Doctoral Dissertation

Improvement of Landscape Community Design Support System by Virtual Reality

バーチャルリアリティ技術を用いた景観まちづくり支援システムの高度化

に関する研究

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Abstract

This research aims to study the improvement of Landscape Community Design Support System by Virtual Reality (VR). This provides supported systems for landscape improvement and community design. This research can be concluded that VR new applications and usable situations are explored in Landscape Community Design. VR was commonly used by stand-alone and face-to-face and synchronous or distributed asynchronous use. In order to solve these problems, advantages of VR and physical model are combined to develop a new presentation system and used cloud-VR in a synchronous distributed type meeting.

Chapter 1 introduces the implication of Landscape Community Design and advances that it is very important to use adequate media for not only specialists but also non-specialists. Further applications were proposed - First, development of a new presentation system by viewpoint linking VR and a Physical model; second, a synchronous distributed VR meeting system.

Chapter 2 reviews previous references and clarifies current problems about VR applications. As a result, characteristics of VR and physical model should be clear, especially the differences of spatial understanding. Thus, a new presentation system by viewpoint linking VR and a physical model can improve landscape availability. Last, a synchronous distributed VR meeting system was proposed concerning about the restrictions of space and time.

Chapter 3 focuses on differences of spatial understanding observed by using physical and virtual models. While participants viewed a physical model and a virtual model in sequence, a questionnaire was used to objectively evaluate these and establish which was more accurate in conveying object size. Consequently, a physical model not a virtual model, tended to allow quicker and more accurate.

Chapter 4 proposes a new presentation system by VR and a physical model, the photogrammetry technique was adapted to link viewpoint information. The developed system used a 2-step calibration and 2-marker method. As a result, accuracy was improved. Moreover, a hearing investigation was conducted. The differences to traditional interface and availabilities of practical scenes were clarified.

Chapter 5 proposes a synchronous distributed meeting by using cloud computing type VR for Landscape Community Design. Two case studies were conducted to review a possibility of realizing a discussion meeting of landscape community design. As a result, the feasibility of distributed synchronous type design meetings using the cloud-VR was high. It increased the opportunities for specialists in remote places to participate in design review sessions.

Chapter 6 concludes the research and future works.

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Chapter 1 Introduction

1.1 BACKGROUND

1.1.1 The Overview of Landscape Community Design

According to the European Landscape Convention (Council of Europe 2000), "Landscape" means: "an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors". Aesthetic nature of landscape could create a better city by analyzing and redesigning city elements scientifically. Moreover, a renovation from current urban space to the future had better share virtual space, and use virtual environment. Because the research's object is community design, it is necessary to introduce the implication of it from the beginning. Community Design is a broad term given to the practices of civic activists, involved citizens and professionals to build stronger and more resilient local communities. This research uses a detail definition of Community Design that mentions from Nishimura (2005) - "Machizukuri" (Community Design in English), literally means "town building" in Japanese, creating physical space as well as human network in local community. Japanese work of Community Design has a subtle nuance of soft-oriented bottom-up community planning activities and/or hand-on community design toward the betterment of the environment. Community Design offers a way of working with communities that involves people with very different needs and aspirations (Gilchrist 2010). It uses the unique knowledge and skills of local people to address the challenges faced by themselves and their community (NEF 2010).

Urban design (Saelens 2003) is a profession that makes decisions about how natural and built elements in a particular space. Landscape Community Design can be defined to form a good landscape or an orderly local area which efficiently employed the characteristic of this area. That is, attempts to improve the local environment through using better scenery are generically called "Landscape Community Design". Urban design and Landscape Community Design have similar definitions. This research targets a design process and creates better landscape that involves not only specialists but also non-specialists such as civilians. Thus, this research used the definition of Landscape Community Design. History of the Landscape Community Design in Japan is simply cited: "In general, evolution of Community design idea is divided into three phase; one, Community design as a protest of the conventional planning in the 1960's and the 1970's; two, Community design as an alternative for planning in the 1980's, and three, Community design as system for local governance in the 1990's and thereafter". Since the 1990s, the systematization of the city planning organization and a standard procedure of Landscape Community Design centering on residents, community participation of local landscape planning began. In 60s and 70s, Landscape Community Design has begun from a thought of landscape or historic protection. However, the organization of public communities after 90s caused it turned to a civilian-center type. Thus, a consensus-building process became very significant in activities of landscape or community design. For example, a series of experimental collaboration between public and private sectors began to be common in many municipalities, such as workshops for the creation of new vest-pocket parks, local collaboration for safeguarding historic houses, and open forum for drafting local master plan (Nishimura 2005). Therefore, it is necessary to step on the stage to get the consensus of the citizens in practical activities of Landscape Community Design. In addition, since the cooperation of a variety of citizens and experts is required, it must build mutual partnership within the persons who participate. A consensus-building process among those people is important to achieve mutual understanding. Further, to open the cooperative process to a public has been needed. In order to build consensus, an easy-understanding media plays an absolutely significant role for non-specialists. Specially, interaction function between human and media has been required in the process (Shipley 2012).

The target of Landscape Community Design includes making nice with the environment through cleaning task or flowers plant, etc. However, this research focuses on creating a space for environmental improvement and maintenance, which exists various stakeholders (specialists and non-specialists) to participate in this process together and then collect their feedback to improve the environment. The process of Landscape Community Design mainly consists of "Conceptual phase", "Planning phase", "Design phase", "Construction phase", and "Maintained phase" (Gudnason 2012). In order to solve problems, which may occur at "Construction" and "Maintained phases", in design phase, improvement of problem-solving capabilities or previous design studies are required in advance, moving (or "load") problems identification and solution backward in time (to the "front" of the process) (Thomke 2000, Peeters 2012). Frontloading therefore is defined as a strategy that seeks to improve development performance by shifting the identification and solving of design problems to earlier phases of a process (Knothe 2012). It is possible to prevent previously protraction of a schedule because of frequent rework and then avoid generating useless cost as well in the field. To realize a frontloading process, it is necessary to seek media or tools which could share images or scenarios of a spatial design among persons of specialists or non-specialists, and then build consensus in earlier phases like conceptual or planning phase.

Related stakeholders generally include project executors (governments, private developers), designer (architects, urban planners and engineers), residents and general citizens (Okada 2013). Because of the various stakeholders, it is necessary to collaborate and build their consensus when launching a new project. Since many differences such as expertise, knowledge and participation levels commonly exist among these participants, brief and exact communication is asked to clearly convey at a discussion meeting or a presentation (Schwilch 2012). For this reason, besides texts and graphs, traditional media such as physical models, sketches, perspective drawing, and photo montage have been used. However, with rapid development of computer technology, easy-understanding virtualization system gained more significant importance. Since it is oftentimes necessary to share three-dimensional (3D) images to study spatial design, 3D Computer Graphics (3DCG), Virtual Reality (VR), 3D Computer Aided Design (3DCAD) and Building Information Modeling (BIM) systems have been developed. Al-Kodmany (1999) suggests that "visualization is the key to effective public participation because it is the only common language to which all participants - technical and non-technical - can relate. Visualization provides a focus for a community's discussion of design ideas; it guides community members through the design process, it raises their design awareness and facilitates better communication." Especially using VR systems (VR: A computer simulated environment that can simulate physical presence in the real world, The Virtual Reality Society of Japan, see also subsection 1.1.2), people could switch between different viewpoints and alternative plans interactively in real time. So that VR is well used as a tool for Landscape Community Design (Westerdahl 2006, Fukuda 2009, Shen 2010, Al-Kodmany 2013).

Thus, in order to easily obtain consensus-building and good ideas among a variety of stakeholders, VR, as a 3D visualization media, is highly expected.

1.1.2 Landscape Community Design Support System

Media, as mentioned above, are not only texts, graphs, sketches or perspective drawings, but also those which more possibly dispose visual information, as known as physical models, 3DCG animation and VR. The latter are now commonly used as general tools to confirm space or volume (Orland 2001, Marini 2012, Hayashi 2013). However, "Currently employed methods of user participation actually disenfranchise the user because the methods of communication have not changed to accommodate a non-design oriented population", that is to say, though traditional media are used in presentation and discussion meetings, it has not been sufficient to deal with space or 3D characters of architectures or cities in the stage of communication because of lacking interactivity (Al-Kodmany 1999). 3D visualization media perform more effectively than fixed viewpoint visualization for multiple users in the process of Landscape Community Design, because they could support to review such as arbitrary viewpoints in real-time. Thus, this research would focus on the arbitrary viewpoint media such as VR and physical model for Landscape Community Design Support Media.

VR is defined by the Virtual Reality Society of Japan (2013) as a computer simulated environment that can simulate physical presence in the real world or imagined worlds. VR is to build a shape or space via 3D data, and provides prediction from all viewpoints in this built space (Burdea 2003, Vince 2004). Once it creates 3D virtual models (See also Fig.1.1 left), it is possible to perform landscape assessment by various viewpoints such as a bird's eye view, travel or flying motion. Furthermore, animation, for an instance, is also able to be developed on the basis of created 3D data. However, to build surrounding areas, facilities and space present unique challenges to interactive VR systems, because of the huge complexity of the geometrical data and the widely varying visibility conditions (Hodgson 2012). Additionally, it is impossible to touch directly and that the sense of distance is elusive. VR interface usually results in real-time simulation of one or more of the user's five senses", namely "vision, audio, tactile, smell and taste" (Tsingos 2004, Coquillart, 2012, Ghinea 2012, de Barros 2013). In the field of Landscape Community Design, vision or visual aspects are mainly studied and others are nearly evaluated. So with regards to landscape, the visual aspects of VR likely will still often be the most important.

A Physical model is a smaller or larger physical copy of an object. In the field of community design or landscape, it particularly means a 3D object into which a real space is reduced according to a constant ratio (Fig.1.1 right). One hand, the strengths of a model are that the user touches the model directly; that several people can examine it at the same time from arbitrary viewpoints, and it allows users to gain an understanding of the entire city. And in the case of public projects related landscape, models develop an perfect recognition and easy understanding of the whole picture of huge facilities, contour of one structure or several ones. On the other hand, the weaknesses are the limit of expression caused by the small scale, a limitation of the range of production, and that study from the pedestrian viewpoint is difficult (Tokuhara 2010).

Despite the digital age, physical models are still used as major tools. Arguing whether a virtual model can substitute for a physical model is an important theme in the field of computer-aided

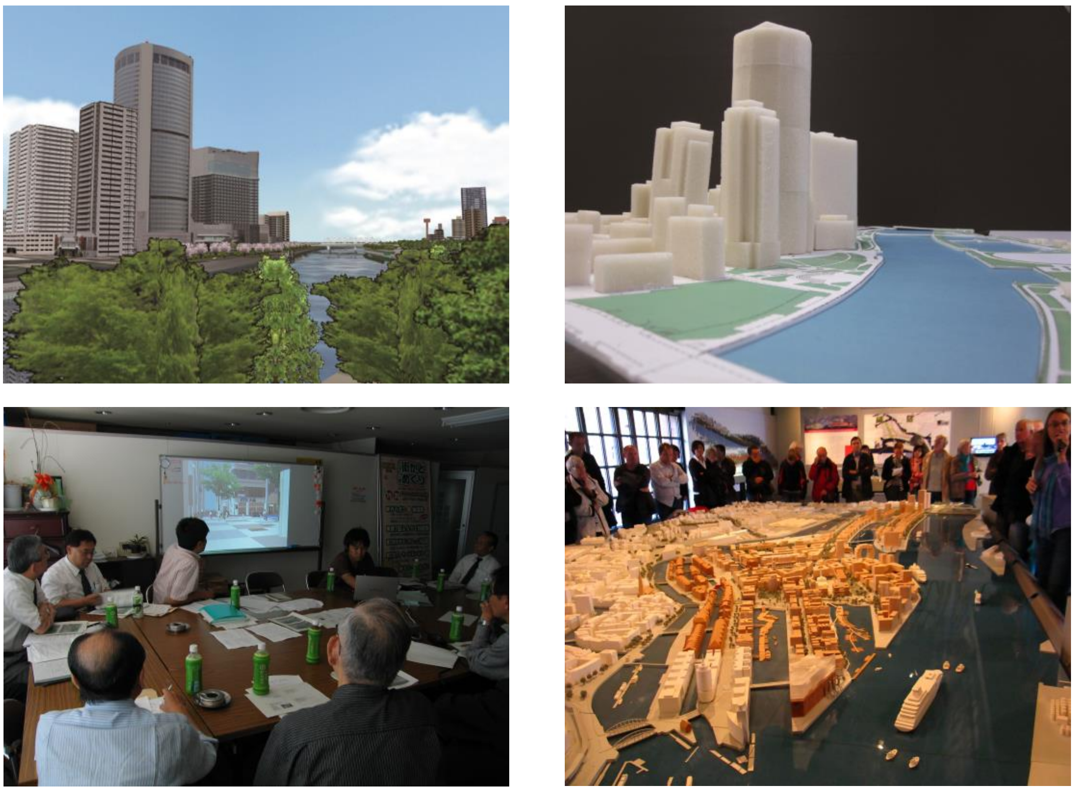

Fig.1-1. 3D visual media: VR and physical model cut (up), VR and physical model use (down)

architectural design. In recent years, physical models have been built from 3D virtual models created by 3DCAD and BIM via a 3D printer or through traditional methods of handcrafting. Numerous studies on Tangible User Interface and Augmented Reality (AR) have combined physical and virtual models (Seichter 2007, Kim 2008, Tokuhara 2010, Wang (2013). The reason why designers still use physical models remains unclear. In addition, physical and 3D virtual models have yet to be differentiated. The answers to these questions are too complex to account for in all aspects. Meanwhile, differences based on a physical-medium model and a virtual-medium model may also be regarded as factors. Thus, this study only focuses on the differences in spatial understanding between physical and virtual models. In particular, it emphasizes on the perception of scale.

As focus on the usage of physical model and VR at present, they have been used together at some design and planning sites. During the planning and design stage, a physical model is used in the first conceptual expansion phase, and then VR is applied in the convergent design phase (Koga 2008). A combination of these two media is expected to support kind of workshop that plans or scenarios could be conducted by physical model and then reflected them on a VR system real-time at there. Both physical model and VR have strengths and weaknesses respectively as mentioned above. Although, in the current presentation they are basically separately used, each weakness might be rectified by using the two media together.

Another situation is that a design meeting is used to traditionally conducting at same time and same place (Face-to-face meeting). However, the mobility of people’s activities, and cloud computing technologies have advanced in the modern age of information and globalization. “The current explosion in mobile telecommunications and computing technologies provides the potential to transform everyday time and space” (Green 2002, Duncheon 2013). Therefore, meetings under restrictions of space and time have been used, so stakeholders in these meetings could exchange ideas or opinions and build consensus without needing to be concerned about time or space. While subsection 1.1.1 mentioned related stakeholders increased in a design process, it became difficult that a large number of them have to share common images and consciousness in the same meeting meanwhile concern time and space to participate it. Moreover, a synchronous face-to-face type meeting demands that all should be there to participate a design process in order to collect more opinions and comments from them. Apparently, it is hard to say that lots of participants could take part concerning restricted time or space. Asynchronous distributed type such as E-mail and blog allows stakeholders participate in the design process at different places and at different times. However, in communication by text, it can be difficult to take in the nuance and atmosphere of the described contents. Additionally, the virtual space can be only reviewed respectively, yet cannot be shared among people’s network. Thus, restrictions of time and space are expected to be deleted, a synchronous distributed meeting type is in need to support.

In a word, VR applications currently dominate two sides, one, indoor and/or independent use; two, synchronous face-to-face or asynchronous distributed use. In order to study the improvement by Landscape Community Design system, this research expects to discuss the possibility of further VR applications.

Both physical model and virtual model have strengths and weaknesses respectively as mentioned above. Might each weakness be rectified and strengths combined by using the two system together to develop a Landscape Community Design support system? In doing so, it is important to examine the differences in spatial reasoning capacity observed by using a physical model and a virtual model, and specifically emphasize perception of the scale of space.

As a question of asynchronous distributed type, how to develop a rich media support system to achieve a state close to face-to-face meeting responding to rapid information and globalization? The system could communicate nuances and atmosphere for helping decision-making. Therefore a synchronous distributed VR meeting could be expected.

1.2 RESEARCH OBJECTIVES

In case of Landscape Community Design, an easy-to-understanding communication and consensus-building process based on public participatory has been required as in an early stage as possible. The physical model and virtual model such as VR can display in arbitrary viewpoint so that they are effective media on the consensus-building process. Due to the distinct characteristics of the physical model and virtual model as mentioned, they are used together in construction sites or for planning or design. This research aims to apply VR which is a 3D real-time visual simulation system, and develop improved support systems of Landscape Community Design and its presentation by it. Moreover, the developed systems would be applied to several practical projects and their effects would be proofed after evaluating validities respectively. More detail, this research would like to reach following objectives that firstly develop an improved support system applied from design experts to civilians. Then, through distributed synchronous meetings which are refer to Landscape Community Design, specialists' comments are extracted, and finally figure out the new availability of VR applications.

1.3 THESIS ORGANIZATION

The thesis consists of six chapter and essentials are noted as following (Fig.1-2).

Chapter 1 introduced the research background in the area of Landscape Community Design. Since a consensus-building process became very significant in activities of landscape or community design, easy-understanding and intuitive media should be required for specialists and non-specialists communication in real-time. Then, related stakeholders and characteristics of 3D visual media were analyzed. Next, the objectives were proposed.

Chapter 2 reviewed previous references of each research aspect mentioned in chapter 1, and noted the state of the art of the main directions of this research, i.e. a new presentation system by viewpoint linking VR and physical model, and a synchronous distributed VR meeting system.

Chapter 3 focused on differences of spatial understanding observed by using physical and virtual models. While respondents viewed a physical model and a virtual model in sequence, a questionnaire was used to objectively evaluate these and establish which was more accurate in conveying object size. Consequently, a physical model, not a virtual model, tended to allow quicker and more accurate comparison of building height.

Chapter 4 studied and developed a new presentation system by viewpoint linking VR and a Physical model, the photogrammetry technique was adapted to link viewpoint information. In order to verify the accuracy of this system, a valuation was evaluated. It turned out that the accuracy was substantially improved. Then, a prototype system for urban design was built and a hearing investigation was conducted by a few users. As a result, problems about practical use and pros and cons of the interface were clarified.

Chapter 5 proposed a synchronous distributed cloud-computing VR meeting system for Landscape Community Design. While the participants shared a 3D virtual space in distributed synchronous environment, two case studies were conducted to review a possibility of realizing a discussion meeting of Landscape Community Design. Firstly, a present plan and other planning designs were predefined; a landscape evaluation by using viewpoint and plan comparison functions was conducted. Then, another evaluation by adding annotation and discussion function was conducted afterwards. As a result, the feasibility of distributed synchronous type design meetings using the cloud-VR was high. It increased the opportunities for specialists in remote places to participate in design review sessions.

Chapter 6 concluded this research and pointed out the future works.

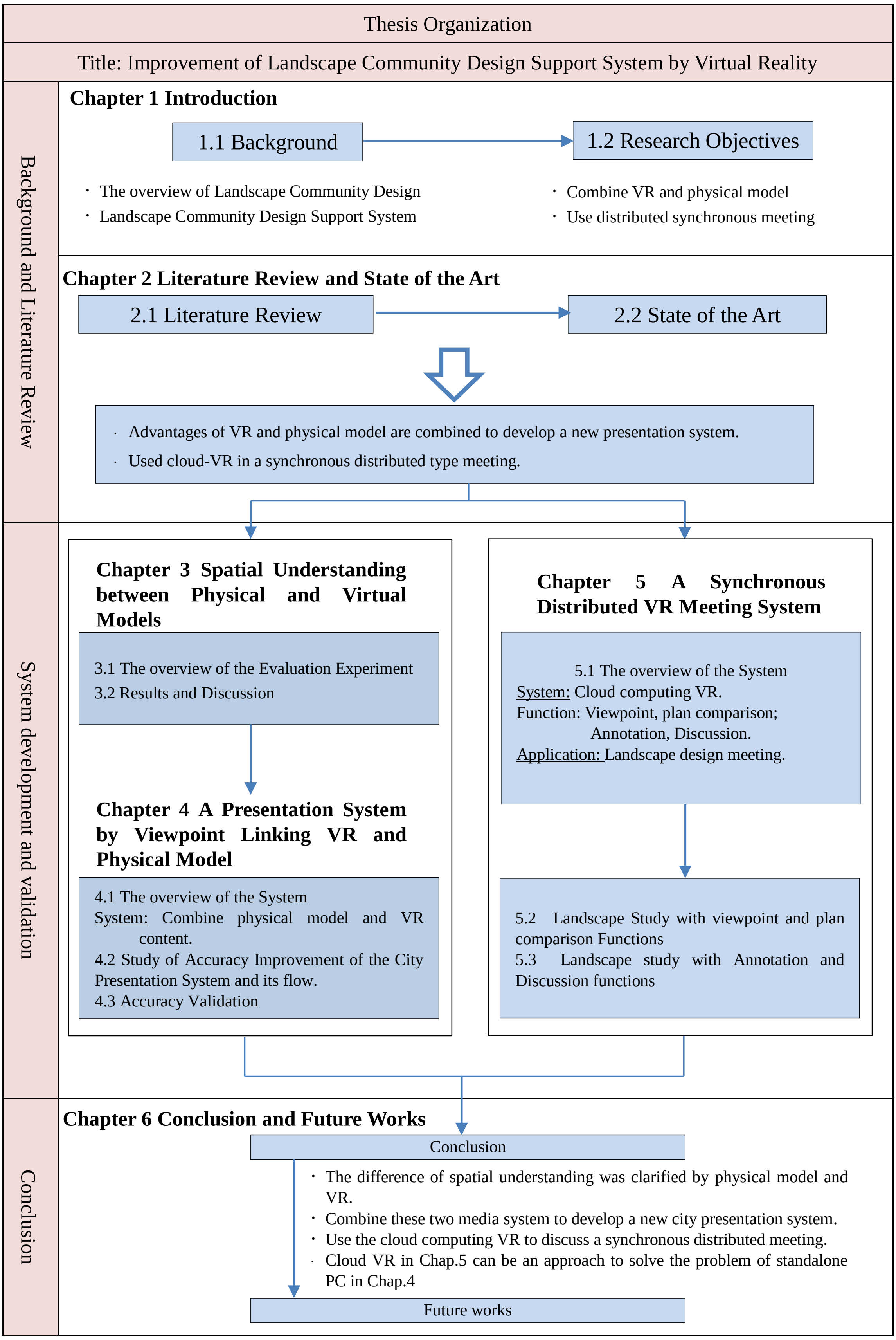

Fig.1-2. Thesis organization

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Chapter 2 Literature Review and State of the Art

2.1 LITERATURE REVIEW

As mentioned in chapter 1, it is necessary to advance a community design process while stakeholders mutually interrelate in the process of conceptual and design phase. However, the related stakeholders apparently have differences from expertise, knowledge to participation levels. So, brief and exact communication among them is required to clearly convey information at a discussion meeting or presentation. In doing so, they are faced with the challenge of communicating their spatial concepts and ideas to the broader public. Moreover, considering various participants, it is necessary to support these kind of meetings that allow them eliminate geographical and time restrictions. In conclusion, this study focuses on the following research aspects.

