Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 2, 15-37
2024
Publisher: Learning Gate
DOI: 10.55214/25768484.v8i2.1082

Designing an immersive visit for public space assessment

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Abstract: The assessment of the quality of public spaces is crucial for fostering community well-being and urban development, contributing to the creation of inclusive, vibrant, and sustainable urban environments. It is possible to forecast the feeling imprinted in people by a future streetscape using virtual reality. Immersive visits are the best technological solution, given that a virtual environment of quality is provided with high quality resolution and urban details. The Architecture, Engineering, and Construction (AEC) professionals involved in a large-scale real estate project under construction provided us with access to the BIM (Building Information Model) architectural plans of the entire infrastructure in the future district. A part of the neighborhood has already been built and is studied in this experiment: a public place with a tram station, a typical shopping street, and a pedestrian way, mainly a public place for leisure activity. These three points of view of interest will be studied with two modalities: real video showing the actual state of the built environment, and immersive visits using head-mounted devices, enabling virtual reality exploration of these public places. This article explains the practical construction of the 3D city model, and characterize the quality of the immersive visits through the use of questionnaires submitted to laypersons (non-expert participants).
Keywords: *3D city model, BIM, GIS, Immersive visit, Infrastructure, Questionnaire survey.*

1. Introduction

The presented work was produced in the frame of a large real estate construction project in a district called LaVallée. The district is being built in a suburb of Paris, France, and covers a spatial extent of 500 m × 400 m, representing an area of 50 acres. It will result in a large modification of the city, as it will house 20% of its citizens. The active mode of transportation, walking and cycling, will be especially impacted; therefore, an assessment of quality of the future public spaces is important.

The Architecture, Engineering, and Construction (AEC) professionals involved in this real estate project provided access to the BIM (Building Information Model) architectural plans of all the infrastructure of the future district: buildings, roads, and sidewalks, vegetation landscape, urban furniture such as benches, poles, and playground, which supply the building of an accurate and enriched 3D model of the neighborhood with its infrastructure, buildings, and streetscape.

LaVallée was imagined as an extraordinary eco-district, revealing a harmony between the city and the landscape. Several issues prevail, such as revealing multiple urban identities, integrating the new eco-district into its environment as a green city, opening up the site, and promoting links between existing neighborhoods.

The site is expected to strengthen the status of city entry with the arrival of the tram, preserve the main routes and the great landscape to create new ecological continuities, and develop a new city polarity to promote meeting, social, and inter-generational diversity. The plateau presents an exceptional landscape value, linked to a lively and heavily wooded relief, carrying motivating

History: Received: 5 December 2023; Revised: 1 February 2024; Accepted: 9 February 2024; Published: 20 February 2024
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situations with the neighborhood Parc de Sceaux just to the east of the district, one of the largest parks in the Greater Paris, France.

Figure 1.
Location of activities in LaVallée neighborhood, and the three point of view (POV) of interest.

Figure 1 shows the district area with its roads, buildings, bus stops, and future activity locations. It is planned as a mixed use land with various ambiances represented, such as a leisure place with a park and recreation area, a shopping mall on a strip boulevard, and a public place with a tramway station. The focus of this work is on the ground floor, as it is an essential part of the vibrancy of the future public spaces.

As shown in Figure 1, a part of the neighborhood has already been built and studied in this experiment: the public place at the south of the district, which is the main entry point because of the Tram station, the shopping street, with shopping stores mainly placed along the main road going from the north to the south of the district, and perpendicularly to the shopping street is a pedestrian way. It is mainly a public place for leisure activities (green circles) called LaVallée's Garden, as it holds a lot of vegetation and kid's playground activities. These three points of view of interest will be studied with three modalities: real video showing the actual state of the built environment, non-immersive visits in the form of videos of 3D scenes extracted from a 3D city model, and immersive visits using a head-mounted display with a HTC VIVE device (a line of virtual and mixed reality headsets produced by HTC Corporation) enabling virtual reality exploration of these public places. This article explains the practical construction of the 3D city model, and characterizes the quality of the immersive visits through the use of questionnaires submitted to laypersons (non-expert participants).

2. Literature Review

A recent literature review of Virtual Reality (VR) applications to the built environment was proposed by Zhang, et al. [1]: most of the works is dedicated to construction, education and safety.

Some human behavior studies are related to spatial perception, emergency planning and energy-consumption behavior.

The most common architecture design features being investigated are the level of natural daylight, the presence of visual cues, the color of surfaces, and openness in space: indeed, their impact on human experience and behavior was proven by previous empirical research such as Ergan, et al. [2] in order to deepen the materialization and experience of the space.

Research papers on streetscapes in a virtual environment that exists tend to evaluate: VR as a tool in learning process [3] the definition of ambiance in architectural projects [4] or the influence of specific factors in ambiances. The latter can be about the role of vegetation [5]: the vegetal configurations promote sensorial trips that hold the inhabitant somewhere else, to an imaginary world where he could regenerate. For instance, in residential courtyard spaces, green vegetation is more emotionally healthy than fitness facilities [6]. It can be the role of water: Sioui [7] highlighted the link between the memory of a place and the emotion that architecture can evoke.

We are interested in this paper because of the studies that used virtual scenes to explore the built environment. Recorded virtual environments were used in Kim and Lee [8] and Mouratidis and Hassan [9] with 360 panoramic videos: participants follow a predefined guided tour in a Head Mounted Device (HMD). The larger the study area, the greater the advantage of VR audit. But the use of HMD makes it hard to investigate a large corpus of participants. A 10-person expert panel participated in all three steps of the streetscape audit in Kim and Lee [8]. All experts hold doctoral degrees in urban design or transportation planning. 28 students participated in the auditing of four streets and four public places in Mouratidis and Hassan [9].

Less immersive virtual environment than Head-Mounted Device (HMD) can be used, such as the study conducted by Kuliga, et al. [10]: the walk-through virtual model is implemented with a desktop screen with a video showing a long route inside a building. Participants are engaged in a guided walk through the building, in an indoor-only visit. The virtual presentation used predefined, directly connected building routes that covered most of the building. Environmental appraisal, participants rated the environment using a custom-made questionnaire. Our experimental protocol also uses videos of guided tours of the virtual outdoor environment.

Such video-guided tours were implemented in Belaroussi, et al. [11] to assess a proposal for the regeneration of the Canal Port of Rimini. A comparison of current scenes of the Canal Port area and of the future scene with modifications to its urban design was conducted using two models of virtual environments. Human participants were shown videos of the rendered results and answered a questionnaire survey related to both scenarios of built environment.

