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Ji-Hyun Lee *Editor*

Cultural Space on Metaverse

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Editor

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ISSN 2214-2541 ISSN 2214-255X (electronic)
KAIST Research Series
ISBN 978-981-99-2313-7 ISBN 978-981-99-2314-4 (eBook)
https://doi.org/10.1007/978-981-99-2314-4

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

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Preface

I am so happy to make this 4th Cultural DNA Workshop after the great success of the previous three workshops in 2015, 2017, and 2019, respectively. Because of the COVID-19 pandemic situation, we cannot hold the workshop offline and use Gather.Town for the workshop. Again, I want to emphasize here that the term 'Cultural DNA' came from the perspective of a *meme*, a socio-cultural analogy to a gene, trying to comprehend the concept of a meme from the various cultural aspects of design and the notion of a genetic algorithm.

This time, we decide our workshop's theme as *Cultural Space on Metaverse.* Due to the pandemic era, many people are spending more time in virtual space and interacting with each other easily. As a result, spatial research in a virtual environment and behavioral research in space are becoming more important. The aim of this workshop is to bring together the researchers from academia and practitioners to share future direction and prospects for virtual space.

This time, researchers from all over the world, as well as Korea, will present fascinating researches at the 4th Cultural DNA Workshop. Many have helped to make the 4th Cultural DNA Workshop happen. First, I would like to thank the members of the program committee, Mi Chang, Gi-bbeum Lee, Joosun Yum, Hao Yun Lee, Juhyun Lee, Ji-Young Yun, Marvin Lee, and Ho Kim for spending their time and effort to coordinate this workshop. Second, I would like to thank the International Relations Team from KAIST for funding. Without these supporters, organizing this workshop would not have been feasible. Third, I want to show gratitude to the 19 participants of this workshop all happy to travel overseas and share their researches: Danilo Di Mascio from University of Huddersfield, UK; Rongrong Yu and Ning Gu from University of South Australia; Yu-Hsiu Hung and Kai-Ti Wang from National Cheng Kung University, Ju Hyun Lee and Samaneh Arasteh from University of New South Wales, Australia; Brandon Haworth from University of Victoria, Canada; Mathew Schwarz and Andrzej Zarzycki from New Jersey Institute of Technology, USA; Jinmo Rhee and Ramesh Krishnamurti from Carnegie Mellon University; Tse-Wei Hsu (Fatty) from Southern Taiwan University of Science and Technology, Taiwan; Andrew Li from KIT, Japan; Gwang Ya Han from Dongguk University, Kyung Wook

Seo from Northumbria University, UK; Joosun Yum, Gi-bbeum Lee, and Ji-Young Yun from KAIST, Republic of Korea.

I hope this workshop will let all participant get along with useful insights and provide an unforgettable valuable time.

Daejeon, Korea (Republic of) Ji-Hyun Lee
August 2022

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Part I
Future Education

Chapter 1
Future Learning in the Metaverse—An Exploration of Virtual Architectural Design Studios

Rongrong Yu and Ning Gu

Abstract This study investigated seven virtual architectural design studios (VADS) at an Australian university, incorporating survey results returned from 47 students and one in-depth interview with the course coordinator. VADS have been attracting increasing interest particularly since the 2020 pandemic. VADS have the potential to be beneficial for students' learning experiences by better facilitating students' ideation process, providing greater accessibility, and enhancing global collaboration among architecture schools. Preliminary results from this study suggest that architectural students have a generally positive experience within VADS, especially in relation to the flexibility offered. These results also identify a need for further development and enhancement of related technologies, to better support the future of architectural design and learning. The results of this study provide an understanding of student and staff teaching and learning experiences of current VADS, which set a foundation for planning and designing of future Metaverse-based architectural education.

Keywords Virtual architectural design studios (VADS) · Metaverse-based learning · Architectural education

1.1 Introduction

In recent years the concept of the "Metaverse"—an immersive cyberspace where people can have advanced and intuitive virtual interactions, has attracted increasing interest as its prerequisite technologies such as virtual reality (VR) and augmented reality (AR) have drawn closer to maturity and widespread adoption. The broad and fascinating potential applications of the Metaverse have not gone unnoticed within the field of design education. Recently growing attention on virtual and blended learning, and potential new applications of the Metaverse, has been accelerating particularly

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_1

since the 2020 pandemic. In order to advance and realise the Metaverse concept towards an effective environment in practice, the creation of different functional, social, and cultural spaces in the Metaverse is especially important [1], of which learning spaces are an important part. Within the Metaverse, besides the inherent benefits of virtual and immersive technologies, designers and students alike have the potential to express themselves more creatively, freed from many limitations and impediments of the physical world. The Metaverse could eventually offer students near-infinite variations of virtual and hybrid experiences, through which they will learn in new and alternative ways, while such experiences may also offer enhanced human interaction via additional spatial and data opportunities [2]. This chapter discusses the readiness of current learning communities for such a paradigm shift, by examining a specific case study of Australian tertiary architectural students.

Architectural design and learning relies heavily on visual representation and interaction [3] and precedent narratives [4, 5], and the Metaverse can inherently bring potential benefits to these areas. In architectural design studios, students learn and trial design strategies and procedures, and develop their proficiency through a regular iterative process of consultation, feedback, and reflection [6]. Traditionally, architecture students learn to design within a physical studio environment, in which a qualified tutor (e.g. a practising architect) periodically reviews their work and progress [7]. The potential value of the virtual architectural design studios (VADS) concept was first identified in the 1990s [8], and since then, the concept has been extensively discussed and developed with each new generation of technological advancement. VADS have the potential capability to support complex interactions in intricate social learning scenarios [9], as well as to promote virtual collaboration between universities globally [10–14]. The functionalities and limitations of the virtual platform itself are key factors of consideration for virtual designs studios, whether it be one of the Learning Management Systems (LMS) such as Blackboard Collaborate Ultra (https://www.blackboard.com/teaching-learning/collaboration-web-conferencing/blackboard-collaborate), or a more generic communication platform such as Zoom (https://zoom.us/) or Microsoft Teams (https://www.microsoft.com/en-au/microsoft-teams/group-chat-software). In recent years as the advancement and adoption of VR and AR technologies have accelerated, researchers are starting to look at the potential of immersive technologies in relation to architectural education [15, 16]. For instance, VR has been found to be able to enhance students' perception of a 3D model, and increase their enthusiasm for participation [17]. Aydin and Aktaş [18] found that VR is stimulating and attractive to students in an architecture design studio, but they also identified limitations relating to dependability, efficiency, and insightfulness during design. As formal tertiary education in the Metaverse is still in its infancy, there is a lack of examples and critical understanding about teaching and learning as well as its facilitation in the Metaverse; VADS being the closest existing practice of this form of teaching and learning, can provide unique insights regarding the design and development of future learning in the Metaverse.

We are at a key juncture, where architectural education and its dominant studio culture have finally reached the point of potentially fully embracing these technologies, and entering the age of the Metaverse. Yet to date there remains a lack of clear understanding in relation to the learning and teaching experiences in various emerging virtual studio design and learning technologies, and the perceptions of students and teachers alike, as well as obstacles and limitations associated with different technologies adopted in such studios. To thoroughly explore these issues, this chapter examines seven VADS at an Australian university, through surveys and semi-structured interviews. In the remainder of the chapter, Sect. 1.2 summarises a literature review about architecture studio pedagogy and VADS, Sect. 1.3 describes the methodology of the study, Sect. 1.4 presents survey and interview results, while Sect. 1.5 concludes with a summary of the main findings, provides suggestions for the future of VADS, and looks into architectural education in the Metaverse.

1.2 Literature Review

This literature review contains two parts of the background information for the chapter. Section 2.1 provides an overview of architectural studio pedagogy in general. This is followed by a review specifically on VADS.

1.2.1 Architectural Studio Pedagogy

An architectural studio is defined as a place where students learn the design process, developing proficiency through a regular process of consultation, feedback, and reflection [6]. Architectural studio is a creative learning space where students work together with tutors to solve simulated real-life design problems [19]. Architectural studio creates a cooperative working environment for students' skill development, which is "*greatly superior to that which could be achieved by the individual student working alone*" [20, p.13]. During an architectural studio, students are expected to apply their knowledge of architectural theory, technology and communication, to a design project; students learn during the process of conducting their design project, with the guidance of their tutors who are ideally professional architects [21, 22]. This approach can be traced back to the model at Ecole Des Beaux Arts (1819–1914) and later further enhanced by Bauhaus in the 1920s–1930s.

Through architectural studios, students develop their critical knowledge, design skills, and creativity [23], particularly their creative learning abilities [24] which are essential for their future professional practice. Studio teaching is project oriented and uses contextual problem-solving approaches [25]. Schon [26] "reflection on action" theory is considered to be an established pedagogical practice in architectural design studios. Hargrove and Nietfeld [27] highlighted the significance of metacognitive knowledge and thinking skills in the studios. Açikgöz [28] developed a model structuring the architectural design studio experience, to assist with students' problem reception and problem solving, which was tested and proven to be effective in their experimental design studio. Kowaltowski et al. [29] stated that analogy is among the most beneficial ways of integrating meaning and communication during design studios. Furthermore, communication and criticism have been considered vital in architectural design studios [30–32].