1. Spatial Understanding between Physical and Virtual Models
2. A Presentation System by Viewpoint Linking VR and Physical Model
3. A Synchronous Distributed VR Meeting System

2.1.1 Spatial Understanding between Physical and Virtual Models

In Landscape Community Design, a consensus building process among various stakeholders, such as project executors, designers, neighborhood residents, users, and the general citizen, is required. Supporting systems that provide 3D images to study and share future spatial designs have been subjected to research.

Visual media, such as physical and virtual models, are used to confirm space or volume in the design and presentation of architectural and urban fields. Arguing whether a virtual model can substitute for a physical model is an important theme in the field of computer-aided architectural design. In recent years, physical models have been built from 3D virtual models created by 3DCAD and BIM via a 3D printer or through traditional methods of handcrafting. The reason why designers still use physical models remains unclear. In addition, physical and 3D virtual models have yet to be differentiated. The answers to these questions are too complex to account for in all aspects. Meanwhile, differences based on a physical-medium model and a virtual-medium model may also be regarded as factors. Thus, this study only focuses on the differences in spatial understanding between physical and virtual models. In particular, it emphasizes on the perception of scale. Thus, to clarify the characteristics and features of these two media is necessary before applying them in presentation and discussion of Landscape Community Design.

Siitonen (1995) used and compared a walk-through VR and an endoscope-photographing model method. He verified which technique is better in terms of manipulating objects, lighting, and spatial reasoning ability through visual observations of outcomes as well as interviews with participants. However, the verification results of his study lacked objectivity because they had not been quantified.

Focusing on spatial reasoning ability by using medium systems, Witmer and Singer (1998) distributed a questionnaire on control, sensory, distraction, and realism factors that contribute to a sense of presence in VR. Furthermore, Lessiter and Freeman (2001) created a new questionnaire that addressed the sense of physical space, engagement, ecological validity, and negative effects. Spatial reasoning ability was compared with the results from IMAX 2D, IMAX 3D, computer games, and videos. Calibrated principal component analysis was also performed. According to these previous studies, the respondents could still experience the sense of "being there" that was elicited by VR even in another scene, but could hardly do so with a real-medium model.

Schnabel and Kvan (2003) examined the perception and understanding of spatial volumes within immersive and non-immersive virtual environments (VE) through comparisons with representations by using conventional media, such as 2D plans. They employed VEs successfully to study, communicate, and present architectural designs. However, VEs are seldom used in actual creation, form-finding, and collaboration in architecture. Seichter (2007) gauged the differences between two AR interfaces through user evaluation in an urban design studio. Although the targets examined were different, these studies would still be helpful in our study, such as in suggesting research methods.

Physical and virtual models, such as VR, can display at an arbitrary viewpoint, and thus, they are effective for discussion and examination. A physical model can be observed from any viewpoint and can show the complete image of a depicted city simultaneously. However, difficulties persist if the pedestrian viewpoint and representation limitations caused by the small scale are considered. VR employs a VE, and thus, providing an eye-level viewpoint of pedestrians and drivers, as well as of other people and vehicles, becomes easy. Moreover, VR can dynamically simulate various effects, such as solar radiation. Nevertheless, problems such as intangibility remain. In addition, possible viewpoints are normally limited to a single place. Physical and virtual models are used together in construction sites, as well as in planning or design, because of their distinct characteristics.

Combining physical and virtual models has several advantages, including ease of fabrication, user manipulation, low cost, and labor. Meanwhile, differences in physical and virtual models may also be regarded as factors. Spatial reasoning refers to the ability to understand the shape, size, location, and texture of an object or space. People have to use numerous clues and to think carefully to apply spatial reasoning. Moreover, how such clues are used remains unclear because of the complexities caused by distances to an object and observation conditions.

As a result from previous approaches, we defined the following research questions for this research aspect:

1. How are the speedy and accuracy while spatial understanding is conveyed between a physical model and a 3D virtual model?
2. What is the difference cognized by people with a physical model and a 3D virtual model?

2.1.2 A Presentation System by Viewpoint Linking VR and Physical Model

A communications design movement for cities that is called "Civic Pride" has arisen and centered in European region (Amin 1999); further improving the value of these cities and making the citizens feel proud. Therefore, finding presentation methods to understand current/future cities intuitively is becoming increasingly important in all fields. Research questions like how to present clearly, briefly and accurately among diverted stakeholders have been reported currently. Ishii (1997) pointed that stakeholders were in critical need of a platform that allows the simultaneous understanding of a wide variety of representations, including drawings, physical models, and digital analysis. After observing the community design and planning process, simultaneous use of physical and digital media in the same space is an important requirement of the design studio. As mentioned in chapter 3, VR and/or physical model could be very helpful media because of the capabilities to deal with 3D space and present from arbitrary viewpoints. Compare to some media which set fixed viewpoints beforehand, 3D visual media are more effective about real-time arbitrary viewpoints review when multi-users participate a discussion. Thus, they have been greatly used as methods of intuitive understanding. In this way, showing 3D images and landscape of a city to many stakeholders is called city presentation.

In the previous studies and the presentation of city design, Matsumoto et al (1992, 1997) have developed a system which allowed the study of the eye-level. The system placed a charge coupled device (CCD) camera in a street of a model, then the camera shoot a video and projected it on the screen. However, the background expression of distant view (sky, mountains, etc.) and trees was too simple to possess reality under the eye level, due to limitations of the model production range. To solve this problem, Seta (1997) used real images of models as background and overlapped it in the realty. The lacking reality problem was somehow improved, however such functions as switching current and alternative plans, day and night view, and dynamic simulation, generating and implementing new objects are still not sufficient. Ohno et al (2001) developed another system combining images photographed from moved CCD camera on top of models with real-time dynamic elements like vehicles and people of digital modeling. However, because a Head Mounted Display (HMD) was indispensable to view the photographed images overlapped with CG images, the system was not satisfied if multi-users review simultaneously from arbitrary viewpoints by using it.

Moreover, in many studies and presentations of urban design, the keyboard and the mouse are generally used to move the viewpoint of VR. However, Fukuda et al. (2006) reported that this is an impediment to non-specialists because it is difficult for them to operate VR by the use of the keyboard and the mouse. TUI has been the object of much research as a possible solution to this problem (Ishii 1997, Rom 2009). Ishii et al. (1997) proposed "Luminous Table" that attempts to address this issue by integrating multiple forms of physical and digital representations. 2D drawings, physical models, and digital simulation are overlaid into a single information space in order to support the urban design process. The Luminous Table was in the very early stages both of as a concept and as a working prototype, dynamic simulation like traffic or pedestrian flow factors were under developing. And the large physical size of the Luminous Table was not easy to manipulate as well. Tonn et al. (2008) developed an interface with which users can operate a 3D CAD model on a real scale with a laser pointer and 3D projector. Fujimon et al. (2004) developed a system that displayed VR contents seen from an avatar after having designed a sensor that could acquire the location information as an avatar of the operator. Moreover, Nagakura et al. (2006) developed an interactive space browser for architectural designs. Moving its lightweight LCD (Liquid Crystal Display) panel over the plan of a building drawing displays a 3D interior view of the building. However, it is difficult to apply these systems to a physical model that is the object of this study because the VR interface of these systems targets flat planes such as maps and drawing. Seichter et al. (2004) developed a system to display virtual 3D models using ARToolkit (a computer tracking library for creation of strong Augmented Reality applications) and HMD. This system can use models and virtual 3D models in an arbitrary mixture. But the system is not able to present a pedestrian’s viewpoint.

Thus far, the shortcomings, which are presented above, are concluded mainly these items - one viewpoint limited, 2D research objects and interfaces.

Because this study is also aiming at improving the accuracy of viewpoint information pointing by a laser pointer, some previous systems (Matsumoto 1992, 1997, Seta 1997) were also necessary to be noted next in detail. A question was raised that how was the extremely limited distance of this previous system when to access the model. Accessible distance limit is the distance when some supported equipment (endoscopic equipment) such as an endoscope used for a model photograph or a small TV camera contacts models without touching them. The physical size of an endoscope equipment varies, for example, the size of the endoscope in a previously report (Matsumoto 1992) was an 80mm generally, and a camera was in the center of it. In other words, distance limit would be 40mm in this case. Supposedly a model in a city street at eye level which is the similar target we want to deal with, this accessible distance was just a distance between buildings in roadside and a camera. That means it is impossible for a camera to reach any buildings within 40mm from the roadside. On one hand, the inaccessible domain is 40m in the case of 1/ 1000 scaled model, 20m in 1 /500 and less than 4m in 1/100. Hence it is difficult to use it on a usual road or walkway. On the other hand, the proposed system of this thesis applies a laser pointer as small points as an input device shooting on a mode. Since all the spot had better be possibly photographed by the web camera on the top, access domain is required as large as possible.

Moreover, Tokuhara (2010) developed a city presentation system, and evaluated validation and usability of it. Regarding to the validation of accuracy, there was an appropriate 10 mm error on resulting from the model of the study. Supposing a scale of the model was 1/1000, the error could be equivalent of 10 m in a real scale. How to decrease the error remains a problem. And practical scenes' availability and challenges are still unknown although high evaluation has been obtained with respect to usability operation, correctness, and response speedy.

As a result from previous approaches, we defined the following research questions for our work:

1. How to combine and use VR and physical model in a presentation with multi-users?
2. How to increase the accuracy of this system?
3. What is the practical scenes' availability?

2.1.3 A Synchronous Distributed VR Meeting System

In field of Landscape Community Design, how to allow specialists and more important non-specialists to enter into the community design process and how to transform public presentation into a means of participatory design have been excessively researched upon so far (Kensing 1998, Saelens 2003). In doing so, it is not only asking for easy-understanding media, as they are discussed in 1.1.2, but also requires appropriate meeting systems of collaborative work. The state of communication is able to be divided by a time-axis and/or a space-axis referring to the types of meetings. As in Table 2-1 (Olesen 1999), it includes same time (Synchronous) and different time (Asynchronous) in terms of time-axis, and same place (Face-to-Face) and different places (Distribution) in terms of space-axis. For instance, people could get together at a certain scheduled time or not, in a single room or via information technology such as the Internet in separate locations, to hold a meeting.

Design meetings have been traditionally conducted in a case of "a same place and time (Synchronous Face-to-Face)". Since people's activities increased and computing technologies advanced in the modern society, they provide the potential to transform communication time and space, participants have started to not consider time or space conditions and when they want to exchange ideas and build consensus in such meetings.

From Table 2-1, it is easy to say that communication has been traditionally held in the same place and at the same time. This type of communication encouraged related participants like subsection

Table 2-1. The time and space matrix

		TIME	
		Same (synchronous)	**Different (asynchronous)**
SPACE	**Same (face to face)**	Same time, Same place ・ Electronic meeting system ・ Group decision support systems	Different time, Same place ・ Digital Kiosk
	Different (distribution)	Same time, Different places ・ Video conference ・ Telephone	Different times, Different places ・ E-mail ・ Bulletin Boards ・ Blog

1.1.1 mentioned to communicate directly through voice, facial expression, and body language in reference to the representations of their plans. However, the mobility of people's activities, and cloud computing technologies have advanced in the modern age of information and globalization. Therefore, Virtual Design Studios (VDS) have been constructed by numerous universities and institutions across the world exploiting new computing and communication technologies (Wojtowicz 1994, Maher 1999, Kvan 2000, Matsumoto 2006). Meetings of a distributed and/or asynchronous type are firstly used which means that stakeholders are allowed to participate in a design process at different places and at different times (Maher 1999, Fukuda 2005, Matsumoto 2006)

Mostly, VDS system developments and design trials of an asynchronous distributed type are used allowing stakeholders to participate in the design process at various places and at different times. This enables expansion of communication opportunities, without a participant needing to be concerned about restrictions of space and time. VDS environments can accommodate a variety of platforms. The loose integration of design intensions and collaborative platforms causes considerable complications in the transition from individual to collaborative sessions. This results from the fact that most of the management of design representations, documentation and other information is done manually. To cope with these issues, virtual design environments include highly integrated applications for design, text and image processing, communication, scheduling, and information management. An essential shortcoming of these systems is the lack of synchronization between the views that different designers have and the context of their communication. However, in communication by text like BBS, E-mail, etc., it can be difficult to take in the nuance and atmosphere of the described contents. Fruchter (2013) reported that one of the problems typically faced in distributed work was misunderstandings in objectives and activities because of the invisible conditions. Since a meeting involving a conversation can solve this problem, communication and decision-making progress quickly. Therefore, this study investigates the capability of a distributed and synchronized type design meeting which allows stakeholders to participate in the design process at different places and at the same time while sharing a 3D virtual space.

In a synchronous distributed environment, different research efforts on design supporting a system for sharing 3D virtual space have been carried out, and showed a number of shortcomings as well. First, there was a system which allowed designers to be physically immersed in their sketches and physical models, literally inside life-size, real-time representations of these, while sharing them remotely with another system of the same sort (Dorta 2011). Safin (2009) evaluated the opportunities and constraints linked to the technological transfer of a sketch-based distant collaborative environment. Darses (2008) described a research project which aims at studying the value of a freehand design environment for architects. This sketch-based modeling software was implemented on a Tablet PC, which provided architects with the possibility to automatically generate 3D views from the freehand drawings. However these studies had poor drawn 3D external representations, which did not fit to the level of abstraction required for handling mental volumetric representations which were cognitively processed by the designers. Furthermore, sketches on whiteboards retained well-known scale problems from sketches on paper, and they did not permit several stakeholders participating in a meeting by using a standard PC.

On one hand, Gu (2009) and Shen (2010) developed a visualization tool on a multi-user platform to represent design alternatives and to supplement traditional presentation materials. They developed functions consisted of alternatives display, VR space and Chat application. Concentrating on VR spatial function related to this thesis, it was a function that while users were gathered at the same time in different places and they could share VR space in the Internet, as well as select alternatives of rebuilding plan by one user and share them simultaneously. However, a speaker's viewpoint was hard to be conceived by listeners because of impossible ability of synchronized view. That is, the speaker and listener could not organize a conversation by sharing the viewpoint meanwhile. Moreover, although a quantitative assessment of the system was conducted among 80 students, such issues as professional evaluation for utilization were not collected. Additionally, when implementing a synchronous distributed meeting under multi-user environment, problems were not only the necessity of a high-performance computer for the client to draw a 3D virtual space, but also requirements like communication speed for synchronizing the 3D virtual space. Actually, these studies also pointed out that audio devices and web cameras are well-suited for online deliberation. Moreover, the data volume of the content of a design study was usually large. Therefore, when drawing 3D graphics using a client PC, a computer with a high-performance Graphics Processing Unit (GPU) was always required. This meant that a standard PC cannot be used in this kind of design meetings making the presented concept hardly applicable. Fukuda (2012), on the other hand, presented another approach towards a distributed design meeting system. It allowed stakeholders to participate in the design process at different places and at the same time while sharing a 3D virtual space.

1. Which cases of Landscape Community Design could apply a VR system in a synchronous distributed meeting?
2. Which functions are effective in Landscape Community Design using a synchronous distributed VR meeting?

At present, previous reviews about synchronous distributed approach using 3D virtual space have not excessively studied, however, it could hypothesize that by the development and improvement of broadband environment and cloud computing technology, previously incompatible restrictions would be reduced so that synchronous distributed meetings would be an important mean of the VDS of the future.

2.2 STATE OF THE ART

So far, a large number of previous studies were referred and cited above, as a result, some inherent problems were clarified. At present, VR applications largely focus on two sides, one, stand-alone use (a separate software, not a part of some bundle or computer process); two, face-to-face and synchronous or distributed asynchronous use. Whether it is possible to improve the usability of VR and other visual media such as physical model has been raised as a new question. In order to improve the effect and usefulness by taking advantage of multi-media, each characteristic and feature of spatial understanding should be highly clear when users share a spatial plan or design. We are dedicated to understanding the characteristic and feature of conveying spatial size by these two media, and then developing a new city presentation system by linking the physical model and VR together. Moreover, not all the users could take part in a meeting or presentation considering the location or time when running a prototype system. Concerning restricted time or space, we also would like to evaluate the effect of a new VR application if under the condition of a synchronous distributed case.

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Chapter 3 Spatial Understanding between Physical and Virtual Models

This chapter focuses on differences in spatial reasoning capacity observed by using a physical model and a virtual model, and specifically emphasizes perception of the scale of space. It explored issues of accuracy and response time through a series of design experiments. While respondents viewed a physical model and a virtual model, a questionnaire was used to objectively evaluate these and establish which was more accurate in conveying object size.

3.1 THE OVERVIEW OF THE EVALUATION EXPERIMENT

During the experiment, the same object depicted alternatively by physical and virtual models was shown to the respondents. Three categories were required. The first category was height comparison of relative sizes, the second was the actual size of a building, and the third was the scale of the physical model. The object used in the experiment was a section of a shopping area (square, 100 m) in Buzenda, Shimonoseki City, Yamaguchi Prefecture, Japan, wherein approximately 30 buildings were built with heights ranging from 3 m to 30 m on flat ground. A digital model for VR was created by using Autodesk 3ds Max® 2010 (Autodesk, Inc., California, USA) and Forum8 UC-win/Road Ver.7 (Forum8, Tokyo, Japan). Fig.3-1 shows the virtual model created by realistically representing the target city for the experiment. The buildings and the ground used a monochrome texture of white and grey, and thus, judging building floor height or road width would be impossible in the experiment. The physical model was derived from the VR digital data and created by using ZPrinter® 650 (3D Systems, South Carolina, USA), a 3D printer with high accuracy. The scale of the physical model was 1/500.

A comparative experiment is required to match the conditions identically, except for the variables. In this study, the proposed physical and virtual models were designed to have the same size and the same façade to define spatial dimension features. To ensure that the models were of the same size, the physical model was created from digital data by using a 3D printer that employs rapid prototyping. If the physical model is traditionally handcrafted and the virtual model is made by CAD, then ensuring that both models will have the same size will be difficult. Therefore, information and communication technology facilitates the preparation in such environmental experiments. VR was performed by stereovision during the preliminary experiment (Olympus Power 3D Media Player with 3D Glasses, Olympus Corporation, Tokyo, Japan). The stereoscopic effect could not be observed because the internal definition for VR in the computer was full size in scale. Therefore, stereovision was not used in this experiment.

During observation, to avoid bias from previous experience in VR operation of the respondents, which could affect the evaluation, the VR camera was set up at an angle of 45° from the ground, thus capturing a fly-through movie (hereinafter “VR movie”) that circles around from a bird's-eye view.

Fig.3-1. Virtual model by realistic representation of the target city in the experiment (up: bird's-eye view, down: pedestrian view)

The respondent sat in a natural position 600 mm from the VR display (21 in.) and viewed the display horizontally. A respondent was not expected to look differently at the physical and virtual models. Thus, we attempted to match the two media in terms of size, viewpoint angle, and brightness. In addition, the physical model was fixed on a turntable that could rotate 360 °(Fig.3- 2).