Most of these studies focus on the psychological aspect of the auditing of public spaces, but barely explain the process used to build the 3D city model, which, at a large scale, is not done manually or at least not completely. Related works of Large-Scale 3D Models in Urban Area includes project based on BIM data [12] (Building Information Model). BIM models represent highly detailed three-dimensional construction plans, but their extensive file sizes, often exceeding 300 megabytes for a simple four-story building, make them infrequently employed in large 3D city models. Consequently, practitioners typically resort to lower Level of Detail (LOD) representations, sufficient for urban planning purposes but lacking the refinement required for a human-centric examination of streetscape design. Such an analysis demands a higher level of finesse, incorporating dynamic elements like vehicles, pedestrians, and bicyclists.

This paper illustrates the procedural steps involved in constructing a 3D city model using static BIM and GIS (Geographic Information System) data. Additionally, it involves the manual inclusion of non-playing characters and decorative urban elements. We conducted the primarily analytical and experimental research in collaboration with architectural partners involved in real estate projects during the final stages of construction. The symbiotic relationship between virtual reality, BIM, GIS, and urban planning is a crucial area that necessitates further exploration for implementation in urban planning and engineering studios.

This study focuses on the intersection of VR, BIM, GIS, and urban design, particularly in the context of real estate projects nearing completion. The integration of these technologies is essential for designing future public spaces, such as sidewalks, gardens, and other communal areas. We overlay the virtual spaces created for experimentation onto real-world locations, enabling a comparison between the virtual and actual environments. This comparison is invaluable in understanding the utility of VR in public space designs.

To assess the quality of different virtual environments within the district, we conducted a study based on a limited set of criteria. Our goal was to identify the types of information that could be gleaned from a virtual setup and pinpoint areas for improvement in achieving a comprehensive characterization of streetscape design.

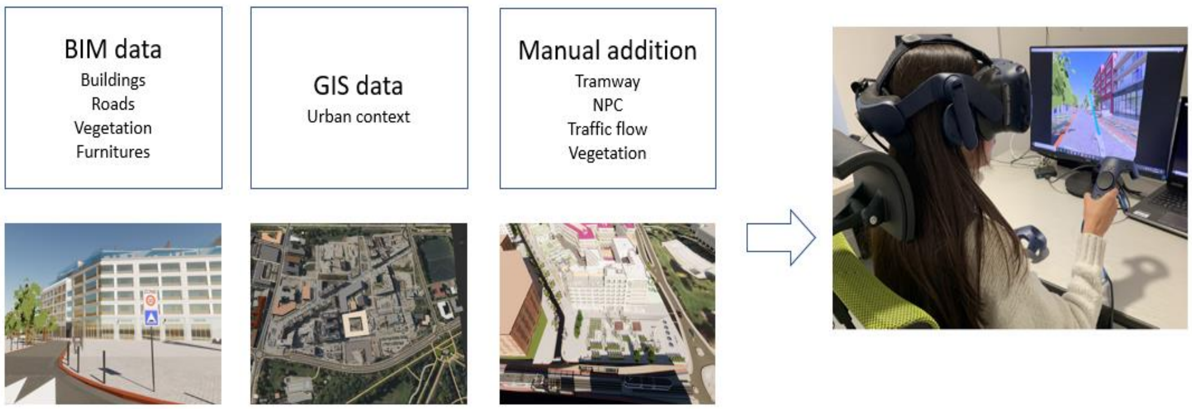


Figure 2.
General workflow of the design of an immersive visit.

3. Methodology

3.1. Position of the Problem

As previously stated, the problem at hand consisted of the generation of a 3D city model, which would later be used in two out of the three methods to characterize the urban area through public space auditing. To ensure the models' use acts as a reflective assessment of the district, several factors had to be considered to promote the required realism and effectiveness, including: accuracy of terrain and topography, layout and placement of buildings, architectural details, landscape and vegetation, lighting and atmosphere, infrastructure and roads, proportion and scale, accessibility and navigation, interactivity and user experience. These factors ensure that the model will not only be visually appealing, but will also highly serve its intended purpose of urban characterization and public auditing.

To ensure that these factors are met, the creation of the model is split into three distinct yet intertwined phases: BIM data of the buildings, street network, urban furniture, vegetation, and the mass plan to ensure the utmost precision of all objects in place, GIS data through Infraworks to ensure the surrounding context of the area is complete and filling all required BIM gaps, and lastly, the addition of specific urban facilities and neighborhood niches through the use of the TwinMotion software. Merging the three sources of input together, the final output comes out as a contextually complete, precisely coordinated, and accurately represented version of the Lavallee district as a 3D city model on TwinMotion. Thus, the project timeline starts with AEC data provided by architectural firms and is transformed into a final prototype on the TwinMotion software, as displayed in Figure 2.

3.2. BIM Data Registration and Reposition

The Lavallee district can be categorized as requiring a large-scale city model, and thus, for the model implementation, the contribution of various architectural firms is required. The current available data is split up into 8 lots, and each lot is comprised of a representative architectural firm that is responsible for the lots' BIM data.

The responsibility of these architecture firms lies in converting GIS data, which places an emphasis on coordinate locations and city scale, into more realistic BIM files of high detail. This is because GIS data solely provides footprints and elevation, which are not enough to completely contribute to an immersive visit later on using virtual reality.

To do so, architectural consultants typically use cloud-based technology such as BIM 360. These technologies permit the visualization of the holistic city, its infrastructure, and some basic landscape data, including trees and vegetation. While the functionality of these models allows for user-interface interaction, they lack realism and require added rendering and editing to improve textures, lighting, and urban details.

Thus, the process begins with the AEC (architectural, engineering, and construction) partners of the project. Each company develops the CAD (Computer Aided Design) drawings of the buildings, terrain, public spaces, parking spots, road networks, urban furniture, such as benches, recreation furniture and vegetation. All developed drawings are centralized on a BIM 360 cloud platform with their coordinates, being tendered as IFC files (industry foundation classes).

Once all the data is compiled into the BIM 360 platform and distributed as Industry Foundation Classes (IFC) files, it is ready to be analyzed. In the project, the reference system utilized was the RéseauGéodésiqueFrançaisRGF93 CC49, as it has been the French three-dimensional geodetic system since 1989 and is easily connected to the rest of the world due to it being based on the European Terrestrial Reference System ETRS89 system. Using common coordinates between different data sets enables the digital models to be connected.

Due to the data in this study being collected from various architectural firms, it prompted a critical issue: the last folder in the BIM 360 set containing the models of the buildings, did not respect consistent georeferenced coordinates, but instead each of the structures had its own Cartesian reference frame.