Teamwork and peer learning is another important aspect of architectural design studios. For example, Emam et al. [33] emphasised the importance of collaborative learning in architectural studios, which allows students to progress their ideas via discussion with peers in small groups. McClean [34] also emphasised the importance of peer groups for studio learning. Corazzo [35] on the other hand highlighted the importance of social interaction in design studios. Similarly, Williams et al. [36] stated that architectural practice involves social practice during architectural learning. For teamwork in the design studio, scholars have suggested that the ways that knowledge may be more effectively communicated and shared [37, 38] are essential and in need of further investigation [39]. Effectively assessing and sharing knowledge is critical for the success of architectural studios.

1.2.2 Virtual Architectural Design Studios (VADS)

VADS research arose in the 1990s [8], with an initial focus on virtual collaboration [10–14]. Research since then showed that VADS can increase the time students focus on reflection [40] and can better facilitate students' ideation than a traditional face-to-face environment [41]. Hong and Lee [42] found that the increasing responsiveness of a virtual design environment can assist students in having an improved diversity of ideas. On the other hand, some scholars believed that certain aspects of architectural studios are difficult to achieve in an online setting, for example, socialisation; therefore, they advocated blended learning [43–45]. In particular, Saghafi et al. [45] suggested that a blended learning mode for architectural design studios will support students with self-determination, self-management, and personalisation of their learning environments.

The significance of communication and interaction in VADS has also been emphasised [9, 46, 47]. As Iranmanesh and Onur [48] pointed out, effective communication, peer connection and interaction, and group work are critical for the success of VADS. Alnusairat et al. [49] found that unfamiliarity with online teaching and learning platforms can potentially have a negative impact on peer interaction. Iranmanesh and Onur [50] suggested that informal peer learning among students decreases in VADS compared to traditional studios. Stahl [51] pointed out that an effective technological interface is needed to properly support a collaborative culture in design and learning. To effectively support communication and interaction, suitable virtual teaching and learning tools are particularly vital [14]. It was also found that advanced visualisation and representational methods are urgently needed for online platforms [52]. There have been various online platforms proposed for VADS, to assist with interaction and socialisation, such as Craig et al. [53], Niculae [54], Schnabel and Ham [55], and Vecchia et al. [40]. However, most of these current tools have certain inherent limitations and ultimately have not been widely applied. Currently, more commonly adopted online tools in teaching and learning can include specific online learning tools such as Blackboard Collaborate Ultra, and more general online communication tools such as Microsoft Teams and Zoom, which are commercially available.

1.3 Research Method

This study adopts a combined method of surveys and an in-depth semi-structured interview, to obtain perception data on both student learning experiences and staff teaching experiences pertaining to VADS. Surveys are a common methodology utilised to collect information from a target group of participants, through their responses to questions, which can be both quantitative or qualitative [56]. The advantage of using a survey is the ability to obtain information in a relatively short timeframe in order to gain and increase understanding of the targeted research area [57]. Semi-structured interviews are a common qualitative research method, which includes a fixed set of questions while the interviewer can also flexibly ask additional ad hoc questions based on an interviewee's answers during the interview session. This method ensures the inclusion of the most important questions closely related to the research topic, and at the same time provides optimal flexibility to extract the most comprehensive and relevant information [58]. This study's survey was conducted with architectural students at Curtin University in Australia. Curtin University was selected for this research, because it is the only Australian university which has provided a fully online architecture program incorporating VADS over the past decade. The seven VADS courses that were selected, were Curtin University's active courses on offer during that semester when the survey was conducted, and survey questionnaires were sent to students enrolled in those courses. Most of the survey questions were structured using a five-point Likert scale for responses (Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree). A multiple choice question and an open question was also added to compliment the Likert-scale questions, to collect additional relevant information for the study. The survey questions were designed from the multiple perspectives of students' learning experiences, the effectiveness of virtual learning tools, communication and engagement with teachers and peers, and student learning outcomes. The survey aimed to explore the students' learning experiences of VADS, their applications of virtual learning tools, and their perceptions including the challenges arising from various aspects of VADS. Table 1.1 shows the survey questions there were distributed to the students.

An in-depth semi-structured interview was conducted with a course coordinator at Curtin University who has had extensive VADS teaching experience. The interview questions were asked from the perspectives of the course context, course organisation, evaluation of student learning outcomes, communication and engagement, and virtual teaching tools. Table 1.2 shows the starting questions of the semi-structured interview.

Table 1.1 Survey questions distributed to the students enrolled in VADS

Categorisation	Questions	Multiple choice answers
Learning experience	My learning experience with this online studio/course is positive:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
	The online lecture information is helpful:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
	The online critique is helpful:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
	Flexible time is the biggest advantage for this online studio/course:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
	Flexible location is the biggest advantage for this online studio/course:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
	Lack of self-learning motivation is the biggest obstacle for this online studio/course:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree

(continued)

Table 1.1 (continued)

Categorisation	Questions	Multiple choice answers
Virtual learning tools	I have experienced difficulties using the online learning tools:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
Communication and interaction	The interaction with my tutor is effective:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
	Better engagement is the biggest advantage for this online studio/course:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
	Difficult to interact with teacher is the biggest obstacle for this online studio/course:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
	Reverse negative for "difficult to interact with teacher is the biggest obstacle for this online studio/course":	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
	Difficult to communicate with peers is the biggest obstacle for this online studio/course:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree

(continued)

Table 1.1 (continued)

Categorisation	Questions	Multiple choice answers
	Reverse negative for "difficult to communicate with peers is the biggest obstacle for this online studio/course":	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
Learning outcomes	This online studio/course effectively helps me to develop my design project:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree
	Overall the studio/course learning outcomes are achieved:	○ Strongly Agree ○ Agree ○ Neutral ○ Disagree ○ Strongly Disagree

Table 1.2 Semi-structured interview questions for the VADS course coordinator

Category	Questions
Course context	Are the online studios/courses synchronised with the on-campus studios/courses? Are most of students international or domestic? For staff, has the teaching load reduced or increased for the online studio/course
Organisation of the online studio/course	How are crits organised What is the biggest challenge for online teaching? What is the benefit of online teaching? How are studio sessions taught? Do tutors have individual consultations with students? How are group discussions run?
Evaluation of students' learning outcomes	Do you think students achieve learning outcomes better for online studios/courses?
Communication and engagement	Do your think students find it difficult to learn from each other for online studios/courses? Do you think students engage better for online studios/courses or for face-to-face ones?
Online teaching tools	Is it difficult to use the current online teaching tools? What are the current challenges of using these tools? How do you organise the studio/course? What online tools do you use for the online lectures and what tools do you use for the online studios?

1.4 Results

This results section presents the two sets of findings, from the student survey and the staff interview respectively, utilising the methods described above.

1.4.1 Student Survey Results on VADS

Forty-seven student survey responses from the seven VADS courses were received. Among the 47 participating students, 68.09% were male students and 31.91% were female; 18.80% were located in the same city as the university, and 81.20% were remote distance education students. The age groups of the students were: 8.33% under 20 years old, 20.83% between 21 and 30 years old, 22.92% between 31 and 40 years old, 35.42% between 41 and 50 years old, and 12.50% above 50 years old. That shows there is a large percentage of students who are mature students aged more than 30 years old (47.92%), which is comparatively rarer in traditional face-to-face teaching and learning settings. Some of those mature students may be working full-time jobs while studying, and the online remote learning model may be providing them with unique opportunities to more flexibly complete their degrees while employed. In addition, it was observed that most of the students (81.20%) were not locally located, which is another indicator that location flexibility is a key benefit that enables remotely located students to enrol in the architectural program. Table 1.3 illustrates the student survey results of each Likert-scale questions (responses are organised as Strongly Agree = 1, Agree = 2, Neutral = 3, Disagree = 4, Strongly Disagree = 5). They are organised based upon the four aspects: learning experience, virtual learning tools, communication and interaction, and learning outcomes. The neutral threshold was 2.5–3.5, which determines that a mean value less than 2.5 is positive, and mean value (μ) higher than 3.5 is negative. From the table, we can see that student learning experiences and learning outcomes are both positive. However, the areas of virtual learning tools, and communication and interaction, are neutral and thus in need of improvement.

The overall student learning experience in relation to online design studios was positive ($\mu = 1.98$). Most students agreed that flexible time ($\mu = 1.49$) and location ($\mu = 1.3$) are very beneficial and are the biggest advantages of VADS courses. Students agreed that the online lecture information ($\mu = 1.92$) and online critique sessions ($\mu = 2$) are helpful. Students held differing opinions regarding whether a lack of self-learning motivation is the biggest obstacle for VADS courses ($\mu = 3.02$, SD = 1.45). Students were neutral regarding the difficulty level of using the virtual learning tools ($\mu = 3.44$). Students tended to agree that interaction with teaching staff is effective ($\mu = 2.13$). And they held differing views about whether communication with teachers ($\mu = 3$, SD = 1.23) and peers ($\mu = 2.96$, SD = 1.22) had created obstacles in VADS. Students also had differing views when asked if better interaction and engagement are considered to be an advantage of VADS ($\mu = 2.77$, SD = 1.26). Students mostly agreed that VADS had helped them to develop their project effectively ($\mu = 2.06$), and their expected learning outcomes had been achieved ($\mu = 1.96$).