At the beginning of the experiment, the respondents were told that the depicted physical model and the VR movie content were part of a city in Japan. However, they were not informed of its name to reduce the effects of different levels of knowledge or preconceptions related to the location at that time. The physical model and the VR movie were each spanned once before the questions were presented. As each question was answered, the response time was measured by a stopwatch until the

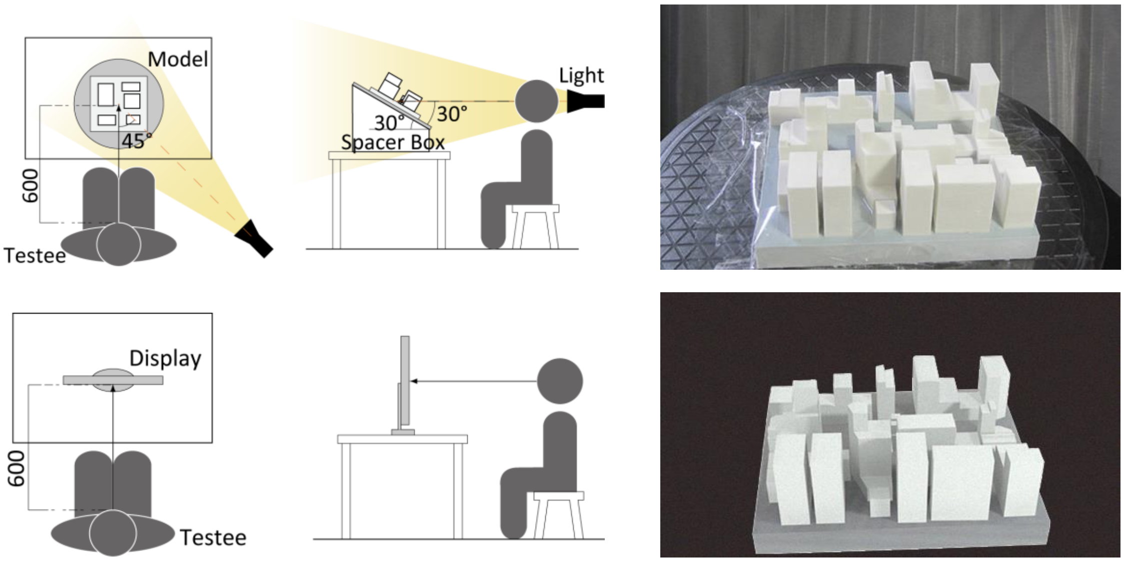

Fig.3-2. Position of a respondent and the media (up: physical model and down: virtual model)

end of the final answer.

The first question was on the height comparison of the buildings. Through this question, we explored dimension accuracy and response speed according to differences in building heights and in the models (physical vs. virtual). The questioner presented the physical model and the VR movie consecutively and indicated two buildings with different heights. The respondent was then asked to answer "which building is higher." Each medium was presented from a still viewpoint to avoid changes in impression caused by pointing the buildings. Four pairs of buildings were presented, and the real height differences were 1.5 m (Building A: 6.5 m, Building B: 5 m), 5 m (A: 15 m, B: 10 m), 10 m (A: 18 m, B: 28 m), and 20 m (A: 30 m, B: 10 m). The respondents viewed the buildings at a 30 ° angle. Fig.3-3 shows the pairs of buildings for height comparison. Fig.3-4 shows the experiment images, and Fig.3-5 illustrates each viewpoint related to the question on height difference.

The second question was on the actual size of one building and the scale of the physical model. Through this question, we explored the spatial understanding of the respondents. The questioner presented a physical model and a VR movie consecutively and asked the respondent to judge the actual size of one building (Fig.3-3, "the building for the question on actual size"). Then, the respondent answered the question "how many millimeters in the physical model" and "how many meters in virtual space."

The third question was on the scale of the physical model. As each question was answered, the response time was measured by a stopwatch until the end of the final answer.

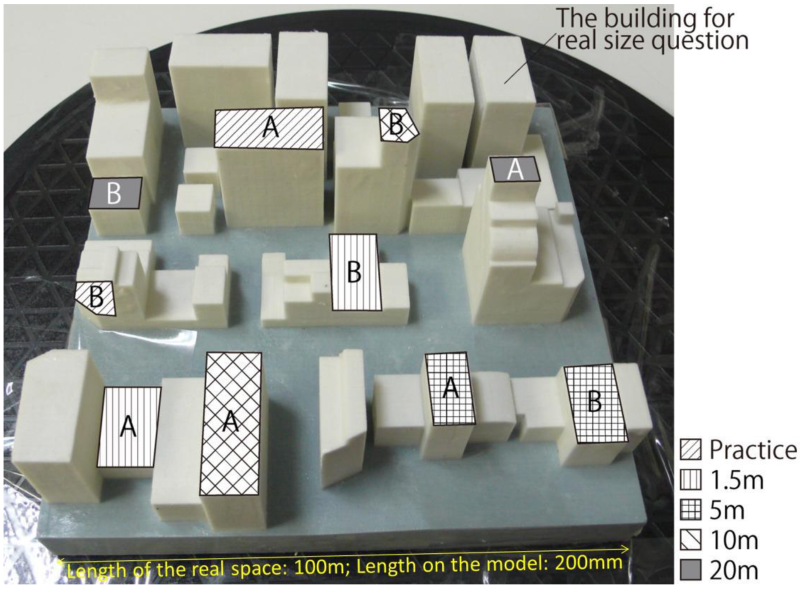

Fig.3-3. The building pairs for height comparison

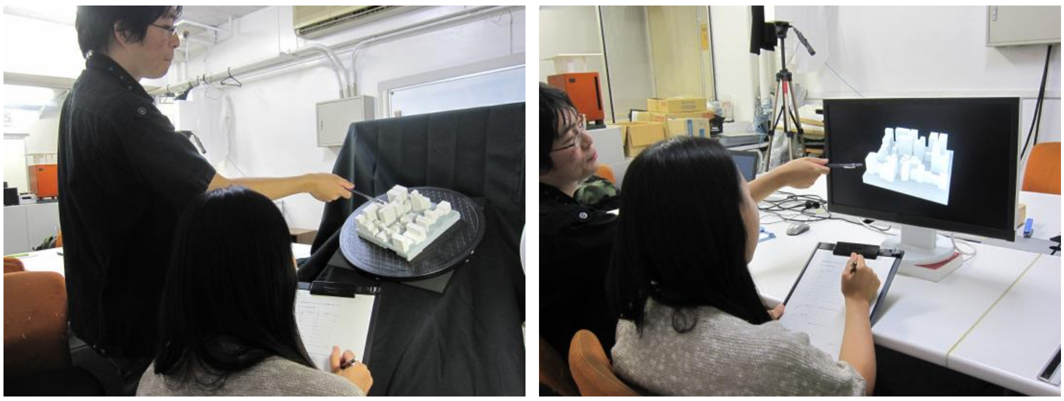

Fig.3-4. The experiment images (left: physical model and right: virtual model)

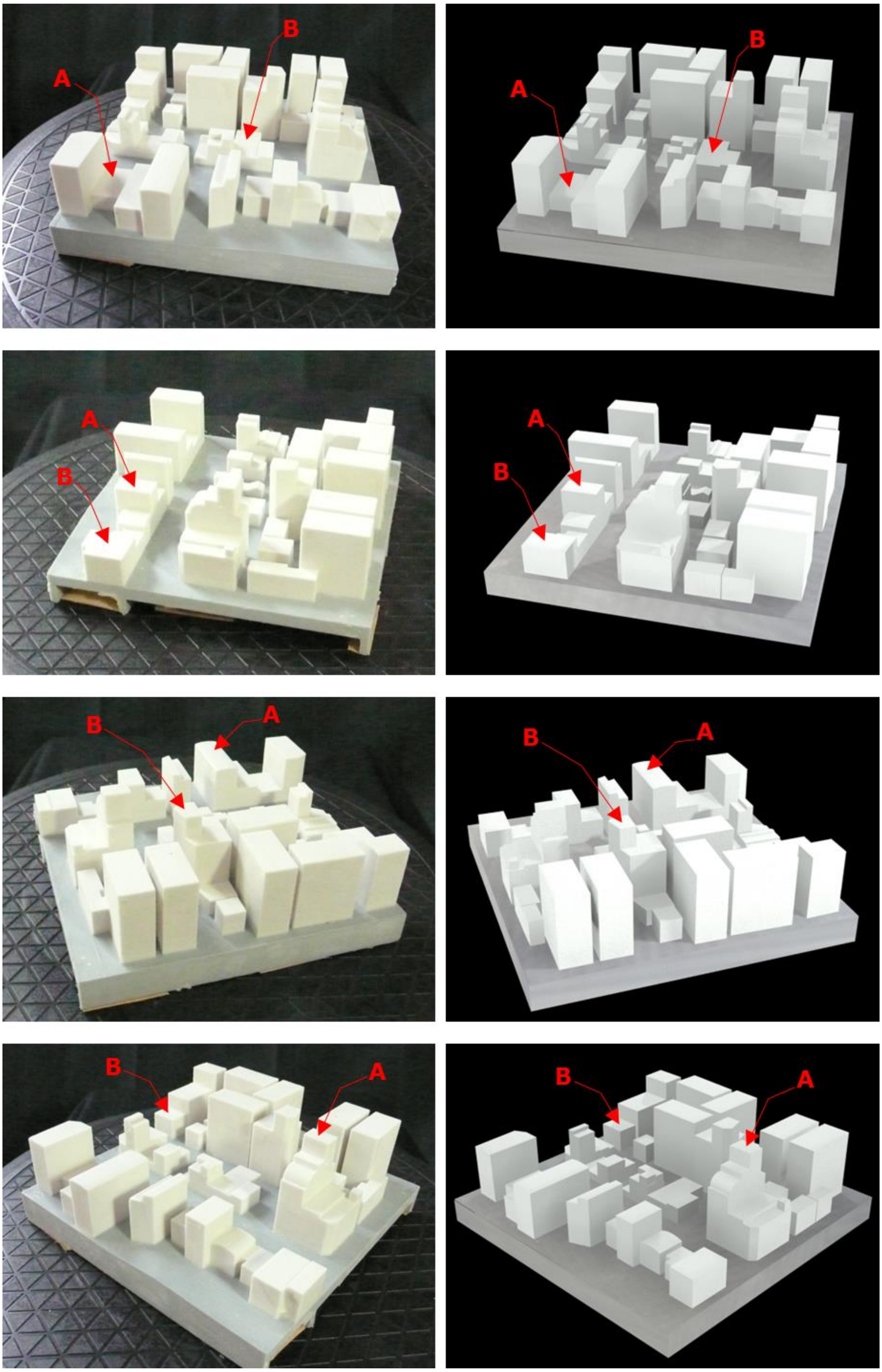

Fig.3-5. Each viewpoint that requires height difference (up: 1.5 m, upper middle: 5 m, lower middle: 10 m, down: 20 m

3.2 RESULTS AND DISCUSSION

Experiments were performed from September 24 (Saturday) to 30 (Friday), 2011 in Room S4-521, Suita Campus, Osaka University, Japan. The respondents were 24 students who belonged to the Graduate School of Engineering in Osaka University. All respondents were in their 20s, among which, 16 were males and 8 were females. To avoid change in impression through the presented sequence of the media, half of the respondents experienced the physical model first, whereas the other half experienced the virtual model first. The experiment was conducted without any conflict.

The statistical analysis presented by using Microsoft Excel 2010 showed that the physical model allowed quicker and more accurate understanding of building height compared with the virtual model. The difference in response time tended to be small for all items if the physical model was first compared with the virtual model. The details of the results are discussed in the succeeding sections.

3.2.1 The Analysis Methodology

A five-point scale was chosen as the response option for the height comparison of the buildings. 1=A is high, 2=A is rather high, 3=same, 4=B is rather high, and 5=B is high. According to the actual height difference, the correct answers were as follows. Number 1 was assigned 1.5, 5, and 20 m; Number 5 was 1 m and 10 m. The mean and variance of the absolute value of the difference in a correct answer and the response in each question were calculated. The response time was set as the average response time for the height comparison of the buildings. To assess the actual size of one building and the scale of the physical model: (i) H_a (mm) was assigned as the height on the physical model, (ii) H_b (m) was the height on the virtual model, and (iii) H_c (m) was the product of building height and scale. H was the correct answer, which was 50 mm for Case (i) and 25 m for Cases (ii) and (iii). The rate of deviation (equation (3-1)) was defined for each H_a, H_b, H_c and H; and the means and variances of these rates were calculated. Exploratory analyses were performed based on the order of the presented media, respondent experience, gender, and the sample.

$$D_x = |1 - H_x / H| \quad (x = a, b, c) \tag{3-1}$$

3.2.2 Analysis for All Respondents

Table 3-1 shows the correctness in the responses to the height comparison. Everyone correctly responded to the height differences of the 10 m and 20 m cases in the physical model and the 20 m case in the virtual model. Therefore, tall buildings were evaluated accurately in these cases. The responses elicited from the physical model were more accurate than those from the virtual model in the 1.5 m case within the statistical significance of 5% (hereinafter called “5%”), and in the 5 m and 10 m cases within the significant difference of 1% (hereinafter called “1%”).

Table 3-2 summarizes some of the results for the response time. The timed responses to the physical model were shorter than those to the virtual model in the 1.5, 5, and 10 m cases within 1%, and the 20 m case within 5%.

Table 3-3 indicates the results for the actual size and the scale of the physical model. The physical model exhibited the lowest rate of deviation and the smallest variance among the respondents for the three items in Table 3-3, namely, D_a, D_b and D_c. By contrast, the variance in scale evaluation exhibited by the sample was large. Moreover, the rate of deviation in the list of physical model×scale was larger than that in the list of virtual model.

Consequently, the physical model tended to allow quicker and more accurate comparison of building heights compared with the virtual model. Therefore, a physical model is more intuitive than a virtual model as a spatial understanding model.

Table 3-1. Correctness of the responses to the height comparison (N=24)

Height difference (m)	Medium	Correct	Mean	|Mean－Correct|	Variance
1.5	Physical model	1	1.29*	0.29	0.71
	Virtual model	1	1.71	0.71	1.54
5	Physical model	1	1.13**	0.13	0.19
	Virtual model	1	1.92	0.92	0.99
10	Physical model	5	5.00**	0	0
	Virtual model	5	3.96	1.04	1.29
20	Physical model	1	1.00	0	0
	Virtual model	1	1.00	0	0

Non*: no statistical significance, *: 5%, **: 1%

Table 3-2. Average response time (N=24)

Height difference(m)	Physical Model(s)	Virtual model (s)	Physical model- Virtual model (s)
1.5	2.01**	3.29	-1.28
5	2.48**	4.38	-1.90
10	1.98**	3.85	-1.87
20	1.55*	2.38	-0.83

Non*：no statistical significance, *: 5%, **: 1%

Table 3-3. Actual size and physical model scale based on the order of the presented media (N=24)

	Physical Model(D_a)	Virtual model (D_b)	Physical model×scale(D_c)
Average rate of deviation	22.50%	72.20%	130.30%
Variance	0.17	1.21	5.78

Non*: no statistical significance.

3.2.3 Analysis of Presented Media Order

Response data divided by each height difference were subjected to t-test analysis. As shown in Tables 3-4 and 3-5, no significant difference in correctness or response time was found. This result suggested that impression change was not related to whether a physical model or a virtual model was used, as previously discussed in section 3-2. By contrast, the response time difference was small for all items if the physical model was first compared with the virtual model. One reason for this finding was that the participants grasped the complete picture during their VR experience because they had experienced the physical model earlier. In addition, the consequences did not vary by gender.

Table 3-4. Correctness of the responses to the height comparison based on the order of the presented media (N=24)

Height difference(m)	Medium	Cor-rect	Mean (Physical model first)	Mean (Virtual model first)	Variance (Physical model first)	Variance (Virtual model first)
1.5	Physical model	1	1.08	1.50	0.08	1.15
	Virtual model	1	1.42	2.00	0.41	2.31
5	Physical model	1	1.00	1.25	0	0.33
	Virtual model	1	1.83	2.00	1.31	0.62
10	Physical model	5	5.00	5.00	0	0
	Virtual model	5	4.25	3.67	0.85	1.44
20	Physical model	1	1.00	1.00	0	0
	Virtual model	1	1.00	1.00	0	0

Non*: no statistical significance.

Table 3-5. Response time based on the order of the presented media (N=24)

Height difference(m)	First Medium presented	Physical model (s)	Virtual model (s)	Physical model - Virtual model (s)
1.5	Physical model	0.96	1.43	-0.46
	Virtual model	1.68	2.94	-1.26
5	Physical model	0.72	1.35	-0.64
	Virtual model	2.12	3.38	-1.26
10	Physical model	3.00	3.04	-0.04
	Virtual model	1.58	3.64	-2.06
20	Physical model	0.60	0.60	0.00
	Virtual model	1.43	2.87	-1.44

Non*: no statistical significance.

3.3 CHAPTER CONCLUSION

This study focuses on differences in spatial understanding observed by using physical and virtual models. In particular, it emphasizes the perception of scale as a fundamental research area in the field of spatial reasoning ability. By using a section of a city in Japan depicted by physical and virtual models, we conducted an experiment involving 24 respondents to answer questions regarding height comparison, actual size, and physical model scale. The condition is buildings and ground used a monochrome texture of white and grey in both physical and virtual model. Moreover, due to validate the difference of spatial understanding in terms of volume which is from VR and physical mode, so this experiment uses this condition. Additionally, this experiment also expected to evaluate the spatial understanding through users' intuition not based the pictures or other factors from models.

The respondents acknowledged that the physical model is more accurate, as well as easier and faster to use. The responses elicited from the physical model are more accurate than those from the virtual model in the 1.5 m case within the statistical significance 5%, as well as in the 5 m and 10 m cases within the significant difference 1%. Timed responses to the physical model were shorter than those to the virtual model in the 1.5, 5, and 10 m cases within 1% and in the 20 m case within 5%. Response time difference also tended to be small for all items if the physical model was first compared with the virtual model. One reason for this finding was that the participants grasped the complete picture during their VR experience because they had experienced the physical model earlier.

Chapter 4 A Presentation System by Viewpoint Linking VR and Physical Model

4.1 THE OVERVIEW OF THE SYSTEM

The developed city presentation system consists of an urban physical model, VR, a web camera, a laser pointer and developed software. Fig.4-1 shows the whole image of the city presentation system developed in this chapter. First of all, the user specifies two arbitrary points where a viewpoint and a main object are defined on the physical model. The user defines the viewpoint and the main object with the laser pointer by pressing the button on it. Then, a VR image that looks at the main object from the viewpoint defined on the physical model is drawn through the laser optical point detection flow, coordinated system conversion flow, and the VR drawing flow. The web camera (two million pixels) is set up 1m above the model. The laser optical point detection flow, the coordinate system conversion flow, and the VR drawing flow are described in section 4.2.

The distance (user-radiant distance) between a radiant of a laser pointer on a physical model and a user depends on a user's standing point and the scale of the model. Normally, it is appropriate 1 - 200cm. And the user-radiant distance is also possible less than 1 cm, if a user wants to irradiate more correctly to somewhere of a physical model. For example, he may put himself as close as the model. Here, the system mainly includes following devices and software, UC-win/Road (FORUM8 Co., Ltd) as a VR software, Sashi - 41 (KOKUYO Co., Ltd, 650 mm wavelength, receivable distance about 30 m in radius) as a laser pointer, and Logicool Webcam Pro 9000 (two million pixels) as a web camera.

In this chapter, a city presentation method offering a united operating environment linking viewpoint information on a physical model and in VR is developed. The photogrammetry technique is adopted as technology to link aspect information. A laser pointer and a web camera are used as input devices.

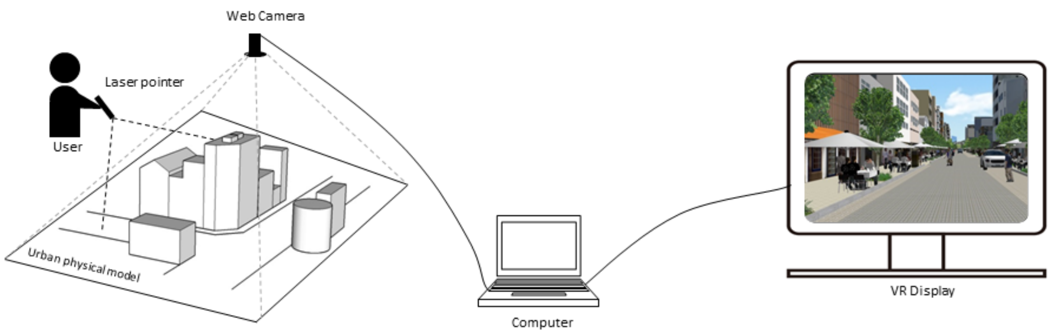

Fig.4-1. Whole image of the city presentation system

As the method of the experiment, the first is to explore an approach to improve the accuracy of previous city presentation system and subsection 4.2.1 described specifics of the developed system. Next, after considering allowable value of variation, accuracy verification was conducted by an experiment to figure out possible factors affecting the accuracy (4.2.2). Finally, a prototype system was built which could apply to the practical urban landscape design and utilization was also reviewed from interviewees with practical experience (4.2.3).

4.2 STUDY OF ACCURACY IMPROVEMENT OF THE CITY PRESENTATION SYSTEM AND ITS FLOW

4.2.1 Accuracy Improvement

Fig.4-2 shows the complete system flow. Basically, there are three major processes as mentioned in section 4.1, namely the laser optical point detection flow, coordinated system conversion flow, and the VR drawing flow. AR Toolkit (HIT Lab) is used in the coordinate conversion flow, in order to realize the geometric integrity when converting the screen coordinate system to the physical model coordinate system. By using the technique which is given the positional relationship with a designated model, a low-cost and easily set-up marker is able to calibrate the laser point's coordinates with none necessity to know the position of the web camera and the physical model. Therefore, the recognition method of the marker it is could be one of the reasons to influence the accuracy. Some previous related reports are noted such as an AR marker tracking method and calibration (Kato 1999), and AR markers setting method for outdoors use (Yabuki 2011).

As a result from the above reported approaches, three possible factors were defined as to cause the errors of specified viewpoints and the main object's coordinates.