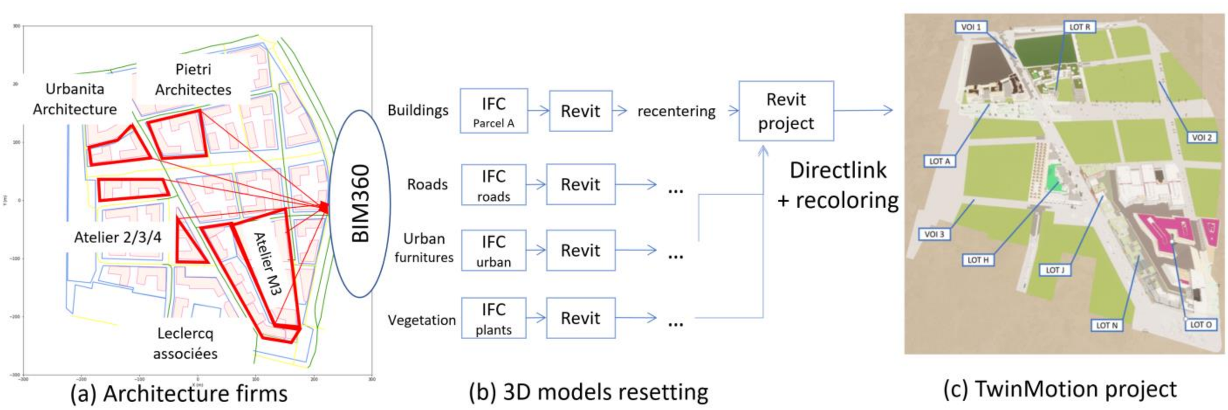


Figure 3.
BIM data are registered to a common frame using Revit and integrated to a twinmotion project.

The IFC files provided comprehensive data on the building's attributes, including the material type of specific portions of the building and the exact location of each individual point on the structure according to the reference frame of the specific file. These location coordinates are the characteristics that had to be examined within their local reference and converted into the RGF93 common reference system, in which one point in the file was to be taken as the reference point to measure all coordinates by. This implies that we needed to transform each buildings origin from its local reference point to the project's overall reference point.

We created a Matlab parser to read the IFC files and extract only the relevant data, simplifying the data set and reducing the complexity of the manual portion of the process. To have a comprehensive model, not only were the parcels assessed, but so were the road infrastructure and the mass plan (general map of the district). Afterwards, an alignment procedure was required to fix the real estate project into one common reference point.

While time-consuming, the most convenient way to ensure absolute precision is through manual alignment of the points on Revit. Considering that loading an IFC file into Revit could take up to ten minutes, the process is quite tedious as the project is incredibly dense, including six parcels, three road networks, and a mass plan. Figure 3a represents the map of the district along with the absolute coordinates of the mass plan, the parcels, the road network, and the result of the model after repositioning.

Following the line of action displayed in Figure 3, post the assembling and repositioning process of the IFC files on a common Revit project. By using a direct link plugin or the Datasmith exporter, the complete Revit project can be exported into TwinMotion, producing an already interesting prototype that is approaching the spectrum of realism.

This file is still considered massively incomplete, as essential aspects of a realistic city model are inadequate, especially in regards to the context of the urban area. For example, since only phase 1 of the project has been completed in reality, meaning that the only IFC coordinate files received and adjusted on Revit are the ones corresponding to phase one; the buildings in the area are currently incomplete, leaving gaps where buildings will be when all phases of the project are complete. An additional example is the lack of surrounding landscapes around the district, as with only the Revit exportation in place, vast nothingness surrounds the district, meaning the district is just independently floating, inducing a lack of realism in those scoping the model.

Additionally, even though the architectural files do contain added greenery and urban furniture, they are incomplete. The landscape of the area still requires the addition of further greenery to promote realism and capture the true essence of the area, it requires additional urban furniture such as benches, trash bins, fountains and bike racks that are mildly present, and it requires representing static and dynamic characters to interact with the area, further enhancing its functionality, such as: seated users, working users, walking pedestrians, and cyclists.

The tramway at the district's border and the general road network surrounding the district are other crucial elements that the model must incorporate from other sources. These are two contextual elements that play a pivotal role in understanding the mobility spectrum of the district and its means of connection to surrounding areas.

3.3. Urban Context and Topographical Integration

After scouring through several potential methods to complete the topography of the area, add in the missing buildings, and align the surrounding context with the district formed by BIM data, the most notable alternative was to use the Infraworks software. The Infraworks model builder command allows for the extrapolation of the complete environment of a desired location, including its road network, buildings, topography, and terrain.

Infraworks allowed for a very simple user-interface interaction, and the procedure was simply as follows: Post-initiation of the software, the option "model builder" is selected. This model then allows for the modelling of any region in the world with OpenStreetMap data available. Thus, the address of the district is searched, and by manually zooming in and out on the area provided, the limits of the area can be chosen. The area will be limited to less than 200 km squared for the software to be able to process it effectively; otherwise, it will be deemed too large. For a more accurate representation of the limits of the selected area, using the polygon function, it is possible to enclose the area that the software needs to model in any preferred shape.

Once the area has been selected, the model is named, and the coordinate system to be used is selected. The ETRS89 system is selected to best match the existing BIM data, and then the model creation commences. Depending on the size of the area, the model builder's processing and preparation time can vary, but typically, on a district-scale, it takes approximately 5-15 minutes and is not a long wait. When ready, the model is then found in the list provided on the Infraworks home screen.

Once this process is complete and the model is opened, the full-scale terrain model is obtained, as illustrated in Figure 4.

Figure 4.
Total context on infraworks.

The model includes the following features:

- Buildings: Developed through OpenStreetMap data collection
- Street networks, highways, and railways: created through the OpenStreetMap rail and highway database
- Topography: using Microsoft Bing Maps Satellite Imagery
- Elevation: Depending on the region of interest's graphical location, global terrain data is used to construct digital elevation models (DEM) of 10 and 30 meters in resolution.

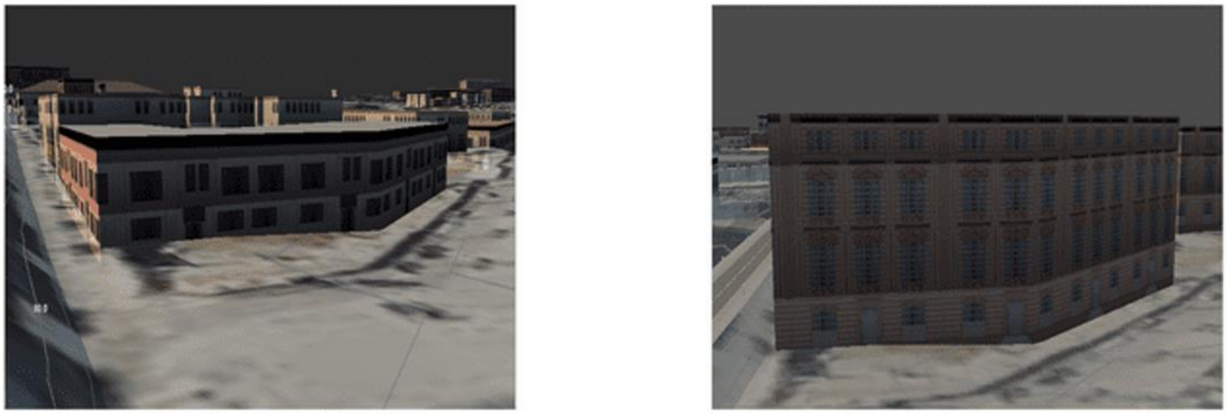
Even though Infraworks was considered the best option in terms of time efficiency, precision, and data availability, there are still various concerns to be handled after the model's creation. These issues were associated with the outdated OpenStreetMap data, the lack of high-definition model building possibilities, and the blemishes in capturing the OpenStreetMap images by the software. The most glaring defects included:

