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Virtual Space and Reality Experiment Systems for "Human-Dimensional" Downtown Planning and Design

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1 ABSTRACT

With the digital transformation that contributes to the urbanism of the human dimension proposed by Jan Gehl, the authors discuss a framework with two pillars of information infrastructure that have emerged recently: mobile-phone location data and three-dimensional (3D) spatial open space data. In recognition of this, we report on research into two experimental systems, namely, virtual space and virtual reality, that use 3D spatial models. The former discusses the primary performance of the experimental system based on a gaming experiment of stopping behavior in the Osu district, a traditional shopping area in Nagoya City, with and without a plan to convert the area into a mall. The latter is a simulation investigation of the effect of signs on wayfinding using the "visibility" parameter from the virtual reality experiment as a vision-driven agent.

Keywords: vision-driven agent, Virtual Reality, Virtual Space, human dimension, digital twin

2 INTRODUCTION

The human-dimensional urbanism that Jan Gehl advocates in "Cities for People" criticizes the lack of consideration for the small and middle scales in urban planning and design that emerged because of the modernism movement and suggests a process that begins with a survey of people's activities, followed by space planning and then architectural design (Gehl, 2012). The methodology emphasizes a small-scale design through an activity survey before space planning. However, the activity survey is a "one-shot" survey conducted by a survey team, and the space design is mainly by hand-drawing, a traditional practice established in the 20th century.

Currently, the digital twin of the 21st century is making "high-frequency" sensing possible in each large-/middle-/small-scale aspect of urban space in principle, and an ecosystem by mushroomed internet of things is being formed. Among these, the authors focus on mobile-phone location data (MPLD) and three-dimensional (3D) spatial open data as new urban information infrastructures. MPLD offers basic statistics on the density of human activity in urban environments from the large to middle scales, such as downtown areas, where statistics have hitherto been unavailable. In addition to Virtual Singapore and Smart City Zurich, the Japanese government's Project PLATEAU has become the leading project.

In this study, we discuss a digital twin framework based on the two pillars of MPLD and 3D spatial open data, with a view to the digital transformation that contributes to urbanism in the human dimension as proposed by Jan Gehl. Section 4 outlines the virtual space experimental system using the Osu area, a traditional shopping district in Nagoya City, as a case study, followed by a confirmation of the basic performance of the system through a "shop-around behavior" experiment and the findings from the experimental procedure. Section 5 outlines a simulation analysis of the effect of signage in a wayfinding situation using the "visibility" parameter (sign detectable ratio) taken from the virtual reality (VR) experiment as a vision-driven agent. In conclusion, the differences between the two experimental systems and their further research development will also be discussed.

3 FRAMEWORK OF DIGITAL TWIN TECHNOLOGIES FOR "HUMAN-DIMENSIONAL" MID-SCALE PLANNING AND DESIGN

To the author, the digital twin of urban planning appears to have two sources. One is the tradition of urban simulation, as discussed by Micheal Batty. From a macroscopic urban planning perspective, one might describe the actual system and its virtual model as "twins" because of the unprecedented level of detail in the spatial elements. Nevertheless, one should remember that in model theory, they are only "homomorphic" in their relationship.

The possibility of a wide variety of sensing systems with high frequencies (short time slice) can be combined in a low-frequency (long time slice) urban simulation model in socio-economic fields, as discussed by Batty (2018) as “frequency.” This opens up the possibility of various compositions that have not been fully explored.

The second is the possibility of viewing the virtual system as a new participatory experience tool, as the Yamu group discussed in a case study in Herrenberg, as an environment for citizens’ “creative” participation and “visioning” experience (Dembski, Wössner & Yamu, 2019). Visioning, in particular, is a process by which urban society creates one of several possible visions of the future. Although they are mirror images, they are more reminiscent of a “metaverse” than a “twin.” However, from the perspective of planning theory, this possibility should be pursued no less than the other.

The framework of the authors’ digital twin technologies is shown in Figure 1. The MPLD above is attractive for its abundance of data, which more than compensates for the current lack of location accuracy of personal cellular phones. It provides basic statistics on the density of people’s activities in urban spaces from the large scale to the middle scale, for which there were no formal statistics before. For details, please refer to other articles (Kaneda, Ota & Zhang, 2022; Ota, Takahashi & Kaneda, 2021).