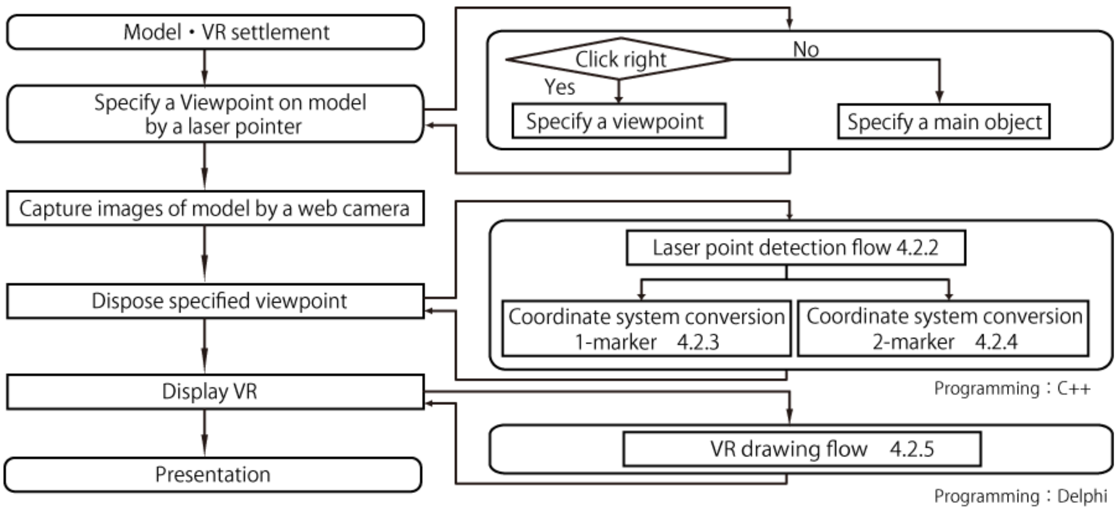

Fig.4-2. System flow (three flows)

1. ARToolkit enclosed algorithm when converting a screen coordinate system to a physical model coordinate system.
2. Focal length, central coordinates and lens distortion of a web camera.
3. The number and angle of markers to be placed.

Factor 1. ARToolkit measured center coordinates of the marker (unit: pixel) and through them to calibrate the value equally millimeters (mm) per pixel in length as a conversion coefficient. So, it was necessary to understand the error caused when detecting the center coordinates of the marker (Section 4.3). Additionally, degree of reliability (0.0 - 1.0) to detect markers was also confirmed. This is contained in the ARMarkerInfo structure and yet not reviewed by a previous system (Tokuhara 2010).

Factor 2. Although the focal length, central coordinates and lens distortion of web camera are called camera parameters which may affect captured images, these parameters are not absolutely same every time because of characteristics of different cameras. Camera parameters could be obtained by the camera calibration method, and errors were also possible to be decreased by correcting camera image in term of those obtained parameters. On contrast to a 1-step calibration method previously described (Tokuhara 2010), this study expected to examine a 2-step calibration method for a higher accuracy (subsection 4.3.4).

Factor 3. Because the previous report verified the only one marker case (hereinafter, 1-marker), so it is necessary to know the two markers case (hereinafter, 2-marker). In this study, (section 4.2.4, section 4.5) demonstrated respectively 1-marker and 2-marker in the coordinate system conversion process. Section 4.2.2 - section 4.2.5 showed that how to detect the laser points by a laser pointer, and all the other processes including the final VR drawing flow.

4.2.2 The Laser Optical Point Detection Flow

This section describes how to detect a point from a laser pointer and obtain its coordinates. The web camera of this system could capture 30 images per second. Here, background subtraction function of OpenCV (Open Source Computer Vision) was used for image processing.

First, the laser optical point detection flow saves an image as a “reference image” from every five images shot by the web camera; the other images are “judgment images”. On the last judgment image, a pixel whose brightness (0 - 255) is higher than the reference image is made a laser optical point candidate by using the background difference function of OpenCV (Open Source Computer Vision Library). If the judgment image has optical point candidates above the “N” threshold which defines the number of pixels with changed brightness, the image is set aside to avoid incorrect detection caused by jiggling of the user’s hand.

The brightness of the pixels indicated by the laser pointer is very low and the brightness of the area surrounding the pixel is also low in contrast. The optical point candidate (the center pixel in

Fig.4-3) is picked up if the absolute value of the difference between the brightness value of the optical point candidate and the brightness value of its 3 × 3 surrounding pixels (these are slash pattern pixels in Fig.4-3) is within 20. Next, the brightness of the pixels picked up is deducted from the brightness of each three outside the circuit of 15 × 15 surrounding pixels (these are grey pixels in Fig.4-3). If the difference of the brightness value is 30 or more, the candidate is detected as the laser optical point and receives the coordinate value as (LaserX, LaserY).

4.2.3 One Marker Coordinate System Conversion Flow

In this subsection, 1-marker is described firstly corresponding to coordinate system conversion. The coordinate values (LaserX, LaserY) which are obtained in subsection 4.2.2 are converted into coordinate values (ModelX, ModelY) in the model coordinate system, and finally they are converted into coordinate values (VRX, VRY) in the VR coordinate system (VCS). Because the screen co-ordinate system of the web camera (SCS) and the coordinate system of the physical model (MCS) are separately defined, the model itself can be freely moved.

The original SCS point is the upper left of the web camera image. The coordinate system that represents the pixel distance in both the vertical and horizontal directions from the origin. Since SCS depends only on the web camera, it is difficult to understand the position relationship between a user – pointed viewpoint or a main object without taking the position of a web camera and a model into account. Moreover, it is easily considered that a physical model may be moved in a presentation and the spatial relationship of a web camera and a physical model may change along with the changed position of the model. Therefore, fixing the spatial relationship of a web camera and a physical model beforehand lacks practicality.

In order to solve the above problem, the MCS defines a reference point as an original point. And the x axis represents the east-west with west in the negative direction (to the left) and the y axis represents the north-south direction with south in the positive direction. The position on a model and on VR system are managed to be corresponded by changing the coordinate values of MCS into the ones of VCS again.

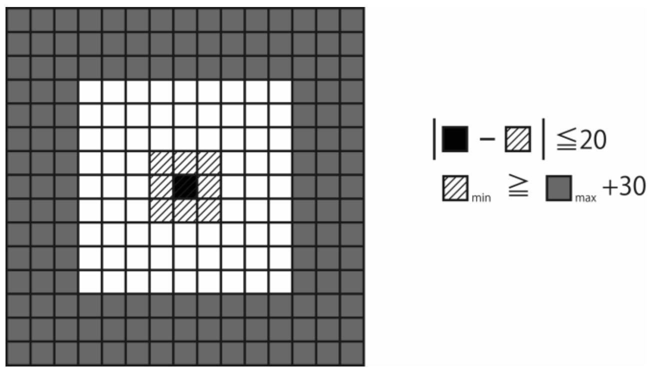

Fig.4-3. Pixels searched for detection of optical point (1 block = 1 pixel)

To define MCS, ARToolkit is used as a basic software library. It is realized by photographing a square pattern which was called marker by means of a web camera, and judging the spatial relationship of the web camera and the marker.

According to Kato (1999), the spatial relationship of a web camera and a marker could be calibrated by the marker. The positional grasp function of the marker in the ARToolkit can obtain the coordinate values of the marker's vertices and center. The original point of MCS is defined as the center of the marker. The values of the four vertices of a marker are able to be obtained in SCS, and a transform matrix then could be calibrated from SCS to MCS based on the transformation of the square marker. This transform matrix consists of 3×4 elements. This 3×4 matrix combined of rotation and translation, which is the right most one column. And the remaining 3×3 matrix, as observed from a web camera, is the rotation including horizontal, vertical and normal directions of the marker. Because the developed software should capture the head - marker, it is sufficient to deal with the only normal direction from the marker. Therefore, in this transform matrix, the upper left 2×2 elements show inclination in a normal direction. And the 2×2 elements of the transform matrix are defined as a rotation matrix. In this flow, 80×80 mm square marker is set up on directly above of the model, so the marker is taken as the original point. Fig.4-4 shows the positional relationship of SCS, MCS, and coordinates of a laser point in one image getting from a web camera.

The coordinate conversion process corresponding to 1-marker is developed by using the above mentioned approaches, and consists of the three following steps.

1) Integration of SCS and MCS

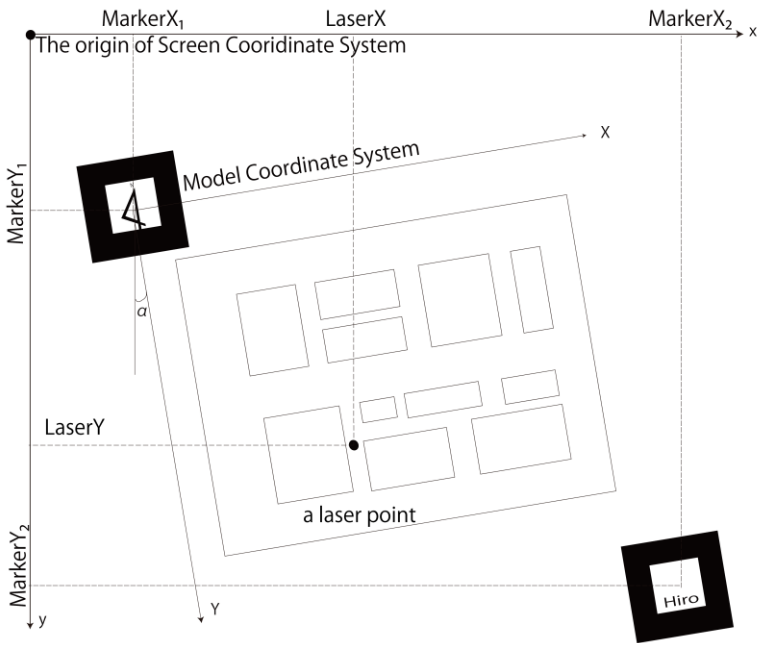

Fig.4-4. Screen coordinate system and model coordinate system

Firstly, to convert the original point of MCS to the original point of SCS, (LaserX, LaserY) is subtracted from the coordination values of the center of marker (MarkerX, MarkerY), and multiplied by the rotation matrix (equation 4-1). The unit of the coordinate values (RotatedX, RotatedY) is the pixel.

2) Conversion to MCS from SCS

Next, unit is converted from pixel to mm. The distance (unit: pixel) between the center of the marker and the vertex in the image is measured by ARToolkit (equation 4-2). This distance corresponds to half the actual length of the marker's diagonal line ($40\sqrt{2}$ mm). So the conversion coefficient (mmPixRatio) is obtained by dividing $40\sqrt{2}$ in the result of equation 4-2 (equation 4-3). Then, the mmPixRatio is multiplied by (RotatedX, RotatedY) (equation 4-4). In this way, the coordinate values (LaserX, LaserY) are converted into coordinate values (ModelX, ModelY).

$$\begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \begin{pmatrix} \text{LaserX - MarkerX} \\ \text{LaserY - MarkerY} \end{pmatrix} = \begin{pmatrix} \text{RotatedX} \\ \text{RotatedY} \end{pmatrix} \tag{4-1}$$

$$\sqrt{(\text{MarkerX} - \text{VertexX})^2 + (\text{MarkerY} - \text{VertexY})^2} = \text{Distance} \tag{4-2}$$

$$\frac{40\sqrt{2}}{\text{Distance}} = \text{mmPixRatio} \tag{4-3}$$

$$\text{mmPixRatio} \times (\text{RotatedX} \quad \text{RotatedY})^T = (\text{ModelX} \quad \text{ModelY})^T \tag{4-4}$$

3) Conversion to VCS from MCS

Finally, the coordinate values (ModelX, ModelY) are converted into the coordinate values (VRX, VRY) in the VCS. VCS defines meter (m) as the unit, x represents the north-south direction and y is the east-west with west in the negative direction. That is, axes of MCS and VCS are parallel. Therefore, the conversion of unit namely the adjustment of the deviation of the origin of MCS and VSC could be performed.

The conversion of unit (from mm to m) means that the values (ModelX, ModelY) are divided by the scale of a model and by 1,000 (equation 4-5).

Then the deviation of the original point from SCS and VCS, which is a constant number, is revised. The constant numbers are obtained before running this flow and are saved as (ReviseX, ReviseY). Constant numbers (ReviseX, ReviseY) are added (ExpandedX, ExpandedY) (equation 4-6). In this way, (VRX, VRY) is obtained. Moreover the height coordinates are necessary to set VR camera, so the height value is assumed to be a fixed value (VRZ). The (VRX, VRY, VRZ) is defined as the camera's position in VR system.

$$\frac{1}{\text{scale} \times 1000} \times \begin{pmatrix} \text{ModelX} \\ \text{ModelY} \end{pmatrix} = \begin{pmatrix} \text{ExpandedX} \\ \text{ExpandedY} \end{pmatrix} \tag{4-5}$$

$$(\text{ExpandedX} \quad \text{ExpandedY})^T + (\text{ReviseX} \quad \text{ReviseY})^T = (\text{VRX} \quad \text{VRY})^T \tag{4-6}$$

4.2.4 Two Markers Coordinate System Conversion Flow

This subsection describes the coordinate conversion process referring to 2-marker. The process is the same to “1) Integration of SCS and MCS” and “3) Conversion to VCS from MCS” stated in subsection 4.2.3. However, “2) Conversion to MCS from SCS” is a different step in this process, so the detail is stated below.

The process of “2) Conversion to MCS from SCS” based on 2-marker uses two markers to complete the unit conversion from pixel to mm. Firstly, distance (unit: mm) of these two markers is already known, and the two center coordinates (MarkerX_1, MarkerY_1), (MarkerX_2, MarkerY_2) of the markers could be acquired by ARToolkit. Then, the same distance (unit: pixel) could be calibrated in term of the values, which is also corresponding to the actual distance of two center coordinates. So the conversion coefficient (mmPixRatio) is obtained by dividing (wmat) in the result of equation 4-7 (equation 4-8). Finally, as in the coordinate system conversion process of 1-marker, coordinates of MCS (ModelX, ModelY) are obtained by using this coefficient in term of equation 4-1 and 4-4.

$$\sqrt{(\text{MarkerX}_1 - \text{MarkerX}_2)^2 + (\text{MarkerY}_1 - \text{MakerY}_2)^2} = \text{Distance} \tag{4-7}$$

$$\frac{\text{wmat}}{\text{Distance}} = \text{mmPixRatio} \tag{4-8}$$

4.2.5 VR Drawing Flow

The coordinate values of the viewpoint and the main object are output to a file named “Laser Position.dat”. In this file, the coordinate values of the viewpoint and the main object are continuously written (Fig.4-5). In the VR drawing flow, the VR software “UC-win/Road” (ver.3.4.11) is used. The authors developed plug-in software to put a camera in the VR at the position the user specifies. The plug-in software inputs a file “Laser Position.dat” and memorizes all the numbers described in the file, ten characters per step. These numbers are substituted into the camera

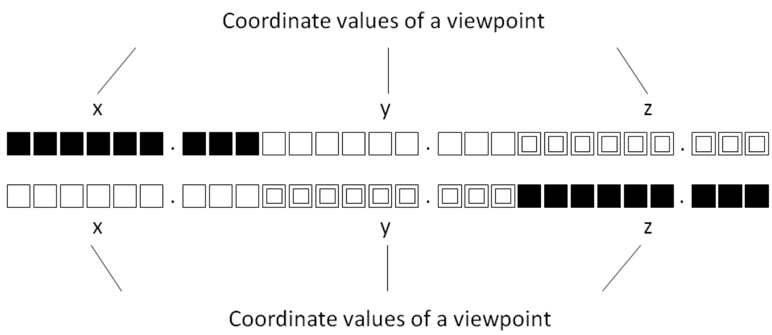

Fig.4-5. Laser Postion.dat

information in the VR. Then “Laser Position.dat” is deleted.

4.3 ACCURACY VALIDATION

4.3.1 Allowable Error

In this study, a city presentation system is a system which uses a laser pointer to point a viewpoint of a city model and a main object, and then the pointed objects or landscape from the viewpoint are displayed in VR system in real-time. As mentioned in section 4.2.1, certain errors happen in the process of specifying a viewpoint and coordinates of the main object. If an error were large, it has become impossible to display the surrounding landscape in VR from a specified viewpoint. Therefore, an accuracy validation is necessary.

Many viewpoints showed on a city model are on the rooftop of a building or a road. Although a width of a road varies diversely, in normal sense it has at least 4 m width referring to road law or building standard. Therefore, this study aims at a system which is also able to specify a viewpoint and a main object toward to a 4m wide road. In this case, the width becomes 4mm of a 1/1000 scale model and 8mm of a 1/500 scale model. In order to adjust to a 1/1000 scale model that is usually used in urban model, the set value of allowable error is 4mm.

4.3.2 Experimental Methodology

For the reason to verify generating factors of an error described in section 4.2.1 (Fig.4-6), following accuracy validations were conducted by using a 50mm - unit grid pattern where markers placed on it and meanwhile were captured by a web camera.

1. Accuracy validation of center coordinates of markers
2. Accuracy validation by 2-step calibration
3. Accuracy validation by 2-marker

Experiment conditions. An average illumination intensity of markers on a desk was 234.6 lx, and luminance of each marker was 18.7cd/m^2 and 23.0cd/m^2 from where a web camera was. So, the lighting conditions were good for detecting markers. Illumination intensity was measured by an illuminometer T-10 made from Konica Minolta and luminance was measured by LS-100 from the same brand.

Experiment approach. After starting the developed software (section 4.1), the experiment was begun once the degree of reliability from extracted markers reached maximum (subsection 4.2.1). Within 1cm of the user-laser distance, the laser pointer pointed each intersection of the grid. Then average values were calibrated after 3 times repeatedly measured in every intersection.

4.3.3 Accuracy Validation as Detecting Center Coordinates

The center coordinates (unit: pixel) of markers are acquired by using the arGetTransMat function of ARToolkit. The acquired center coordinates hereinafter referred as experimental values are used to

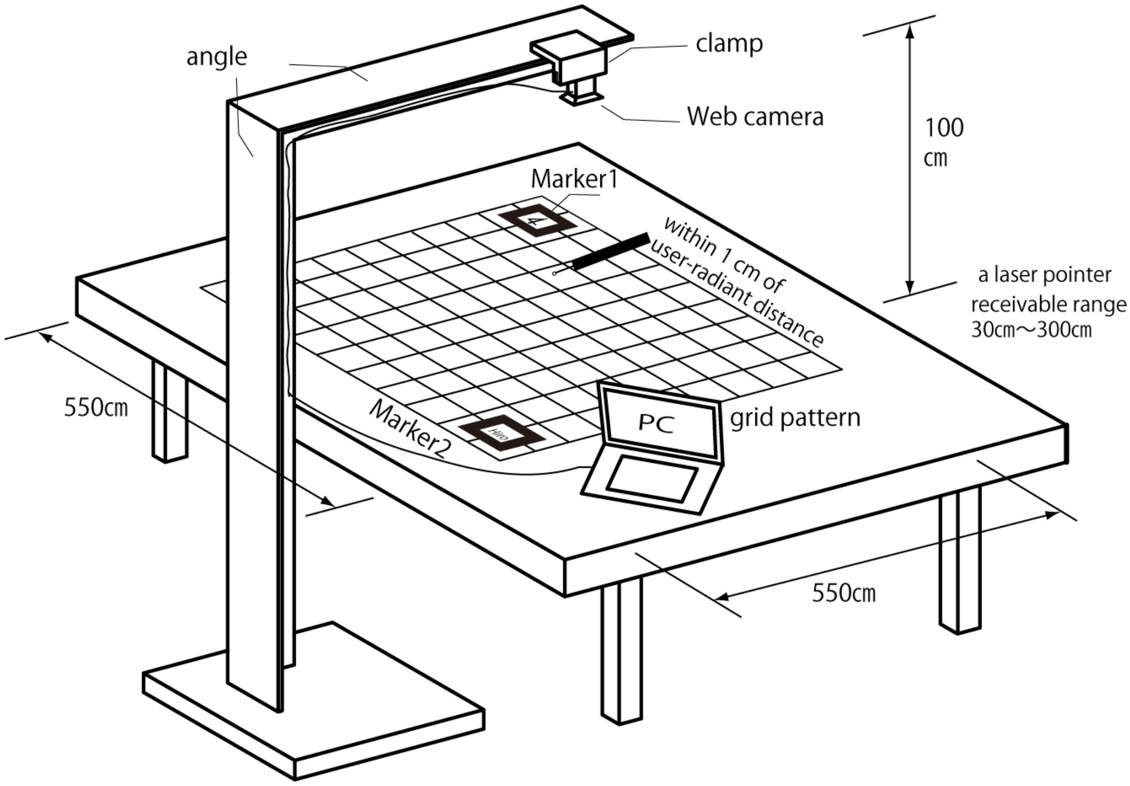

Fig.4-6. Accuracy validation system

compare with a true value. A true value here is the center values of an image captured by a web camera and is measured by Adobe Photoshop (image processing software). In other word, since two markers are used, the distance between markers is $450\sqrt{2}$ mm. The reliability of markers showed a high value of 0.94 in the middle of the experiment. The picture captured by the web camera is shown in Fig.4-7.

Results are showed in Table 4-1, Table 4-2, and Table 4-3. In Table 4-3, the difference of a true value and an experimental value equals 0.0012 mm per 1 pixel. So in the case of 1/1000 scale model, although appropriately 1.2mm error would occur at the normal scale, it could be just neglected. That is to say, accuracy is high at the time of detecting center coordinates of markers.