- Problems in the terrain's elevations, with random areas being higher than others unconventionally
- The tramway is missing because the data is from before its construction.
- Road curvature inaccuracies with some roads and road features looking unrealistic
- There are inaccuracies in the curvature of some roads, and certain road features appear unrealistic.
- Certain regions have terrain gaps
- Certain buildings are elevated above the terrain
- The REVIT data already covers the buildings in question

We directly fixed certain issues in frameworks, reserving others for after we exported the model into TwinMotion. The fixes on Infraworks included alterations to the road network,

ISSN: 2576-8484
Vol. 8, No. 2: 15-37, 2024
DOI: 10.55214/25768484.v8i2.1082

terrain levelling, removal of unnecessary buildings, and the adjustment of road features. Each of these is simply done by selecting the blemish in mind, and using the software-produced index points to alter levels, shapes, and directions, allowing for the smoothening of curves in road networks, the levelling of the road and terrain's elevation, the fixing of roundabout shape and realism, removal of buildings, and building height adjustments. Examples of the more critical changes can be seen in Figure 5 with the modification of building elevation and Figure 6 with the removal of pathways.



a) Low building elevation

b) Realistic building elevation

Figure 5.
Building elevation fixes.

a) Unrealistic excess pathway

b) Removed pathway

Figure 6.
Removal of excess pathway.

As shown in Figure 7, some coarse forms of buildings inside the future district had to be removed before being replaced by our high-level BIM models. Figure 8 illustrates one of the main problems with Infraworks: the quality of roundabouts, which usually have to be corrected. Another problem usually encountered is the elevation of roads, as can be seen in Figure 9: they had to be fixed to a correct level to join our 3D model.

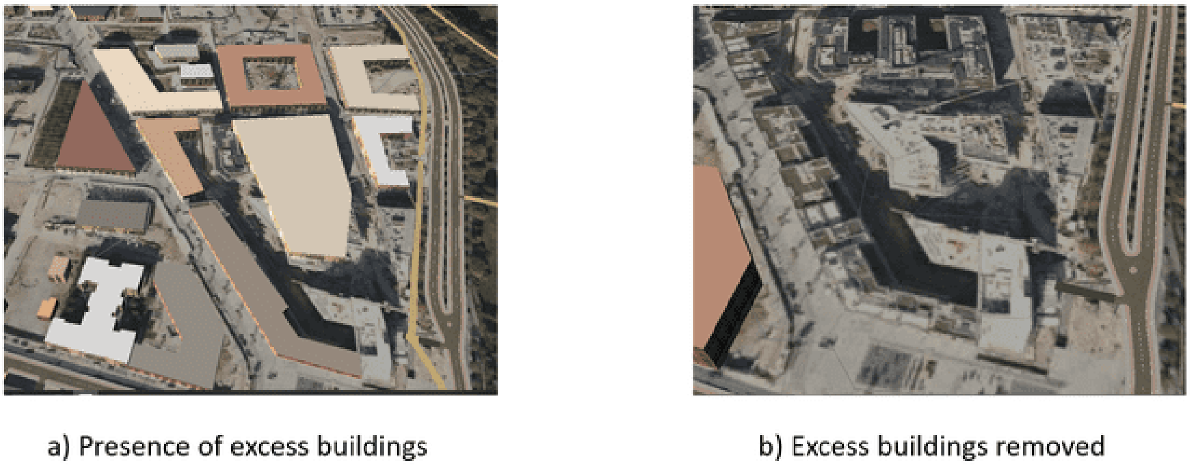


Figure 7.
Removal of excess buildings.

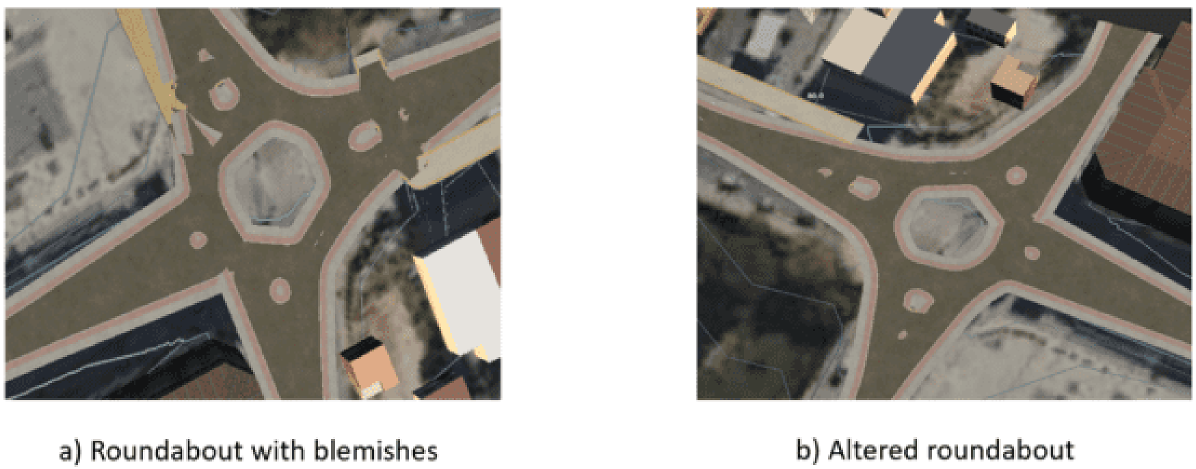


Figure 8.
Altering of roundabout geometry and blemishes.

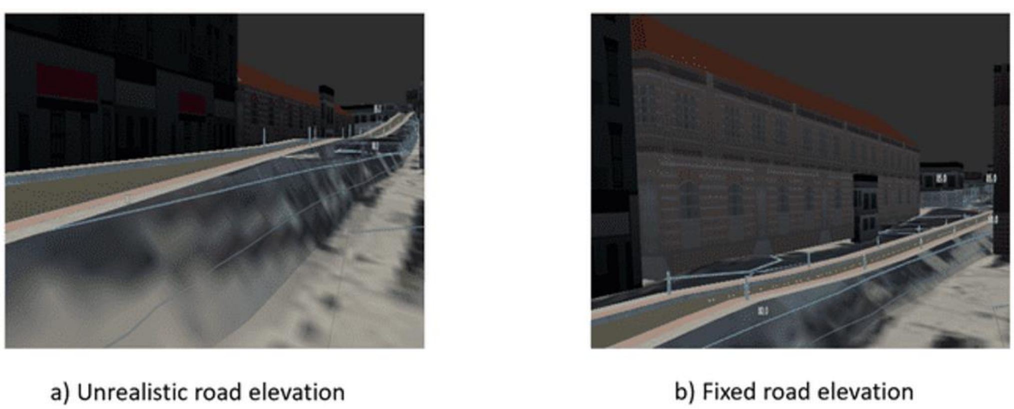


Figure 9.
Road elevation levelling.