As discussed in the research method, additional information was obtained via a multiple choice question and an open question added to the end of the student survey to compliment the Likert-scale questions. Figure 1.1 illustrates the answers to the multiple choice question, about the particular stages of the student's design project which benefited from VADS. The results showed that students considered concept design to be the stage that had benefited the most from VADS (29%), followed by project brief and site analysis (20%), and digital modelling (17%). The least beneficial stage was physical modelling (6%), which is understandable, since those tasks are predominately expected to be completed in a physical and not a virtual environment. From the results, we can infer that VADS benefits students the most during early design stages.

At the end of the survey, there is an important open question—"Do you have further comments about this studio/course?"—which was added to the end of the survey to allow us to gain an overview of topics that were of most concern to VADS students. Figure 1.2 shows the coding percentage of the topics, based on student answers to that open question. The coding percentage represents the frequency in each of the coding categories. From the figure, we can see that the coding percentage of "communication with teachers" has the highest percentage (25%), followed by "online learning tools", "time management", "flexible time and location" all occupying approximately 15% each, while the least mentioned topic from the students' answers was "motivation" (3%).

Table 1.3 Likert-scale student survey results (Strongly Agree = 1, Agree = 2, Neutral = 3, Disagree = 4, Strongly Disagree = 5)

Categorisation	Questions	Mean score	SD	Category mean score	
Learning experience	My learning experience with this online studio/course is positive	1.98	0.99*	1.95	Positive
	The online lecture information is helpful	1.92	0.77*		
	The online critique is helpful	2	0.95*		
	Flexible time is the biggest advantage for this online studio/course	1.49	0.83*		
	Flexible location is the biggest advantage for this online studio/course	1.3	0.62*		
	Lack of self-learning motivation is the biggest obstacle for this online studio/course	3.02	1.45		
Virtual learning tools	I have experienced difficulties using the online learning tools	3.44	1.07	3.44	Neutral
Communication and interaction	The interaction with my tutor is effective	2.13	1.06	2.74	Neutral
	Better engaging is the biggest advantage for this online studio/course	2.77	1.26		
	Difficult to interact with teacher is the biggest obstacle for this online studio/course	3	1.23		
	Reverse negative for "difficult to interact with teacher is the biggest obstacle for this online studio/course"	3	1.23		

(continued)

Table 1.3 (continued)

Categorisation	Questions	Mean score	SD	Category mean score	
	Difficult to communicate with peers is the biggest obstacle for this online studio/course	2.96	1.22		
	Reverse negative for "difficult to communicate with peers is the biggest obstacle for this online studio/course"	3.04	1.22		
Learning outcomes	This online studio/course effectively helps me to develop my design project	2.06	0.84*	2.01	Positive
	Overall the studio/course learning outcomes are achieved	1.96	0.78*		

*SD < 1

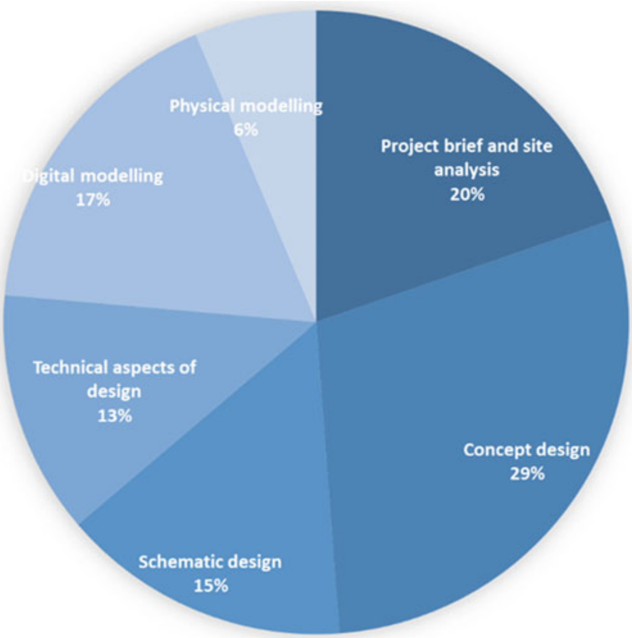

Fig. 1.1 Design project stages that benefit from VADS

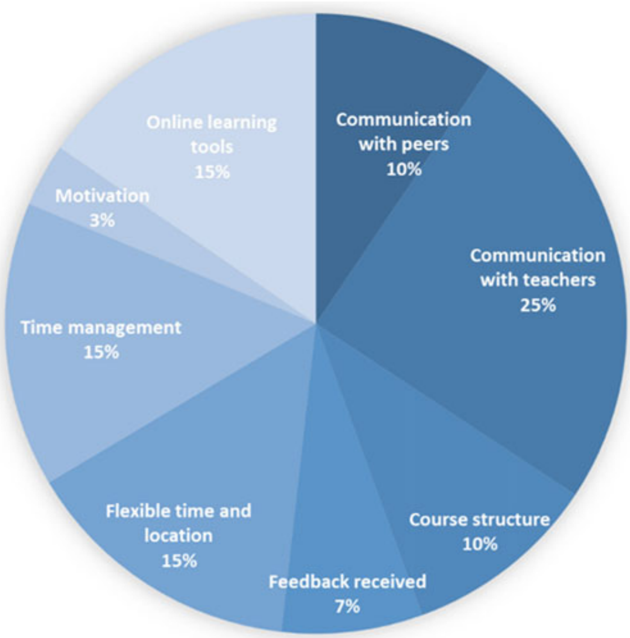

Fig. 1.2 Topics that were of most concern to VADS students

1.4.1.1 Learning Experience

Figure 1.3 illustrates the matrix coding of the positive versus negative answers to the aforementioned open question—"Do you have further comments about this studio/course?"—in order to further explore students' learning experiences in VADS. From the figure, we can see that students were very positive about the time and location flexibility that online studios and courses can provide. As students commented: "*The ability to continue to work full time and study is a fantastic opportunity*". "*I have done two years undergraduate studies over four years while working full time*". They also had more positive experiences (11.54%) than negatives ones (7.69%) in terms of time management. One student noted that "*The online studio could be more effective with a project timeline of what was expected to be produced by students [...] could help students manage workload better and learn when to stop designing and start producing, while keeping up with the level of work done by other classmates*". Students were relatively negative (3.85%) regarding the feedback they received, as they generally perceived face-to-face feedback would help them more than online feedback, and also not being able to receive live feedback in class was perceived as being a disadvantage.

Students held both positive (7.69%) and negative (7.69%) attitudes towards self-motivation. Generally, VADS requires higher self-discipline and self-motivation from students; there are both advantages and disadvantages of VADS, in relation to keeping students motivated. Some students felt they had a lack of self-motivation, while others considered the flexibility in terms of time and location, and easy access to online resources, to actually be beneficial "*in terms of self-motivation, self-reliance and self-confidence*".

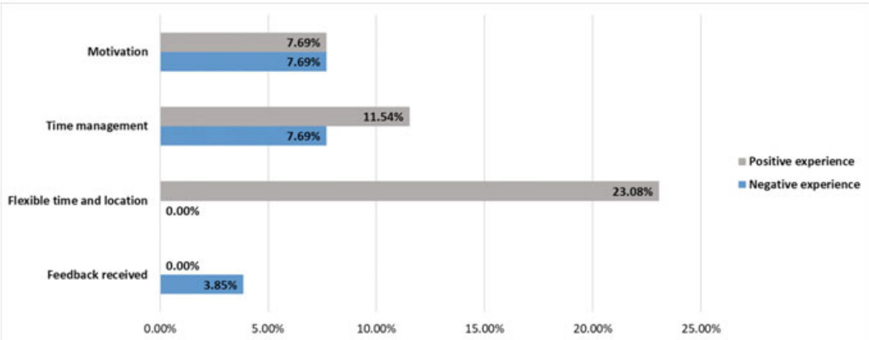

Fig. 1.3 Matrix coding of VADS in relation to students' positive versus negative learning experiences based on an open question

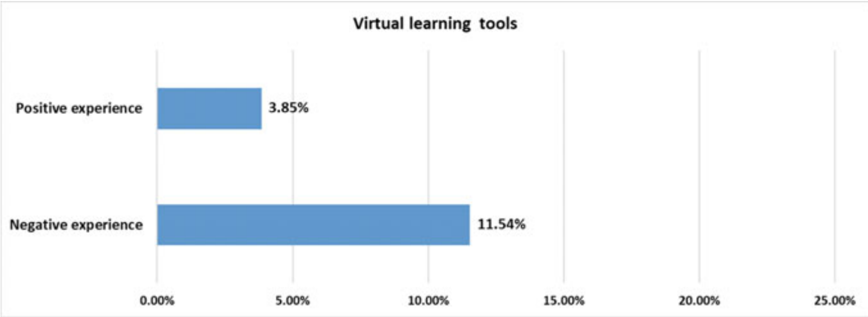

Fig. 1.4 Matrix coding of the positive versus negative student perceptions in relation to virtual learning tools in VADS based on an open question

1.4.1.2 Virtual Learning Tools

Figure 1.4 describes the matrix coding of the positive versus negative answers to the same open question but in relation to virtual learning tools. Results show that students generally had more negative experiences (11.54%) than positive (3.85%) ones regarding virtual learning tools. As students commented: "*Collaborate Ultra is good for sharing documents of information, but lacks a fair amount of flexibility to draw over and share ideas through sketching. It's too artificial, and ideas are then limited to what the program can do, rather than your thought process*". Students also commented on the inconvenience of network drop-outs or other technical issues with cameras/microphones malfunctioning when interacting with Collaborate Ultra. However, they also reported that some benefits arose from the use of virtual learning tools, such as by recording the studio session students can rewatch them to heighten their understanding, and it was also noted that "*technology helps to keep emotion out of the discussion*".