The 3D spatial data for planning and design in the middle scale, which is the focus of this paper, were easy to obtain in the past. However, significant progress has been made in developing various BIM cloud-sourced open databases. Virtual Singapore and Smart City Zurich 2018 are pioneering examples and offer great urban planning potential, especially for citizen participation (Schrotter & Hürzeler, 2020; Virtual Singapore, 2018).

The Japanese government’s Ministry of Land, Infrastructure, Transport, and Tourism’s PLATEAU project is a national policy project that will be launched in 2020 and that has presented standard specifications for CityGML covering not only buildings but also terrain, roads, and urban facilities, intending to develop urban spatial data in Japan. It has also made remarkable progress in providing city governments with digital data for primary urban planning surveys based on the Urban Planning Act (Project PLATEAU, 2020).

Next, we will discuss our methodology for planning and designing middle scale urban spaces in the 21st century, which is established through the development of MPLD and 3D spatial data. The systematic data science that deals with the relationship between middle scale urban space and user behavior is an attractive theme for the authors.

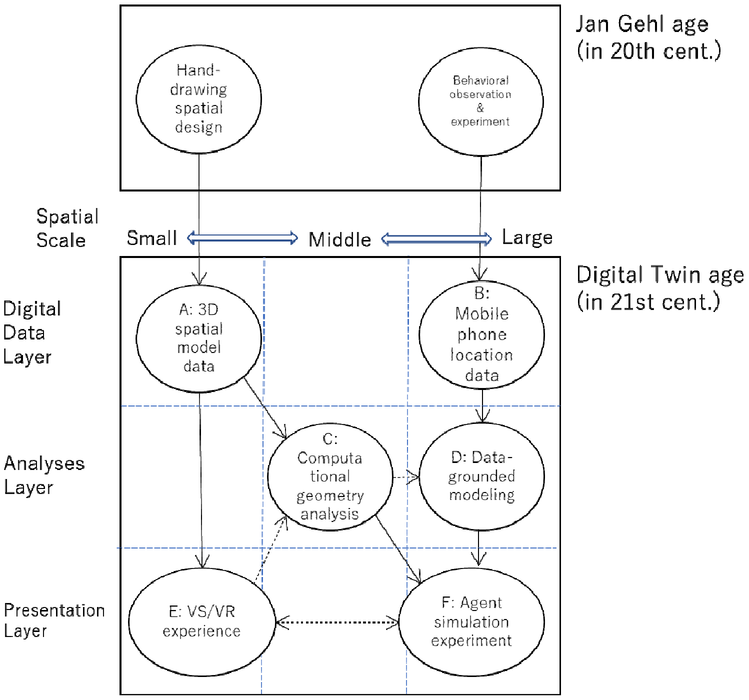


Fig. 1: A framework of digital twin technologies for human-dimensional downtown planning and design.

Space Syntax from UCL, which works with the interaction between user behavior data of urban space and visual data of the built environment, is one of the scientific methods that we have been focusing on. The rise of Space Syntax as a universal urban science in the 21st century is partly due to the widespread use of computational geometry that combines network theory, such as visibility graph analysis and agent analysis (Turner, 2001; Turner & Penn, 2002; Turner et al., 2001). The author's research has also confirmed the contribution of urban form factors to the number of pedestrians on the streets. However, new data science requires an easy-to-understand 3D extension methodology.

Section 4 of this paper deals with the possibility of a virtual space and VR experimental system that contributes to downtown planning and design research by creating and using 3D spatial data. This system enables us to efficiently explore the direction of the "future environment" desired by people and its specific image by collecting and analyzing the user's subjective sense of liveliness and behavioral data in the virtual space under certain experimental conditions. The experiment conducted by the authors in the Osu district, a shopping district in Nagoya City, is still in the primary stage of comparison with actual data. Nonetheless, the experiment's core functionality, such as behavior prediction and consumer attractiveness, has been proven. The Osu district is a "human-dimensional" shopping district. It is being developed in much greater detail than the LOD1 provided by Project PLATEAU, and it is necessary to proceed while incorporating issues from CG research, including the uncanny valley.

The invention of EVA by Turner & Penn (2002) was the invention of the vision-driven agent model, which has great potential as a tool to "constructively" examine the influence of visual-spatial characteristics such as wayfinding behavior simulation. The authors have been working on the development of VD18s, VD19, and VD22 as agent models for use in 3D spaces, as shown in Section 5 (Kaneda et al., 2019; Maekawa et al., 2022).

