VR Panoramas

Visualizing urban context using 360° spherical images

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VR photography is the interactive viewing of panoramic photographs using a 360° spherical view. This paper focuses on the use of VR photographs of the urban environment to improve spatial understanding. These photographs can be embedded into a modelling environment as a set of VR panorama hotspots. When users navigate to one of these hotspots, they are able to see how their proposed building or structure relates to the visually detailed view of the urban context. The proposed approach has been implemented in a parametric modelling application called Möbius Modeller. To demonstrate the power of immersive VR, a series of example models are presented that include VR panorama hotspots.

Keywords: *Virtual Reality, Urban Modelling, Urban Context, 360° Spherical Images.*

INTRODUCTION

Over the last 25 years, researchers have been investigating how immersive Virtual Reality (VR) might be applied in architecture and urban planning. This research focuses on leveraging immersive VR for designing buildings within their surrounding context. More specifically, the research explores how immersive VR experiences can be embedded into parametric modelling design tools.

Architectural and urban designers often have difficulty in visualizing how the buildings and structures they design will fit into the urban context. Most designers work with 3D digital modelling tools that allow 3D models to be visualized form various perspectives (also referred to as non-immersive VR). Usually, a birds-eye view will be used. However, these approaches make it difficult to understand the space from the point of view of a person that is inside the space. Spatial depth cues and peripheral vision are critical aspects that are missing. In addition, the typical geometric models tend to be highly simplified, resulting in an impoverished experience. Immersive VR using Head-Mounted Displays (HMDs) can be highly effective in helping designers to better understand the architectural and urban spaces they design.

El Araby (2002) has reviewed the potential of VR in urban design, highlighting the potential of VR to evaluate proposed urban projects and designs. Schnabel (2004) focuses on how VR can improve spatial understanding. Ghani et al (2018) have identified six key elements required for creating an effective VR experience for architectural and urban models: 1) contextual setting, 2) interactivity, 3) navigation, 4) level of detail (LOD), 5) viewpoints, and 6) auditory environment. Kim and Kim (2019) use VR as a way of evaluating urban spaces, exploring the ratio of the depth-to-height of virtual models of urban spaces. Globa et al. (2019) propose the idea of “Sensory Urbansim”, and explore the integration of 360°degree images, 360°degree videos, and audio tracks into the VR experience, in order to give the viewer a richer sense of place.

This paper reports on the integration of a VR viewer into a parametric modelling tool called Möbius Modeller (Janssen et al., 2016, *Möbius Modeller*, n.d.). Möbius Modeller is being used as a pedagogical platform for teaching Spatial Computational Thinking. In the course, learners write computational procedures that generate 3D model. The VR viewer allows students to explore and evaluate these models using immersive VR. The aim of the research is to develop a simple low-cost way of improving spatial understanding. The aim is not to create highly realistic models or advanced virtual reality experiences. The effort required to develop the VR model should therefore be minimal.

This paper focuses on a specific feature: the inclusion VR photographs of the urban environment into the VR environment. These photographs can be embedded into the 3D modelling environment as a set of VR panorama hotspots. The user is then able to visualize their proposed buildings or structures within the urban context. The advantage of this approach is that, on the one hand it requires no additional modelling effort, while on the other hand it can generate a rich visual experience. When users enter one of these hotspots, they are able to clearly see how their proposed building or structure relates to the visually detailed view of the urban context.

We argue that the inclusion VR panorama hotspots into the VR environment is able to improve spatial understanding. To demonstrate the power of immersive VR, a series of example models are presented that include VR panorama hotspots.

VR PANORAMA HOTSPOTS

VR environments allow users to move around a 3D model using a first person point-of-view (POV). For this research, we are focusing mainly on desktop VR environments, where the user is seated at a desk. The user may either view the model through the computer screen, or they may use a HMD. With the latter, the user gets a more immersive experience, with the movement of the head being automatically translated to the rotation of the camera in the virtual environment.

Various types of navigation are typically supported. Two common approaches are walking and teleporting. Walking allows the user to move around the model, with an automatic application of gravity pulling the user down onto the ground plane. Teleporting allows the user to jump to different locations in the model.