1.4.1.3 Communication and Interaction

Figure 1.5 shows the matrix coding of the answer to the same open question, but in relation to communication and interaction. The results reveal that students had more negative experiences than positive experiences (3.85%) regarding communication with teachers (7.69%). There could be several limitations that might have led to the ineffectiveness of communication with teachers. Firstly, students could only show their design as static PDF copies of the project file, rather than the actual works they were currently developing in their software tools. This limitation made it hard for teachers to assist with the student's live design process. Secondly, the student's online experience could also heavily depend on the teacher's capability in using the virtual teaching tools, as one student commented: "*The online experience is heavily weighted on whether the tutor understands how to present ideas and critiques due to*

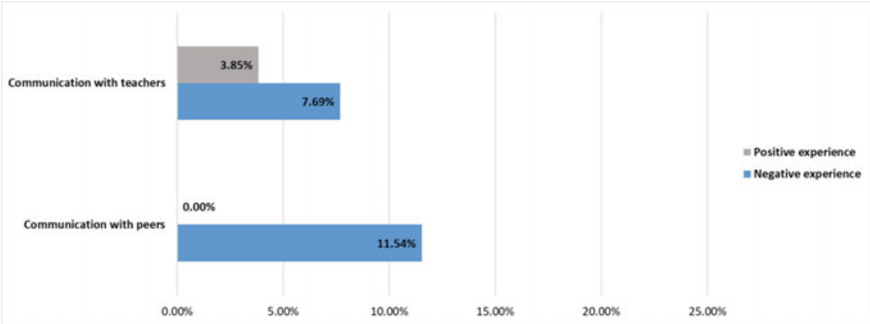

Fig. 1.5 Matrix coding of the positive versus negative student perceptions in relation to communication and interaction in VADS based on an open question

the layout and working area". Thirdly, students tended to expect to receive feedback through discussion boards in a relatively more prompt manner, which if implemented could further add to the teaching staff's existing workloads and may not be feasible in many cases. An expectation by students for near-immediate online feedback has been increasingly noted in VADS, more so than in face-to-face studios and courses. Interestingly, communications with peers were all perceived as negative experiences (11.54%) according to the answers to the open question, as one student commented: "*Group work has proven difficult, every time it is incorporated into the syllabus, group projects have proven problematic*". However, teamwork is one of the known challenges in design pedagogy even in traditional studios.

1.4.2 *Studio Coordinator Interview Results on VADS*

The following results have been achieved through an in-depth semi-structured interview with a VADS course coordinator. He has extensive VADS teaching experiences at Curtin University. The interview questions were asked based on the following categories including the course context, course organisation, evaluation of student learning outcomes, communication and engagement, and virtual teaching tools. The results are presented based on the emerging themes below from the interview transcripts.

1.4.2.1 Accessibility and Flexibility

The studio coordinator agreed that the biggest advantages of online studios are accessibility and flexibility, as he mentioned: "*Getting people access to a university to study, especially architecture […] who just would have no opportunity otherwise*". Many students enrolled were part-time and aged over 35 with a full-time job and/or families, for whom it would be almost impossible to come back to a university and spend five years to study architecture full-time traditionally. The online architectural program through VADS provides them with opportunities to more flexibly study architecture, that is to have flexible options to study architecture and to complete the degree at the student's own pace.

1.4.2.2 Teaching Staff's Workload Impact

The studio coordinator flagged teaching staff's workload considerations as being one of the prime challenges with the current teaching of VADS, noting that "*Workload is a big issue for us with the online program […] Generally staff has more workload*". The main issue in this area currently being, that online teaching tends to be a more time-consuming process for staff, but that is not being accurately calculated and factored into the university staffing workload estimates. An increased student tendency to rely on detailed email communication, results in significant additional time, including after-hours, required from teaching staff, as was mentioned that "*the online program […] parts of that […] those things that have to be by email […] is always a bit slower*". And ultimately, such additional workload result in teaching staff having less time to spend on the core parts of the studio and course delivery, compared to its traditional on-campus form.

1.4.2.3 Virtual Teaching Tools for VADS

The main virtual studio teaching tool Curtin University uses is Blackboard Collaborate. Some technical frustrations about current virtual tools for teaching design were raised by the studio coordinator, noting that "*With Collaborate itself, if there's too many videos on, sometimes it can slow down the connection*", some of which appeared to worsen as the number of participants increased, as exacerbated by the weak internet connection. Some of the technical limitations of the tools were also noted, such as "*The Blackboard Collaborate drawing tool is pretty rudimentary and there's only one line weight, which is probably the worst thing about it*", and if the tutor only used a mouse, it would be difficult to draw accurately. However, if a tutor used an iPad with a stylus potentially, the issue could be mitigated. It is evident that more design-oriented tools and features together with appropriate guidelines are urgently needed for the success of VADS.

The strategic use of synchronous vs. asynchronous VADS sessions was highlighted, as the coordinator noted that "*We try not to have formal lectures during the synchronous sessions*". This is because the students could better use their time watching the video during their own time before the session, and then during the studio sessions the tutors could focus on answering students' questions. The more effective synchronous sessions were comprised of "*web conferencing sessions […] using Blackboard Collaborate. So […]students can post up their work. They can discuss things between themselves and then they can get feedback from the tutors.*

[…] Tutors can obviously talk to them about the work" but additionally "*they have a one-on-one with other students in the session watching along, as well […] other students who are in the session can ask questions and make comments as they go in the chat without everyone having to have their microphone on at the same time*".

And the more effective asynchronous sessions, according to the interview, were not only comprised of the aforementioned lecture recordings, but also a closed social network site (which refers to as *ePinup* at Curtin University) in which students could post images of their work and other students and tutors could comment on it. There are significant benefits to such an asynchronous component in VADS, particularly for immediate feedback.

1.4.2.4 Student Engagement and Peer Interaction

Student engagement is a challenging issue for VADS. One of the challenges that was highlighted, was that some students had poor attendance for their online classes, as well as a low rate of accessing their online course materials. Although interview findings suggested that if students were competent enough then sometimes they could still complete courses without strong engagement, however that could still leave many students behind who cannot successfully complete a challenging course without adequate engagement. It was noted that while a wide range of student engagement levels existed already with traditional on-campus studios, the problem is that with VADS, there is "*a much bigger range or much bigger numbers, proportion of the students at the bottom end who tend not to engage because it's just out of sight, out of mind*". One of the potential factors leading to the problem could be that "*when there's no […]students around you it's a lot harder, and online students rely a lot more on self-discipline and kind of internal motivation. And so if they don't have that, then it can be a lot easier to let go*". A consequence of this lack of engagement was felt early on in the architecture program, since usually there was a huge drop in enrolment numbers from first year to second year in the program.

The view was expressed by the studio coordinator that student interaction with peers was also more challenging in a virtual learning context, with more effort required compared to on-campus learning. To aim to mitigate that challenge, the use of an internal social networking site was encouraged for students to share their ideas with peers; however the social connections still seemed to be more effective in a face-to-face setting, and in relation to online social networking the studio coordinator commented that "*social connectedness is harder to maintain and establish*".

1.4.2.5 Learning Outcomes

The greater variation in the age range of students enrolled in the online architecture program was noted to have an impact on their learning outcomes, as "*our median age was 35 for the online course […] when we have written assignments and essays, you have 35 years olds that are just better at writing than 22 years olds or 20 years* *olds […] older students are a lot better quality than what we have on an on-campus course*".

VADS having smaller groups of students studying together, compared with typically much larger on-campus groups, were also highlighted. Since in on-campus studios with larger groups, students were more likely to see what other students are doing, especially from the top students in the group. However in VADS, it was less frequent for "*top students to pull other students up with them*", and ultimately, the overall results could be less predictable. Since due to the relatively smaller student numbers of VADS, the results can be "lumpier".

1.4.2.6 Limitations of VADS

According to the interview, the first noticeable limitation was regarding site visits. There were generally two methods of conducting site visits in VADS. The first method was that site visits were handled by instructing online students to simply find a site in their local area that was meaningful to them, and students needed to take photos and get approval from the tutor to ensure the site meets the criteria set in the project brief. The other option was to use "siteless" projects, when students only needed to do the general research without the context of a site.

Another limitation was in relation to conducting physical modelling work in a VADS context. Substantial room for improvement was highlighted for leveraging potentially beneficial technologies to enhance current online studios. The studio coordinator signalled difficulties with currently integrating the more physical aspects of architectural learning into an online delivery method, as he stated that "*we can do the parametric and computational design and that's fine, but then the manufacturing and fabrication side of it is something that is very physical*" and gave examples of new architectural on-campus facilities being built centred around makerspaces including "*3D printing and CNC machines and laser cutters and robot arms*" which he could foresee being an increasing challenge to integrate into VADS. Potential solutions for the future, could include students emailing their files to an on-campus 3D printer or laser cutter, and then onsite staff assisting students with printing of their parts and mailing it back to students. The coordinator also suggested that it was simply not realistic in online studios to replicate the same full learning experience to students that on-campus studios may provide, for example, in most VADS the teaching staff simply could not "*look over someone's shoulder and say, 'You know, you should keep your pen more upright' […] so there's obviously things like that about the techniques that's hard*". However this does not necessarily to be perceived as a shortcoming, rather perhaps it is opportunistic to create a unique experience for VADS by making full use of its advantages and potential and to provide students with the option to select the learning mode that best suits their needs.