Among the behavioral measurements by the virtual space and VR experimental systems, the authors focus on the easy use of the eye-tracker system. Currently, urban behavior analysis has been constrained by the premise that "attention is a resource," as stated by H. A. Simon and later, but the eye-tracker system opens the door to measuring the micromotive behavior of subjects through microbehavior. These possibilities will stimulate research in multiple directions, and in Section 5, the authors report their use in refining vision-driven agent modeling.

Section 5 of this paper discusses a case study of the wayfinding behavior of a 3D conical vision-driven agent, in which "visibility data" obtained from a VR environment experiment were used as a parameter to reproduce the wayfinding behavior in a subway station, and the assessment by sign layout setting was analyzed.

4 VIRTUAL OSU: VIRTUAL SPACE EXPERIMENTAL SYSTEM IN THE CASE OF DOWNTOWN OSU

4.1 Aim for Virtual Osu

The Osu district is a 400-m-long, 600-m-wide shopping district with 1,200 shops comprising mainly small-scale stores positioned south of Wakamiya Odori Street, midtown of Nagoya City. This area, which combines numerous temples and commercial streets, can rightly be called the highlight of the Chukyo area (population of approximately 10 million in Aichi, Gifu, and Mie prefectures) that constantly attracts diverse customers, including men and women of all ages, with its fascinating "hotchpotch" of the old and the new. As the features of this area, there are nine shopping streets with a grid-like shape layout, each of which attracts specific customers with a characteristically detailed shop configuration. There are 20,000 visitors per day on weekdays and 30–50,000 on weekends and holidays, and foreign tourists have been visiting recently. This is also the district where the authors have continued their research for more than 20 years (Kaneda, 2020).

In this section, Osu's virtual space experimental system is created and actual performance related to the detailed design of shopping mall facades, among others, is confirmed through an experiment on stopping behavior with and without a test mall plan.

4.2 3D Spatial Model of Osu

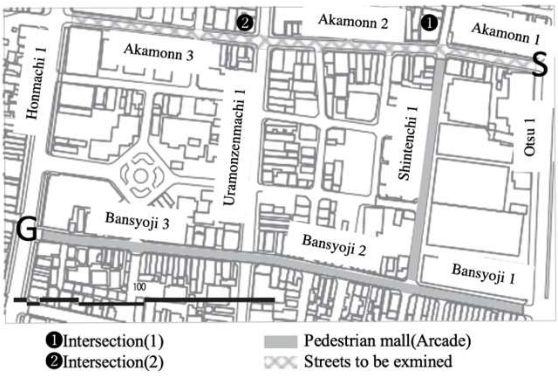
On the basis of the literature (Gehl, 2013a, 2013b), the system functions and spatial model introduced to measure urban attractiveness and comfort in the human dimension are shown in Table 1. Figure 2 depicts the size of the Osu region that this study specifically addressed. The Akamon-dori, Otsu-dori, Shintenchi-dori, Uramonzenmachi-dori, Honmachi-dori, and Banshoji-dori collections of street portions from six different streets were used as the unit area for the virtual space experiment. Unity ver2019.2.8f1 was used to construct the virtual space experimental system (Kino et al., 2020). A spatial model of the existing street and a street believed as a pedestrian mall on Akamon-dori was created. The virtual space model was modeled in Rhinoceros based on real-space, and textures were applied by UV mapping in Maya. The virtual space model used in the experiment was based on actual measurements, and the level of detail was equivalent to level of details (LOD) 3 in CityGML (Hirate, 2020). Before and after Akamon-dori was transformed into a pedestrian mall, the facade of buildings along the street remained unchanged. The experimental area’s dimensions, street’s width, and positioning of the buildings were based on Osu Street’s real dimensions, with a 7.5-m maximum height for each structure.

A plan and a cross-section of the street where the pedestrian mall was studied are shown in Figure 3. Examples of street components and dimensions are depicted in Figure 4. The subject’s walking speed was set to 3.0 m/s at full speed and 1.5 m/s at half speed. The subject’s position in the virtual space was recorded every second as coordinates, and the walking path trajectory was recorded by outputting a csh file. An eye mark was used to capture eye movement, and the monitor’s gazing point was produced as two-dimensional coordinate data.

