Effectiveness of Activity Expression in VR System to Build Consensus for Public Space Planning

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Abstract: The objective of this study was to clarify the effectiveness of expressing activities in a virtual reality (VR) system for public space planning to support consensus building with citizens, based on the idea that it is important to consider people’s activities when creating attractive public spaces. We constructed a VR system comprising a background expressed in 3D computer graphics (3DCG) and activities expressed in real video image. As a result of the evaluation experiment, it became easier to visualize the utilization of space by expressing an activity. Although its effectiveness was clarified, some problems regarding the functioning of the system were highlighted.

Key words: Public space, activity, consensus building, virtual reality, simulation.

1. Introduction

1.1 Background and Purpose

Public spaces, including public land such as roads and plazas, and private land, such as open spaces, that are created by developers so that bonuses like floor area ratio and building height regulation can be obtained are not attractive and are not widely used by people. This occurs because of top-down development by the administration and businesses, accompanied by a lack of consideration for people’s activities. Gehl [1] highlighted that the activity of people in a city is one of the important attractions of the city. In February 2020, the Japanese Road Law was revised, and a road law was enforced to create a lively road space where pedestrians could pass and where their safety and comfort was ensured. In Japan, thus far, roads have been considered primarily for traffic, but for the first time, pedestrian activities on the road have been considered. Therefore, there is a growing social interest in making public spaces high-quality spaces centered on human activities rather than efficient public space. As the consumption style of urban dwellers changes with the development of electronic commerce, the role that cities are required to play is changing. It is necessary to transform them into an experience-based space where people can enjoy not only purchasing but also staying, and public spaces are considered important for this. From the perspective of avoiding top-down development, there are an increasing number of cases in which urban planning is progressing while building consensus with citizens through workshops. In such workshops, simulation tools such as architect models and computer graphics (CG) have been used to convey the plan in an easy-to-understand manner to citizens who do not have knowledge of urban development and architectural planning. In recent years, spatial reproducibility has been improved by utilizing new technologies such as virtual reality (VR), but the target of the simulation is almost all hardware, such as building volume and cityscape, and humans are only slightly attached. To create a human-centered public
space, it is necessary to proceed with a hard plan while considering activities. It is expected that citizens will be able to visualize how space will be used by expressing the activities and improving their understanding of the plan. The purpose of this study is to develop a system that can promote consensus building by improving a plan while imagining the scene of space utilization in a virtual space where activities are visualized in workshops at the public space planning stage. In this study, as the first step, we aim to clarify the effectiveness of activity expression in public space planning by constructing a VR system that does not express the activity and a VR system that does express it and performing system evaluation through trial experiments.

1.2 Previous Related Research and the Position of This Research

Among the previous studies, in terms of research on activities in cities, Arima et al. [2] focused on the relationship between the spatial characteristics of a street and the activities of visitors. Okudaira et al. [3] analyzed the effect of the presence of temporary environment settings, such as garden parasols, on the occurrence of activities. Regarding the method of consensus building in workshops, Fukuda et al. [4] proposed a design method with citizen participation by utilizing VR and planned a public space by incorporating the proposed method. Koga et al. [5] proposed a new consensus-building method with the participation of citizens by assembling a workshop using both model and VR technology and comparing the features of both tools. Ohata et al. [6] and Arima et al. [7] clarified the effectiveness and issues with a system that used GIS and VR technology to support the workshop. Although there are studies on activity evaluation in cities, there are many unknowns regarding spatial planning methods that induce activities. In addition, although there is a wealth of research on the accumulation of technology for supporting consensus building with citizens using simulation tools, the simulation target is mostly hardware. Based on these studies, the present study verifies the effectiveness of extending the simulation target in public space planning to activities, planning the space while considering the activities, and building consensus with citizens.

2. Research Method

2.1 System Development Method

First, we summarize the requirements for developing the VR system and consider the development environment. The elements to be expressed in VR are divided into “spatial elements such as building volume” and “people’s activities that are the subject of this research”, and we examine each method of expression to determine the specifications before development.