Table 4-1. True values of markers

	X (px)	Y (px)
Marker1	38.00	38.00
Marker2	379.00	367.00

Table 4-2. Measured center coordinates of markers

	X (px)	Y (px)
Marker1	37.23	37.45
Marker2	378.33	369.94

Table 4-3. Difference of true value and measured value

	mmPixRatio
True value	1.3372
Measured value	1.3360
Difference (｜True value - Measured value｜)	0.0012

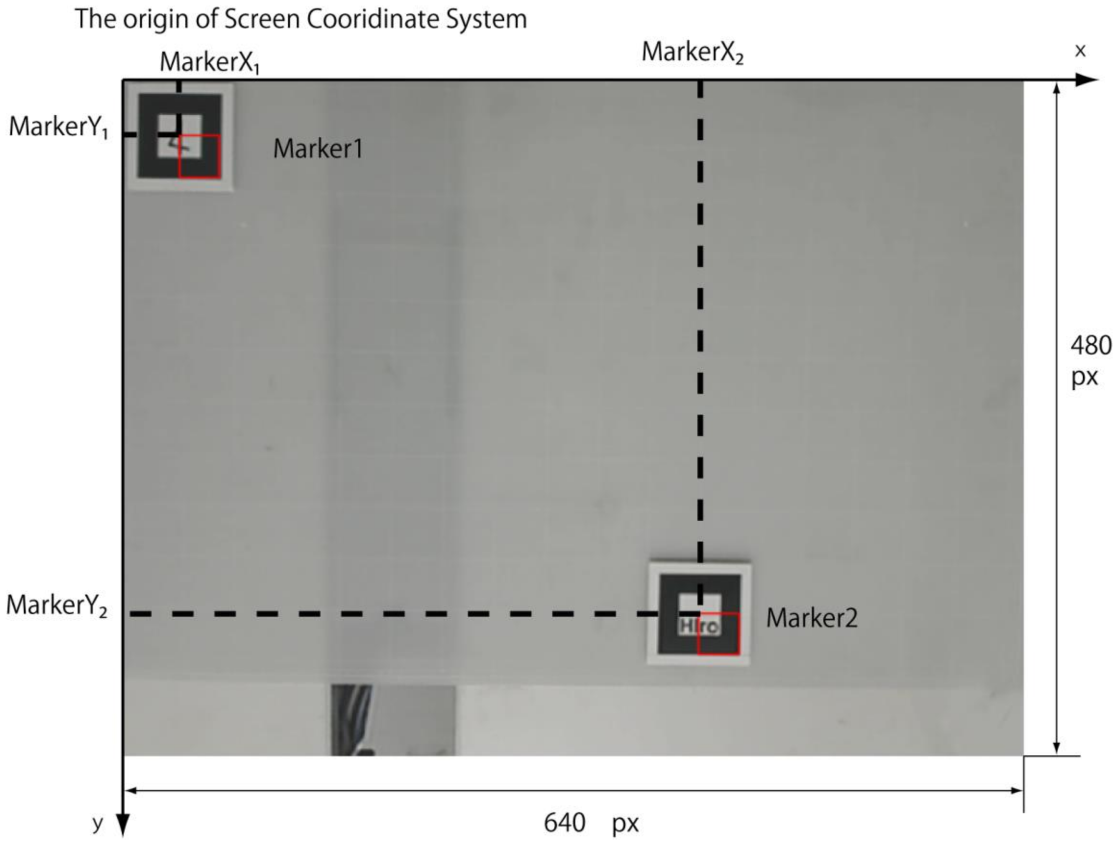

Fig.4-7. An image captured from a web camera

4.3.4 Accuracy Validation by Two Steps Calibration

A laser pointer was used to point to MCS every 50mm beginning from the center of a marker in both x and y axes. Then, values (ModelX, ModelY) were obtained with the developed software. Next, the absolute difference of values and measured value was calibrated. Additionally, the laser pointer's range covered 0 - 450mm starting with the origin as the center of a marker. Here firstly used one marker.

The result of an average error, together with a previous study (Tokuhara 2010) of 1-step calibration is shown in Fig.4-8 and Fig.4-9. Average errors acquired by 1-step calibration before are 11.84mm in x axis and 10.04mm in y axis. However, the average errors of 2-step calibration are 5.52mm in x axis and 4.03 in y axis. As a result, accuracy improvement in x axis and y axis are raised by 53.4% and 59.8%. Hence, 2-step calibration should be used in the next sections.

4.3.5 Accuracy Validation by Two Markers

Experiment approach is similar to subsection 4.3.4; except 2-marker is placed on a diagonal line of a one-side 450mm square (Fig.4-10). Moreover, 2-step calibration is used and reliability of marker detection is 0.882.

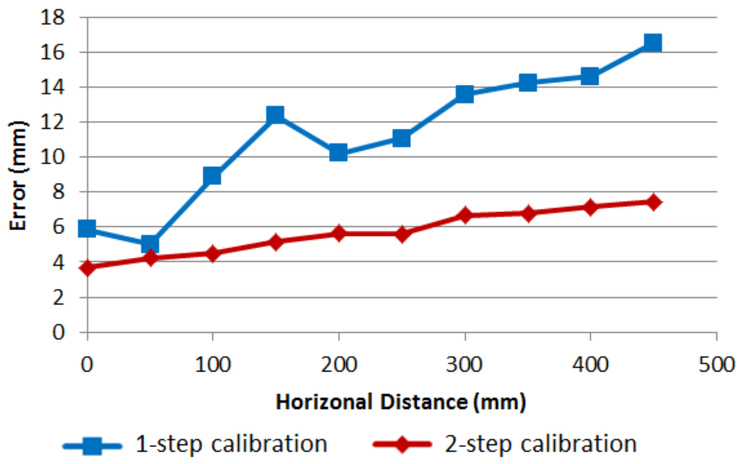

Fig.4-8. Errors per x distance

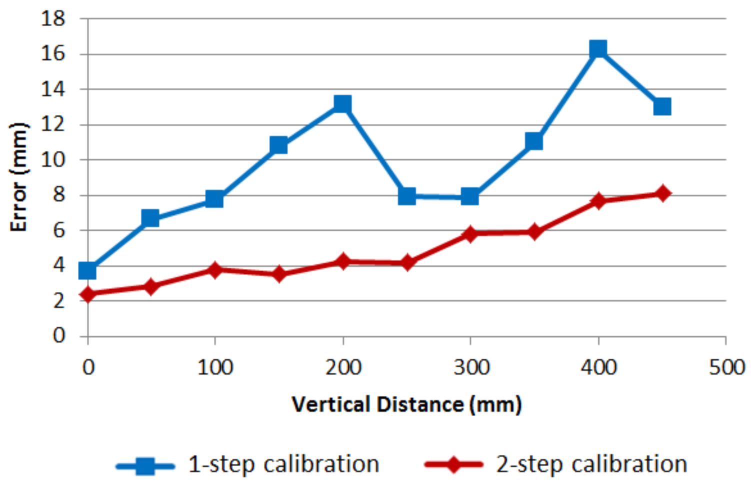

Fig.4-9. Errors per y distance

The result of average errors showed in Fig.4-11, Fig.4-12, and Table 4-4 is that the error becomes more than 3 mm by 1-marker and less than 3mm by 2-marker. Contrast to an increased trend of 1-marker, errors change small as increased the distance from the marker accordingly. Furthermore, except the origin of y (y = 0), errors by 2-marker are always smaller referring to each indicated point of x and y. So it is easily to figure out that 2-marker performs better for reach the requirement of the allowable error 4mm (see subsection 4.3.1).

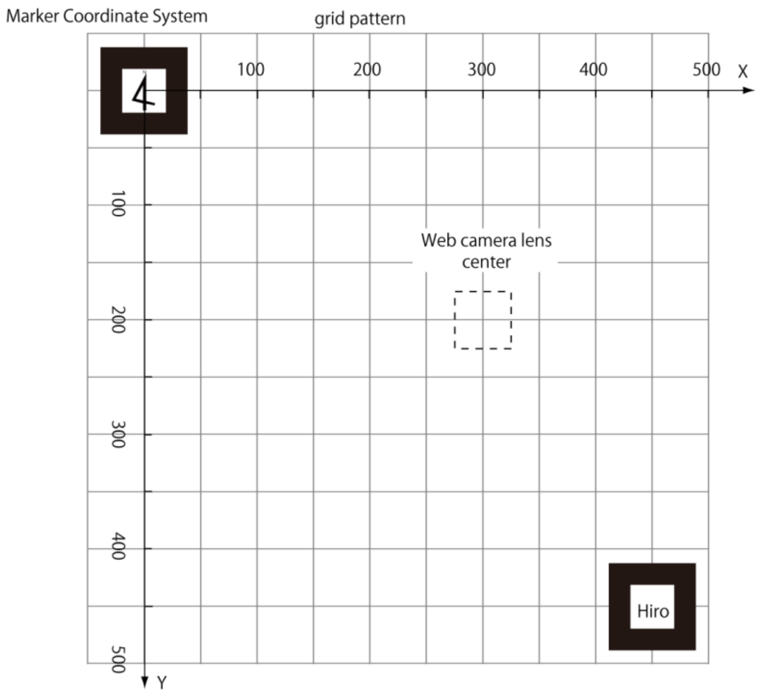

Fig.4-10. The range of accuracy validation

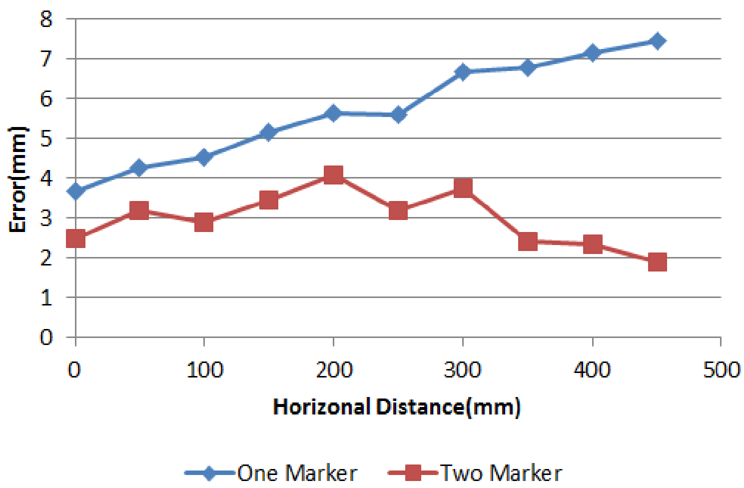

Fig.4-11. Errors per x distance

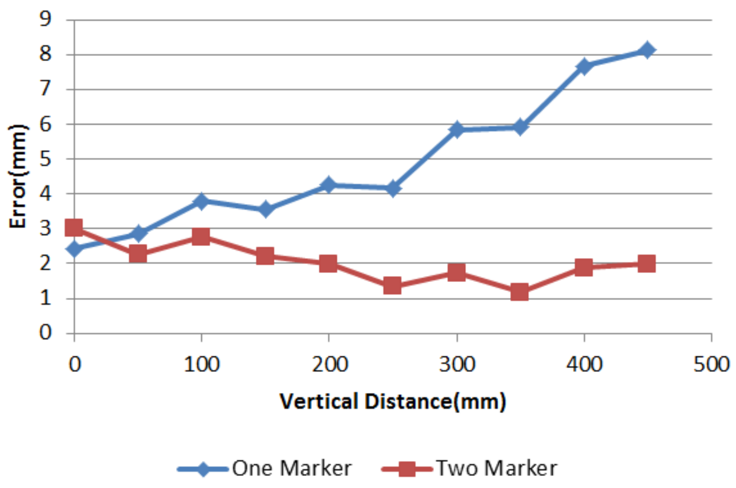

Fig.4-12. Errors per y distance

Table 4-4. Average error values of markers (mm)

	x	y
1-marker	5.5161	4.0300
2-marker	2.9694	2.0390

4.4 AVAILABILITIES FOR PRACTICAL APPLICATION

4.4.1 Investigative Method

A usability evaluation was conducted (Tokuhara 2010) and there were 36 participants to join it and made a questionnaire after experiencing the 1-marker system. The operability, accuracy and response speed have been positively appraised. As a further step, this study tried to figure out the possible availabilities for a practical application through a hearing investigation of related specialists. In doing so, a prototype system was developed for a real urban project collaborated by the specialists. A maintained street project where it was in Schimonoseki, Buzenda, Yamaguchi Prefecture, Japan was proposed in this hearing investigation. Table 4-5 showed the investigation status.

Fig.4-13 and Fig.4-14 illustrates the developed prototype system including a ground plan, complete system image and verification image. Fig.4-15 shows the physical model and VR cut.

The created physical model is 1/500 scale and 1160 (west-east) × 200mm (north-south) in a part

Table 4-5. Investigation status

	Date	Place	Status	Number of People
First	November 9th, 2010	Simonoseki	After conference	4
Second	February 16th, 2011	Osaka University campus	In the middle of conference "spatial discuss"	1

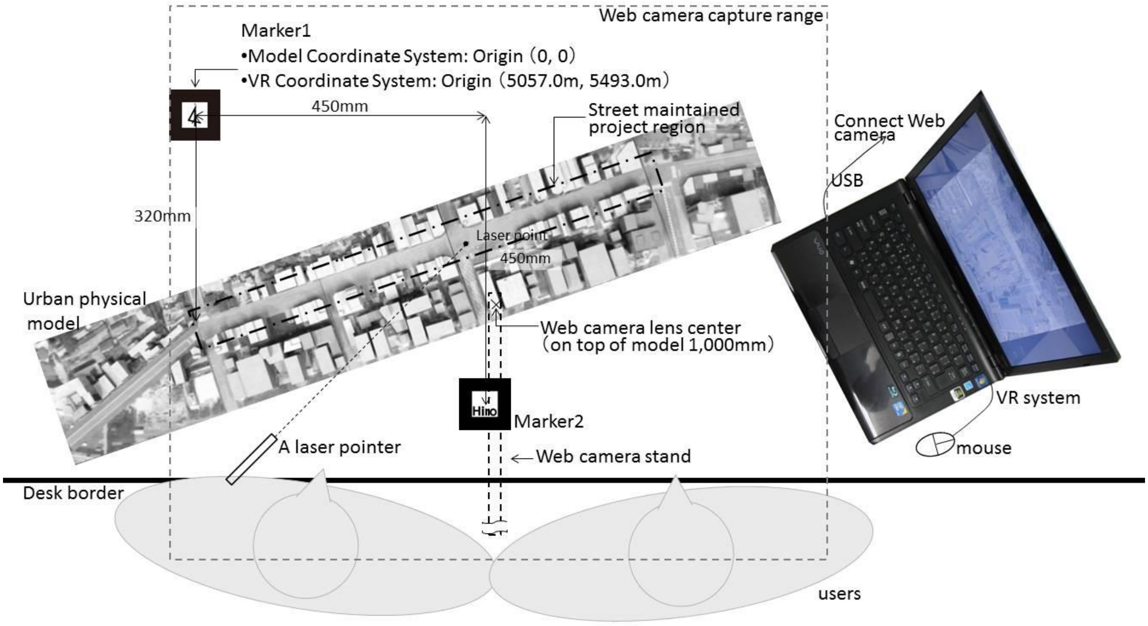

Fig.4-13. Prototype system arrangement

Fig.4-14. Whole image (left), investigation image (right)

of Hosoe, Buzenda. The plaster model is created from VR digital model (e.g. shape, texture) by a 3D printer (ZprinterR650) and has 0.1mm accuracy. And VR includes surrounding area of 10km around the created model. Due to match a marker's four cardinal points to the model's direction, the marker is placed with rotating 20 degrees. A web camera is installed on 1m of a desk, for the reason to enable it to overview two markers and the whole area of the proposed project. The system uses 2-marker and 2-step calibration mentioned in section 4.3.

Hearing investigation was conducted after experiencing the prototype system. Availabilities for practical application were clarified and differences with traditional interfaces such as a mouse or a keyboard were reviewed too.

Fig.4-15. Physical model (up) and VR (left: present, right: plan)

4.4.2 Results

1) Difference compare to traditional interfaces

Positive opinions on the developed system

- Using a laser pointer, every participant is able to check from the viewpoint which he wants to see.
- VR has normally peculiar restrictions that only a part of 3D virtual space can be browsed. However, the developed system enables to overview the whole picture of the target region on the basis of a VR model.
- Participants' conversation could be generated with the help of using a model and a laser pointer.

Some negative comments of this system

- Examination from a dynamic viewpoint movement i.e. a walking pedestrian or a driver’s viewpoint is not yet impossible by a laser pointer, so a traditional interface is necessary to be combined.
- The change of the present state and proposed alternatives plans which is an important function at the time of design study is still impossible by a laser pointer, and combined use of a traditional interface is also necessary.

2) Feedback for Practical Application

Opinions about possible availabilities in practical situations

- A pattern could be presented in which two or more persons participate easily by using the developed system. Conceptual or presentation phase may better apply to this system rather than a design scene that mostly designs detail contents do.

An Opinion about problems and improvements of this system's functions

- It is also required to add certain viewpoints into the menu because of frequent use such as a viewpoint in the moving route along a road.

Opinions about the system's management

- It is necessary to create some extent VR model covering a whole region so that a participant could point an object on a model and describe it on VR system.
- Certain time past during a prototype system being produced may cause spatial variance in comparison to the beginning time. Thus updating the model and VR according to the change would be a problem.
- The cost of a system including model produce is a concern.
- The whole system device is large and hardly movable.

4.5 DISCUSSION

The interface of this system was highly evaluated by participants; because it can allow them specify their own viewpoints, which are not possible realized in traditional interface. The usability demonstrated that a participant could take perception or feelings through a repeat operation when he pointed an object on a model by a laser pointer and meanwhile the object was displayed on VR system. However, abundant functions provided by VR such as dynamic viewpoints or change of different alternatives have not yet installed into the prototype system, so traditional interface are required in fact. Therefore, it is necessary to improve the system. And future review needs many investments to be added considering this study limited to 5 specialists. Moreover, it is necessary to use video to observe the quantity of participants' conversation, although such opinion as "Participants' conversation could be generated with the help of using a model and a laser pointer." was received.

Next, some other opinions were received about practical application, noted that participants could indicate ideas or current problems in a workshop, or an exhibition to make a presentation. Moreover, when particularly pointing a viewpoint, a participant's head may enter into the model and the web camera, which could result in recognizing no laser points. Additionally, if VR display is out of the vision field that a user would like to specify by a laser pointer, the laser pointer and VR contents could not be seen simultaneously. That is, it is necessary to place VR display within the vision field of laser points and avoid shading the web camera detecting those points. System utilization will be in need of more effort and improvement in future. And to solve the problem i.e. VR display and laser points could not be seen simultaneously, cloud computing type VR (see more detail in chapter 5) may a potential attempt that allow participants from any position.

4.6 CHAPTER CONCLUSION

As a previous study, Tokuhara (2010) developed a city presentation system. It described a system of VR and physical model viewpoint linking; the photogrammetry technique was adapted to link viewpoint information. However this original system used 1-marker method to develop, and it had low accuracy and lacked practical scenes' usability. This chapter proposed a new system by 2-marker and 2-step calibration to improve the accuracy. Then it increased the accuracy of it in order to satisfy a city presentation case. Furthermore, a hearing investment was conducted with specialists by applying this system to a practical project, and related availabilities and challenges were selected after it. Important results include:

- The web camera captured one laser point on the physical model by a laser pointer, and the error occurred during the conversion flow of MCS. Here, accuracy improvement was performed including the following experiments, one, Accuracy validation of center coordinates of markers; two, Accuracy validation by 2-step calibration and three, Accuracy validation by 2-marker.
- It was clarified that the difference of a true value and a measured value is 0.0012mm per 1 pixel while detecting a center coordinates of a marker and the difference thus could be neglected.
- Through the accuracy verification by 2-step calibration, the average errors became 5.52 mm in x axis, and 4.03 mm in y axis. Compared with 1-step calibration, 53.4% is improved in x axis as well as 59.8% is in y axis. So the accuracy has been improved sharply by 2-step calibration.
- Through the accuracy verification by 2-marker, the average errors became 2.97mm in x axis, and 2.04mm in y axis compare to more than 4mm by using 1-marker. Moreover, although error changed increasingly in the case of 1-marker, it has minor influence related to the distance enlarged from a marker.
- As mentioned above, it was suggested by using 2-step calibration and 2-marker that could fulfill the requirement of 4 mm allowable error in subsection 4.3.1. That is, the system could apply to 1/1000 scale model, an actual width of 4m of a road.
- After running the prototype system by a few specialists, a hearing investigation was conducted. As a result, pros and cons compared to traditional interface were commented as well as possible availabilities and challenges. Additionally, it became clear through observation that it is necessary to avoid shading a web camera when detecting a laser point and place VR display within a user's vision field when indicating a laser pointer.

- Moreover, at the time of system management, it became clear through observation that it is necessary taking care that a shelter does not enter between a web camera and a radiant and to arrange a radiant and VR display within the limits of a user's view.

CHAPTER 4 REFERENCES

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Chapter 5 A Synchronous Distributed VR Meeting System

A synchronous face-to-face type meeting demands that all stakeholders should be in the same place to participate a design process. Asynchronous distributed type such as E-mail could allow stakeholders participate in the design process at different places and at different times. However, in communication by text, it can be difficult to take in the nuance and atmosphere of the described contents. To improve the possibility that allows stakeholders to held a design meeting at different places and at the same time while sharing a virtual space, this study investigates the capability of a distributed and synchronized type.

5.1 THE OVERVIEW OF THE SYSTEM

5.1.1 Cloud Computing Type VR

In this study, the cloud-computing type VR (hereinafter called "cloud-VR", FORUM8 2011) is adopted as a 3D virtual space shared system which could be used in a face-to-face and/or distributed, synchronous and/or asynchronous design meeting. In the presented cloud-VR concept, contents are transmitted by the video compression method of the H.264 standard (Note 1), because images can be quickly transmitted in high quality and do not require a well-equipped client PC. Fig.5-1 shows the general system architecture that contains two main components of the cloud VR architecture, the server and the client. Commands about viewpoint changes, plan changes, etc. of the 3D virtual space on the client are calculated from the VR contents on a cloud computing VR server. Then the calculated contents are displayed in real time on the client as a video, using the H.264 standard. A user who interacts with the cloud-VR system can operate the virtual space or change plans of the displayed contents.

