggested having the tool project onto 2D horizontal and vertical surfaces, similar to how a spray can would work. This would allow users to highlight boundaries and compartmentalize the site to aid in the discussion into urban agriculture. Following this suggestion, it was also highlighted that with different zones, different colors would be required to help differentiate the drawings created.

7.4. Lighting & Baking

Following the updates to the Alpha build, users resonated with the newly implemented sun path, suggesting that further times/positions of the sun could be added to hone in on shadow positions. Users also suggested that pre-defining frost pockets with zones/areas may be easier to interpret than adjusting the position of the sun. Users also suggested that the baking had been improved since the last build, making it feel less 'glitchy'.

7.5. Audio

The final feedback stage suggested that adaptive audio could improve realism and immersion whereby audio responds intelligently to user action. A single beehive, for instance, would sound different from a group of six beehives and not necessarily six times the volume of a single beehive. This approach might also avoid audible feedback loops that result in intense, confusing and unrealistic sounds

7.6. MiniMap

Following feedback and in addition to the added sun positioning feature, users suggested that having a compass would have been essential for understanding and orienting oneself in relation to the north. Furthermore, to be sure that they were planting and orienting their plants in the correct direction to ensure optimal growth, a feature that would be valuable to gardening.

7.7. 360 Photograph Walkthrough

Feedback discussed that the photos gave a sense of scale, particularly due to having people in the photos. Suggesting that human scale should be implemented within the digitally created VR scene also.

Figures 2 a): Sun positioning; b) Minimap & upper perspective; c) OSM model & billboard text; d) Drawing tool

7.8. Locomotion and Scene Transitions

After a second round of feedback, the 360 walkthrough scene was added which also comprised use of the scene loader to enable transition between each of the various 360 degree photos as part of the walkthrough scene.

7.9. Modeling and UV Mapping

The final round of feedback discussed the idea of including 360 photos with people, for scale reference, inside the 3D constructed scenes as well. The gardening site scene was noted as somewhat repetitive, further development might seek to add variation. Additionally, for the spawn feature, a method of vertical spawning could be provided - not only on the ground plane - so that elements such as climbing walls and green walls can be included.

8. Concluding Comments and Future Research

This research focused on the development process of a Virtual Reality (VR) experiment, which was driven largely by feedback from community stakeholder groups. This paper outlines the Alpha and Beta development phases, as well as the 1st and 2nd rounds of participant feedback. It details the process and improvements made to the VR application.

While developing, emphasis was placed on using predominantly free or open source tools, rather than "off-the-shelf" solutions and software. A cost-effective alternative to proprietary software, this strategy also encouraged customization and collaboration - Github enabled developers to collaborate. Unity game engine enabled a high degree of customization and, while more challenging than some off-the-shelf VR solutions, proved advantageous due to the greater level of flexibility that met the requirements of this research design. Similarly, the utilization of OpenXR standard significantly reduced development time, eliminated compatibility issues, improved user experience and performance reliability.

Through investigation of the areas discussed by participants in different stages of this study, and in particular that of the beta phase of development, the research can be further developed with continued development of the application. Feedback suggested that various modalities and optimizations could be implemented to improve the spawn in place system, particularly with regards to the 'snapping' functionality. Additionally, it was suggested that a 'world' grid system be developed to aid with space planning, allowing the placement function to be guided for ease-of-use.

Participants also advocated for more customizability regarding the spawnable 3D objects, expressing that the ability to manipulate and transform the pre-defined metrics of the objects would be constructive. This was partly resolved through inclusion of the drawing tool which provided a 'sandbox'-type, or open-ended, creativity tool.

Several potential routes for development became apparent through the development stage were not highlighted by user participants, which was due in some part to being concerned more with back-end than front-end software (i.e. the functionality or data management of the application as opposed to that of user-facing). More advanced methods for data collection could be utilized, such as logging and storing user inputs digitally (hard drive or cloud-based) to be analyzed at a later point, and for example, facilitated through inclusion of metadata to enable description, assessment and management of the data to take place.

Another consideration not discussed by participants but considered important by the developers is the development of an augmented reality (AR) application alongside a VR counterpart. This could enable the user to interact with their environment more effectively, as well as providing an additional layer of immersion. A test run and pilot study could be run in the same regards as has been carried out with this research for VR.

On the way towards an extended study and further research there is scope for extension towards other urban spaces each perhaps presenting their own obstacles and possibilities. Although many of the above-mentioned areas were concentrated and improved during the several rounds of iteration for application development in this study, there is still more work to be done in those areas, which will set the target for future research in many of those areas.

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