2.2 System Evaluation Method

To evaluate the developed VR system, we conducted a trial experiment and questionnaire survey with a total of 23 people. The subjects included citizens who are working on public space planning at the site of town development or who have similar work experience, administrative relation persons, and private sector (Table 1). The evaluation incorporates the following three points: (1) practicability, including ease of image of space utilization; (2) functionality, such as system operation; and (3) comprehensive evaluation and points for improvement. Regarding practicality, we prepared three patterns based on the developed system and verified the difference in practicality depending on the presence or absence of activity. Furthermore, when activities are included, the differences between the cases in which the expressions are stationary and those in which the expressions are moving are also compared and verified. The three patterns prepared are version A (hereinafter, ver.A), which does not include activities; version B (hereinafter ver.B), in which the activities are expressed as a still image; and version C (hereinafter, ver.C), in which the activities are expressed as moving
Table 1  Subject list of an evaluation experiment.

| No. | Attribute       | Sex | Age |
|-----|-----------------|-----|-----|
| 1   | Citizen         | Male | 37  |
| 2   | Citizen         | Male | 76  |
| 3   | Citizen         | Male | 37  |
| 4   | Citizen         | Female | 35 |
| 5   | Citizen         | Male | 40  |
| 6   | Citizen         | Male | 61  |
| 7   | Citizen         | Male | 70  |
| 8   | Citizen         | Female | 22 |
| 9   | Citizen         | Male | 24  |
| 10  | Citizen         | Male | 38  |
| 11  | Administrative officer | Male | 38 |
| 12  | Administrative officer | Male | 37 |
| 13  | Administrative officer | Male | 30 |
| 14  | Administrative officer | Male | 45 |
| 15  | Administrative officer | Male | 53 |
| 16  | Administrative officer | Female | 39 |
| 17  | Administrative officer | Female | 36 |
| 18  | Administrative officer | Female | 47 |
| 19  | Private sector  | Male | 37  |
| 20  | Private sector  | Male | 42  |
| 21  | Private sector  | Male | 54  |
| 22  | Private sector  | Male | 47  |
| 23  | Private sector  | Female | 25 |

images. In addition, we compare whether there is a difference in the evaluation tendency among a citizen who does not have specialized knowledge, an administrative person, and a private business operator who is in the position of the planner. Regarding functionality, we verified the consistency of the specifications adopted in this study. Finally, we evaluated the effectiveness of activity expressions through a comprehensive evaluation.

3. Overview of the System to Be Developed

3.1 Requirements That Are Required in a System

In the system developed in this study, it is important that citizens imagine the usage scene of the public space. Therefore, it is necessary to be able to simulate various usage methods by expressing the activities of people as a pattern of space usage in the virtual space and then changing the type, amount, and arrangement of the activities. There are three requirements for this system: “to be able to construct a public space under planning”, “to be able to express activities and change them freely”, and “to be intuitively operated by users”. To meet these requirements, we examined the system specifications.

3.2 Examination of the Specifications of the System

3.2.1 Examination of the Spatial Element Construction Method

Regarding the method of constructing the public space under planning, CG and VR have been used as consensus-building methods for building plans, as shown in Section 1, and there is a wealth of accumulated research regarding these methods. In a study in which some environments are constructed with CG, an environment is constructed in the redevelopment planning area by combining “all-round live-action images of the target area taken with a spherical camera” and “CG perspective image of the planned building” using image editing software. The advantage of this method is that spatial elements other than the planned site are highly realistic because they are real images, and the work efficiency is high because only CG modeling of the planned building is required. However, because it is an all-surrounding image, even though the subject can move his or her line of sight in the VR space by swinging the head, etc., the viewpoint is fixed at the center of the all-surrounding image, and the viewpoint cannot be moved forward, backward, left, or right. In addition, if the planned site is not a vacant lot, it may be difficult to replace the CG perspective, which is shot using a live-action moving image and incorporates the existing buildings. Conversely, as an example of constructing all environments with CG, a study by Toda et al. [8] utilized a game engine. In this research, all spatial elements were constructed with CG. Although this method involves tasks that require modeling skill and labor, the user can freely move the line of sight and the viewpoint. Which method is appropriate depends on the size of the target public
space, etc., but considering the degree of freedom of functions such as viewpoint movement, we adopted the method of constructing all spatial elements with CG in this research.