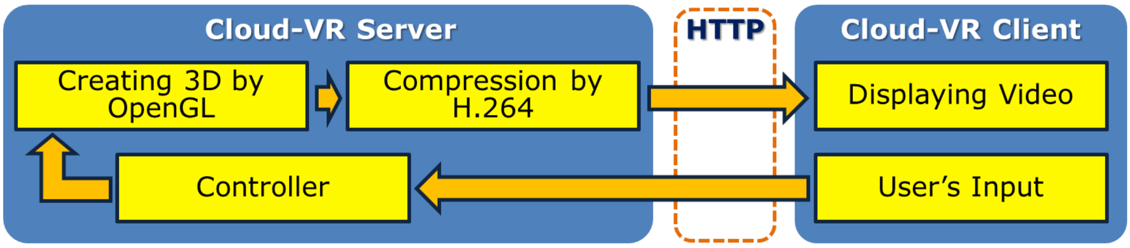

Fig.5-1. Configuration of data transmission in Cloud-VR

To account for multi-user access, which is inherent to the presented concept, the system needs to show clearly who is currently operating. Therefore, this concept has the following merits:

1. A highly efficient graphics environment is not required in a client allowing for use on mobile devices in addition to high-performance PCs.
2. Several participants can share a position or viewpoint, design scenarios, or the VR setup in synchronization.

3. The VR system or 3D contents such as physical models are edited and unified by the management on the server side.

Fig.5-2 shows how a user can interact with the application. On the left, a user simply operates the system menu on a laptop. She clicked a menu to change the VR content, such as switching between different viewpoints. On the right, the user operates the system and browses the VR content on a tablet PC in a touch-based manner. Normally, the main menus of cloud-VR include basic functions such as viewpoint, move, travel on road and alternative plans change to enable the user experience a 3D virtual space.

Fig.5-2. Use of Cloud-VR: Windows laptop (left), Android tablet (right)

5.1.2 Usability in Cloud-based VR Systems

Since a distributed and synchronized meeting is valid at different places and at the same time while sharing a virtual space, it is necessary to perform a usability of this meeting type. Usability is an essentially important aspect for cloud-based Virtual Reality applications even more than for other interactive applications. The visualization of data using VR methods provides the opportunity to considerably reduce the cognitive effort needed by the user to gather, interpret and understand the presented information in a spatial context. This is due to the fact that VR removes the abstract representation on a map or in the form of plain text and instead displays the information in direct relation to the perceived real objects and locations. However, this statement only holds true if the VR visualizations are intuitive and strike the right balance between richness of the provided data and information overload, between necessary detail and simplicity.

Usability generally constitutes a quality criterion that describes how simply and intuitively user interfaces can be interacted (Nielsen 1993). Usability is defined in the ISO 9241-11 norm as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (International Organization for Standardization 2006). Nielsen's (1993) original definition contained three more aspects as a part of system acceptability: learnability, memorability, and errors. The following paragraphs lay out for each parameter 1) a general description of the criterion and 2) how the concept presented in this paper accounts for the parameter.

Users: This parameter describes users or user groups in terms of their pre-knowledge, experience, usage context (physical, technical and social), age, etc. For VR-based meeting systems, the typical user is 20-60 years old (independent of gender) and accesses the geo-portal in an office environment. The typical user has considerable experience in design meetings and uses design software several times a week. Furthermore, the user knows how to transfer information from one system to another in order to support their tasks.

Goals: This parameter defines which tasks a user performs with an application and which goals shall be achieved. For the presented VR concept, the goal is to hold a virtual meeting in the fields of architectural and urban design. The actual tasks a user performs are simultaneous oral discussion, free-hand sketching and annotating.

Context: This parameter defines the usage context composed of the physical context (physical environment, degree of mobility, etc.), the technical context (type of device, device capabilities, used software, etc.) and the social context (distractors, interaction with other persons, public or private environment, etc.). For the presented VR approach, users will typically be inside in private space and not move around, e.g. sitting at a table. They use a standard tablet PC. The user is usually in company of one or more persons sharing the interest of retrieving information about the discussed planning issue.

Learnability: Learnability indicates how easy it is for users to perform the defined tasks the first time they use an application. For the concept presented in this paper we decided to give the user a short visual introduction into the functionality of the application. Here, it is crucially important to find the optimal trade-off between a comprehensive textual introduction (too much textual information can potentially overburden the user and result in fading interest) and conveying the necessary information needed for the user to operate the application with confidence.

Efficiency and Effectiveness: These parameters state how quickly (in terms of time and effort) and to what degree (how effectively) users can perform a certain task once they have established proficiency in using the application. As the presented cloud-based VR concept focuses on real-time information retrieval and display, the user interface's design has to be as simple as possible to be comprehensible in very short time. The VR view on a tablet PC provides an ideal representation for the user to quickly grasp and understand 3D data related to the current location and context as opposed to a small section of a map. Thus, the major part of the viewport contains the VR image including the virtual, dynamic geo-objects. The relevant virtual objects (e.g., buildings, roads, natural features, annotations, etc.) are represented in a generalized manner to optimize information density on the screen. More detailed information about particular objects, further information or object settings need to be available on demand with a simple click on a specific object. This results in the central advantage that users do not have to interact with the application via complex hierarchical menus to accomplish their central tasks.

Memorability: Memorability defines how easy it is for users to reestablish their proficiency when they reuse an application after not having used it for a certain period. Generally, we expect users to install the application and use it for a specific period (e.g. a particular planning project), and then approximately once every other week. To account for this usage pattern, the presented concept displays icons that are more easily to remember than text-based menus. Furthermore, our concept uses context-based menus to maximize intuitive handling of the displayed virtual information.

Errors: This parameter indicates how many errors users make and how these errors affect usage of an application, i.e., how users recover from these errors. In the presented concept, we focus on the creation of an error-tolerant application which is designed to prevent errors caused by the accidental interaction. One strategy to avoid incorrect user actions is to use distinctive and clearly identifiable icons for all buttons. Additionally, the icons are big enough so that they can be easily clicked. This aspect is seemingly trivial, but it has been neglected by a large number of mobile applications even though it is especially important in the described mobile context where clicking precision is compromised when the user is moving around in outdoor environments. If, despite these measures, a user inadvertently performs an undesired action, it can be reversed easily at any time without having to restart the application. Furthermore, we also consider situations that are mistakenly perceived by the user as an error. These often occur during longer waiting times when either the application does not immediately respond to any user input or the user does not get any instant feedback on their interaction. To prevent this behavior, all images are loaded in the background when starting the application in order to decrease loading times during its use and to enable a smoother interaction flow in the application.

Satisfaction: Finally, satisfaction describes how subjectively pleasant it is for users to use the application. Therefore, the presented concept strongly focuses on fluent transitions between different viewing angles. Besides the visually appealing presentation it conveys the impression of continuously moving around an object as opposed to a discrete sequence of chronological steps. Here, particularly the display of geo-objects is highly resource-consuming. Thus, as many calculations as possible are performed either in the background or during the initialization process in an asynchronous fashion when starting the application in order to minimize loading times while using the application, and overly complex animations and large graphics are avoided.

The above paragraphs contain a basic description of the single parameters and their use in the presented VR-based meeting concept. More detailed information on the definition of the criteria can be found in the ISO 9241-11 norm (International Organization for Standardization 2006) and in Nielsen (1993). The description of our considerations in the design phase of the concrete application of the concept for validation purposes is descriptive and has not been validated in a user study as the goal of this paper is not a usability evaluation, but the demonstration of the opportunities of the integration of a cloud-based VR meeting system into design meetings.

5.2 LANDSCAPE STUDY WITH VIEWPOINT AND PLAN COMPARISON FUNCTIONS

In the Landscape Community Design by VR, viewpoint and plan comparison function are two most important functions. Section 5.2 uses these two functions of cloud-VR system to perform a synchronized distributed meeting. Then the validity to a Landscape Community Design support system is clarified in the end.

5.2.1 Experimental Methodology

Table 5-1 shows the overview of this evaluation. In this study, a presenter explained the planning content to a reviewer, who was a specialist of landscape and community design. Firstly, a landscape design support system based on a cloud-VR was constructed (Fig.5-3). The participants were 23 people and they made a distributed and synchronized type meeting of landscape design for 30 minutes (Fig.5-4). A 3D content was installed into cloud-VR, which was a street maintained project. The street in Shimonoseki, Yamaguchi Prefecture, Japan was extension of 350 m and the width of 15m. According to a landscape evaluation, the target is in the center shopping street of Shimonoseki,

Table 5-1. The overview of the evaluation

Date	9th February - 2nd March, 2011
Duration	Exclude 25～90 min of preparation，about 25min by all participants of step 1 - 3 in 5.2.2. Time span from step 4 depends on participants.
Content	A street maintained project in Shimonoseki, Yamaguchi Province. Area of 2.7 ha, road extension of 350 m and the width of 15m.
Method	After landscape community design experiment and then collect questionnaires by E-mail.
Survey items	0) Individual attributes a) Influence of latency in the Internet transmission. b) Deterioration of the quality of the VR image by the Internet transmission. c) Difference from a same room and same time type meeting. d) Availability for the actual design process
Collection	22 piece (95.7%)
Individual attributes	1) Gender: Male=19 (86.4%), Female=3(13.6%) 2) Age: 20s=8(36.4%), 30s=7(31.8%), 40s=7(31.8%) 3) Address: in Osaka=9 (40.9%), Hyogo=8(36.4%), Tokyo=2 (9.1%), Shiga=2 (9.1%), Chiba=1(4.5%) 4) Career: Civil servant=8(36.5%), Foundation=2(9.1%), Construction&Community development consultant=3(13.6%), IT=1(4.5%), Education/Institution=3(13.6%), Student=2(9.1%) 5) VR Experience: first time=5(22.8%), within 1 year=11(50.0%), 1-3 year=1(4.5%), 3-5 years=3(13.6%), 5~=2(9.1%), 6) Use frequency: Everyday=1(4.5%), 1/week=2(9.1%), 1/month=5(22.7%), 1/6month=1(4.5%), 1/year=5(22.7%), less than 1/year=2(9.1%), No answer=1(4.5%), No use=5(22.7%)

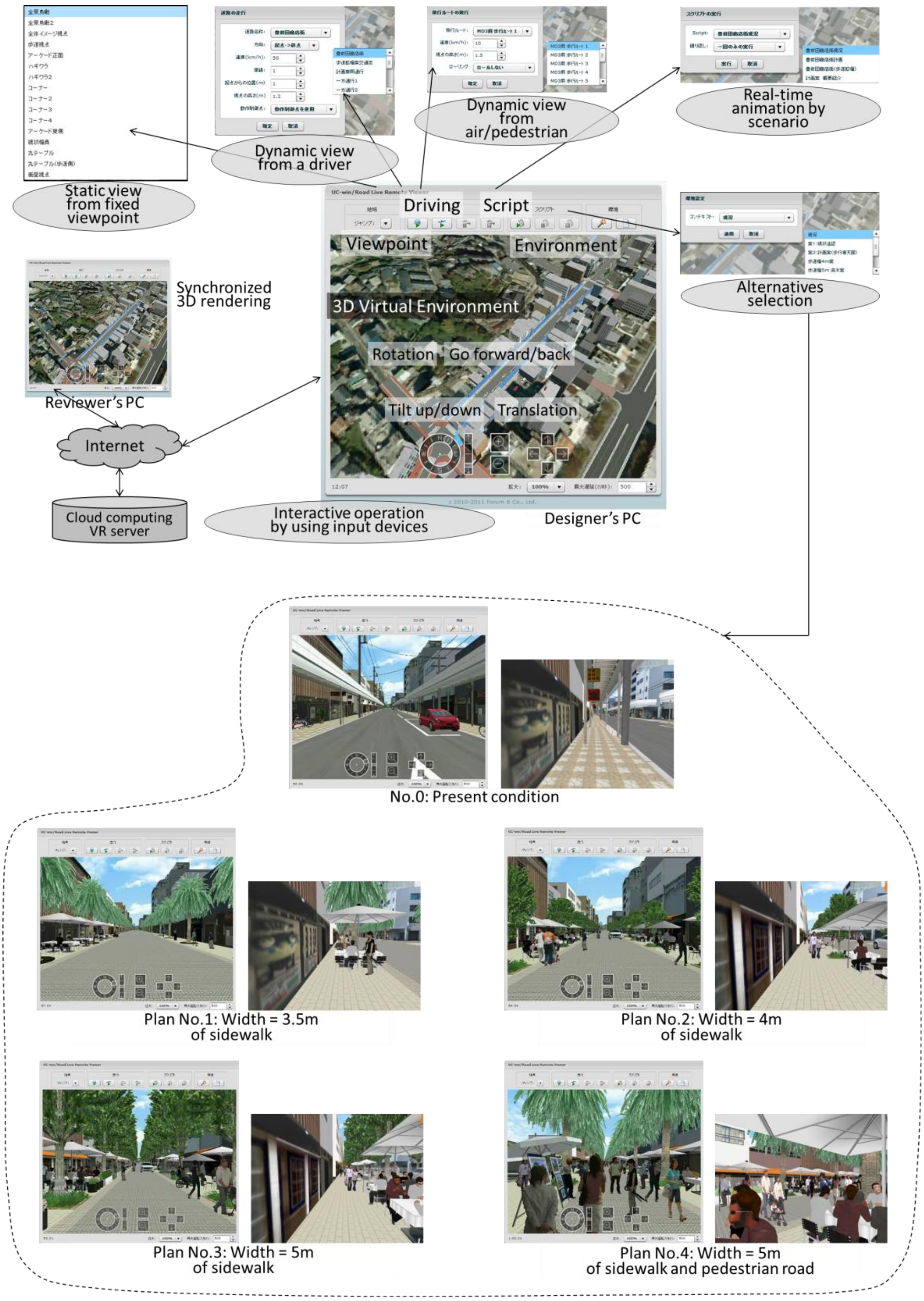

Fig.5-3. Developed landscape design support system

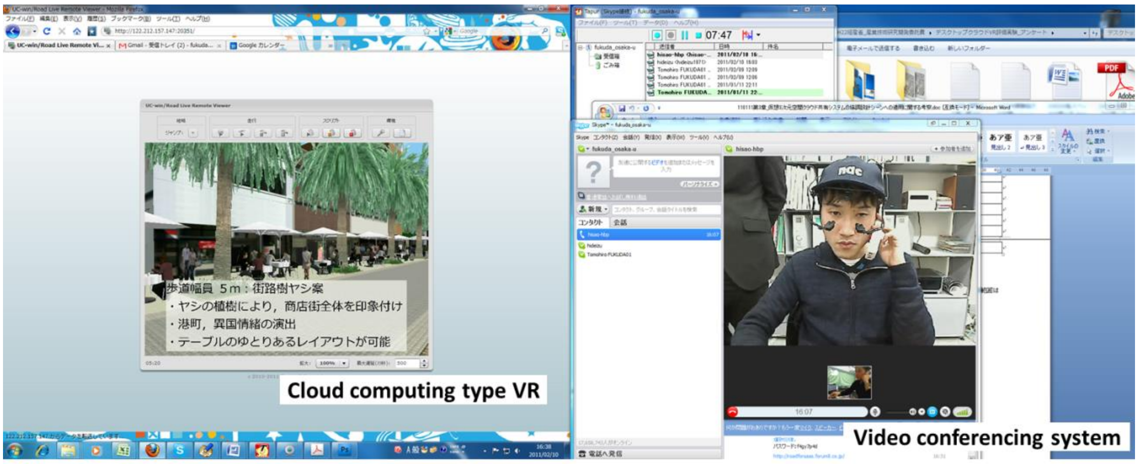

Fig.5-4. Experiment screen shot with video conferencing system.

where requires to revive because of problems such as decreasing population, decreasing visitors and low land usability. If focus on street trees, dangerous walk environment resulting from destroyed arcades and disorder of landscape resulting from power lines and poles are current problems. So, in order to realize a city that “come to walk, come to excursion”, it is necessary to not only lay arcades and wire underground, but also design a width 15m road of a drive way plus a sidewalk.

Regarding the content of the experiment, the designer presented four kinds of street design proposals, after explaining the current problem. Each design differed in the width of the sidewalk from 3.5 m, 4 m, and 5 m. Also, the way of using the sidewalk and building differed according to the width of the sidewalk. As the method of presentation, after looking down at the whole, a real-time walk-through along the sidewalk was carried out. Since traffic changed with the change of lane distribution, a simulation of the traffic stream is also carried out. A reviewer asked and comments operating the cloud-VR, after listening to a designer’s presentation.

Menu at the top of the screen

- Position: Main predefined positions
- Travel - Travel on road: Travel on predefined route, speed and viewpoint height can be changed.
  - Walk around: Walk on predefined route or fly. Objects are those not in “Travel on road” menu. Speed and viewpoint height can be changed.
- Script: Animation of predefined scenario.
- Environment-context: Predefined plans. For instance, present conditions, sidewalk 3.5m, 4 m, 5 m and pedestrian road.
- Configure: Traffic (Vehicle) on/off.

Menu inside screen: interactive operation

- Pan: Change horizontal view direction by clicking icon as a compass.

- Tilt: Up or down viewpoint.
- Walk: Click “+” to move forward, click “–” to move back.
- Translation: Translation by arrow icons.

Various types of client PC could be used for the experiment. The lowest spec PC with Intel Pentium M of CPU, 480 MB of RAM, on-board type VRAM, running Microsoft Windows 2000 was actually used in the experiment. The display resolution of the cloud computing type VR was 800×600 pixels. As regards the 22 subjects, six subjects (27%) used a video conferencing system (Skype), and 16 (73%) did not use one. Seventeen subjects (77%) had used a stand-alone type VR before and five subjects (23%) had not used one.

5.2.2 Experimental Detail

The following steps of the experiment were described:

1. A presenter explained the aiming of the experiment.
2. A presenter explained the operation menu of cloud-VR, while showed a current 3D content to explain the present characteristics for a reviewer.
3. After finishing the description of the planning project, a presenter explained the detail content of street maintain plan. A street maintenance’s plan aimed to improve the environment, set up street trees and parasols of shops in roadside. Some positions related to a scenario were used to move and review in different cases.

    i) Sidewalk width is the same to the present plan (sidewalk width 3.5m). Withdrawal arcades and power poles and keep sidewalk width same (drive way 8m). Secure sufficient pass way (2m) and set small type parasols. A drive way keeps same as present.

    ii) Sidewalk width 4m plan. Withdrawal arcades and power poles and change sidewalk by 4m (drive way 7m). Secure sufficient pass way (2m) and set four-person parasols. A drive way keeps the same as present. Secure sufficient pass way (2m) and set eight-person parasols.

    iii) Sidewalk width 5m plan. Withdrawal arcades and power poles and change sidewalk by 5m (drive way 5m). Because it needs to consult administrator for both side traffic, one way pass is highly possible in this plan.

    iv) Pedestrianization plan. Namely no vehicles in iii) plan. That is for irregular uses such as a flea market or showpiece in the drive way.

4. After the end of explanation of the experiment, users could freely operate cloud-VR and discuss plans or VR content.

5.2.3 Results and Discussion

A questionnaire was implemented after the experiment. The questionnaire result was scored using a 5-point scale to evaluate the items of “Influence of latency in the Internet transmission”, “Influence by deterioration of the quality of the VR image”, “Difference compared to the traditional same-room and same time type meeting”, “Availability for the actual landscape design process”.

The method of scoring is shown below.

- Influence of latency in the Internet transmission (5 full points): no influence at all=5, no influence=4, either=3, influence=2, large influence=1.
- Influence by deterioration of the quality of the VR image (5 full points): no influence at all=5, no influence=4, either=3, influence=2, large influence=1.
- Difference compared to the traditional same-room and same time type meeting (5 full points): no difference at all=5, no difference=4, either=3, difference=2, large difference=1.
- Availability for the actual landscape design process (5 full points): very useful=5, useful=4, either=3, not useful=2, not useful at all=1.

1) Questionnaire items

Questionnaire items and results are shown below. Table 5-2 shows the average values and variation by each attribute. Table 5-3 shows t-test and Table 5-4 shows the correlation coefficient. The questionnaire results are shown in Fig.5-5.

Influence of latency in the Internet transmission. The first item is an influence of latency in the Internet transmission. As a result, more than 50% subject answered “no influence at all”. However, “large influence” was selected over 30%”. The influence of latency through the Internet transmission is assessed differently by individuals. A problem which is clear is that it is difficult to quantitatively grasp the change in communication delay time, which is called latency. The meeting was carried on in the experiment, checking mutually the contents displayed on the PC of the designer and the reviewer through conversation.

Influence by deterioration of the quality of the VR image. The second item is a deterioration of the quality of the VR image by the Internet transmission. As a result, over 80% thought that it has no influence or little influence. The deterioration was small. A score above four points (80%) was obtained from the subjects who used VR.

Difference compared to the traditional same-room and same time type meeting. The third item is the difference between the traditional same-room and same time type meeting and a distributed and synchronized type meeting. As a result, “no difference” possessed more than 38% and “difference” possessed 40%. Subjects who use a video conference system and a VR system frequently considered that the difference was small.

Availability for the actual landscape design process. The final item is availability for the actual landscape design process. As a result, over 90% thought the system could be used in an actual townscape design process. One comment was that more participation of specialists who work at places distant from the planned construction site had been achieved. When specialists use the cloud computing type VR system at a busy time in a meeting, the system can respond also to detailed changes. On the other hand, differences in the contents of a design may appear due to differences in the color of the display of the client PC. Preparation by checking a user's PC spec. and the Internet connectivity is also needed.

Correlation coefficient by each item. "Difference compared to the traditional same-room and same time type meeting" and "Availability for the actual landscape design process" has very small correlation. Namely, the less influence compared the same room and same time type, the higher possibility in the actual landscape design.