Once these minor yet vital modifications are made, the model is ready to be used and exported

ISSN: 2576-8484
Vol. 8, No. 2: 15-37, 2024
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to TwinMotion. To use the model in alignment with the existing TwinMotion model, it should be exported as an FBX file: FBX (Filmbox motion) is an Autodesk file format and a popular 3D data interchange format utilized between 3D editors and game engines. We use the entire created model, not a partial polygon, so it's crucial to select the "export entire model" tab. Once the model is exported, it is vital to ensure that a folder with textures is also saved on your computer, as this folder is what gives texture to the context. If it is missing, all context will appear as basic white shapes.

After importing the file into TwinMotion, you need to manually align it with the BIM data. This is done by selecting the FBX file in Twinmotion and translating and rotating it until it falls directly below the BIM file. Since this portion is done manually, some errors can be seen, and there may be minor gaps between the two models. A simple solution to these gaps is the addition of basic fillers such as sidewalks or a bike path. Once we align them on the horizontal plane, we must manually edit the terrain's elevation, which is not exactly level, to ensure that the context is realistically below the BIM file at all points. Building heights are seen as realistic, and all additions to the context that need to be visible, are so. Figure 10 displays the resulting design.

Figure 10.
Alignment of urban context with existing BIM data.

3.4. Modifications and supplementations on TwinMotion

Post-integration of the required context into the model, the model now includes high definition buildings rendered to realism and placed with accuracy on top of coarse contextual data. The rest of the work to be done to finalize this increasingly realistic model is on TwinMotion. Additions on TwinMotion comprise the following:

- Additional benches should be placed in areas that require seating.

DOI: 10.55214/25768484.v8i2.1082

- Additional vegetation, such as trees and bushes, in areas where they exist in reality.
- Static characters display the use of urban furniture more clearly.
- Dynamic pedestrians are moving around the area to display its functionality.
- Dynamic cyclists using bicycle paths.
- The tramway.
- The trams.
- Tram stops.
- Bike racks and trash bins.

Figure 11 illustrates the resulting addition of a tramway station to the 3D city model. Figure 12 shows some examples of added urban furniture and static non playing characters. Moving cyclists, as shown in Figure 13, and pedestrians, as illustrated in Figure 14, are dynamic elements. Figure 15 shows the result of additional vegetation elements from a recreational point of view.

Figure 11.
Addition of tramway, tram stop and tram.

Figure 12.
Additions of benches, trash bins, bike racks and static users.

Figure 13.
Dynamic cyclist interacting with bike path.

Figure 14.
Dynamic pedestrian interacting with pedestrian path.

Figure 15.
Addition of vegetation such as trees, flowers and bushes.

With all these additions set in stone, the model is now complete. Combining all the needed elements, including coordinate precision, relevant scaling, geometrical accuracies, urban context, functional understanding, and aesthetic ambiance.

With the file completed, we can see the total statistics of the 3D city model displayed in Table 1.

Table 1.
Statistics of the virtual environment project.

Number of polygons	Number of objects	Texture size	File size
50,700,000	84,900	6.7 GB	1.17 GB

4. Results and Discussion

4.1. Experiment Setup

A critical point in the process is determining whether or not this method of 3D modelling is sufficient, to do so; a virtual reality experiment was set up, in which users wore a VR head-mounted device (HTC vive-pro 2) and were placed into 3 scenes from the model. During the VR experiment, the participants would perform 360-degree static turns in the area from different points of view, analyzing aspects such as the urban details, surrounding environment, light and shadows, scaling, and the overall realism of the scene. To retrieve their opinion on each of the scenes, a questionnaire was setup to ask about all of these details, while also collecting information about the quality of their VR experience, to help understand where some of the problems faced came from.

The 3 scenes were selected meticulously and with grand purpose. After analyzing the totality of the constructed area, the 3 scenes were selected because, first of all, they cover 3 distinct parts of the land mass, as each of the scenes is placed in a different portion of the district. Additionally, all of the scenes considered have different land uses. One of the scenes is a public space, another is a shopping space, and the final one is a green-based residential space.

The public space was chosen as it constitutes the entry into the district and is the point at which the district is connected to the new tram line in the area. The space contains essential urban footprints such as benches, bike racks, and the ability to choose between various modes of transport, as it has plenty of space for pedestrians and cyclists and is surrounded by vehicle-oriented streets and a tram. The area additionally displayed plenty of vegetation and places for people to shop, constituting activities.

We chose the shopping street because it serves as the district's main thoroughfare. The street stretches all the way from the north of the district to the south of it, connecting to exterior main streets in the process. The street is also the best view point to display the dynamic interaction of residents and visitors with the area, as it constitutes spaces to walk, bike, shop, and sit. Additionally, the street is a connector to the 2 other scenes in the test.

The last scene, the residential space, was chosen due to its completely unique land use in comparison to the other 2 spaces. While the other 2 spaces were more oriented towards visitors constituting the main street and the entrance to the district; the residential space targets the residents specifically. It is located at an intersection within the district and highly prioritizes greenery and a relaxing aesthetic, giving participants a great outlook on what vegetation in 3D models looks like.

When analyzing these 3 scenes, users were also granted the opportunity to see what these scenes looked like in reality, with videos of the 3 scenes taken on site being played during the questionnaire. This helps with drawing a comparison between reality and the 3D model, to truly understand the effectiveness of this form of auditing.

A side by side comparison of reality and the model is shown in Figures 16a and 16b for the point of view of the main public place. Figures 17a and 17b illustrate, respectively, the real environment and the virtual environment of the shopping street POV. Figure 18a shows real pictures from the

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ISSN: 2576-8484
Vol. 8, No. 2: 15-37, 2024
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leisure place POV, which can be compared to the simulated virtual environment displayed in Figure 18b.
Scene 1: Public place

Figure 16a.
Real scene: Pictures taken from the site LaVallée (Already built).

Figure 16b.
Virtual environment of LaVallée.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
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Scene 2: Shopping street

Figure 17a.
Real scene.

Figure 17b.
Virtual model.

Scene 3: Residential space

Figure 18a.
Real scene.

Figure 18b.
Virtual model.