1.5 Discussion and Conclusion

This chapter presents student survey and teaching staff interview results pertaining to VADS at an Australian university. The findings suggest that students generally have positive experiences with VADS; however, a few areas are in need of improvement, such as virtual/online teaching and learning tools, and communication and interaction with teachers and peers. With current trends pointing towards increasing attention on virtual and blended learning, and potential applications of the Metaverse, the future of architectural education is rapidly evolving. Higher education in the Metaverse is still a new phenomenon, and VADS are the closest current practices of this form of teaching and learning. The results of this study allow us to more critically understand students' learning and staff's teaching experiences in current VADS, which can provide a foundation for designing and developing future learning in the Metaverse. The following recommendations have been summarised for future virtual, blended and ultimately Metaverse-based learning, which is especially pertinent to the evolution of architectural education.

Firstly, the effectiveness of the technology used for supporting the virtual teaching and learning environment, is key to the success of VADS. The quality of the technology itself has a significant impact on students' virtual or online learning experiences. As Komarzyńska-Świeściak et al. [59] suggested, VADS "*leads to frustration when instructors' and students' expectations are beyond the technological capabilities*". Architectural education has specific requirements in terms of visual representation and 3D modelling, for instance that the drawing and modelling tools need to be usable and contain enough specialist functionality for the teaching staff to effectively communicate their intents to students. Furthermore, contemporary design studios significantly utilise digital design tools; in that context, there is currently an urgent need for virtual teaching and learning environments to have these technological capabilities associated with digital design, as well as to allow teachers and students to work on digital models more intuitively and collaboratively. Such advancements in VADS may result in more effective and engaging environments supporting student learning across disciplines [47, 60]. The results of this study suggest that students are generally neutral about the difficulty level of using virtual learning tools. This is expected since newer generations of students are already familiar and fluent with digital tools and media in their everyday lives, so potentially they will be able to work and communicate far easier in virtual design and learning environments compared to older generations [61]. Nevertheless, naturally there may still be an adjustment period required for both students and teaching staff to adapt to the emerging technologies [62], but they are less likely to become significant barriers in VADS.

Secondly, a significant benefit of virtual learning or Metaverse-based learning is the inherently increased accessibility and flexibility offered by such a learning mode. As shown by our study, virtual learning has enabled and facilitated much wider access to premium architectural education. Students and teaching staff will not be limited by their physical locations, allowing potentially access to students globally. The flexibility of virtual teaching can also make it more accessible for architectural academics and practitioners despite geographical barriers, to give guest lectures or to participate in virtual critique sessions that can provide students with greater exposure to more diverse and high-quality research and professional expertise. Since its origin, and as echoed by Wake and Levine [63], VADS have indeed created more possibilities for collaboration between different architectural and design schools across the globe. Flexible learning schedules offered by VADS will also make quality education more accessible to more students, especially those students who need to juggle a working life and study commitments together.

Thirdly, our results have shown that effective communication with teachers and fellow students is an important aspect affecting students' experiences in VADS, especially in relation to support for peer learning. Iranmanesh and Onur [50] emphasised a significant decline in student interactions with peers in the context of VADS. Due to such a lack of interaction compared to face-to-face settings, it can be difficult for students to build up social networks. Being physically present on-campus with interactions such as receiving immediate feedback, has a real impact on student motivation during design studios [64]. Future learning environments in the Metaverse should provide students with effective means for peer communication and network building, to improve the peer support and learning which is largely missing in current VADS. Specifically for architectural students, there is a need to effectively and conveniently share media-rich information such as images and digital models, in order to facilitate effective communication with both the teachers and peers. In addition, enhancing the ease for staff to provide rapid quality feedback to students in a virtual setting should be an important practical consideration, due to its implications for effective student/teacher communications, and maintaining a manageable workload for teaching staff.

Finally, some of the inherent limitations and barriers of current VADS, should be aimed to be minimised when designing and developing future Metaverse-based learning, via both technological advancement and pedagogical innovation. VADS and Metaverse-based learning for architectural education does not necessarily need to be limited to replicating traditional design studios. There is a real opportunity to create a unique learning environment and unique learning experience, by taking full advantage of new technology's potential, to better support a broader student cohort and their diverse needs. Our future studies can focus on the technological development of Metaverse learning environments incorporating immersive technologies, and further evaluation of students' and teaching staff's experiences in those new technological environments. Since the present study has a limited sample size of seven VADS courses, another future extension of our research can be to enlarge the sample size, to more specifically categorise different types of VADS and institutions to produce more generalisable results.

Acknowledgements The authors are grateful for the generous support from our extended collaborators who helped us to develop the project and collect data, especially Professor Michael Ostwald, Mr. Steven Feast, and Dr. Henry Skates. We would like to thank Curtin University for assisting in the recruitment of student participants from the Curtin University architecture program. We also thank all of the students who participated in our survey. Some results of this chapter are based on materials that were previously published in the international journal *Architectural Science Review*, and they have been extensively extended with new contents and adapted appropriately for the chapter.

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Chapter 2
Panopticon of Virtual Classroom: Evolution on Teacher–Student Relationship in Distance Education

Tse-Wei Hsu

Abstract Are educators the conquerors or refugees from colonialism? In recent years, digital tools are actively used to teach online. However, today's young students, known as Generation Z, are already familiar with the established order, solidarity and all kinds of techniques in the virtual world. One who wants to use traditional classroom authority to rule this democratic and free online world is just like a mantis trying to stop a chariot. This research uses action research and participatory observation to explore the conflict and mutual compromise between the teacher–student relationship from classroom to online platform. This research points out a few common issues of distance teaching today, including: students become pure listeners, are distracted easily, have lost the space perception, etc. Finally, three principles are proposed for building a metaverse classroom: (1) redefining the self-identity of teachers and students, (2) re-establishing the teaching order, (3) characteristics that the virtual classroom should have.

Keywords Metaverse · Mixed reality · Distance teaching · Online to offline

2.1 Research Issue

> To get out of the classroom and back to reality, we have to escape from the four walls of monastic space and look down on our past selves sitting in the classroom from the windows of the universe [1, p. 3].

In recent years, there have been many diverse successful cases of using digital technology to assist teaching in school. There are too many outstanding examples such as pre-recorded courses, digital learning platforms, and various digital tools integrated into the teaching context to list out here. However, under the influence of the COVID-19 epidemic in 2021, teachers' attitudes toward the integration of digital

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_2

tools into teaching have changed from "be able to" to "must to." The lack of complete interaction in teaching in the digital environment has reduced the effectiveness of learning. On the one hand, it is impossible to grasp the expressions of the students, or that feedback is reduced. On the other hand, the private environment lacks the atmosphere of the classroom space, which also reduces the concentration of students.

Reviewing the situation of distance learning from 2021 to 2022, the distance learning environment has not yet developed soundly in Taiwan. Most students and teachers conduct teaching and participate at their own houses or dormitories. Risks of grouping students in certain teaching venues are too high due to the COVID-19 pandemic. Neither parents nor school policies encourage traditional physical classes in groups. There is also a certain possibility that the re-emergence of such infectious diseases will lead to the recurrence of national compulsory distance learning.

Based on the above, the problems caused by using the most common "conference call services" for "synchronous online learning" include:

- Overlapping and unclear sound.
- Poor streaming video quality.
- Inattentive students and influencing factors.
- Unruly students and weak classroom discipline.
- Unable to grasp learning situation of students.
- High cognitive load caused by digital interface.

Some of the above problems, such as streaming video quality, can be solved with "video pre-recording" for "asynchronous distance learning." Students watch the video and complete assignments, quizzes, or exercises of this class by themselves.

However, one is still unable to make immediate adjustments in the teaching process through traditional physical class interaction. When a teacher is reviewing students' results of quizzes or assignments, it is too late to realize that students are not keeping up with the pace or that they misunderstand specific content of the class.

In comparison of learning results between distance learning and physical classes from students' feedback, if the program adopted one-on-one teaching, the difference of the two learning methods is small. However, teaching is conducted to a group, and physical classes can have more learning effects [2].

2.2 Development of Teaching Technology

With the advancement and development of internet technology, there are countless strengthening technologies in applied teaching, which are mainly divided into Learning Management Systems (LMS) and Conversational Technologies. However, little progress has been made or even ignored in the creation of classroom atmosphere.

LMS is used to manage and track students' learning process and performance continuously in various training and learning activities. It allocates various learning resources such as registration and login system, class timetable, learning materials, teaching resources, and online learning delivery [3].

The progress of conversational technology relies on expansion of network bandwidth, which shortens the physical distance of reality and allows conversations to span time and space. The online conversation with video, as opposed to pure audio communication, also adds visual assistance and emotional transmission to result in an interactive experience that is closer to face-to-face communication. However, there is still no substitute for the full experience that face-to-face conversations can bring.