Table 5-2. Average value (upper) and variation (lower) by each attribute

		Influence of latency in the Internet transmission.	Deterioration of the quality of the VR image.	Difference from a same room and same time type.	Availability for the design process.
Male (N=19)		3.421	4.316	2.944	4.263
		1.924	1.006	1.114	0.316
Female (N=3)		3	3.333	2.667	4.333
		1	1.333	0.333	0.333
Video telephone: Yes		4	4	3.5	4.5
		1.2	1.6	0.7	0.3
video telephone: No		3.125	4.25	2.667	4.188
		1.85	1	0.952	0.296
VR experience: Yes	**High frequency(N=8)**	3.375	4	3.429	4.5
		1.411	1.333	0.619	0.286
	Low frequency(N=8)	3.556	4.444	2.778	4.111
		2.028	1.028	0.944	0.361
VR experience: No		3	3.8	2.4	4.2
		2.5	1.2	1.3	0.2
All subjects (N=22)		3.364	4.182	2.905	4.273
		1.686	1.058	0.943	0.289

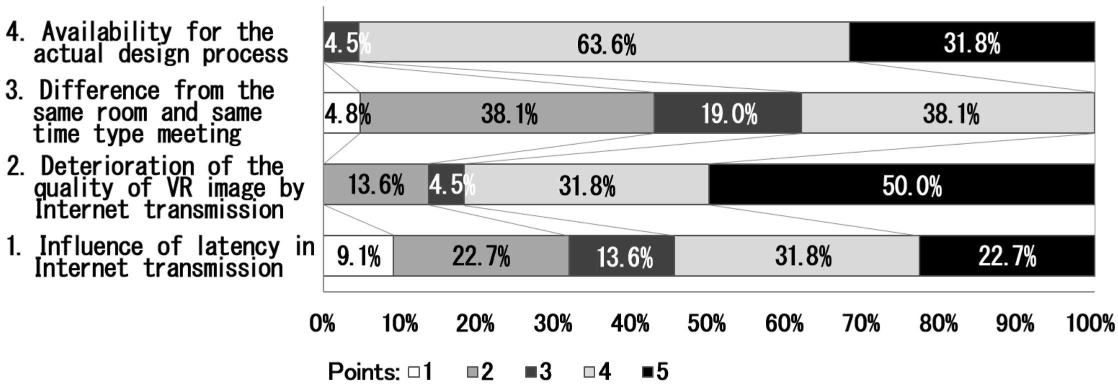

Fig.5-5. Questionnaire result (N=22)

Table 5-3. T-test results by each attribute

Condition			a) Influence of latency in the Internet transmission.	b) Deterioration of the quality of the VR image.	c) Difference from a same room and same time type.	d)Availability for the design process.
Gender	Male	Female				
Video telephone	Yes	No			△	
VR experience	Low frequency	Low frequency				
	High frequency	No				
	No	High frequency			▼	

No △/▼: no significant difference; △, ▼: Significant difference 5%; △: left is larger ▼: right is larger

Table 5-4. Correlation coefficient by each item

	Influence of latency in the Internet transmission.	Deterioration of the quality of the VR image.	Difference from a same room and same time type.	Availability for the design process.
Influence of latency in the Internet transmission.	1			
Deterioration of the quality of the VR image.	0.393	1		
Difference from a same room and same time type.	0.396	0.061	1	
Availability for the design process.	0.249	0.321	0.499	1

2) Availability of Landscape Community Design

Some results and problems about the availabilities of landscape community design were concluded (Table 5-5). Users included several specialists who were away from the planned site. Desktop PCs were mainly used in this study so the future would use smart phone instead. Although smart phone performs not as well as PC, it is also suitable for cloud-VR.

Next, cloud-VR in this system could not share users' mouse, so the reviewer did not understand where the speaker meant (Table 5-6). And during the discussion, since comments or opinions should link to the location, discussion function is necessary when using 3D spatial space. The differences of displays may occur participants' different understanding of a plan, although the evaluation of landscape included colors. Furthermore, more intuitive interface is also required in this type of meeting. Because in the same room, VR experienced users usually operate more, but in different places, all participants have to operate by themselves. In the preparation of a meeting, it is important to know users' PC operation configuration. As mentioned in subsection 5.2.2, various connectivity environments are important for the Internet. And database is necessary to understand the situation of connectivity. Moreover, distributed meeting could hardly offer the same feeling or sense like face to face type at present, so it is necessary to choose the right functions which apply the characteristics of this kind of meetings. Annotation and discussion functions are necessary to support users to understand easier the knowledge or content in the process of a meeting.

Table 5-5. Approach in Landscape Community Design

Object	Landscape Community Design, government, city-provided housing, etc. urban road maintenance, street development project, land readjustment project, etc. hard business.
User	Academic expert, consultant, etc. not residence in the planning place.
	Specialists who live far use in a meeting. Face-to-Face synchronous type costs travel fees and scheduled arrangement.
	Pressed deadline. Need to discuss details but cannot do it by face-to-face.
Terminal device	Smartphone users increase. Computing capability supports 3D drawing.
Distributed usability	Restricted VR view time in face-to-face synchronous type, but freely in distributed one. More local comment could be collected for a plan.
	Announcements upload in Cloud-VR URL, civilians freely talk in home. Result in deeper understanding.

Table 5-6. Problems in Landscape Community Design

Operation	Mouse pointer could not share in the screen. Especially non-specialists could not use professional words so they strongly expect to point the screen directly.
	Annotation function is necessary.
	Difference of color change caused by each display.
	Intuitively use an interface.
Preparation	Confirm the installation of specification or software.
Actual meeting	Guidance of operation and meeting management.
	The Internet connection consideration especially in a large size conference.
	Planners in a far place inform local people ideas or samples.
	Unlike face-to-face situation, communication is hard to be raised by gesture or reference term.
	Difficult to be used by severe users as landowner.
Other	Information leak possibly by capturing cloud-VR screen.

5.3 LANDSCAPE STUDY WITH ANNOTATION AND DISCUSSION FUNCTIONS

As a result of section 5.2, several functions should be included in the further step. In this section, annotation and discussion function would be designed, implemented and evaluated. The annotation function allows freehand sketching in a 3D virtual space and the discussion function allows stakeholders' real-time text discussion about a place in a 3D virtual space to facilitate study of a spatial design. In a word, the system can use a 3D virtual space, and meanwhile necessary sketches or memos can be added in a synchronous distributed type design meeting.

5.3.1 System Design

1) Annotation Function

Apparently, when using a 3D virtual space to explore design approaches, people expect to be able to draw sketches and add figures and memos to the 3D virtual space. For instance, people need to draw arrows or sketches to indicate their notes and changes to a plan or VR content in a collaborative design work. Thus, annotation can be defined as freehand sketching and annotated text in a 3D virtual space in the context of this paper.

For annotation, an intuitive and seamless interface is necessary so that a designer's thoughts or a meeting may not be interrupted. Although a system targeting pen-based interaction can already add annotations to VR contents and show them on a digital board (Fukuda 2009), such a system is intended for synchronous meetings where all participants are in the same place. Another system (Jung 2001) has been established by using Java3D and the Virtual Reality Modelling Language (VRML), but these technologies are only suitable for asynchronous distributed meetings. In contrast, the presented approach aims to develop a system that can be applied to a synchronous distributed design meeting.

The annotation functionality cannot only be used to include 2D information, but also to identify a certain position in 3D virtual space. In addition, a virtual camera must be set up to describe annotations. The functions for the annotation functionality can be summarised as follows:

- Saving an annotation in XML format: Each annotation has a category, a project id, and content information.
- An annotation can be opened and closed in the 3D virtual space.
- In the "Closed" state, a new icon is shown at the position where a new annotation is placed. Users can open it by clicking on the icon.
- In the "Open" state, a virtual camera is placed at the position of an annotation and its contents are shown. When the VR virtual camera moves away from the position of the annotation, the content of the annotation gradually becomes transparent until it completely disappears.

- In the "Edit" state, a camera is placed at the position of an annotation, and its content is shown. While editing in a 3D virtual space, no other operations are allowed.
- To close the window, a user can choose between saving and discarding changes generated by the editing process.
- An annotation can be copied and cancelled.
- When opening or editing an annotation, the background is supposed to be translucent for a simple editing operation.

Also, a format of an annotation requires the following conditions.

- Show the format in 2D.
- Enable drawing of freehand sketches and basic shapes.
- Enable clicking on shapes (a polygon, circle, textbox, etc.) and select one.
- After selection of a shape, enable users to change its colour and transparency.
- After selection of a shape, enable users to change the colour, size and transparency of the border line.
- After selection of a shape, allow movement of the shape by dragging a mouse.
- Resize the shape if a form is resized or a vision field is changed.

2) Discussion Function

In synchronous distributed design meetings sharing a 3D virtual space, verbal discussion is carried out by using a video conferencing system. However, the conversation is not stored after it has finished. In addition, although a common text-based chat system can store the contents of a conversation, it is difficult to specify the position and range of the virtual space. In order to solve these problems a system linking the subject of a discussion to its position in the 3D virtual space has been developed (Fukuda 2005). However, this development is only suitable for asynchronous distributed meetings and only allows for specifying a limited number of points.

In order to account for the requirement of a certain range besides one point as a discussion area, the discussion function presented in this paper can display a discussion board upon a point or an area whose radius can be defined by a user. Furthermore, since it is difficult to discover a discussion board in the wide range of a 3D virtual space, adding viewpoint information with a discussion board is a useful feature. The following instructions describe the designed functions and concepts:

- Creating a new discussion or its area: A user creates a new discussion board at any point in a 3D virtual space. The discussion board has a category, a project ID, longitude, latitude, a radius of the discussion area (0 in some case) and a password.
- Viewing an existing discussion or its area which has already been created.

Edit an existing discussion or its area: A user can edit the discussion or its area which has already been created. In our case, "editing" means revising the discussion board information, including adding, modifying, and deleting comments as well.

5.3.2 Validation

In order to validate the concept presented in section 5.3.1, a prototype system was implemented based on the specifications described in the previous section. The next paragraphs of this section describe the general functionality and design of the application, while the annotation function and the discussion function are described in separate subsections.

The application is designed be used in design work, e.g. a user can sketch simple models or text in a point or an area. For testing purposes, the content of the cloud-VR system was shown on a Windows laptop PC and Android OS tablet in a synchronous distributed design meeting. During this meeting, design work was being performed, along with the use of a video conferencing system, such as Skype (Klock 2008) or Google Hangout (Xu 2010), for oral communication amongst the participants of the meeting. Combined results from the examination led to the following conclusions.

As a case study, the process of architectural design and urban landscape examination is defined. Fig.5-6 shows the user interface for a VR-based planning project, i.e., a renovation project in the Shimonoseki Buzenda shopping street (100m wide at a length of 350m), in Shimonoseki (Yamaguchi Prefecture, Japan). The figure shows the basic VR meeting interface including the annotation function on the right and the video conferencing system on the left.

1) Annotation function**.**

The annotation functionality in the prototype system has been implemented according to the design decisions presented in subsection 5.3.1. Fig.5-7 shows the workflow of the annotation function. First,

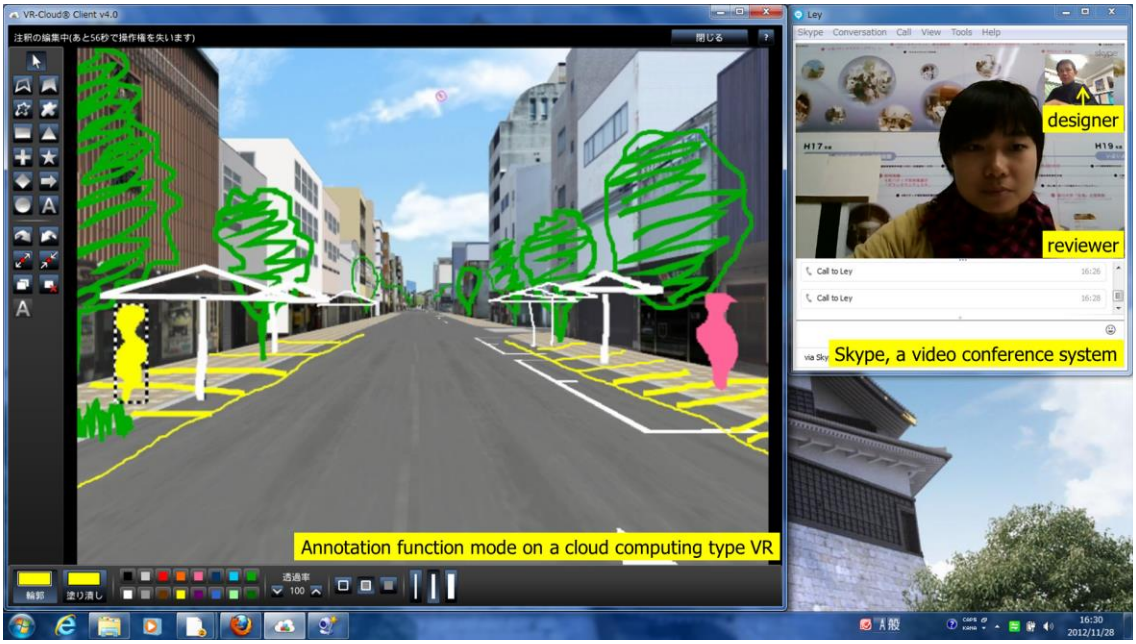

Fig.5-6. Screenshot of a synchronous distributed design meeting using cloud-VR

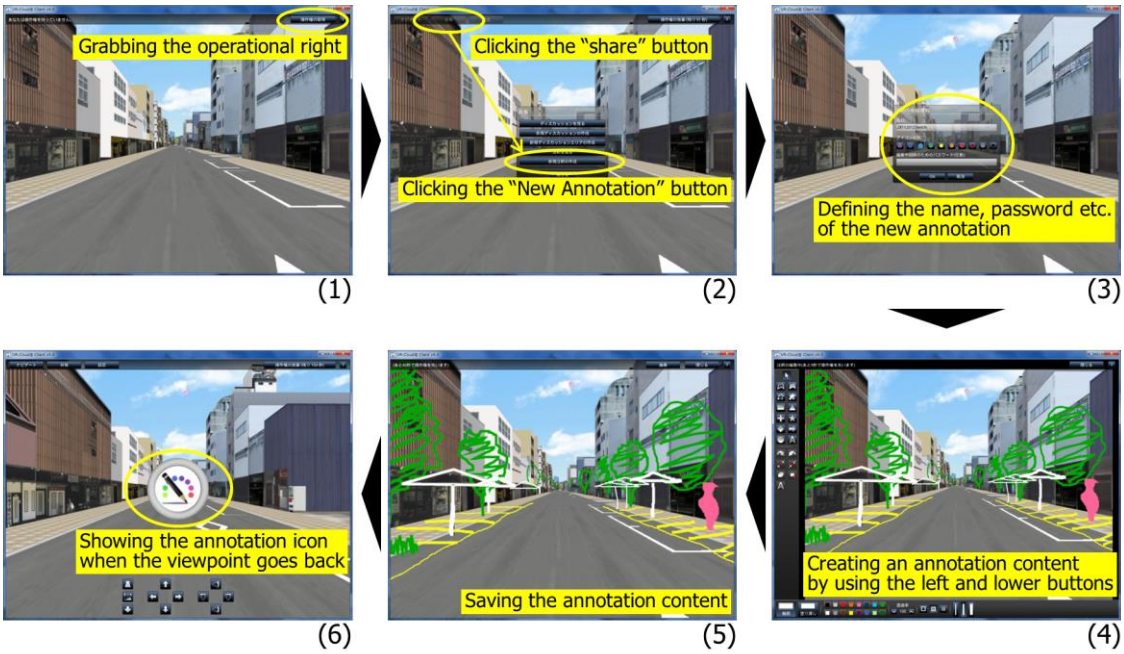

Fig.5-7. Flow of the annotation function

(1) a user clicks the annotation symbol and (2) creates a new annotation. Then (3) the user defines a name, password to this new annotation and (4), (5) the user can edit it like add text, draw sketches and (6) save it in the end.

The main menu for creating new annotations and editing existing annotations provides the following functionality.

- Right button: cancel and save the edited operation
- Left button: tool buttons for drawing and editing a shape
- Bottom button: select color and set transparency or frame when drawing shapes.

To consider the case of an architectural design meeting, a project was assumed to reconstruct a low layer residence which had become obsolete due to collective housing developments. As conditions for the target site, the dimensions of the plot were 17.6m in building width, 6.8m in building depth, and 12m in road width. Additionally, the building coverage ratio (the size of the constructed buildings floor plate, i.e., first floor total area as compared to the total size of the plot of land) is 80% and the floor area ratio (the total floor area of the building constructed - first floor, second floor, third floor, etc. - as compared to the size of the plot of land) was 600%. The case assumed a business district, including a fire protection zone.

In the actual virtual meeting, three designers, who were separated in different locations, used the annotation function and examined the situation in the early stages of the architectural planning process. First, the meeting members could make themselves familiar with the conditions and the present situation of the site using fly-through and walk-through operations in the 3D virtual space of the cloud-VR. Next, the master architect examined the building volume to determine the design conditions for building coverage and floor area ratio. As a result, it was decided that a seven-storey building could be built. The first floor was intended for shops and the second to seventh floors for dwellings. A separate entrance to the apartments had to be established on the first floor.

As Fig.5-8 shows, while talking to the members through the video conferencing system, the master architect used the annotation function of cloud-VR and expressed the disposition and the rough sizes of items such as the housing entrance, a store, stairs, and an apartment with sketches. Looking at the sketches drawn, the design members studied the spatial composition and finally determined an initial proposal. Then, 3DCAD was used to create a more concrete design proposal based of the contents of the initial sketches. Therefore, a 3D model, which defined the room arrangements and opening sections, was imported to cloud-VR, and a more detailed design examination was carried out.

As for the urban landscape design use case shown in Fig.5-9, it was assumed that a street has to be renewed and its sidewalk widened. In this case, a draft of where to place trees, street lamps and benches needed be made taking account numerous factors such as safety, function, security and infrastructure. Furthermore, according to the draft, tree species, lighting and bench forms could be selected and defined. Using the VR system, the participants of the meeting could place a line around those areas which needed to be revised, show which elements have to be moved using arrows, or note detailed information. An enclosed line enabled users to highlight important issues to be addressed. Also, participants were able to intuitively share the content by browsing the screen in the real time.

2) Discussion function

The annotation functionality in the prototype system has been implemented according to the design decisions presented in subsection 5.3.1. Fig.5-10 shows the workflow of the discussion function. First, (1) a user clicks the symbol for starting a discussion. Then (2) the user opens and creates a new