System functions	Evidence from Jan Gehl’s references	Number
Walking trajectory	General knowledge of gait patterns can be obtained.	2) p. 39
Optional activities	City quality is so crucial for optional activities.	1) p. 134
Walking speed	Pedestrians usually walk faster on streets that invite linear movement, and their pace falls while traversing squares.	1) p. 120
Eye Movement	Heads move from side to side, and walkers turn or stop to see everything.	1) p. 120

Spatial models	Evidence from Jan Gehl’s references	Number
Steet components	Street patterns, the design space, rich detail, and intense experiences influence the quality of pedestrian routes and the pleasure in walking.	1) p. 129
Facade	The quality of the ground floors is so crucial to a city’s overall appeal.	1) p. 81

Table 1: Desired functions and their sources of the virtual space experimental system. 1) Gehl (2013a), 2) Gehl (2013b)



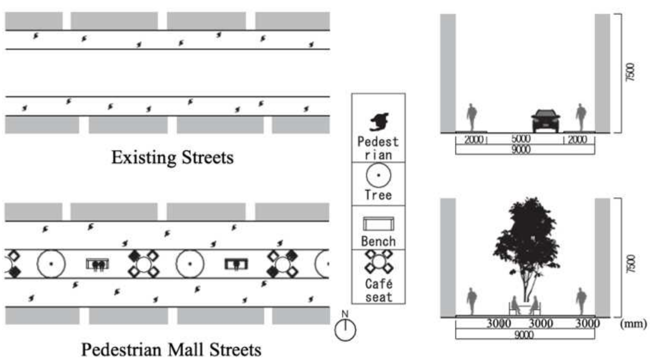


Fig. 2: Osu area targeted for the virtual space experimental system. Fig. 3: Plan and cross-section of Akamon-dori.

Fig. 4: Examples of street components and dimensions.

4.3 Virtual Space Experiment

This experiment was designed to explore the factors of passing/stopping behavior and awareness evaluation by having the subjects walk through the unit space of the investigation (Figure 2) with and without the pedestrian mall on Akamon-dori under the experimental conditions. A walking experiment was conducted from the east end of Akamon-dori to the west end of Banshoji-dori to evaluate the effectiveness of the experimental system (marked S to G in Figure 2). The experiment's summary is shown in Table 2. In the experiment, we took up unscheduled stopping behavior, which is one of the optional activities in shopping areas. We implored the participants to stop at a store and take a picture. After completing the walk, the participants watched a video recording of the experiment. They conducted an impression assessment and a post-experiment questionnaire (Kozaki et al., 2017; Ministry of Land, Infrastructure, Transport and Tourism, Government of Japan, 2020). Thereafter, the same walking experiment was conducted on the designated streets. Fifteen subjects were tested in the existing Osu area. Then, five subjects were tested in each case of low (0.047 persons/m²), medium (0.133 persons/m²), and high (0.218 persons/m²) pedestrian density on a street that was created to be a pedestrian mall on Akamon-dori. Figure 5 depicts the space in the four instances. Additionally, pedestrian density was a requirement for the trial as a factor affecting awareness.

(A) Walking trajectory recordings: Figure 6 depicts the route choice rate and the number of pedestrians at intersections (1) and (2), following the walking route trajectories recorded in the experiment. At both intersections (1) and (2), the route choice rate of Akamon-dori increased because of the conversion to a pedestrian mall.

(B) Optional activities: Subjects were asked to stop at stores and take pictures as optional activities during the walk. The experiment's outcomes were calculated and written down. The individuals in the investigation's walking path trajectory records of the store stops and images are displayed in instances in Figure 7. The number of alternative activities per person at locations in retail districts is shown in Figure 8. Streets with a sample size of four or larger were selected, and the number of store stops and the number of photographs taken were tabulated. The subjects' head movements when selecting a route and product and their shopping search behaviors were observed when they stopped at stores. Product search and shopping behavior were mainly observed in the subjects' gaze toward the street components that made up the building facades and store product shelves. Optional activities were more common in Akamon 3 and Shintenchi 1. This is due to numerous open facades and the high density of stores. The number of optional activities was low in Akamon 2 and Honmachi 1. This is because some buildings are under construction and several of the facades are closed because of the sparseness of the facilities.

Date	Nov. 9–13, 2020	**Subject**	15 engineering students
Method	(1) Practice of spatial cognition in virtual space. (2) Conduct a virtual space experiment (screen recording and action logging will be conducted at the same time as the start of the experiment). (3) Evaluate impressions of the streets while viewing the recorded images and conduct a post-experiment questionnaire.		
Assumed situation	(1) Visiting alone to accomplish an errand with no time constraints. (2) Going through the main street. (3) Look at a map and know the location of the destination in advance. (4) Permission is granted to go sightseeing at your own discretion while heading to your destination.		
Cases	Existing case/pedestrian mall case of Akamon street with pedestrian density (low/medium/high).		

