LOCAL WISDOM, 16 (1): 97 - 108, 2024
Local Wisdom Scientific Online Journal
ISSN: 2086-3764

Effectiveness of a Planning Support System Targeting Rebuilding in Immersive Virtual Environment

Yuya Yamato[1*], Taisei Osada[1], Pindo Tutuko[2], Dinh-Thanh Nguyen[3], Nurul Aini[2]
[1]*Department of Civil engineering, National Institute of Technology, Fukui College, Japan*
[2]*Department of Architecture, Universitas Merdeka Malang, Indonesia*
[3]*University of Science - Vietnam National University Ho Chi Minh City, Viet Nam*
Corresponding Author: yamato@fukui-nct.ac.jp

Abstract

Resident participation is an essential part of community development. In order to reflect residents' opinions, it is considered necessary to conduct workshop. We apply the community development guidance method (hereinafter, CDGM). The CDGM is a method that allows the replacement or deregulation of some of the regulations of the Building Standard Law by the agreement of the residents of a certain area. However, it takes a deal of time and effort to build consensus among residents, and the CDGM is to obtain their consensus. Therefore, this study is to examine effectiveness of an immersive planning support system for architectural rebuilding using virtual space and the CDGM. We believe that an immersive planning support system in a virtual environment is effective because it allows residents to enter and experience the street after the plan has been updated, making it easier for them to imagine the street. As a result, we confirmed the applicability of this technology to community briefings.

Keywords:
resident participation; community development guidance method (CDGM); virtual space; immersive planning support system.

Article History

Received	:	Jan 5, 2024
Accepted	:	Jul 7, 2024
Published	:	Jul 15, 2024

1. Introduction

Resident participation is a critical component of successful community development. To ensure that residents' opinions are reflected in planning processes, conducting workshops has become an essential approach. However, traditional workshops are often limited in scope, focusing primarily on group visualizations of drawings and plans. This method, while useful, frequently falls short in fostering a sufficient understanding among residents. In recent years, workshops have expanded to include specialized topics, such as design proposals for public spaces and streetscape regulations. Yet, a major challenge persists—there is a lack of tools that effectively support creative intellectual activities and facilitate mutual communication among participants. As a result, the process of building consensus and sharing a collective vision is time-consuming and labor-intensive.

Although various design methods have been introduced in recent years, most still rely on traditional materials, such as paper, pens, and physical models, which are often used to support intellectual activities and communication. However, these tools have limitations. Writing on paper, for example, does not always promote smooth communication due to individual differences in expression and visualization abilities. Additionally, constructing and altering physical models can be a demanding task, making revisions to plans both time-consuming and cumbersome.

In contrast, the past two decades have seen significant advancements in 3D digital tools, which are increasingly being adopted as planning support systems (Lewis & Lange, 2015; Lovett et al., 2015). These tools, particularly 3D visualizations, offer substantial benefits by providing realistic, interactive urban and geographic models. Such models are now being applied in participatory planning systems to enhance the understanding of design proposals and their impact (Jaalama et al., 2021; Virtanen et al., 2015). 3D visualizations are used to inform and raise awareness among the public and other stakeholders about the various phenomena affecting the planning area and the living environment (Eilola et al., 2023). However, despite VR's important contribution to collaboration among practitioners, for architects, immersive VR struggles to integrate with three dimensions (Portman et al., 2015).

This study takes Mikuni, Sakai city, Fukui Prefecture, Japan as a case study (figure 1). The Mikuni is located at mouth of the Kuzuryu River, which flows toward the Sea of Japan, and prospered as a port of call for Kitamae-bune ships traveling around the Sea of Japan. The urban area was formed along the Kuzuryu River. From the Taisho and Showa eras, Mikuni expanded and developed between the hills and the river.