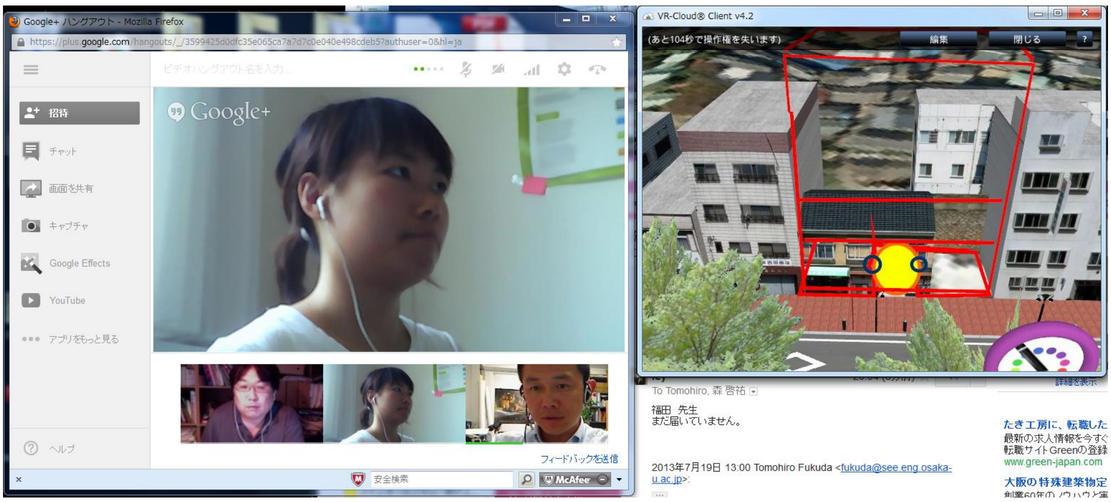

Fig.5-8. Architectural design study using the annotation function on a cloud-VR

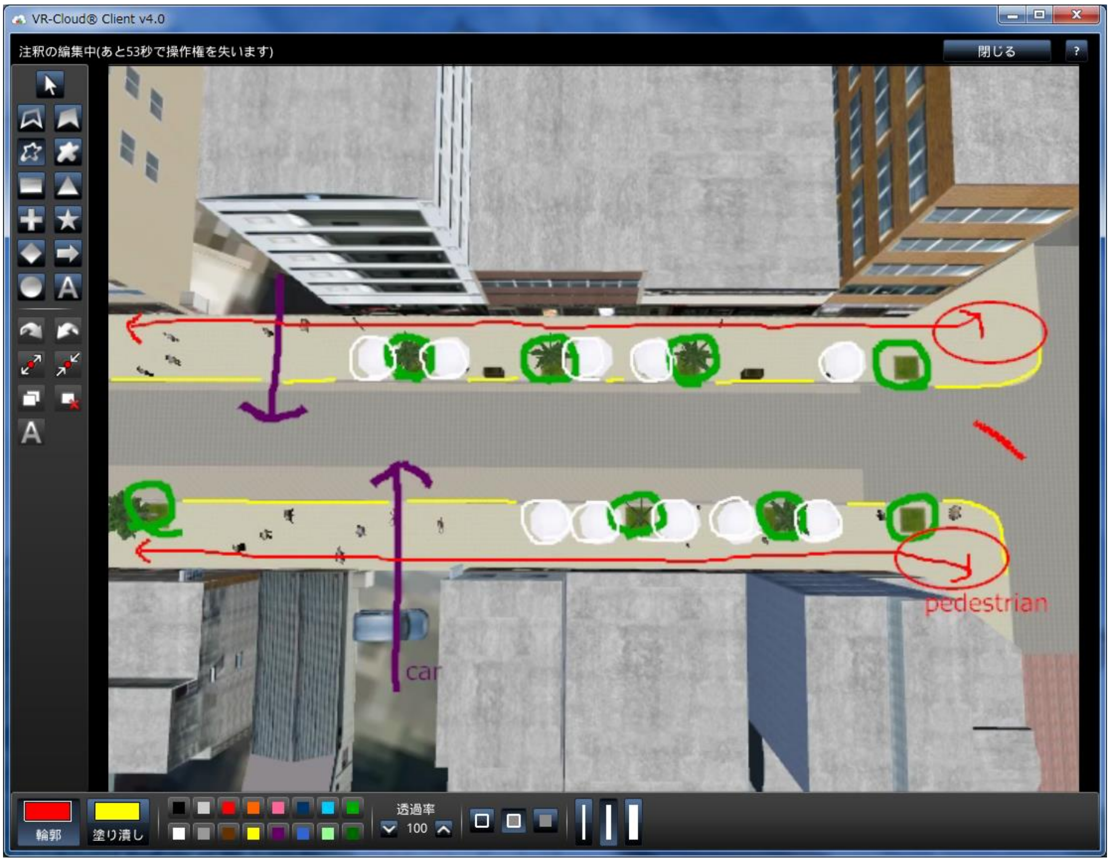

Fig.5-9. Urban design study using the annotation menu on a cloud-VR

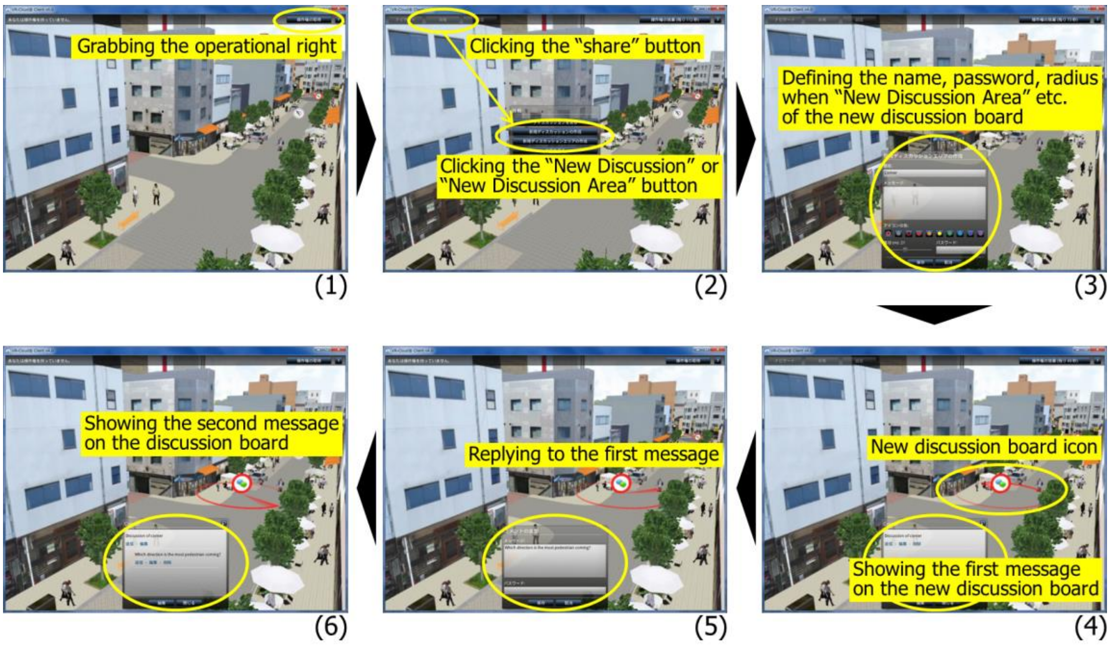

Fig.5-10. Flow of the discussion function

discussion board. Next (3) a name and password are defined and add (4) input or (5) a reply message and (6) finally save it.

For the actual validation, another imaginary planning project was assumed: In order to offer resting areas, a small park shall be planning in the shopping street because it is easy for people to gather there. To agree on a design for that purpose, the designers could set up a discussion board to debate questions such as from which direction people visit the shopping street or which intersection gathers the largest number of people. Then consultants who understand the amount of pedestrian traffic can provide the corresponding answers. Next, designers receive those answers and discuss the position of the small park. Using discussion area function it is possible to specify the approximate area used for discussion. Fig.5-11 illustrates how this subject is being discussed.

5.3.4 Results and Discussion

Section 5.3 described the annotation and discussion functionalities, and illustrated how they can be used in a virtual design meeting. Even though the annotation function worked well in the fictitious use case, there are still some open issues that need to be addressed in future work:

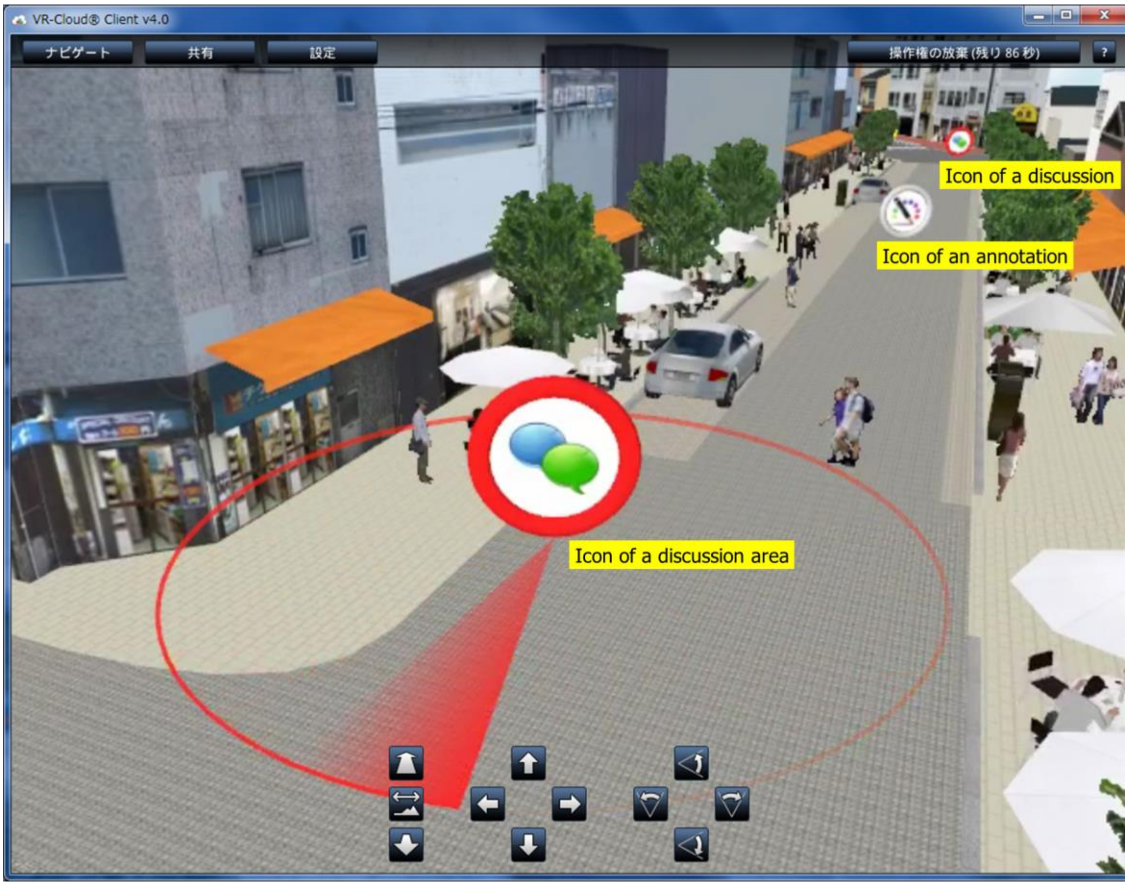

Fig.5-11. Icons for both annotation and discussion functions

- Editing of annotations is limited to one client, i.e., presently two or more users cannot simultaneously use the annotation function. Furthermore, an annotation item could not be opened or re-edited before other users have closed it. Therefore, when operation control is frequently changed between several users, an interruption of thinking and a discontinuation of conversation occurs.
- The content of annotations needs to be linked with the displayed plan. In a design process, several plans are registered in the VR system, and they are usually discussed by comparing them to each other. The developed annotation function was realized to connect viewpoint information. However, no link has yet been implemented between the annotation content and the displayed design scenario. Therefore, the annotation content sometimes does not match the displayed design scenario to which it should correspond.
- Since orthographic projection on VR is not yet available, it is difficult to correctly sketch in accordance with the scale.

For the discussion function, the following issues remain to be solved:

- Just like for the annotation function, editing of discussions is limited to only one client, i.e., presently two or more participants cannot simultaneously use the discussion function. More, a discussion thread cannot be opened or re-edited before other people have finished typing and have closed it. Therefore, when operation control is frequently switched between several users, it is easy to block the thinking processes and conversation of the users. As a result, it is necessary to inform the participants of this procedure during a video conferencing system.
- Spatial information is yet to be integrated into the discussion function in a way that when users discuss one object or one district through a chatting system, they could view and edit the spatial information.
- A discussion area can only be defined as a round shape. Even though this is sufficient for demonstration purposes, the shape of a discussion area is not limited to a circular form in real-world planning processes. For instance, discussion areas defined by the vertical surfaces of a building façade, the line of a pedestrian path, or a polygonal shape created by a freehand drawing could be implemented.

5.4 CHAPTER CONCLUSION

In the spatial design fields of Landscape Community Design, a consensus-building process among a variety of stakeholders such as project executors, architects, residents, users, and general citizens is required. New technological developments such as cloud computing and VDS enable the creation of distributed meeting systems.

This chapter presents a concept for a synchronous distributed meeting system in architectural and urban design processes using annotation and discussion functions, which are essential for virtual 3D spaces in order to allow for free-hand drawings, live discussions and simultaneous feature editing. A prototype system has been developed and validated in the course of a hypothetical architectural and urban design process.

For the concept in this chapter, a number of essential requirements were extracted for using a VDS system, which are 1) no need to use high-performance PCs, 2) several users can share a viewpoint from a 3D virtual space, 3) annotation and discussion functions are integrated. The contribution of this research is as follows:

- A cloud computing type VR system was built and it was approved by a design review meeting following a case study experiment. The feasibility of distributed synchronous type design meetings using the cloud computing type VR is high. It increases the opportunities for specialists in remote places to participate in design review sessions. On the other hand, there is concern about whether the Internet access would be available at meeting times.
- Those who use video conferencing, and who use VR frequently think that there is little difference between these systems and same-room synchronous type meetings. It is important that participants can check the situation of understanding mutually by video conferencing.
- The annotation function seamlessly enables users to draw sketches and shapes and add memos in a 3D virtual space by freehand drawing. As viewpoint information is also saved when writing an annotation, it has proven easy to reproduce. Yet, some issues remain including the fact that annotation editing is limited to one person, so several people cannot edit the annotation function simultaneously. Also the content of annotations needs to be linked with the displayed plan.
- The discussion function enables users to combine information from a point or a certain area with textual discussions on a 3D virtual space. Future work on the discussion function should address the issues that discussion editing is also limited to the only one person, and two or more people cannot type comments at the same time. Additionally, it is necessary to be able to specify a discussion area in various forms apart from just circular shapes.

CHAPTER 5 NOTE

Note 1. H.264 standard is a video compression format, and is currently one of the most commonly used formats for the recording, compression, and distribution of video content.

CHAPTER 5 REFERENCES

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Chapter 6 Conclusion and Future Works

6.1 CONCLUSION

The vast majority of the research studies into improvement of Landscape Community Design support system by Virtual Reality. This provides supported systems for landscape improvement and community design. This research can be concluded that VR new applications and usable situations are explored in Landscape Community Design. VR was commonly used by stand-alone and face-to-face and synchronous or distributed asynchronous use. In order to solve these problems, advantages of VR and physical model are combined to develop a new presentation system and used cloud-VR in a synchronous distributed type meeting. Table 6-1 summarized the main results in this research.

Chapter 1 introduces the implication and brief trend of Landscape Community Design and then advances that a consensus-building process among a variety of participants has been required. Therefore, it is very important to use adequate media for not only specialists but also non-specialists. After clarifying the characteristics of physical models and VR as 3D visual media, further applications are proposed for Landscape Community Design - First, development of a new presentation system by viewpoint linking VR and a Physical model; second, a synchronous distributed VR meeting system.

Chapter 2 reviews previous references and examples of each aspect mentioned in chapter 1. And it clarifies problems about VR applications at current condition. As a result, people expect an easy-understanding media which enables simply convey information in the area of Landscape Community Design. So, characteristics of VR and physical model should be clear, especially the differences of spatial understanding. Then, each weakness could be rectified by using the two systems together. Thus, a new presentation system by viewpoint linking VR and a physical model can improve landscape availability. Last, a synchronous distributed VR meeting system is proposed

Table 6-1. Summary of main results in the research

	Research Questions	Main Results
Chapter 3	・ How are the speedy and accuracy while spatial understanding is conveyed l? ・ What is the difference cognized by people?	・Clarify features of spatial scale in the spatial understanding capacity. ・A physical model performs quicker and more accurate under a circumstance.
Chapter 4	・ How to combine and use VR and physical model in a presentation with multi-users? ・ How to increase the accuracy of this system? ・ What is the practical scenes' availability?	・ Accuracy Improvement was validated. ・ A hearing investment was conducted with specialists by applying this system to a practical project, and related availabilities and challenges were selected.
Chapter 5	・ Which cases of Landscape Community Design could apply a VR system in a synchronous distributed meeting? ・ Which functions are effective in Landscape Community Design?	・ A cloud computing type VR system was built. ・ Availability of Landscape design meeting was evaluated by two case studies. ・ Annotation and discussion functions were also highly evaluated.

concerning about the restrictions of space and time to increase the availability of Landscape Community Design meeting.

Chapter 3 focuses on differences of spatial understanding observed by using physical and virtual models. While participants viewed a physical model and a virtual model in sequence, a questionnaire was used to objectively evaluate these and establish which was more accurate in conveying object size. Consequently, a physical model, not a virtual model, tended to allow quicker and more accurate comparison of building height.

Chapter 4 proposes a new presentation system by viewpoint linking VR and a Physical model, the photogrammetry technique is adapted to link viewpoint information. A previous study has problems of low accuracy and lacked practical usability. Thus, the improved system uses a coordinate system conversion by 2-marker method. As a result, accuracy is improved that could meet the requirement of 4mm allowable error, i.e. 1/1000 scale model with an actual road width of 4m. Moreover, a hearing investigation is conducted by a few participants. The differences to traditional interface such as mouse or keyboard and availabilities of practical scenes are clarified. Additionally, it is necessary to exert efforts that any shelter does not enter between a web camera and a radiant and arrange a radiant and VR display within the limits of a user's view.

Chapter 5 proposes a synchronous distributed meeting by using cloud computing type VR for Landscape Community Design. While the participants share a 3D virtual space in distributed synchronous environment, two case studies are conducted to review a possibility of realizing a discussion meeting of landscape community design. Firstly, a present plan and other planning designs are predefined; a landscape evaluation by using viewpoint and plan comparison functions is conducted. Although a high evaluation is given to the distributed and synchronized discussion, freehand such as sketch or memo menu should be used too. Then, another evaluation by adding annotation and discussion function is conducted afterwards.

In conclusion, Chapter 3 and 4 focuses on physical model and VR of 3D visual medial. Because these two media have different features, it is necessary to clarify them firstly and then each weakness could be rectified by using the two media systems together. As a result, the differences of spatial understanding are concluded and an improved presentation system by viewpoint linking VR and a physical model is developed.Chapter5 built a VR meeting system to held a design discussion and evaluate it by sharing a 3D virtual space simultaneously at distributed places.

Although Chapter 3, 4, and 5 discussed two different topics, they have relation of each other. Considering the VR technique, in the developed system in chapter 4, only one standalone PC was set in this case, thus, a user must stand within the vision field of the PC display and also see the physical model at the same time. To solve this problem, cloud computing VR in the next Chapter 5 could be an approach (Fig.6-1). Several PCs can be set around the physical model; every PC can share the same VR contents. Users could stand in any position to review one or more displays.

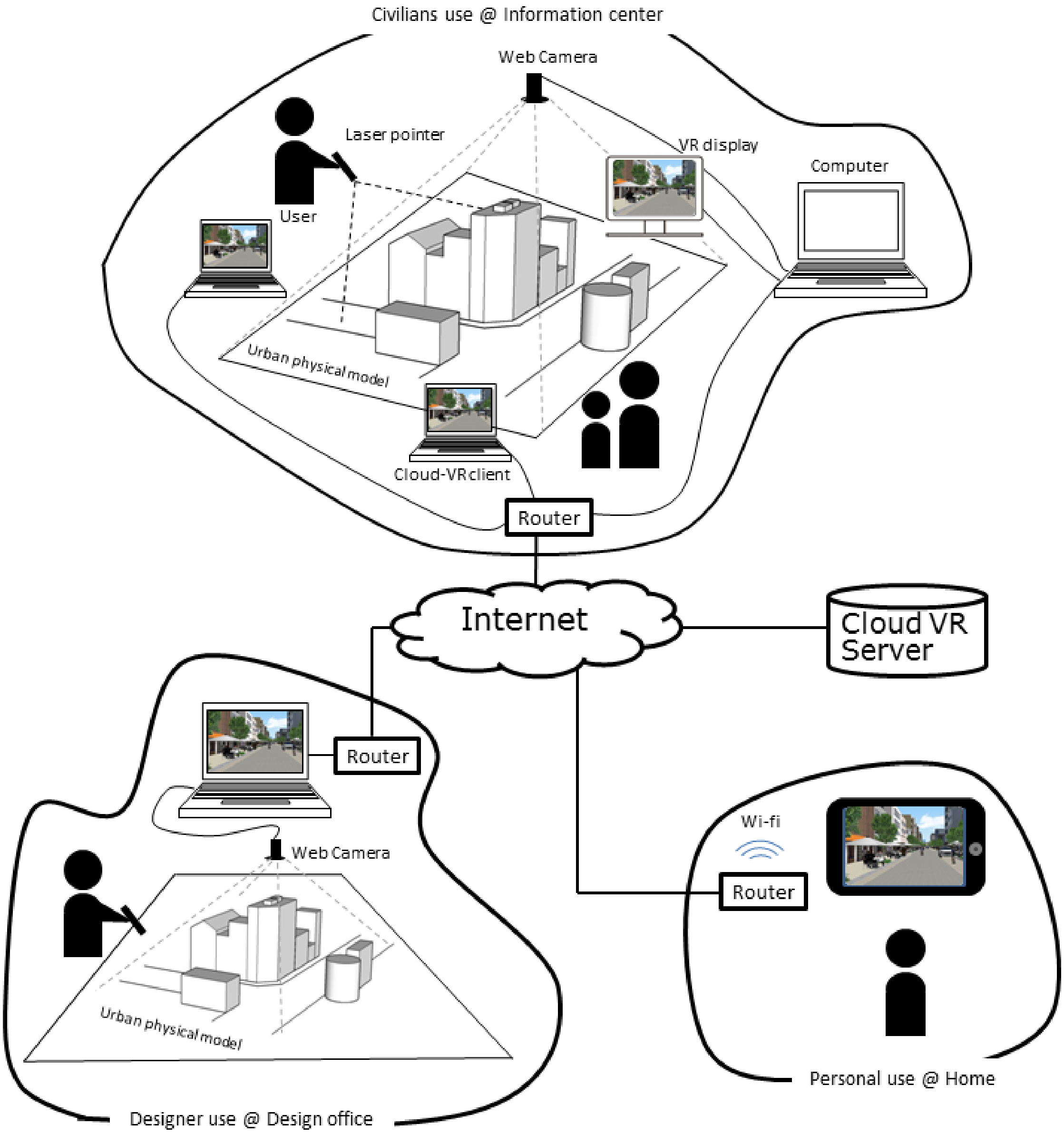

Fig.6-1. The integration system of Chapter 4 and Chapter 5

6.2 FUTURE WORKS

The future work should be able to visualize more environmental factors in the developed city presentation system by viewpoint linking VR and a physical model. Currently the result of the environmental simulation could not be reflected in a physical model. In other words, users could not display a visualized virtual elements or simulations on a physical model. Such as heat or wind, environmental simulation is necessary to overlap on the physical model. Regarding to a practical use, AR could be a proper technology to visualize environmental modeling through a 3D sensor in the next step.

Next, a new modeling function should be included in a cloud-VR environment in the future. A present 3D cloud-VR system offers predefined modeling and only allows certain developer produce modeling. Because 3D models are not yet reviewed, it requires a new function to create and input new modeling in the cloud-VR. Moreover, some architectural 3D models produced by BIM contain abundant architectural information, thus how to use them within a cloud-VR system becomes another future work.

Furthermore, with the development and popularization of 3D printer, community designers at distributed places could use the presentation system of Chapter 4 to hold a landscape design meeting and other related members who are apart from the main site could join the same meeting by using the system of Chapter 5. It is highly possible technically, although the validation has not been executed.

In the end, we hope that our attempt will create a greater interest in VR applications of Land Community Design. We believe that VR will no more be limited to the work of computer scientists. This tool will be of great value to scientists, engineers and educators.

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To their endless help, love, and support, no matter the outcome…

To my parents, the greatest parents in the world…

To my hometown, my past, present, and future…