Table 2: Virtual Osu experiment.

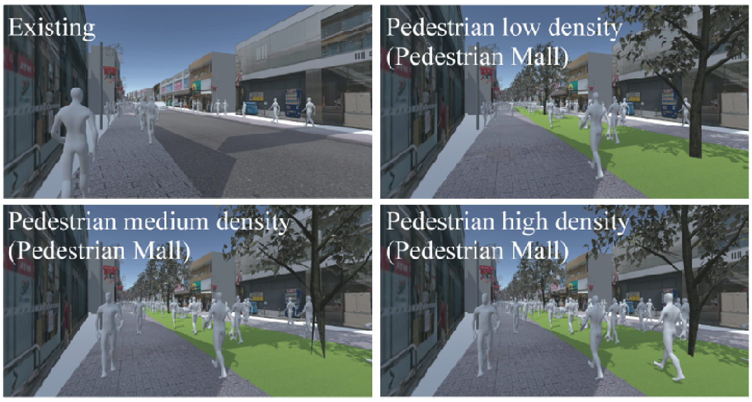
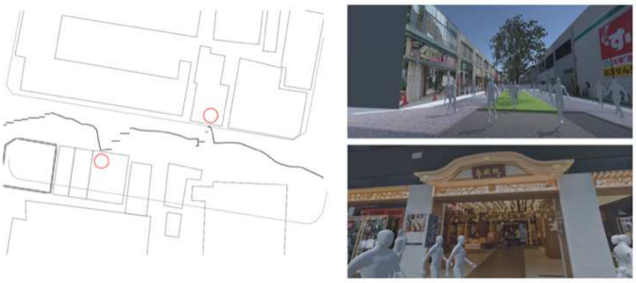


Fig. 5: Space in the four cases used in the experiment. Fig. 6: Route choice rate and the number of pedestrians at intersections.



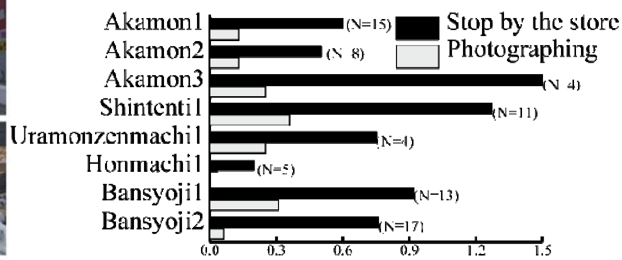
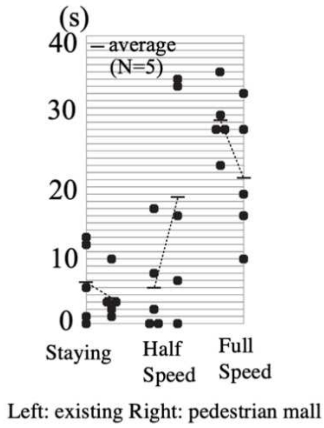


Fig. 7: Examples of recorded store stops. Fig. 8: Number of optional activities per person at shopping district sites.

(C) Walking speed: The walking speed at Akamon 1 is depicted in Figure 9. The distance traveled by the subject per second was calculated from the coordinate data that recorded the subject’s position in the experiment. A speed of 2 m/s or more was given full speed, 1 m/s or more but less than 2 m/s was considered half speed, and less than 1 m/s was considered stopping. The half speed time tended to increase and the full speed time tended to decrease on the streets converted to pedestrian malls compared to the existing streets. It is assumed that the pedestrian mall has increased the number of streets that people want to see at a leisurely pace. Conversely, stopping time decreased. This may be because the system has lost its novelty and the subjects have become more adept in the gaming operation.

(D) Eye movement: Subjects’ eye movements were recorded as eye marks from the video recorded in the experiment. The number of eye movements at Akamon 1 is shown in Table 3. The eye marks registered in the experiment were recorded as the gazing zones shown in Figure 10, which are located in the street components. The streets were categorized into five zones: the sky above, left wall, right wall, road surface, and the back of the street toward travel. Then, the wall was classified into gazing zones for each store, and the road surface was categorized into three zones. In addition to the gazing zones, gazing at street components was recorded separately. Then, 20-s eye mark positions were recorded every 0.3 s, and the number of eye movements was tabulated. On the pedestrian mall transformed streets, the number of eye movements rose higher than that on the previous roadways. The pedestrian mall is claimed to have increased the number of attractions on the route.