VR panorama hotspot are points in the 3D model linked to VR photographs of the urban environment. Within a VR environment, the user can navigate to these hotspots, either by walking or teleporting. Once they arrive at the hotspot, the VR photographs are loaded, allowing the user to visualize the 3D model within the urban context.

VR Photographs

VR photography is the interactive viewing of panoramic photographs, encompassing a 360° spherical view. The images are typically unwrapped into a standard rectangular image, where the top and bottom areas of the image are stretched. Figure 1 shows such an image of an urban context.

Figure 1
A VR Photograph, unwrapped into a rectangular image

Various technologies exist for creating these images. Cameras with fish-eye lenses or glass optics mounted on the lenses can capture spherical images as a single photograph. Setups with multiple lenses can be used to capture multiple images that are then stitched together to form full 360° spherical images. In addition, apps for mobile phones exist that allow multiple overlapping images to be taken that are then automatically stitched together by the app. An example is the Google Street View app (Google Street View App, n.d.).

Finally, another source of VR photographs are platforms such as Google Street View. These images are mostly taken by cars with specialized cameras mounted on the roof. Various tools exist for downloading such images. For example, Street View Download 360 (Street View Download 360, n.d.) is a user-friendly tool for downloading images from Google Street View.

Foreground and Background Images

When embedding a VR photograph inside a 3D model, the objects in the photograph may be either in front of the model or behind the model. As a result, in order to create the correct optical effect, each panorama hotspot will require two images: a foreground image and a background image.

These images form two spheres, centred on the camera location. The 3D model can then be placed in the space between these two spheres. Figure 2 shows a diagram of the setup.

The two images are identical, except for the fact that the foreground image is edited to make certain areas transparent where the 3D model will appear. The background image will be completely opaque. For the example that follows, Figure 1 is the background image and Figure 3 is the foreground image.

Figure 3 shows the same image as in Figure 1, except that the black area in the centre of the image is transparent. This area is where the 3D model will be visible.

The foreground sphere has a small radius, typically 1 m. For the background sphere, the radius needs to be large enough so that the it completely encompasses the 3D model. Typically, we set the background radius to 5km. The foreground and background images are then mapped onto to these spheres as materials.

Figure 4 shows a simple 3D model of a building massing being viewed from a VR panorama hotspot. The images used for the hotspot are those in Fig. 1 and 3. It can be seen that certain trees and the road sign appear in front of the 3D model.

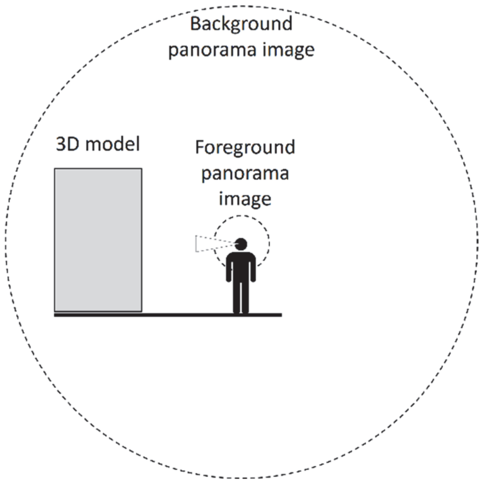

Figure 2
Section showing the foreground and background spheres

Figure 3
Image for the hotspot foreground

Figure 4
A 3D model viewed from a panorama hotspot

As long as the user remains at the location where the VR panorama hotspot was created, the model will remain aligned with the VR photographs. At this location, the user is also able to rotate their camera in any direction. (On a computer screen, the camera is rotated by dragging the mouse, while with a HMD, the camera is rotated by moving ones head.) Once the user starts moving away from the hotspot, the alignment will break.

Geo-referencing

In order for the 3D model and the VR photographs to be properly aligned, they need to be placed in the same coordinate system. The most straightforward way of achieving this is to geo-reference both the 3D model and the VR photographs. Once they are correctly geo-referenced, the two datasets can then be easily integrated into a single model.

The 3D model is created using a Cartesian coordinate system with an origin that is typically placed close to the structure being modelled. In order to geo-reference the model, the latitude and longitude of the origin needs to be specified, as well as the north direction.