3.2.2 Examination of How to Expression Activities

Regarding the method for expressing people’s activities, there is a method that expresses people, such as visitors, who are performing activities by using three-dimensional (3D) CG, and another method expresses live-action by capturing the images of actual people. There are two types of expressions in each method: static expressions and moving expressions. When modeling a human with 3DCG, it is arranged as a 3D object in the virtual space, e.g., a spatial element, so that the user can view the space without failure, even if the user moves the viewpoint. Conversely, compared with structures such as buildings, human beings have a complicated shape; hence, modeling accuracy and high technology are required for realistic expression. When a moving image is being created, it is necessary to add animation data, such as motion capture, to the modeled person. Depending on the accuracy of the animation data, it may not move smoothly, similar to a robot. For live-action expression, a person performs an activity in a uniform environment, such as in front of a green background, and we acquire images using a camera. By chroma-keying the image and mapping it on a plate-shaped object placed in the virtual space, we can express an image of the activity. The advantage is that if an environment that is easy for chroma-key processing is provided, realistic expressions can be created. The disadvantage is that it is represented by mapping on a plate-like object; hence, if the user moves the viewpoint or changes the angle of the activity, the user’s viewpoint and the object surface will not face each other, and the image will be distorted. Comparing these two methods, we considered that the expression of people’s activity is the main subject of this study; hence, it is important to have realistic images. Therefore, we adopted the expression that utilized the mapping of live-action material.

3.2.3 Examination of the Development Environment

Based on the aforementioned examination results, we decided to express the spatial elements as 3DCG and the activities as live-action. We examined the environment for developing a system that complies with this specification. To meet these requirements, it is common to develop software that has a rendering engine, the so-called game engine, which can freely create interactive content using a graphical user interface. In the present system, we constructed a system using Unity1, which is a game engine. Unity has functions such as rendering, object placement, illuminance setting, and command input. In addition, various parameters can be changed using a mouse, and the VR space can be constructed to have intuitive operation. Moreover, the VR space developed using Unity is compatible with various platforms2.

3.2.4 Examination of the VR System Interface

We examined the method of presenting and operating the VR system to users. We used a head-mounted display (HMD) to browse VR. It is more immersive than the method of displaying VR on a monitor, etc., and the sensor detects the swinging angle and position movement of the wearer and reflects it on the line of sight and viewpoint of the VR space to enhance the immersive feeling. Regarding the user’s operation, it is common to use a controller, but some users may be unfamiliar with the operation, which may affect the evaluation. Therefore, we adopt a method in which the user gives verbal instructions to the operator. The operator could reflect the instructions by operating a mouse. In addition, according to the specifications of this system, the user

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1 A game engine with an integrated development environment provided by Unity Technologies.
2 Unity supports PC (Windows, macOS, Linux), smartphones (iOS, Android), game devices (PlayStation4, Xbox, Nintendo Switch), VR (Oculus, HTC, PlayStation VR) and other platforms.
can move around in the VR space within the range of the length of the cable connected to the HMD. As described above, the activity is represented by a two-dimensional real-life moving image, and to prevent distortion of vision, we decided that the user can swing around, but the range of motion was restricted.

4. Developed System

4.1 System Constitution

We built the system in Unity according to the specifications examined in the previous section (Fig. 1). Spatial elements, such as buildings and plazas, were installed in the VR space constructed by Unity, and still and moving image activities were prepared there. The users wore the HMD and verbally instructed the operator to place furniture or activity, and the operator placed the furniture or the activity by operating the mouse according to the instructions.

4.2 Construction of the Individual Components

4.2.1 Construction of Space Elements

Regarding spatial element construction, the main evaluation target of this study is the effect of activity addition; thus, to avoid bias caused by the quality of spatial element construction, we decided to use

![System configuration diagram.](image1)

![The floor plan of virtual public space targeted by this system.](image2)
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Fig. 3  Furniture and activities which we shot.