Subject	Existing	Pedestrian Mall	Difference
A	30	38	8
B	27	27	0
C	25	28	3
D	19	27	8
Average	25	28	3

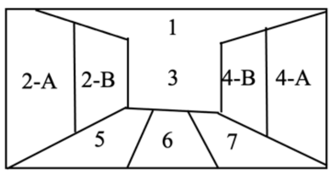


Fig. 9: Time per walking speed. Table 3: Number of eye movements in seconds at Akamon-dori. Fig. 10: Gaze zone position.

(E) Impression evaluation: at the end of the walk, the participants completed an impression evaluation questionnaire while watching a video recording of the experiment. Figure 11 depicts the impression evaluation of the four instances at Akamon 1. Pedestrian mall streets received higher ratings in all situations, particularly on high density streets. The low score for “Have good visibility” may be due to the large number of pedestrians obstructing visibility. The low scores in the “Want to walk” category are thought to be because people do not want to walk on streets with too many pedestrians. Additionally, the “Adequate sidewalk width” was significantly improved by the pedestrian mall conversion, which means that dissatisfaction with the existing sidewalk width was eliminated. Medium density was the highest for “Adequate traffic volume,” which means that respondents felt that neither too many nor too few pedestrians were adequate. Although the facades did not change before and after pedestrian mall conversion, pedestrian density and pedestrian mall conversion may affect the impression of neighboring buildings as pedestrian mall-converted streets tend to be rated higher in the items related to surrounding buildings as well. The impression ratings for each street are shown in Figure 11. The reason for the higher assessment of the Honmachi-dori in the items related to street composition can be attributed to the presence of trees as street components and wider sidewalks. Shintenti-dori and Banshoji-dori received high ratings for surrounding buildings, possibly due to the full-cover arcade and dense store density. The low evaluation of Uramonzenmachi-dori in the "Want to walk," "Want to stay," and "Want to come back" categories are thought to be due to the street's low attractiveness. The increase in the selection ratio of Akamon-dori above is believed to be due to an improvement in the impression evaluation.

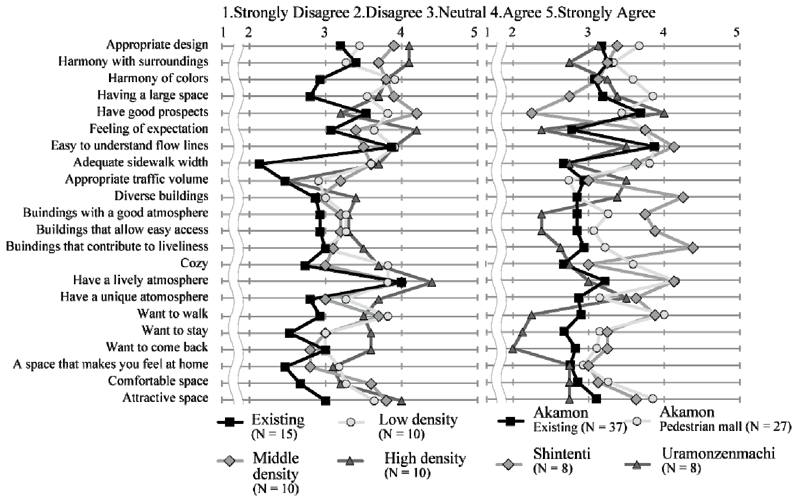


Fig. 11: Impression evaluation at Akamon-dori and on each street.

4.4 Further Development Directions

The virtual space experimental system's repeatability and operability will be improved in the future.

On the basis of the above research, future work will include constructing a system for VR experiments to acquire behavioral sequences such as eye and head movements in shopping district spaces. The objective is to clarify pedestrians' dynamic spatial awareness and to help in creating an urban area with a rich walking experience. Using the Osu shopping district as the research target, we will analyze the impact of pedestrian flow and density on people's route choices and behavior.

The analysis will be conducted from two axes: an actual space experiment and a VR experiment. In the real-space experiment, subjects will be asked to walk in the actual Osu shopping district as a preliminary experiment and their behavior logs will be obtained. The VR experimental system will be built based on the real-space investigation. A spatial model of the simulated case will be produced, and the subjects will be requested to walk in the same manner. As a behavior log, we will record the travel trajectory, starting spots, time, and optional activities and locations. We are also planning to analyze the behavior factors based on the records using a questionnaire survey.