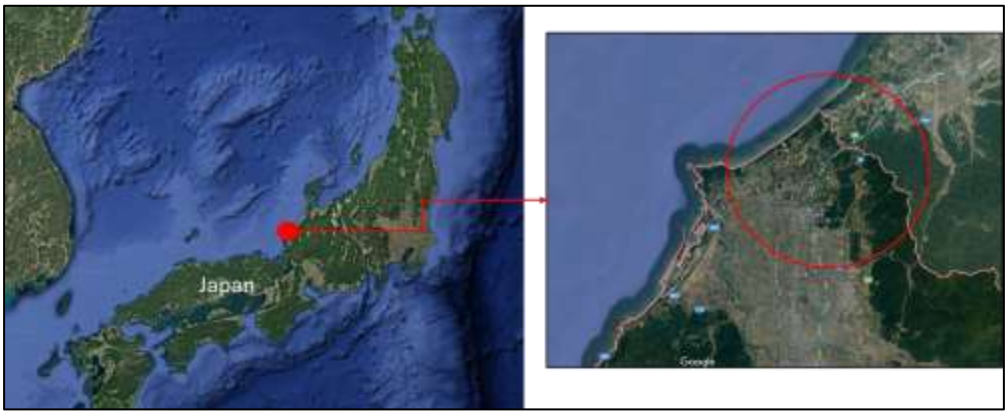

Figure 1. Case study area Fukui prefecture, Japan

The area has many remaining historic urban areas, with issues such as a concentration of narrow streets, a series of narrow lots (Figure 2). As a result, there are areas where rebuilding is difficult under current regulations of the Japanese Building Standard Law, and it is difficult to secure a certain level of living space and living environment. The Japanese Building Standard Law requires a road width of at least 4 meters for ambulances and fire trucks to pass through. However, many roads in the area are less than 4 meters long. To solve these problems, we apply the community development guidance method (hereinafter, CDGM). The CDGM is a method that allows the replacement or deregulation of some of the regulations of the Building Standard Law by the agreement of the residents of a certain area. However, it takes a deal of time and effort to build consensus among residents, and the CDGM is to obtain their consensus. Therefore, this research aims to assess the effectiveness of an immersive planning support system for architectural redevelopment using virtual reality. We hypothesize that an immersive planning support system is effective in facilitating community consensus, as it allows residents to experience a virtual simulation of the proposed street after redevelopment, thereby enhancing their ability to envision and support the planned changes.

Figure 2. Narrow streets, a series of narrow lots

2. Literature Review

There are several studies of resident participation using virtual spaces. Communication using virtual space is needed for planning, its evaluation, and the final phases of planning (Staffans et al., 2020). There are studies that utilize virtual space to evaluate the cityscape perception and the landscape to better understand it and analyze its challenges (Zhang & Zhang, 2021), and studies on resident participation using virtual space, which point to the need for greater awareness of the purpose and goals of communication to overcome the process of participatory resident participation, studies (Staffans et al., 2020). Develops a survey tool to elicit visualization and preferences for each policy, discusses the strengths and weaknesses of this survey tool, and states that it is an effective way to support the creation of normative landscape scenarios in a participatory planning process (Celio et al., 2015).

Laufs et al. (2020) present security interventions in smart cities by category. In the field of building planning, systematic reviews are recognized as a method for evidence-based practice (Hall et al., 2017). There are studies that summarize definitions and structures that allow the usefulness of 3D geovisualization, including additional abstract information, to be considered and evaluated (Bleisch, 2012), as well as studies that state that non-photorealism, as a primary technique for effectively communicating complex spatial information, provides an excellent means for visual abstraction and an excellent foundation for developing new cartographic concepts for visualizing geographic information, including exemplary city models and landscape models (Döllner, 2007). Authorities and urban professionals are expressed hesitancy to introduce Virtual Geographic Environments (VGE) into practice, and some studies are evaluated user performance when operating VGE by involving participants in common tasks performed in participatory sessions (Chassin et al., 2022). Through the public participation process, it was found that using 3D models to provide information about site conditions and planning can improve public knowledge and help them understand proposed land use plans and their impacts (Konisranukul, 2013). Takafumi et al., (2007) conducted a study on the use and evaluation of VR systems in city planning workshops. They showed that the system was effective in deepening participants' spatial understanding, deepening spatial discussion, imagining life scenes, and concretizing and sharing future visions.