We developed the following questionnaire to test the various scenes and the overall VR experience:

The following questions were based on ratings from 1-5, with 1 being not at all, and 5 being very much so for all factors:

- Rate the presence of shaking in the image felt throughout the scene:
- Rate the frequency of loss of image felt throughout the scene:
- How close is the size of the building compared to the real ones?
- How much realism do the urban details give the space?
- Overall, how realistic did you find the spaces shown?

These 2 other questions followed a different format:

- Place a check on any of the symptoms you felt during the virtual scenes (nausea, eye strain, headache, blurred vision, loss of focus, none).
- Rank the following characteristics from 1-5 as being the best, on how much realism they give the space (wall and roof materials, possibility to look everywhere. Scale (actual size), the environment, light, and shadows).

The number of participants who took part in the test was 15, all of whom consisted of various different ethnic backgrounds and were a combination of researchers, students and teachers, whose ages ranged from 20-56, thus providing an overall outlook that does not solely hang on age or experience.

4.2. Experimental Results on Realism

To best assess the use of models as such in the long-term for activities such as public space auditing and stakeholder meeting visual representations, the realism of the model when compared to real life was prioritized. To best assess the results, all answers to the questionnaire were subjected to a bar-graph format, to try and distinguish how the majority felt and if any outliers were present. To exploit the results best, responses scoring 1 and 2 are grouped together to represent an unrealistic interpretation, while responses scoring 4 and 5 are evaluated as a realistic evaluation, and 3 is considered a neutral evaluation.

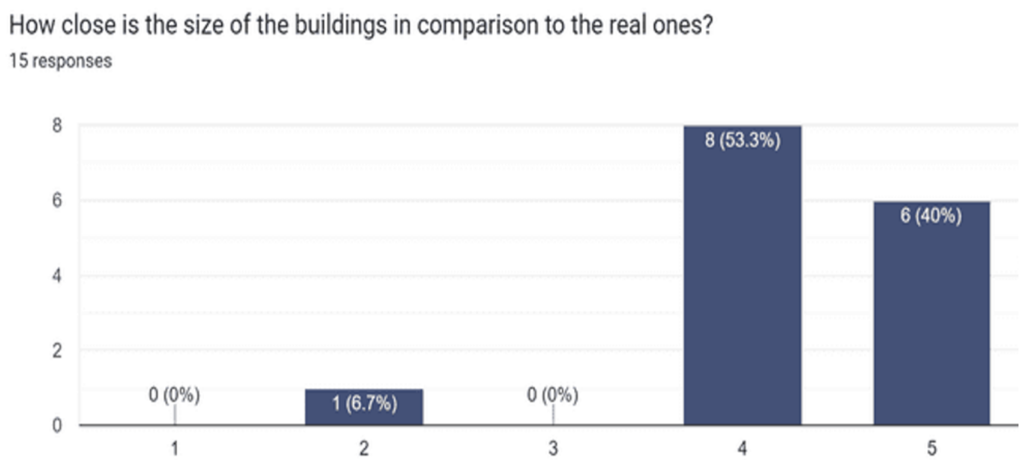

Figure 19.
Plot on the building scale realism.

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ISSN: 2576-8484
Vol. 8, No. 2: 15-37, 2024
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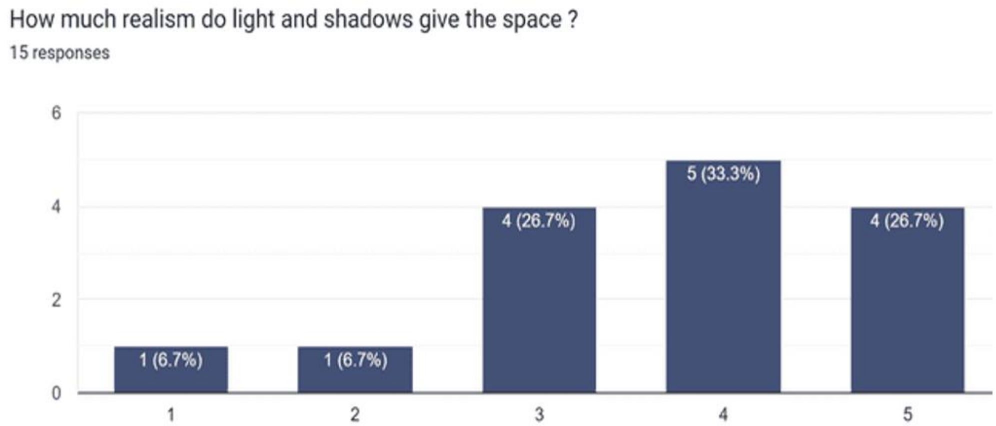

Figure 20.
Plot on the light and shadows realism.

In regards to the scaling of the buildings, as displayed in Figure 19, it was considered quite realistic, with 93.3% of the results being in the 4 to 5 range and only 6.7% (1 result) indicating that they found it unrealistic. Additionally, since the they answered with 2, they did not find it to be completely unrealistic. The results display that when comparing the buildings in the experience, to those in the realistic videos, people viewed them as quite similar in size, thus inducing a sense of realism in the experience.

However, Figure 20 shows, the light and shadows don't produce results that are positively skewed, with 26.7% of respondents remaining neutral and 13.4% finding it unrealistic. Still, 60% of users felt as though the light and shadows were realistic. A potential reason for this reduction in reality is due to the VR setup. To reduce the lagging felt in the scene when wearing the device, the graphics visualization of the scene had to be reduced from ultra-definition to medium definition, and one of the factors more prone to the effects of this are the lights and shadows.

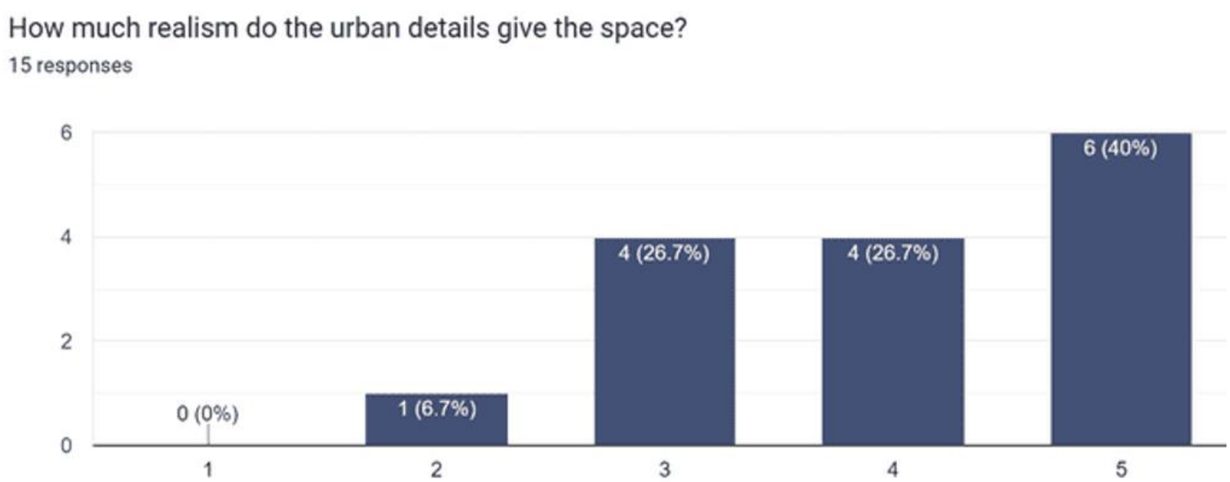

Figure 21.
Plot on the realism of urban details.