5 VD22: COMBINATION STUDY BETWEEN VR EXPERIMENT AND VISION-DRIVEN AGENT SIMULATION

5.1 Introduction

Because the guide signs show the destination information, the layouts of the guide signs will affect the pedestrians' wayfinding behavior in subway stations. This part proposes a vision-driven pedestrian agent model VD22 that simulates the pedestrians' wayfinding behaviors on a three-dimensional walking surface by detecting signs, which can help the urban designers and managers evaluate and improve the layouts of the guide signs. A VR experiment was conducted to measure the internal parameter, sign detectable ratio, for introducing the model VD22. Finally, the efficacy of the VD22 model was confirmed by comparing the agent simulation results with the VR experimental results.

5.2 VR Experiment

We selected the Oasis 21 Square, which includes two subway stations and an outdoor square space. An immersive virtual reality environment was built on Unity (ver2019.2.8f) to design the VR experimental system, in which the spatial and temporal data can be recorded in real time. Using the VR equipment with an eye-tracking function, the participants' gaze points can also be recorded. The subjects were divided into two groups of 30 architectural students. Each participant was required to complete three tasks. The participants in the experiment had a first-person perspective and could move and rotate in the visual space using the VR controller.

We calculated the sign detectable ratio proposed by Iwata et al. (2013) and Gu et al. (2015) based on the calculation method of the sign detectable ratio in the horizontal and vertical directions in a hemisphere area. We also examined the read ratio of each sign and the walking trajectory of the pedestrians. The results showed that the pedestrians' walking trajectory was directly related to sign recognition. This demonstrates that an appropriate layout of guide signs will quickly and accurately guide the pedestrians to their target destinations.

5.3 VD22 Pedestrian Agent Model and Agent Simulation

Vision-driven pedestrian agent models, namely, VD18s (Yokoyama et al., 2020) and VD19 (Maekawa et al., 2021) built by our laboratory based on the EVA model (Penn et al., 2002), are vision-driven agent models that detect the sign and perform the wayfinding behavior according to the sign information direction. Model VD19 encoded the ratio as a sign detectable probability measured by Iwata et al. (2013), which achieved the wayfinding behavior by detecting signs in three-dimensional space. However, owing to the constraint of sign detectable ratio in vertical directions, model VD19 could not move on three-dimensional surfaces such as stairs and slopes.

VD22, a 3D vision-driven agent, is an enhanced version of agent model VD19. Agent model VD22 was built by importing the sign detectable ratio measured in the VR experiment. It approaches its move on the three-dimensional walking surface by accurately detecting signs in vertical directions. Agent model VD22 always follows guide signs to its destination. It will perform a natural movement requiring the direction of the deepest sightline without detecting a sign. It moves at a walking speed of 1.0 m/s, which reduces to 0.75 m/s when moving on stairs and slopes, and decisions are made at 0.3-s intervals with a constant probability. The spatial and sign recognition by agent model VD22 and the dimensions of the visual range used in agent model VD22 are shown in Figure 12.

We implemented agent simulation 100 times of Tasks 1 and 2 (both are approximately 100 m of unmanned subway transfer corridor, including stair climbing), each using our new agent model VD22. Compared to the VR experiment, the agent model maintained a constant speed throughout the process, except for some pauses and deceleration during sign recognition. Regarding the walking trajectory, it was generally straight compared with the results of the VR experiment.

5.4 Comparison of the Simulation and VR Experimental Results

To compare the walking trajectory between the VR experiment and agent simulations, we established three patterns for each task and determined the proportions of the patterns in Tasks 1 and 2. The findings demonstrate that the proportions of the patterns in Tasks 1 and 2 simulation results are highly comparable to those in the VR experiment, which confirms our new agent model VD22, and the sign detectable ratio determined in the VR experiment and encoded into agent model VD22.

An analysis of variance was used to determine the difference in walking distance and time of the results between the agent simulations and VR experiments for Tasks 1 and 2. There is no significant difference in walking distances in Task 1 (p-value > 0.05) and Task 2 (p-value > 0.05). However, in terms of walking time, there was a significant difference in Task 1 ($F = 7.7$, p-value < 0.001) and Task 2 ($F = 5.2$, p-value < 0.001). The VR experimental results are significantly longer than the simulation results, which is linked to the following two factors:

a) The VD22 model is incapable of detecting pauses and deceleration.

b) The participants were unfamiliar with how to move using the VR controller, which led to some time spent during the experiment.