There are several studies of potential future tools for planning assistance. It describes the usefulness of urban planning using virtual space and mentions that it will be effective in the future (Cirulis & Brigmanis, 2013; Yuan et al., 2023). Focused on the use of computer graphics and 3D models as innovative means of providing information, and proposed a consensus-building method for sharing information and reflecting the opinions of interested parties in the participation of local residents by creating a video based on the future image of the road space depicted by VR (Sanchez et al., 2017; Yuki et al., 2018). Eriko & Akinori, (2011) used VR to create two conflicting images of the future city of 2050. They argued that this would reduce the difference between the citizens' images of the future and the VR. Miki & Akinori (2009) created a time-staged CG animation of Utsunomiya's future image and showed that it is an easy-to-understand information provision tool.

3. Case Study and the CDGM

The A city, Fukui Prefecture, has a historical townscape. For the case study area, a "road to be widened" and "buildings to be renewed adjacent to the road (No.1 to No.17)" are designated (Figure 3). This area has a building-to-land ratio of 60% and a floor-area ratio of 160%. The surrounding road is a 2-paragraph road as stipulated in the Building Standard Law, and the purpose of this project is to widen the subject road to a width of 4 meters or more. The houses No. 7, 8 and 9 are historical buildings and will not be reconstructed. The average width of Road A is 3.1m. Therefore, the front part of houses No. 7, 8, and 9 shall be widened by 1 m on the opposite side, and the other parts shall be widened by 0.5 m on both sides. 0.5 m or 1 m road widening does not affect buildings, i.e., houses with a setback of more than 0.5 m or 1 m shall not be reconstructed. Vacant houses and garages are not renewed, and are assumed to be demolished or moved.

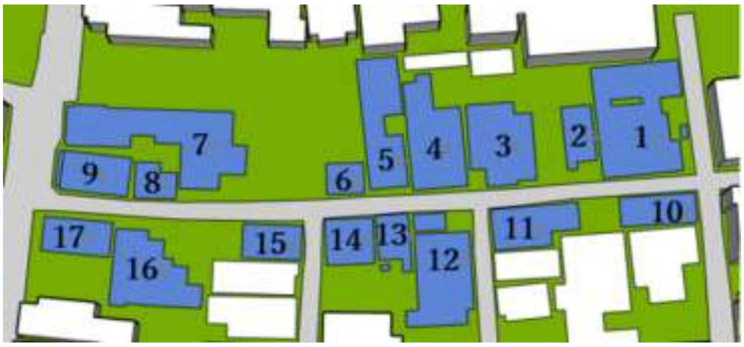

Figure 3. Outline of Target Districts

Some areas have problems such as aging buildings, low seismic and fire resistance, and narrow roads for convenient transportation and living environment. The CDGM include district planning with "streetscape guidance", "special permission for building-to-land ratio", "three-section roads", and "the system for designing buildings in rows" (a type of method for guiding community development). The special permission for building-to-land ratio allows deregulation of the designated building-to-land ratio on the condition that the wall line is designated on the adjacent land boundary side to secure lighting and ventilation, and that the wall line is designated on the road boundary side to create an integrated and continuous open space that is effective in securing functions necessary for evacuation and firefighting. The goal is to promote the renewal of old buildings by expanding the building area. The benefit of this system is the ability to maintain or expand the building area. In the area of this study, when the road is widened, the building area may become smaller if the building is reconstructed according to the designated building-to-land ratio. Therefore, it was decided that the building-to-land ratio would be deregulated through a special permit for building-to-land ratio. In this study, the building-to-land ratio is expanded from 60% to 70%.