The results to this question were quite similar to the previous one, in which the majority of answers once again determined the details to be realistic (66.7% this time) and not many deemed it unrealistic, as can be seen in Figure 21. Though once again, a large chunk of the pool of participants (26.7%) deducted a neutral response. This garners a similar reasoning to the previous question, as many of the urban

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 2: 15-37, 2024
DOI: 10.55214/25768484.v8i2.1082

details, including vegetation and street furniture, were heavily reduced in quality when the definition of the scene was reduced. Overall, though, a very positive response in terms of urban details realism.

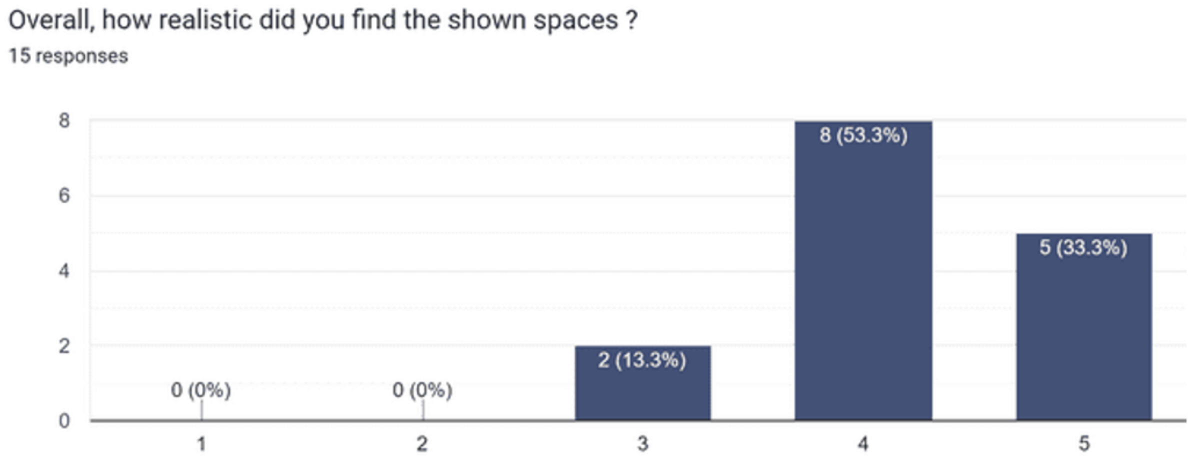

Figure 22.
Plot on the overall realism of the shown spaces.

Out of all the questions displayed so far, the one in Figure 22 is by far the most critical. The question places an overall view on the total experience of viewing scenes using the virtual reality format. This question helps give a general outlook on the realism of the experience and how immersed people felt they were when analyzing the scenes. The results were overwhelmingly positive, with not a single person believing that the spaces were, in general, unrealistc. Only 13.3% of the participants were neutral in this regard, meaning they could not decide whether it was unrealistic or not, as they probably felt that certain aspects were real and others were not. While, a whopping 86.7% of the participants felt that the experience was realistic. This strongly implies that it is possible to reproduce realism using the methods proposed by this study. To best understand which factors can be improved to aid in generating even more realism and which factors are already sufficiently undertaking their responsibilities; a comparison between the different factors displayed in the virtual tours can be made.

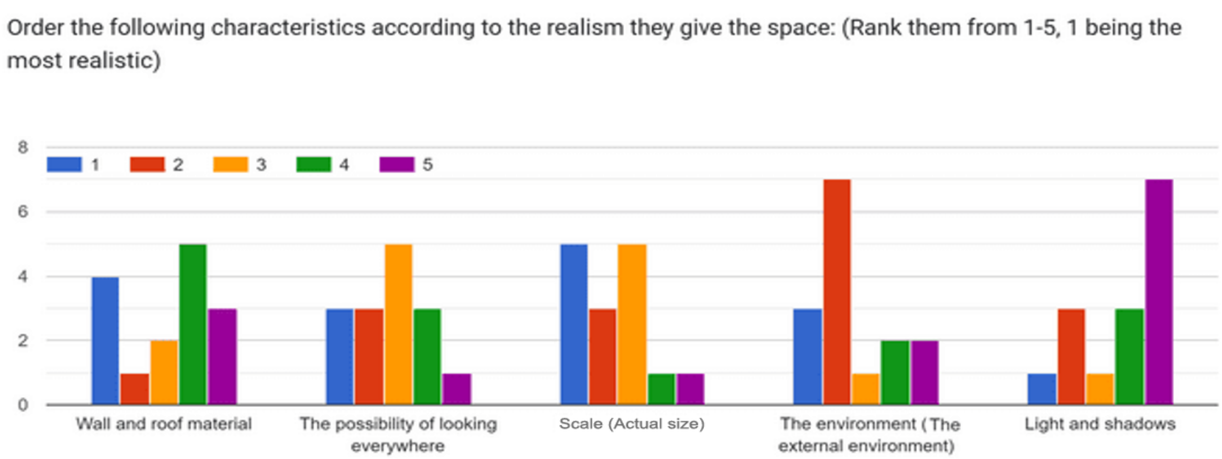

Figure 23.
Ranking the realism of each of the main characteristics.

In Figure 23, as mentioned in the question, the ones ranked 1 are the most realistic, and the ones ranked 5 are the least realistic. As this question is meant to place these characteristics in order rather than rate them, The characteristics that obtained the most realistic results are the scaling (actual size) of aspects in the scenario and the external environment (the surroundings, furniture, vegetation, urban details), meaning that these two details are already quite sufficient in the way they are produced, and people feel quite immersed when in between buildings and feeling the environment of the area. On the other hand, as expected, the worst results were achieved by the light and shadows, and once again, this goes hand in hand with the graphics reduction that had to be made. A solution to this could be to use a PC with a higher graphics processing unit to be able to maintain the ultra-quality file and read each frame fast enough to decrease lag. Additionally, on the TwinMotion forum, many users seem to be facing the same problems with their higher-resolution models, and the solution could come internally in future versions of TwinMotion.