Table 2  List of patterns of live-action material.

| Material | Type of furniture | Content of activity                  | Shooting format | System ver. |
|----------|-------------------|--------------------------------------|-----------------|-------------|
| a        | Bench             | -                                    | Still image     | Ver.A       |
| b        | Table set        | -                                    | Still image     | Ver.A       |
| c        | Bench             | Sit alone                            | Moving image    | Ver.C       |
| d        | Bench             | Two people sit down and chat          | Still image     | Ver.B       |
| e        | Bench             | Sit alone and use a smartphone       | Moving image    | Ver.C       |
| f        | Table set        | Two people sit down and chat          | Moving image    | Ver.C       |
| g        | Table set        | Two people sit down and use a computer| Moving image    | Ver.B       |
| h        | Table set        | Two people sit down and chat          | Still image     | Ver.C       |
| i        | Table set        | Two people sit down and read a book   | Moving image    | Ver.B       |
Fig. 4 Conceptual diagram of mapping of shooting materials.

existing high-quality materials\(^3\) in the Unity Asset Store. The target is a setback space of 110 m\(^2\) along the main road in one corner of the space (Fig. 2).

4.2.2 Activity Expression

To capture the live-action material of the activity, several patterns were prepared for each material, such as the furniture without the activity for ver.A, the still image with the activity for ver.B, and the moving image with the activity for ver.C. These scenes were shot in front of a green screen (Fig. 3, Table 2)\(^4\).

To reflect the captured live-action material in the VR system, we installed a plate-like object for mapping shooting materials in the VR space built with Unity. We mapped the activity that we shot to that object with chroma-key processing with the plug-in\(^5\). Chroma-keying makes the green background transparent, and the outlines of the plate-like objects disappear, making it appear as if only the captured activity is there (Fig. 4).

4.2.3 System Interface

In the VR system developed in this research, the user can install activities in the VR space, change the amount, and change the placement while wearing the HMD. These instructions, such as “arrange four tables around a tree” and “arrange two activities where two people talk to each other on the building side”, are verbally conveyed to the operator. Then, the operator operates the system as instructed to reflect these expressions.

5. System Evaluation

5.1 Overview of Evaluation Experiments and Questionnaires

In the evaluation experiment, 23 subjects were targeted, and the author first explained the functions and operating methods of the system. Then, the subjects were provided the setting of being a participant in a public space planning workshop, and the subjects have tried the three systems, i.e., ver.A, ver.B, and ver.C. The intent of the trial experiment was to imagine the space utilization scene while changing the type, amount, and position of furniture and activities. We then conducted an evaluation questionnaire (Tables 3 and 4) regarding the practicality and functionality of the system. With respect to the practicality of the system, we prepared the following three questions: (Q1) the ease of visualizing how space is used, (Q2) how to feel the bustle caused by changes in the amount of furniture and activities, and (Q3) how to feel the bustle caused by changes in the arrangement of furniture and activities. Then, for each item, we performed a comparative evaluation of the three systems on a number line from -2 to 2 points\(^6\). Regarding functionality (Q4 to Q9), we asked for a

\(^3\) “Japanese Dosanko City” provided by ZENRIN in the Unity Asset Store was used as the material for the spatial element.

\(^4\) The types of activities are considered to be diverse, but in this study, the number was limited because the focus was on the effect of adding activities.

\(^5\) Applied the plug-in “Chroma KeyKit” provided by NEXWERON in Unity Asset Store.

\(^6\) Evaluation of three systems was performed steplessly on a number line of -2 to 2 points, but in the totalization, it was converted to a 0.1 point unit.
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Table 3  List of System evaluation questionnaire.

| Evaluation axis | Questionnaire contents |
|-----------------|------------------------|
| Practicality    | Q1 Could you imagine how the space was used in each of the three systems? |
|                 | Q2 Did you feel the change in the bustle by changing the amount of furniture and activities? |
|                 | Q3 Did you feel the change in the bustle by changing the arrangement of furniture and activities? |
|                 | Q4 Did using the HMD help you to grasp the space easily? |
|                 | Q5 Did you change the amount and placement of furniture and activities as you wish? |
|                 | Q6 What do you think about how to change the amount and placement of furniture and activities? |
| Functionality   | Q7 Does the inability to change the angle of furniture and activities affect it? |
|                 | Q8 Is it necessary to be able to see the space while moving the viewpoint? |
|                 | Q9 Is it necessary to be able to simulate sound as well? |
| Comprehensive evaluation | Q10 Is it effective to represent people’s activities in public space simulations? |
|                  | Q11 System improvements and notices |

Table 4  List of answer options for each questionnaire.