Similarly, for each VR photograph, both the location and direction of the VR photograph need to be specified. For the location, the latitude and longitude where the photograph was taken needs to be specified. For the direction, the horizontal angle of the VR photograph needs to be specified.

Once both the model and the VR photographs are geo-referenced, the locations and directions of VR photographs can be translated to the Cartesian coordinate system. For each panorama hotspot, foreground and background spheres are created and rotated to match the VR photograph direction. The foreground and background images are then mapped onto these spheres.

Verifying Alignment

In order to verify the accuracy of the geo-referencing, additional geometric entities can be created in the 3D model that can then be checked for alignment with the VR photograph. The foreground image should be temporarily disabled so that the alignment of the entities in the 3D model with the background image can be checked.

As part of this research, numerous alignment tests were performed for a range of VR photographs downloaded from Google Street Maps. In these tests, two types of entities were added to the geometric model. First, a circle was created, centred on the VR photograph, with a radius of 4.5 km. The alignment of this circle with the horizon in the VR photograph could then be verified. Second, a series of vertical lines were created at corners of buildings in the surrounding urban context. For each vertical line, Google Maps was used (with satellite imagery switched on) to extract the exact latitude and longitude of the corner of the building. These coordinates were then converted to Cartesian XYZ positions, and vertical lines were then generated matching the height of the building.

Figure 5 shows an example of the same model as shown in previous figures. In this case, the foreground image has been disabled. A horizon circle and two vertical alignment lines have been created (extruded to increase their visibility). In this case, it can be seen that the alignment between the model and the VR photograph is good.

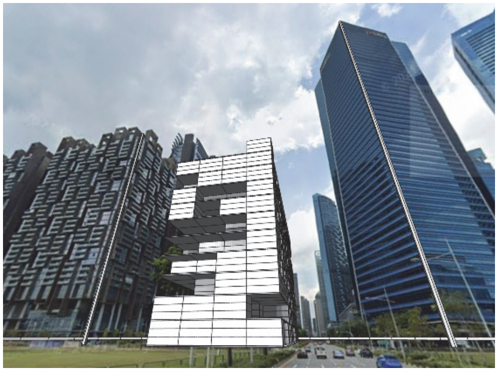

Figure 5
Horizon circle and vertical lines for verifying alignment.

VR Photograph Tilt Correction

The alignment tests performed during the research showed that in general, the accuracy of the location and direction of the VR photographs tended to be high. However, the main issue was that when the VR photograph was taken, the camera was often tilting. This tilt would then result in significant discrepancies in the alignment between the model and the VR photographs. An additional issue was that for most VR photographs, tilt is more difficult to record. For the images downloaded from Google Street view, the location and direction can be retrieved, but there is no information on any tilt.

To address the tilt issue, an additional setting was added, that allowed the VR image spheres to be tilted. This setting was adjusted interactively by the user. The tilt discrepancy is typically most visible in the misalignment between the horizon circle and the horizon in the VR photograph. Based on the discrepancy, the user is able to iteratively adjust the tilt correction settings until a good horizon alignment is achieved.

INTEGRATION IN MÖBIUS MODELLER

VR panorama hotspots have been implemented in Möbius Modeller, a web-app for parametric modelling (Möbius Modeller, n.d.). In Möbius Modeller, users create computational scripts for generating 3D models using a visual programming language. The user first creates a flowchart consisting of a series of nodes with links. In each node in the flowchart, the user then defines a procedure using a click and fill-in-the-blanks programming style.

The models that are generated can be view in three different viewers: the CAD viewer, the Geo viewer, and the VR viewer. The CAD viewer provides a typical viewer found in most modelling programs. The Geo viewer provides a viewer for geo-referenced models. The viewer is integrated with image tile services such Open Street Map and Google Maps. Finally, the VR viewer allows the user to navigate the model from a first-person POV.

Möbius Modeller has support for geo-referencing models. In the script that generates the model, the user can specify the geolocation and north direction of the Cartesian coordinate system. In the Geo viewer, the model will then appear in the correct geolocation. An example is shown in Figure 6.