4. 3D Modeling and Hololens Manipulation

3D modeling

(a) Before widening
To provide a clearer understanding of the road widening process, two comparative models were created: one representing the state before the road widening and the other after the widening. The streetscape was meticulously reconstructed by utilizing the exact measurements of the houses, road widths, and setback values gathered from on-site surveys. For added realism, photographs of the actual houses were applied to the exterior walls of the 3D models, ensuring that the visual representation was as close to reality as possible (Figure 4). This approach allows stakeholders to visualize the original condition of the street and understand the spatial impact of the planned modifications. By creating a faithful digital replica of the environment, the "before widening" model serves as an essential baseline for evaluating the changes brought by the project.

(b) After widening
For the after widening model, a combination of image processing and 3D modeling techniques was employed. The images were initially corrected and refined using Adobe Photoshop, ensuring that textures and details remained consistent. The 3D model was then created in SketchUp, based on the before widening model to maintain continuity and accuracy. During this process, the building area and total floor area were recalculated to ensure that both the building-to-land ratio and the floor-area ratio adhered to local zoning regulations. This means that the rebuilt structures conform to legal standards that control the density and bulk of buildings in relation to their plots. The houses in this model were reconstructed following these guidelines. It is important to note, however, that the after widening model presented in this study is merely an illustrative example of potential redevelopment. In real-world scenarios, rebuilt houses may take various shapes, sizes, and architectural styles, depending on individual preferences and further design adjustments (Figure 5).

When planning for the reconstruction of homes after widening, line restrictions must be considered. These restrictions are critical regulatory tools that dictate how far a building can extend within its plot to ensure that the residential environment remains healthy and liveable. They prevent issues such as overshadowing or poor ventilation between neighboring properties by controlling the building’s height and placement relative to property boundaries. The specifics of these restrictions can vary significantly from one area to another. In this particular area, a diagonal setback rule applies, where a diagonal line is drawn at a ratio of 1:1.25 from the edge of the street adjacent to the house (Figure 4). This ensures that buildings do not excessively block sunlight or airflow to surrounding properties, creating a balance between urban development and environmental comfort. These regulations play a pivotal role in the design of the after widening model, ensuring that the proposed reconstructions comply with local guidelines while accommodating the physical expansion of the road.

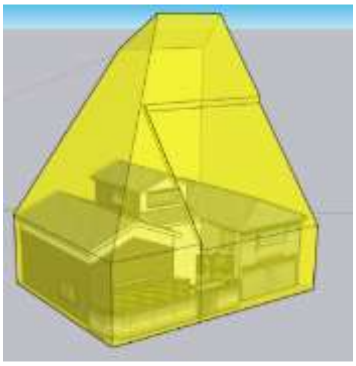

Figure 4. Line restrictions

Figure 5. 3D model of after rebuilding

3D model of the townscape

A 3D model of the townscape of the case study area before and after the road widening was created using the 3D models of the houses and the widened road (Figures 6 and 7). To make the model more realistic, plantings and utility poles were also reproduced.

Figure 6. Townscape before rebuilding

Figure 7. Townscape after rebuilding

Hololens manipulation

Microsoft HoloLens 2 is employed to set up and interact with the virtual environment. The 3D model can be viewed by opening it in the SketchUp Viewer application, which is compatible with HoloLens. This application offers two primary modes for manipulating the model: tabletop mode and immersive mode.

In tabletop mode, the digital 3D model is displayed as if it were a physical scale model placed on a surface. This mode allows the user to explore the model by walking around it, viewing it from all sides. Users can interact with the model by rotating, scaling, and moving it, much like they would with a physical object (Figure 8). This provides a highly intuitive and accessible way to examine the overall layout and proportions of the design, simulating a real-world architectural model but within a digital space.

In contrast, immersive mode places the user directly within the virtual streetscape, allowing them to explore the 3D model from a first-person perspective, as though they were physically inside the environment. By switching between a bird's-eye view in tabletop mode and the ground-level experience in immersive mode (Figure 9), users can make direct comparisons between the "before" and "after" states of the road widening project (Figure 10). This feature enables users to gain a deeper understanding of how the changes will affect the spatial relationships within the environment, including how buildings and roads interact.