| Questionnaire | Evaluation |
|---------------|------------|
| Q1 | -2 points | -1 points | 0 points | 1 points | 2 points |
| Could not | Could not do much | Can not say either | A little done | Did it |
| Q2 | Could not feel | Could not feel much | Can not say either | Felt a little | Could feel |
| Q3 | Could not feel | Could not feel much | Can not say either | Felt a little | Could feel |
| Q4 | Not helpful | Not helpful much | Can not say either | A little helpful | Helpful |
| Q5 | Could not | Could not do much | Can not say either | A little done | Did it |
| Q6 | Hard to do | A little hard to do | Can not say either | Somewhat done | Did it |
| Q7 | Affect | Slightly affect | Can not say either | Does not affect much | It does not affect |
| Q8 | Unnecessary | Not much needed | Can not say either | Somewhat necessary | Necesssary |
| Q9 | Unnecessary | Not much needed | Can not say either | Somewhat necessary | Necesssary |
| Q10 | Not effective | Not very effective | Can not say either | Somewhat effective | Effective |

Table 5  Average evaluation of system practicality based on the presence or absence of activity.

| Q | system ver. | citizen (n=10) | B-A C-B | administration /business (n=13) | B-A C-B | total (n=23) | B-A C-B |
|---|-------------|----------------|---------|---------------------------------|---------|--------------|---------|
| Q1 | Ver.A | 0.21 | 1.07 | 0.16 | 0.78 | 0.18 | 0.91 |
|    | Ver.B | 1.28 | 0.85 | 1.95 | 0.35 | 1.09 | 2.30 |
|    | Ver.C | 1.36 | 0.08 | 1.29 | 0.35 | 1.32 | 2.30 |
| Q2 | Ver.A | -0.12 | 1.27 | -0.49 | 1.67 | -0.33 | 1.50 |
|    | Ver.B | 1.15 | 0.37 | 1.18 | 0.32 | 1.17 | 0.32 |
|    | Ver.C | 1.52 | 0.37 | 1.49 | 0.32 | 1.50 | 0.34 |
| Q3 | Ver.A | 0.24 | 0.91 | -0.48 | 1.56 | -0.17 | 1.28 |
|    | Ver.B | 1.15 | 0.35 | 1.08 | 0.37 | 1.11 | 0.36 |
|    | Ver.C | 1.50 | 0.35 | 1.45 | 0.37 | 1.47 | 0.36 |

5-level evaluation of the overall system, regardless of the three versions. Regarding the overall evaluation, the overall system effectiveness (Q10) was evaluated on a 5-point scale, and improvements and notices (Q11) were asked to be provided as the free description.
5.2 Evaluation Results

5.2.1 Practicality Evaluation of Simulation Including Activities

The evaluation results regarding the practicality of the system including activities are summarized in Table 5. In terms of how easy it is to visualize how space is used (Q1), there was a large difference in evaluation between ver.A and vers.B and ver.C. By contrast, the difference between ver.B and ver.C was slight. This is probably because the activities prepared in this system were not accompanied by large movements such as sitting and chatting, and there were few visual differences. Comparing the citizens with the administrations and businesses, the citizens had a slightly larger evaluation difference, depending on the presence or absence of activities. Therefore, it can be observed that the activity expression is effective to some extent for understanding the image of space utilization for the citizens, who are considered to have poor spatial imagination compared with the public administrators and business associates involved in planning. Differences were also observed in the presence or absence of activities in terms of how users perceive changes in the bustle by changing the amount of furniture and activities in Q2 and by changing the layout in Q3. However, unlike Q1, there was a larger difference in evaluation depending on the presence/absence of activity in the administrator/business operator than in citizens. In particular, Q2 was evaluated highly for how it felt the change in activity owing to quantitative changes inactivity.

5.2.2 Evaluation of the System Functionality

The evaluation results of the system functionality were compiled (Table 6). From the question in Q4, it was found that the use of HMD contributed to the ease of grasping the space. Although many subjects were able to change the quantity and arrangement of furniture and activities in Q5, the method was not necessarily easy to perform, as reflected in the result of Q6. We adopted a method of verbally instructing the operator considering resistance to controller operation, but a problem can be considered to be associated with this method. In Q7, concerning not being able to change the angle of the furniture and activities, 70% of the subjects answered that they “affect” or “somewhat affect” the usability of the system. This is because the method of shooting activity in live-action and mapping it on a plate-like object in the virtual space has the drawback that it appears distorted because it does not directly face the viewpoint when the angle is changed. This can be considered to lead to a low evaluation. Regarding the necessity of moving the viewpoint in Q8, most of the subjects answered that it is necessary. This is also because the furniture and activities are plate-shaped and will appear distorted when the viewpoint moves. Regarding the question about sound in Q9, the answers vary, but 70% answered “necessary” or “somewhat necessary”. It can be said that there is a close relationship between the liveliness generated by the activity and the sound, and this may be a subject for further study.