Figure 6
Geolocation of the 3D model in the Möbius Modeller Geo viewer

Creating VR Panorama Hotspots

Once a geolocated model has been created, the user can then add multiple VR panorama hotspots around the model, in order to be able to visualise that model in its urban context. To create a VR panorama hotspot, the following three steps are required:

- First, the user creates the two 360 spherical images for the hotspot and saves them in an online location. The user may go out and photograph the background image, or they may retrieve an existing image from some other source. The foreground image can be created by editing the background image, making certain areas transparent.
- Second, the user records the location and direction of the VR photographs and maps them to the Cartesian coordinate system. In Möbius, a function is provided to map geospatial coordinates to Cartesian coordinates.
- Third, the user creates a point object with specific data attributes attached. In Möbius, support for user-defined attributes is built into the modelling system. In the VR Viewer, such point objects are recognised and additional entities are created in order in order to instantiate the VR panorama hotspot.

The data attributes attached to the point object are the settings required for creating that hotspot. The following settings are required:

- **name**: The name of the hotspot. This name can be used for teleporting to the hotspot.
- **background_url**: The URL of the background image.
- **foreground_url**: The URL of the foreground image.
- **rotation**: The rotations of the background and foreground images, to match the VR photograph direction.
- **correction**: The correction of the VR photograph tilt, specified as two angles: azimuth and altitude.

User Interaction

When the VR viewer encounters point objects with these attributes, a VR panorama hotspot will be automatically generated. For each hotspot, two spheres will be created: the foreground sphere and the background sphere, centred on the point object. The spheres are rotated and tilted to match the settings in the point object. Finally, materials are created from the VR photographs, which are then applied to the spheres.

The hotspot spheres are generally set to be invisible. Only when a user navigates into a hotspot (either by walking towards the hotspot or by teleporting to the hotspot) do the spheres become visible. The user then sees the 3D model within the context of the VR photograph. If the user moves away from the hotspot, then the spheres dissolve.

The existence of a hotspot is indicated by an octagonal marker in the 3D model, as shown in Figure 7. These markers make the user aware of the existence of a hotspot as they navigate around the model. The user can walk towards any hotspot markers, and as they come close the will automatically be snapped to the hotspot. At that point, the spheres become visible and the user will then see the model in the context of the VR photographs.

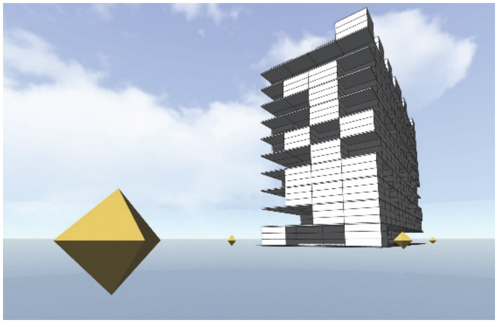

Figure 7
Octagons indicating the location of VR panorama hotspots

Software Implementation

Möbius Modeller is an open-source web application written in TypeScript, using the Angular framework. For implementing spatial modelling functionality, the core programming library is Threejs (Threejs, n.d.). The Geo viewer is developed using iTowns (iTowns, n.d.). The VR Viewer is developed using AFrame (AFrame, n.d.).

For implementing the VR panorama hotspots, various custom components have been developed and added to the AFrame viewer. All source code is available on Github (Möbius Modeller Github, n.d.).

IMPROVING SPATIAL UNDERSTANDING

Over the past three years, a course at the National University of Singapore has been used Möbius Modeller to teach Spatial Computational Thinking. In the latest iteration of the course, this included the use of VR panorama hotspots. This iteration of the course was taught from January to April 2022, with a total of 290 students.

In the course, students were tasked to create an algorithm for generating a building structure or massing. Students started by choosing an existing building, which served as a source of inspiration for creating their algorithm. They were then required to write a spatial algorithm that was able to create design variants loosely based on the selected building.

A series of VR panorama hotspots were created for the students and they were asked to visualize their parametric models using these hotspots. In some cases, students also created their own customised VR panorama hotspots.

Figure 8 shows a series of examples of the models created by the students, visualized using VR panorama hotspots. After having completed the course, students were asked to reflect on the experience of viewing their generated 3D models using VR panorama hotspots. Students emphasised the fact that the VR hotspots were able to significantly improve spatial understanding. They reported that the visually detailed VR photographs gave them a better sense of scale and materiality as compared to typical site models consisting of simple extruded blocks.