The SketchUp Viewer application integrates seamlessly with HoloLens, allowing the 3D model to be projected into the user's surroundings in real-time. This makes it possible for users to visualize and interact with the model in augmented reality, enhancing their ability to assess andmodify the design. The following figure illustrates the user's view through the HoloLens, showcasing the interface and the way the virtual model is overlaid on the physical environment.

Figure 8. Townscape at Actual size

Figure 9. Townscape in virtual environment

Figure 10. Outline of townscape

5. Result and Discussion

The survey involved 100 students from the National Institute of Technology, Fukui College. These participants were asked to view the proposed urban development plan, which applied the Community Development Guidance Method (CDGM), using a HoloLens2 mixed-reality device. Following their immersive experience, participants completed a questionnaire to assess the effectiveness of the virtual presentation (see Figure 10).

Table 1 summarizes the results of the questionnaire. When asked, "Is the explanation easy to understand?" 80% of respondents gave a positive response, selecting "good" as their answer. This indicates that the use of immersive technology, such as HoloLens2, successfully enhanced the clarity of the proposed plan. Additionally, 90% of respondents answered "good" to the question "Do you understand the technology?" This suggests that the majority of students were able to comprehend the underlying technology used in the virtual presentation, demonstrating the ease of use and accessibility of HoloLens2 for non-experts in technical fields.

A key observation from the survey is the higher percentage of respondents who considered this technology necessary for future community briefings, particularly when compared to the question, "Do you think the residents will understand at the presentation?" This indicates that the participants recognized the potential of HoloLens2 and virtual simulations to effectively communicate complex urban planning concepts to the general public. The favorable response also underscores the importance of incorporating advanced visual tools like mixed-reality technology in engaging and educating community members during planning processes.

Initially, the study aimed to test the proposed plan on actual residents of the area by allowing them to experience the simulation using HoloLens2. However, due to the restrictions imposed by the COVID-19 pandemic, the project had to be conducted online. In the online survey of residents, some concerns were raised regarding the feasibility of the road-widening proposal, particularly in relation to budgetary constraints and long-term planning considerations. These concerns highlight practical challenges that need to be addressed when introducing new urban infrastructure projects.

Despite these concerns, more than half of the residents responded positively to the question, "Is the explanation easy to understand?" This suggests that even in an online format, the immersive technology was effective in improving residents' understanding of the proposal. Furthermore, a significant proportion of respondents agreed that this technology would be beneficial for future community briefings, particularly for presentations aimed at explaining complex urban development plans to non-expert audiences. This confirms the potential applicability of HoloLens2 and similar immersive planning tools in facilitating public engagement and consensus-building during the urban planning process.

Figure 11. Experiment in virtual environment

Table 1. Result of experiment(N=10)

	Good	**Slightly good**	**General**	**Slightly bad**	**Bad**
Is the explanation easy to understand?	80%	0%	10%	10%	0%
Do you understand the technology?	90%	10%	0%	0%	0%
Do you think the residents will understand at the presentation?	70%	20%	10%	0%	0%

Is the 3D model of the town easy to understand?	70%	30%	0%	0%	0%
Would you like others to know about the techniques?	90%	10%	0%	0%	0%

6. Conclusion

In this study, we attempted to develop a planning support system by simulating the rebuilding of a historical area as a case study, considering the application of the CDGM, and displaying the created 3D model in a virtual environment. Moreover, if this research is implemented in society, it is thought that local governments will be able to efficiently hold explanatory meetings for residents, which will lead to the formation of consensus with residents. In addition, some residents pointed out budgetary concerns and the feasibility of widening the road in the survey. In this case, the width was widened to at least 4 m to allow for the passage of ambulances and other large vehicles. However, in the event of an earthquake or other disaster, consideration must also be given to whether the width will allow large vehicles to pass through and whether residents will be able to evacuate. It is a big decision for residents to renew their buildings. Therefore, in order to promote rebuilding, appropriate evidence and data are needed, and this research should be carried out together with disaster simulation and evacuation planning.

Acknowledgement

This study is supported by the Hokuriku Regional Management Service Association.

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