Conference call services such as Google Meet, Zoom, and Microsoft Teams have been commonly used in distance learning in Taiwan in the past two years. These services are mainly used for participants to interact with facial streaming, presentation, conversation and discussion. But these softwares' shortcoming is the weak presence of the participants. For online meetings with more than 30 people, it will be difficult for the host to track every participant; thus, the quality of interaction and conversation is reduced.

Teaching in the classroom is a many-to-many interaction among teachers with their students and students with their peers, who are all participants in physical class. The physical classes have their own disciplines and rules but are distorted and deteriorated in the context of distance learning. The distortion is that disciplines are no longer actively followed, and the deterioration is the evolved learning habits and methods.

In the preliminary period, this study had tried to conduct distance learning several times by using online virtual space service, but most of the feedback received by students was negative. The reason is that extra operational cognitive resources were required to move the avatar in the virtual space by using the mouse or keyboard shortcuts. The curiosity about the new interface may also prompt students to constantly wander in the virtual space, which was causing visual interference for teachers and other participants.

The evolution of teaching skill also involves incorporating more diverse learning methods. Numerous digital tools, brand-new teaching methods, and constantly stacking content all show the evolution of teaching of this era, which not only deepens the richness of learning, but also deepens the difficulty of learning. The difficulty of learning is not only in "learning and how to use learning tools" but also faced with more sources of information in the surrounding, with large screens, small screens, and the always present social messages.

Garrison and Anderson [4] believe that a good online lecturer should be able to create a continuous, shallow-to-deep, and interactive scenario during the course and establish a reassuring online environment to encourage learners to put forward multiple perspectives and comments on the topic of the seminar. They also suggested that online lecturers should make students feel the following atmosphere:

- Feel welcome and needed.
- Have a sense of honor to belong to an important community.
- Be able to control by oneself.
- Expected concrete results.
- Willingness to join the conversation.
- Occasion to facilitate conversation.

- Dare to ask questions on points one may or may not understand.

Keller proposed a systematic design pattern of learning motivation called attention, relevance, confidence, and satisfaction (ARCS) [5]. This model is constructed on four factors:

- Arouse students' attention and interest in one thing, that is attention.
- Let students discover the relationship between this matter and themselves, that is relevance.
- Make students feel capable and confident to handle it, that is confidence.
- Sense of accomplishment and satisfaction after completion, that is satisfaction.

The whole process emphasizes on the fun of learning, by keeping the learners' interest through a series of reinforcement strategies to improve teaching and learning effects [6].

According to the time or space separation of teachers and learners, distance learning can be divided into two modes: synchronous and asynchronous online learning. Asynchronous online learning is when there is a time-spatio separation between teachers and learners, and they are not online at the same time. The students use the digital tools to submit homework, express opinions through online discussion boards, or interact with others [7].

Common asynchronous online learning applications include database or web-based systems where teachers store learning material or class notes as files or images, so that students can watch or read at any time. Asynchronous online learning environments typically utilize media technology to deliver class content and provide two-way interactions among teachers and their students, students and their learning material and peers. The challenge of practicing distance learning is to face the aforementioned distortion of disciplines and deterioration of rules of class.

What teachers are forced to face are: learning new technologies, large or immobile devices, unstable network bandwidth, inattentive or nonparticipating students, small or uncertain audiences, and little interactions in the class. Those listed above are all the dilemmas or disadvantages for teachers to promote distance learning. This also shows that teaching methods do not evolve with the same merit with the addition of digital technology. On other points of view, distance teaching even accelerates and increases students' learning gap and increases the burden of after-school homework.

2.3 Discipline and Space

The challenges and difficulties we previously highlighted might not solely stem from technical issues like bandwidth limitations or information processing capabilities; rather, it could be a deficiency of disciplinary measures and organizational structure among teachers.

We all know that sticks can't be used in virtual space, but what can be discussed is to rebuild a disciplined space. The teaching environment this study investigates is not in a physical space. It can be an asynchronous distance learning scenario where teachers and students are neither in the same area nor online at the same time and how to build a disciplined space to make both students and teachers experience the spatial authority in physical classrooms.

Let us discuss the authoritarian factor of space in real classrooms first. This study conducted a questionnaire with 110 Taiwanese college students to investigate the authoritarian factor that students felt in the classroom and initially classified them into three categories: sight, distance, and sound.

Students will obey the discipline in classrooms because they feel invisible pressure from those three authoritarian factors in the space. Then the author added more lecturers and peers to increase authoritarian factors again and recorded the pressure index that the participating 110 college students feel. Data was recorded using a 5-point Likert scale, and results are shown below.

Table 2.1 shows that 74.55% and 42% of students feel pressure in the classroom due to the sight from the lecturer and peers, respectively; there are 71.82% and 39.09% of students who are stressed as a result of the distance from the lecturer and their peers respectively.

However, compared with the authoritarian factors above, the voice of instructors or peers in the classroom influenced fewer students, which also indirectly confirms that distance learning with only voice conversations is hard to stimulate students' motivation in learning or requires students to obey the classroom norms.

This paragraph discusses the teacher authorities in the teaching process, including the authority for the interpretation of teaching content, the authority for the option in teaching methods, and the authority for the evaluation of students' learning [8].

Although teachers have legal authority over students, students have the knowledge of how to respond. Students react negatively and show by their passive learning motivation, unconcerned teacher–student interaction, and the learning outcome that is far from goals to express disagreement with those teachers' authority [9, 10].

In recent years, the embodiment of distance learning is like students "listening" to the online interactive courses like radio programs, "playing" the pre-recorded courses as background music, and also "watch the end" directly by operating the video at the platform, or "hand in homework directly" without participating in any course. There's no doubt that it will substantially decrease the learning effect when students cannot follow the teaching guideline to learn step by step.

Table 2.1 Pressure index of authoritarian factors from Taiwanese students

Authoritarian factors	Pressure index (%)
The sight from the lecturer	74.55
The distance from the lecturer	71.82
The sight from peers	42.00
The distance from peers	39.09
The voice from lecturer in the classroom	38.18
The voice from peers in the classroom	27.27

Fig. 2.1 Panopticon. *Source* Sydney Criminal Lawyers, 11/07/2017 Photo by Paul Gregoire & Ugur Nedim, https://www.sydneycriminallawyers.com.au/

2.4 Reconstruction of Spatial Order and Redefinition of Roles

Continuing the topic on the influence of the authoritarian factor of space, the British philosopher Jeremy Bentham proposed a "panopticon" in 1785. A panopticon is a building where annular surroundings are divided into separate single cells (Fig. 2.1). There is a surveillance building in the center with a surveillance room on the top. The open side of the surveillance room will have a semi-transparent structure like shutters to block sight from outside. Prisoners who live in those single cells would not be able to know whether there is an overseer watching them or not. Michel Foucault [11] believed that prisoners will follow the disciplines and rules set by the overseer at all times in this unequal sight situation.

This research does not regard students as prisoners but wishes to point out an interesting social relationship through this theory. "Sight" (or gaze, observe) is one of the few remaining tools that teachers can use to manage students in modern classrooms. All the punishments that may influence students' right of education are forbidden,[1] including corporal punishment and oral abuse. Without tools, the difference between teachers and students comes from external social tacit understanding that gives teachers higher social status (compared to students). This provides an external advantage for teachers to use their authority, so that students obeying teachers' order has become a norm [12].

As Michel Foucault said in "The Birth of the Clinic," a doctor's gaze at his patient is a performance of showing power. In other words, a gaze from the leading position

[1] Corporal punishment has been prohibited in Taiwan through law amendment on 2006/12/12.

is also a gaze from the dominator. It is also a one-to-many interactive relationship between participants in a traditional classroom [13, 14].

How a teacher judges a student if he/she is concentrating on his/her learning tasks is through sight. Students can see each other in the classroom, too. In that case, they form a mutual restraint. The transformation from hierarchical observation to peer-to-peer observation aims to empower students as overseers in learning tasks. This shift seeks to redefine the dynamics of sight-restricting relationships, allowing students to take an active role in monitoring and facilitating their peers' learning processes. The implementation of this approach involves the following specific methods:

- Announce the degree or percentage of completion of the preview items.
- Announce the degree or percentage of completion of the learning tasks in the learning process.
- Announce the results of students after completing the learning tasks.
- Give all students differentiating power, including evaluation of learning outcomes and attendance records.

The participants already have tacit agreement while learning together in a course. For those who interfere or drop out, the course will be intervened and coordinated by teachers.

However, compared to the panopticon, the difference is that the "administrator" has absolute authority and disadvantageous to the "resident." The administrator/overseer will create an illusion by hiding their line of sight so that residents feel they are always under surveillance. On the other hand, teachers' sights are singular and easy to perceive in traditional classrooms.

The teachers and students in the classroom can upgrade the students' position from residents to administrators based on the differences in teaching activities. For instance, teaching methods like flipped teaching, peer review, group discussion, and so on allow students to take the floor or host, in turn making a specific student to become an administrator. In this concept, if the power could be extended again to students or peers at proper timing, the goal of reversing the role of the panopticon could be achieved and allow residents to also become an invisible administrator.