Most of the students used the computer screen to view the models. However, students who had access to HMDs did also test viewing the model using the headset. For those students, they reported that the headset gave a stronger immersive experience. However, when it came to improving spatial understanding, the added benefit of the HMD over the computer screen was limited.

At the end of the course, a survey was conducted to gather feedback from students. The two main questions of the survey were as follows. a) Do you think VR panoramic hotspots help you understand the urban context of a design? b) Do you think VR panoramic hotspots help you understand the scale of a design? For each question, respondents could select from a five-point rating scale, with one being "Not helpful at all", and 5 being "Very helpful". In total, 55 responses were received. Figures 9 and 10 show the results of the survey.

Figure 8
Examples of student projects

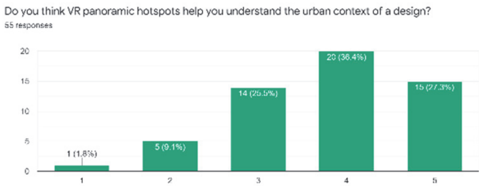

Figure 9
Survey responses for urban context.

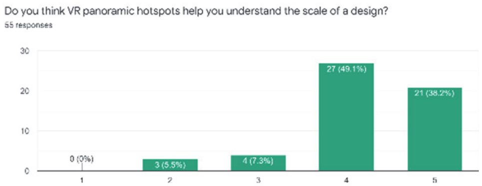

Figure 10
Survey responses for design scale.

For the first question regarding the urban context, 64% gave high scores of 4 or 5, while only 11% gave low scores of 1 or 2. For the second question regarding the design scale, 77% gave high scores of 4 or 5, while only 6% gave low scores of 1 or 2.

In addition, students were also asked to give additional feedback as text input. The feedback was nearly all positive. For example, one student stated that VR hotspots "could be useful when sharing one's design with their critics/clients, so as to better persuade them on the relevance of the scale/context of their design". Another student responded that it allowed "designers to feel the space and experience the area, making it easier to feel how the structure will be experienced".

A number of students also made suggestions to improve certain aspects of the user interface. For example, suggestions to improve the navigation between VR panorama hotspots, using clickable embedded arrows similar to Google Street view.

FUTURE WORK

The research has implemented a basic prototype of VR panorama hotspots in Möbius Modeller. The results have been very promising. Nevertheless, there are many further potential avenues of research.

Three areas of possible improvement have been identified that would make the use of VR panorama hotspots more streamlined.

- First, given a depthmap of the background image, it should be possible to automatically generate the foreground image from the background image. (A depthmap is a greyscale image, where the value of each pixel indicates the distance from the camera to the object in the scene.) Platforms such as Google Street View already generate such depthmaps.
- Second, using machine learning techniques, it should be possible to automatically detect and correct the tilt angle of a VR photograph. The algorithm would need to detect a series of points on the horizon line in the image. Based on the distortion of the horizon line, a tilt correction could then be automatically derived.
- Third, given a particular site, it should be possible to automatically extract a set of VR panorama photographs close to the site, from platforms such as Google Street View. This would then mean that clusters of VR panorama hotspots could be automatically generated with minimal effort.

In addition to these three improvements, many other improvements have been considered, focusing on various aspects of the user experience. These include the issue related to the navigation between VR panorama hotspots, raised by the students.

DISCUSSION

This paper focuses mainly on the implementation of VR panoramas in the Möbius Modeller parametric modelling tool. An area of potential future application is the use of Möbius models with embedded VR panoramas to support participatory design workflows and practices.

Möbius Modeller is an open-source web application that is free to use without any limitations. The application includes extensive tutorials and integrated help, to enable users to learn the software. This makes the application highly accessible to anyone with access to the internet.

For supporting participatory design workflows, a key feature within Möbius Modeller is the ability to easily publish models online, with a single click. By publishing a model, a URL is generated that can be shared with anyone interested in viewing the model. Alternatively, the published model can also easily be embedded in other websites or blog posts.

When publishing, various settings can be specified that customise the user interface for the end-user of the published model. This includes creating a minimal interface and an option to specify the 3D viewers. This allows collaborative workflows to be created between people with varying levels of expertise.