4.3. Experimental Results on VR Experience

In an experimental field that does not have a large quantity of predecessors creating similar studies, it is essential to criticize the method in which the experiment is being carried out in order to characterize the problems that need to be modified in the future. To do so, prior to carrying out the experiment, hundreds of trials were internally completed to understand which issues and negative symptoms were common occurrences. After the trials, it was concluded that the issues encountered included some shaking of the image during tours, partial temporary loss of image, and symptoms such as nausea, headaches, eye strains, blurred vision, and loss of focus. To put these to the test, 3 questions in the questionnaire were presented to 22 participants.

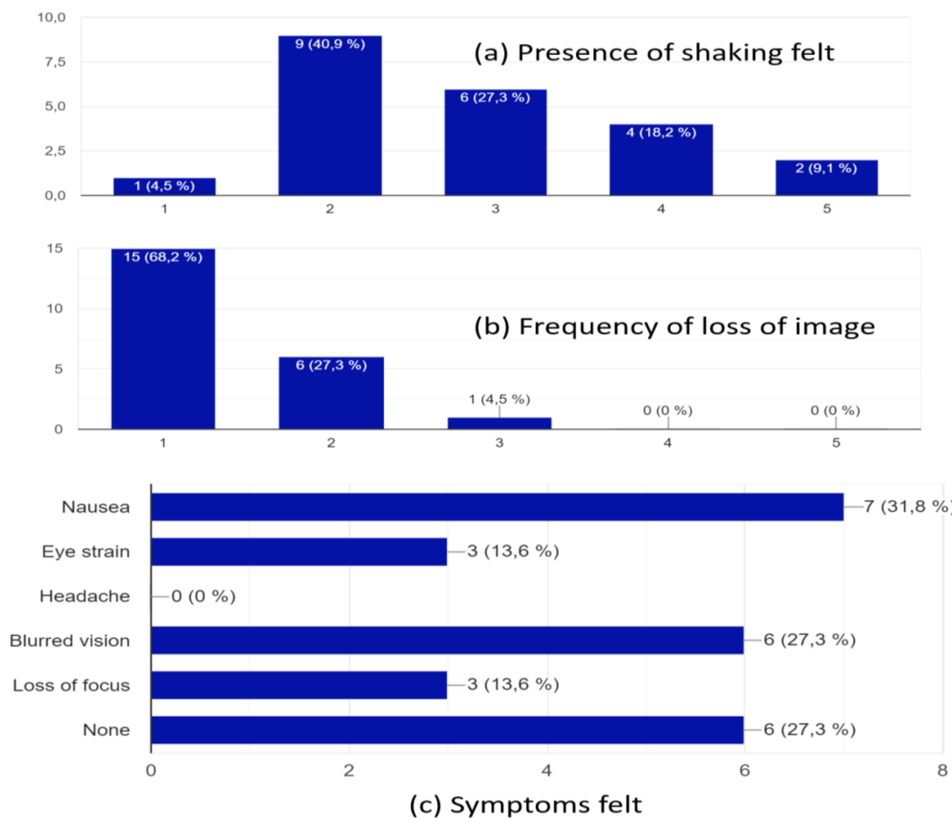

Figure 24.
Experiences felt by participants throughout the VR experiment.

In terms of loss of image, it's clear that it's not a common occurrence, as displayed in Figure 24b, as only one person cited neutrality and the rest did not feel loss of image. On the other hand, shaking was much more frequent, with 28% citing the feeling of shaking and 27% being neutral, making it common enough to be a problem, as shown in Figure 24a. This could be affecting the sense of realism, as constant shaking can take away greatly from the sense of immersivity. This sense of shaking once again is a testament to a higher technological requirement and the need for improvement from the side of TwinMotion. Additionally, many common VR symptoms were felt by users, which could have affected their sense of realism, as reported in Figure 24c. Symptoms related to eyes such as eyestrains and blurred visions were commonly cited by those who wear eyeglasses, both when removing them during the experiment and when wearing them, as the setup of the headgear is not highly accommodating for those who wear glasses, and when removing them, it is quite common to have a reduction of vision.

5. Conclusions and Perspectives

Overall, the presented study establishes the integral role of the E3S research program in contributing to the advancement of sustainable urban development, with the perfect example being the case study of LaVallée's eco-district in the suburbs of Paris. The integration of the work done by architecture, engineering and construction professionals, mixed in with the delivered access to BIM architectural plans and the integration of context, greenery, and urban furniture through a mix of Revit, Infraworks, and Twin Motion has facilitated the creation of a precise and complete 3D model of the neighborhood. LaVallée's concept as an eco-district, harmonizing streetscape and city, addresses several urban necessities and emphasizes the importance of building a pedestrian-oriented, interconnected living environment. The study's exploitation of already built sections, especially in regards to the selected points of view (residential, public, and shopping street), set the stage for experiencing immersive virtual reality visits, that can come forth to push the agenda of using VR, rather than traditional images and presentations, in order to promote realism in space auditing and design testing [13]. Thus, the research not only provides a handbook for the construction of the 3D city model, but also evaluates the quality of immersive visits through participant feedback, placing the significance of user experience and stakeholder satisfaction at the forefront of shaping the success of urban development initiatives. While the concept is effective in its own right, it does come with some gaps and limitations. First of all, to further incite more realism in the model, another step can be taken after TwinMotion, like using a software such as Unreal Engine, to provide further rendering to urban furniture and vegetation, as to make them look more realistic. Additionally, the method used to assess these areas and their realism was not perfect. As mentioned several times, shaking of the image was a frequent problem, and the reduction of the definition of the scenes created a reduction in the immersive realism. In the future, similar tests can opt to use PCs that are geared towards gaming and that are typically more accustomed to handling high definition virtual reality scenes due to their higher GPU (Graphics Processing Unit) and frame rate capacity. Moreover, it is within the responsibility of urban and architectural software like TwinMotion to continue further developing their VR option, as to allow it to be even more customizable to better fit each individual PC. Furthermore, to make the visit even more immersive, rather than having the participants survey the scene from a static position, allowing them to move around the scene could further enhance the immersive feel and give participants a better understanding of the district's future scope. Regardless, the study was a large stepping stone in prompting the creation of 3D models and displaying their use in public space auditing and design presentation. In summary, LaVallée exemplifies a blueprint for eco-districts of the future, not solely emphasizing environmental sustainability, prioritizing social and cultural integration. The experiment's multi-faceted approach, of utilizing real-world scenarios, virtual simulation, and participant feedback provides an overall comprehension of the district's dynamics and exhibits the potential for developing urban spaces that prioritize the well-being of residents and their environment alike.

Funding:
This research is supported by Excellenc ES – City FAB, by France 2030 (Grant number: ANR-21-EXES-0007).

Institutional Review Board Statement:
Not applicable.

Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Competing Interests:
The authors declare that they have no competing interests.

Authors' Contributions:
All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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