The virtual social space established through this kind of sight relationship will help to upgrade the participation and the concentration of students by supervision between peers. Just like what this research mentioned above, what students should respect is not the role of the teacher, but to agree that classrooms are an authoritative existence. The most important part to rebuild order is that all the participants (teachers, students and observers) understand each other's role and respect their own power.

2.5 Metaverse Classroom

The concept of the metaverse is open-minded and autonomous. It is an opposite and conflicting concept against traditional classrooms. The order of the classroom includes teachers' authority, sense of classroom space, and peer pressure. There are also many fixed linear structures of time and effect verification that cannot be rearranged when designing the courses.

The necessary items in the classroom are "participants," "sensory stimulation that can be detected" and "order." The "order" here means the establishment and maintenance of the school's rules. It is a relatively stable relationship mode, structure, and status built in the process of teaching interactions of classroom participants [15].

Considering what the public defines as metaverse, the imagination of a metaverse classroom might have the following characteristics:

- Space: Full with virtual avatar with full-body motion capture and move freely in a virtual space which is similar to a classroom environment.
- Role: Everyone can teach, and everyone can learn.
- Freedom: Learn anywhere, learn anytime, learn on demand.
- Boundless: The concepts of classes, departments, colleges, groups, and schools are gradually weakened or disappeared altogether.

The following section will describe the four characteristics in detail:

2.5.1 Space

The space in this study is not exactly a virtual reality of a three-dimensional space generated by digital technology, but an "environment" provided with order, discipline and participants' power that this research previously mentioned. Perhaps, it will be easier to understand if we regard "space" in this study as "classroom discipline of virtual social space." Of course, this study will introduce some methods to establish order and maintain discipline by means of digital technology, which is still in the digital design.

The classroom order should contain specific learning goals to allow the participants to track their current progress, track each other's information to see whether they have participated or not. It should have a specific course evaluation system, and specific ways to participate in the course, such as synchronous learning, asynchronous learning, due time, subjects.

This study emphasizes the authority factor formed by participants' sight, so it needs a system to make participants feel they have partners. For instance, when learning in the virtual social space, a learner should have another participant to accompany and learn with them. Although in the asynchronous learning scenario, a student who started learning activity first may not have a classmate. The virtual character (NPC) can play the role of accompanying the first participant to learn together.

The participant's sight includes a learning progress mutual review of participants in the course. The learners preview prior to class and the understanding of teachers about their students can be fulfilled by the digital management system nowadays. The learners' learning status and the teachers' compliance to the progress and syllabus are very important in the course. It helps learners realize whether they are ahead or behind in the course progress. Students comparing each other's results or work after learning allow learners to evaluate their own results or against others' after finishing a task. Observing the footprint of other learners, or observing where others excel or make mistakes are all parts to a learning process.

It is true that evaluation in courses involves students' privacy. This study considers from the point of view of classroom management, announcing students' learning results by stage helps participants finish their tasks positively because they care about their performance. However, the method or degree of the content announced needs to be considered precisely. For example, do not announce ranking, convert scores into ranking, or simply announce complete/incomplete.

2.5.2 Role

Just like the feature of the metaverse, one is free to play a role of someone else, although there are limits to role play in the virtual social space in the classroom. Like the definition of gender, you can play the role of a teacher, or a student, or both characters, or none of these characters. Role play is a process of building identity. These characters are all endowed with the holy missions to teach and learn, and finally gain achievement.

The standard and value of the learning or teaching achievement can be redefined through blockchain technology or non-fungible token. A learner who has good learning effectiveness may become an educator in the future. The way to be certified is to transform the learning record into a transcript NFT.

A similar concept has gradually been established where senior high school students would import E-Portfolio before applying to college. The purpose is to try to allow the data that students submit to the colleges to be more closely representing who they are and show their personality, as opposed to a short-term pitch for the application. Without a doubt that every movement of the policy will bring countermeasures at the same time. Currently, the E-Portfolio is to be uploaded once every semester. Users who do not comply to the discipline still can take chances to upload information that is not real. This relies on the self-discipline of units of all levels and the moral compliance of students.

Extending the E-Portfolio and combining the concept of blockchain, from uploading data every semester to uploading every performance in detail may cause students afraid to make mistakes. However, no one is perfect. What educators care about the most are the changes they make and how they amend to the right path as students face difficulties. What can show the potential of students is not dependent on how many things they did open and aboveboard but dependent on whether they could hold their will when met with difficulties and frustrations.

To educators, the processes of giving knowledge, completing the credits (learning tasks), or giving digital certificates to learners can also accumulate their own teaching energy according to the teaching experiences. Of course, the premise is that there is still a decentralized supervision system to avoid refreshing teaching records through loopholes in the system.

2.5.3 Freedom

Today, the public discussion of distance teaching with no space limitations should not only focus on transforming traditional teaching materials into online audio but to consider the audience's misunderstanding of the meaning of certain vocabularies.

Maybe the cause of tired hearing is because of the long time required analyzing language connections. Random video learning lacks support from the system, and the learners lack motivation and self-discipline, so it is easy to lead to poor learning effectiveness.

Full digital distance teaching is not restricted to the teaching method to teachers. On the contrary, there are many multi-media or digital interfaces that appear to enhance traditional teaching progress. It allows educators to realize what changes are happening in the teaching field through replacing the slide machines (traditional slides) with digital lecterns. It is also time to accept that the way of learning is no longer limited to showing slides on the stage, but a multidimension distributed knowledge system architecture.

Autonomous control of the learning period is also a reason that metaverse is gradually built. Teachers provide pre-recording courses and a complete learning verification system for students to learn online in their free time. Although there are many private companies that have built digital teaching platforms that already fulfill the vision above, there are still many limitations to practical operation in formal schools.

Take courses; for example, it has a start and end time such as one semester, one school year or credits lessons, whole course hours, and single week hours. There is still a concept of "interval" in human life. Under normal physical and psychological conditions, it is still customary for teachers and students to arrange work or study in "weeks."

Let students decide when they want to do self-learning in units of weeks. Teachers could allow more time limits like handing in two learning progress within two weeks. For those who delayed learning or late submission, there should be rules or systems to respond and remedy. It is also recommended to arrange face-to-face QA sessions after pre-recorded courses. No matter what students do in real courses or online courses, they need opportunities to return to reality. It is important to get a balance between self-learning and checking their learning effect, in order not to fall into the cliché for the purpose of completing.

2.5.4 Boundless

Gaining knowledge is boundless. Even if someone finished the specified scope of courses or earned a degree, it is just understanding part of the knowledge. If we regard knowledge that we should learn as an ontology, going through all nodes does not equal to getting a full picture. Having the basic ability to understand the whole picture is the most important significance in the learning progress.

Knowledge can be traded. It is the same way that educators interact with each other nowadays. Teaching and learning enhance each other. If one uses metaverse technology systematically, such as blockchain transcript or NFT transaction mentioned above, to exchange what each other has learned, boundless teaching content can be found on today's Internet. As long as the learners are willing to give time and passion, they are bound to receive everything they want to learn.

2.6 Conclusion

Metaverse virtual classroom or the so-called the virtual realm of classroom order should have several characteristics:

- Asynchronous and synchronous teaching at the same time.
- Learning both off-site and on-site at the same time.
- Verifiable teaching index and completion rate of partners.
- Traceable teaching contents and completion rate of partners.
- A knowledge system with the function of teaching, self-learning, verifying qualifications, and trading of knowledge.

There are more options for distance online teaching and more possibility of interaction without a software interface framework. However, there is limits to modern technology, as it is still impossible to transmit 100% of information through the internet compared with face to face. Compared to field teaching, online teaching or virtual technology must have some sort of information distortion or barriers of emotional judgment, that is the reason why visual avatars are used.

The teaching process relies on facial expressions, voices, and on-site interaction to obtain immediate responses from students. Students cannot concentrate on distance online teaching because it is not real enough. Field teaching can appeal to the audience through face-to-face presentation. However, if it is an online video conference service, the interaction with each other will turn from space sharing to a single screen sharing, from a space to a window. By establishing the classroom order in virtual social space, the educators' sense of immersion and participation can be rebuilt.

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Part II
Simulation in Virtual Space

Chapter 3
Latent Space to Support Virtual 3D Models

Jinmo Rhee and Ramesh Krishnamurti

Abstract This paper examines the potential of latent space in exploring digital realities. Latent space is a topological vector space of embedded data features so that, feature-wise, data that resemble one another are positioned more closely in latent space. That is, the distance between two points in latent space is a measure of similarity of their corresponding embedding data. Latent space has lower dimensionality than the original feature space from which the data points are drawn. We explore the relationship between feature space and the respective geo-physical qualities by statistically defining characteristics of the latent space. Through a case study, we demonstrate of how latent space can intervene in digital space using architectural, urban, or cultural properties from a geo-physical world. We conclude with a discussion of the potential application of latent space to the reconstruction of virtual 3D models.

Keywords Data space · Latent space · Transition · Deep learning · Virtual reality

3.1 Introduction

It is not uncommon in the world of digital twins and metaverse for concepts of digital spaces to be intertwined with real geo-physical entities and spaces. Digital spaces are typically reconstructions of geo-physical spaces where the three-dimensional modeling space is central to this reconstruction. However, there is potential for such digital spaces to be more than mere reflection of geo-physical space by including considerations of multi-dimensional data flows and features. For this, we consider the concept of latent space in machine learning and examine its potential in exploring digital realities.