For example, a designer can develop a complex parametric model with embedded VR panorama hotspots. In order to get feedback on the design, they can then publish the model with a minimal user interface, with the VR viewer selected as default. Clicking the link, participants will then be presented with the model in VR in their web browser. The complexity of the parametric algorithms can be completely hidden, making it easy for non-experts to interact with the model in VR and to change parameter settings to generate parametric variants.

In addition to Möbius Modeller, various other related web applications have also been developed, which we refer to as the Möbius Ecosystem (*Möbius*

Ecosystem, n.d.) These related applications could also be integrated into participatory design workflows. For example, Möbius Evolver is a cloud-native platform for evolutionary optimisation of designs. The evolved designs can automatically publish, together with a set of VR panoramas. For participatory design, a potential scenario is a designer evolving an optimised population of design options, with citizens or stakeholders viewing the optimised design in VR and proving feedback.

To some extent, such participatory workflows can be created using other existing commercial and proprietary tools. However, the complexity of creating the workflow is significantly higher and the requirement to purchase commercial software makes it inaccessible to many participants. With the Möbius Ecosystem, creating such workflows is relatively straightforward and all the software is free.

CONCLUSIONS

The research set out to explore how VR could be used to improve spatial understanding in design. More specifically, the focus was on improving the spatial understanding of how proposed buildings or other structures can fit into the urban context.

In order to achieve such an improved spatial understanding, the research proposed to make use of VR photography, which creates 360 spherical images. The main advantage of this approach is that it is able to give the user a detailed view of a building in its urban context without requiring any additional modelling.

The proposed approach of using VR panorama hotspots has been implemented in Möbius Modeller. Users are able to create hotspots by adding point objects to the model with certain attribute data attached. Users are then able to rapidly generate model variants and to evaluate those variants in their urban context.

Recently, the use of VR panorama hotspots has been demonstrated and evaluated in a course at the National University of Singapore. In the course students generated a wide variety of parametric models, and visualised those models using VR panorama hotspots. The feedback regarding the effectiveness of the hotspots in improving spatial understanding was very positive.

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REFERENCES

El Araby, M.(2002) Possibilities and constraints of using virtual reality in urban design. In *Proceedings of the 7th International CORP Symposium*, Vienna, Austria, 27 February–1 March 2002; pp. 457–463.

Ghani, I., Rahman, N. A., Nayan, N. M. and Bahaluddin, A. (2018) Experiential Virtual Urban Environments: A Preliminary Investigation, *Journal of the Malaysian Institute of Planners*, 16 (1), 25-37.

Globa, A., Wang, R. and Beza, B. (2019) Sensory urbanism and placemaking exploring virtual reality and the creation of place, in *CAADRIA 2019*, pp. 737-746.

Janssen, P, Li, R, and Mohanty, A (2016) Möbius: A Parametric Modeller for the Web, Proceedings of CAADRIA 2016, 30 Mar - 2 Apr 2016, Melbourne, Australia, pp. 157–166.

Janssen, P., Bui, T. D. P., & Wang, L. (2022). Möbius evolver: Competitive exploration of urban massing strategies. In I. As, P. Basu, & P. B. T.-A. I. in U. P. and D. Talwar (Eds.), Artificial Intelligence in Urban Planning and Design (pp. 293–321). Elsevier. https://doi.org/10.1016/B978-0-12-823941-4.00015-9

Kim, J and Kim, S (2019) Finding the Optimal D/H Ratio for an Enclosed Urban Square: Testing an Urban Design Principle Using Immersive Virtual Reality Simulation Techniques, *Int J Environ Res Public Health*. 2019 Mar 9;16(5):865.

Morgan, C. L. and G. Zampi (1995): *Virtual Architecture*; London: B. T. Batsford Ltd.

Möbius Ecosystem. (n.d.). https://mobius .design-automation.net/
Möbius Evolver. (n.d.). https://github.com/design-automation/mobius -evo
Möbius Modeller. (n.d.). https://mobius -09.design-automation.net/
Schnabel, M (2004) *Architectural Design in Virtual Environments: Exploring cognition and communication in Immersive Virtual Environments*. Thesis (University of Hong Kong)