| questionnaire | evaluation (n=23) |
|---------------|-------------------|
| Q4 | Did using the HMD help you to grasp the space easily? | 1.74 |
| Q5 | Did you change the amount and placement of furniture and activities as you wish? | 1.00 |
| Q6 | What do you think about how to change the amount and placement of furniture and activities? | -0.35 |
| Q7 | Does the inability to change the angle of furniture and activities affect it? | -0.87 |
| Q8 | Is it necessary to be able to see the space while moving the viewpoint? | 1.74 |
| Q9 | Is it necessary to be able to see the space while moving the viewpoint? | 0.83 |
Table 7  The average value of the overall evaluation of the system.

| Question                  | Evaluation (n=23) |
|---------------------------|-------------------|
| Q10 Is it effective to represent people's activities in public space simulations? | 1.91              |

Table 8  Answers about system improvements and awareness.

| Answer classification    | Answer content                                                                 |
|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| Furniture/activity related| When a walking person is expressed, the sense of realism increases.                                                               |
|                          | It is better to bring in a variety of people such as strollers with children and the elderly.                                   |
|                          | If the types of activities increase, users will feel more realistic.                                                            |
|                          | It is better to put furniture other than chairs such as fountains, planting zones, flower beds.                                 |
|                          | It is good to know the effect on the surroundings when you put the trash.                                                       |
|                          | If we can see the inside of the surrounding building, you can easily see the usage image of public space.                       |
| Spatial element related  | In this system, the characteristics (doorway) and usage of the building (wall surface) are unknown.                               |
| Environmental element    | It would be nice to be able to change the morning, noon, and evening times.                                                      |
|                          | I wish I could change the weather.                                                                                               |
|                          | Make everything more realistic I would like to see the bench and people in 3D.                                                    |
| Reality related          | Bench and people also want to see what is expressed in 3D.                                                                     |
|                          | It may be more realistic and better to use actual images.                                                                        |
| Function/operation related| You should also touch the five senses other than vision, such as sound and light.                                                 |
|                          | It is desirable that the HMD user can directly operate the simulation.                                                          |

5.2.3 Overall System Evaluation and Improvements

Regarding the overall evaluation of the system in Q10, 21 out of 23 people answered “effective” and 2 answered “slightly effective”; this was regardless of subject attributes such as citizens, administrators, and business operators (Table 7). Regarding the improvement of the system in Q11, many respondents sought to enhance the types of activities that can be expressed and enhance the furniture related to the activities. There was also an opinion that the activity should be expressed in 3DCG (Table 8).

6. Summary

In this study, to promote consensus building between developers and stakeholders such as citizens at workshops in the public space planning stage, we constructed a VR system that represents the activities of people. Then, we attempted to clarify the effectiveness of the activity expression in public space planning by evaluating the system through trial experiments for citizens, administrative staff, and private business operators. As a result, the effectiveness of the system could be clarified by the evaluation that the system that includes the activity expression is easier to use than the system that does not include the activity expression, regardless of the attributes of the subjects. Conversely, negative evaluations were found regarding the method of expressing the activity with the live-action material adopted in this research, and the method in which the subject verbally instructed the operator to make changes.

In the current system, as a first step, only the function of visualizing the utilization scene in the planned public space is provided. However, at the workshop scene, to discuss and improve the plan while simulating the activity, it is desirable not only that the activity can be operated interactively, but also that the hardware, such as the shape of the public space to be planned, can be altered. Furthermore, in the current system, the activity is such that its contents are performed in advance, and the activity does not always occur there. Activities should reflect a realistic simulation based on behavior models, such as the actual flow and stopping of humans. For that purpose, it is necessary to represent humans with 3DCG and
incorporate behavior models into the animation data applied to them. While solving the issues obtained in this evaluation questionnaire, we plan to work on implementing these functions and upgrade the system version.

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