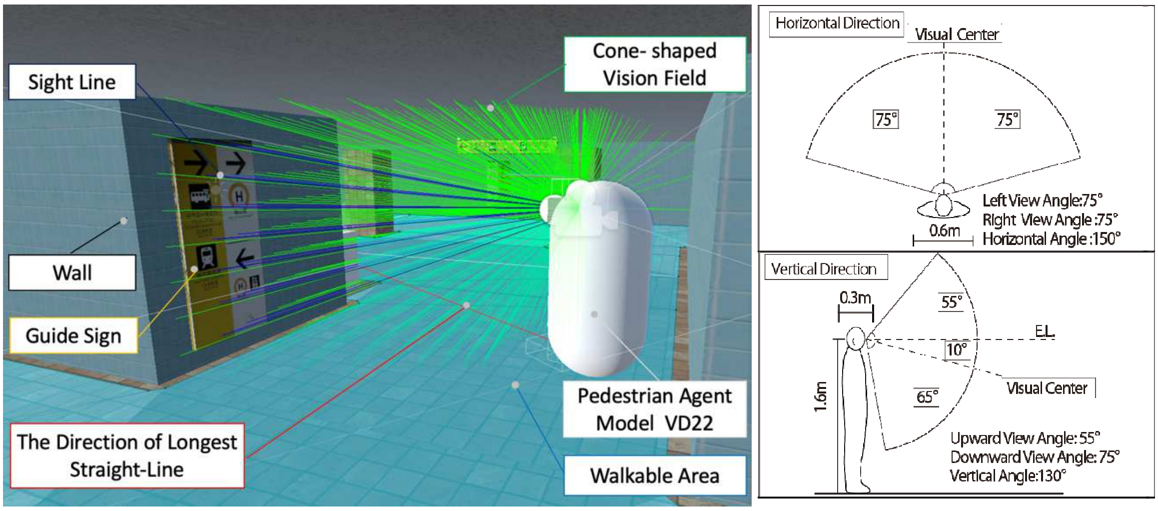


Fig. 12: Spatial recognition and sign recognition (left) and the dimensions of the visual range of agent model VD22 (right).

5.5 Summary and Future Work

We built a vision-driven agent model VD22 to simulate the pedestrians' wayfinding behavior by detecting guide signs, which will help the urban designers and managers improve the layouts of guide signs in subway stations. A VR experiment was conducted to obtain the internal parameter, sign detectable ratio, in the horizontal and vertical directions. Our new agent model, VD22, can perform a wayfinding behavior on a three-dimensional walking surface. Finally, the effectiveness of the VD22 model was validated by comparing the results of agent simulation and VR experiments.

The VD22 model was created at a barren metro station. Future studies might benefit from an agent model that handles stops and decelerates under varied pedestrian concentrations. To identify the parameters for the new agent model, an examination of guide sign identification and pedestrian wayfinding behavior at different pedestrian densities will be necessary.

6 CONCLUSIONS

In this paper, we positioned virtual space and VR as significant digital twin technologies that contribute to human-dimensional urbanism and reported on the research of two experimental systems in which the authors were involved. This digital twin was triggered by two IT innovations, namely, the mobile-phone location and 3D open data, and is the confluence of two different sources: urban simulation and participatory experience tools.

Virtual Osu, described in Section 4, is a virtual space environment based on a 3D model of the Osu shopping district. Its fundamental performance as a virtual space experimental system was demonstrated through a gaming experiment conducted as a mall planning and design case study. The concepts of walking trajectory, optional activities, walking speed, and eye movement can be treated as the "human dimension" mentioned by Gehl. The analysis of the subjects' spatial behavior in the virtual space was confirmed to simulate their actual behavior by comparing it with the data of their actual shop-around behavior obtained from the questionnaire survey. The factor analysis using PLS regression obtained the effect analysis on the facade's details. Nevertheless, owing to space limitations, the report will be left to the next issue (Hirate, 2021).

For the sign layout problem described in Section 5, we measured the sign detectable ratio in human sign recognition using VR experiments, conducted a vision-driven agent simulation with these parameters as input, and confirmed its reproducibility. Virtual space and virtual reality require many 3D building models, but VR is characterized by conversion to viewpoint-centered coordinates using immersive VR goggles. It is also capable of unprecedented micromotive analysis, such as eye movement, opening the way for innovative future exploratory research. These combinations of the elemental technology of this digital twin stimulate remarkable research.

7 ACKNOWLEDGEMENTS

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