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_3

Latent space is a topological vector space that represents an embedding of data features. Each point in the latent space represents a feature embedding of the original data space (Fig. 3.1). Data that resemble one another have similar feature embeddings; that is, the distance between two points in latent space is measure of resemblance between their corresponding original data (Fig. 3.2). In general, the dimensionality of latent space is smaller than its original data space counterpart. Latent space has the following two characteristics: embedding and ductility. These terms are explained below.

Latent space can exist as a virtual space, or it can be augmented with geo-physical models. In general, when the latent space has dimensionality larger than three, it is hard to visually grasp or tract. Dimensionality reduction techniques, for example, principal component analysis (PCA) and t-distributed stochastic neighbor embedding (t-SNE), are used to visually understand the distribution of feature embeddings. These reduction techniques project feature embeddings into visualizable dimensions, while preserving their characteristics and relationships in the data. This projection is recognized as a representation of latent space. Post-processing the projected feature embeddings enables an analysis of the distribution of the original data through the

Fig. 3.1 Distributions of original data in geo-space (left) and their feature embeddings in latent space (right)

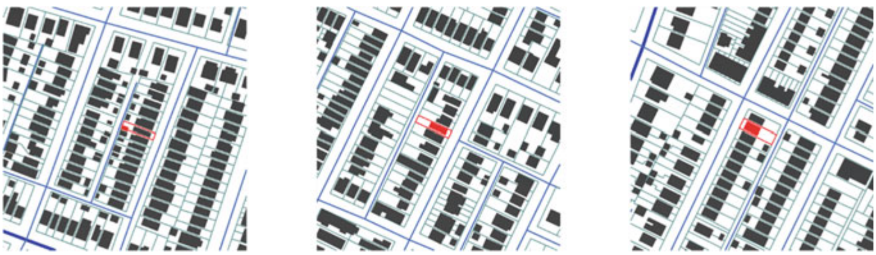

Fig. 3.2 Examples of data which are geospatially distant but closely positioned in latent space

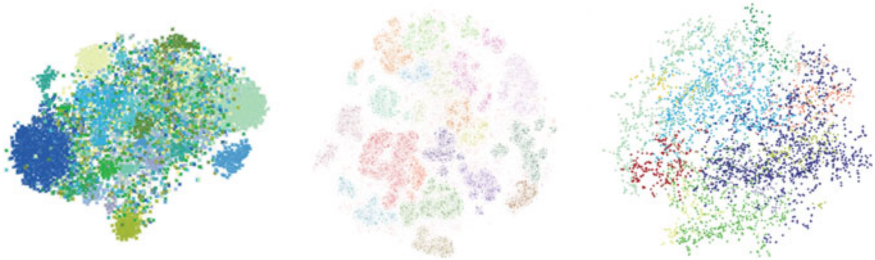

Fig. 3.3 Examples of visualizations of projected latent spaces with clustering

latent space. Although characteristics of the original data can be analyzed through projections, visually the latent space is still intractable—latent space resembles, topologically, a distributed point cloud. See Fig. 3.3.

Latent space represents feature data—that is, information which is extracted, filtered, and curated according to a specific intention for a given geo-physical space. Latent space has a shape which is determined by the manner in which the original data is transformed. For instance, for a given data space, feature embeddings constructed by a PCA yield an orthogonal latent space; that is, each feature point is represented by three coordinates (fx, fy, fz). For the same data space, the latent space constructed from t–SNE is clustered, which can likewise be represented by three abstracted coordinates (lx, ly, lz). Latent space is ductile because relationships between data points can change according to user intention.

Latent space can be made tractable by combining the results of the analysis with data from the geo-physical space. This coupling is important in that it enriches the information in the geo-physical space. By implementing this coupling, the potential of virtual or augmented reality expands our conventional understanding of geo-physical data and relationships.

3.2 Background

The potential for combining conventional understandings of geo-physical spaces with statistically processed high-dimensional data is being explored in various ways.

For instance, at Carnegie Mellon University, computational design researchers have been analyzing design principles of everyday objects such as cars and chairs, by constructing latent spaces of these objects through deep neural networks [1]. The neural networks abstract the data on the objects by encoding them as feature vectors in latent space. Design ideas can then be investigated by exploring and examining feature embeddings in this latent space. See Fig. 3.4.

Jaime de Miguel, a computer scientist, along with his collaborators, employed a deep neural network to present a method for form finding of structural typologies in architectural design [2]. They developed a connectivity map—connected lines on

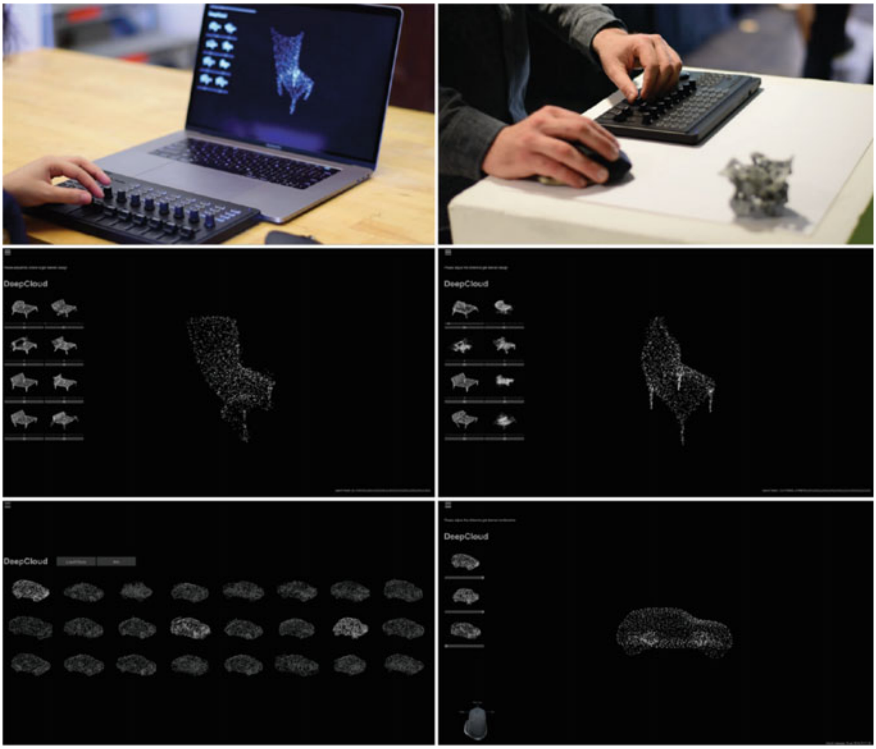

Fig. 3.4 Design instrument, deep cloud, based on point cloud data and deep neural networks. Deep cloud allows designers to analyze the morphological features of an object design and its variations. By synthesizing a feature embedding in latent space, deep cloud can suggest new form of an object. Images from deep cloud: the application of a data-driven, generative model in design, by Ardavan Bidgoli and Pedro Veloso (reproduced with permission)

a three-dimensional grid—to represent building forms. Figure 3.5 illustrates such a connectivity map. The network was trained to capture morphological features from the connectivity map data and distribute it in latent space. By interpolating the sampled data in latent space, the researchers were able creating new form and to identify positions representative of specific geometric instances of a building type.

In urban analysis, morphological feature embeddings in latent space are used to compare urban environmental classes [3]. A neural network is used to capture morphological features of city space from satellite images, classifying these into urban types. By distributing the morphological feature vectors to latent space, urban environmental structures of six different cities were comparatively analyzed, presenting how and what urban types exist.

Latent spaces have been used to analyze urban fabric and structure. For example, Rhee et al. have demonstrated the features of the patch-work style urban structure of Pittsburgh, Pennsylvania, using synthesized urban form data and latent space analysis [4]. A dataset of urban forms to represent morphological features of individual city

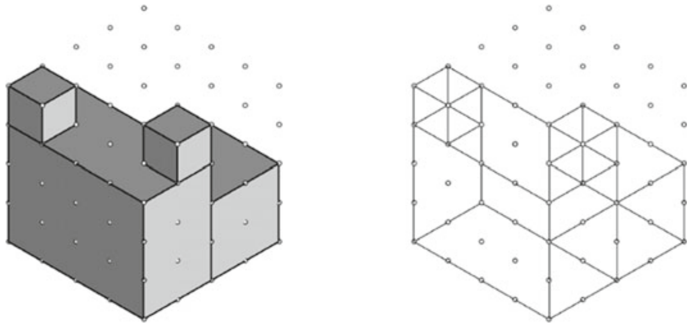

Fig. 3.5 Surface representation of a building form (left) and connectivity map representation (right)

spaces in Pittsburgh was created. Each data point was formatted as an image that included a building footprint with shapes of its immediate urban context, such as neighboring building footprints, terrain, and street networks. By clustering the feature embeddings of the dataset in latent space, it was possible to classify Pittsburgh urban types based on individual morphological characteristics of buildings and their urban contexts.

Mapping the information of urban type from data space back to geo-space, a morphological pattern emerges and redefines the city structures with subtle distinctions in the urban fabric. Patterns work as new inspirations for understanding city spaces. By observing the site where two different urban fabrics conflict, we can identify detailed configurational differences in city spaces. Furthermore, overlapping the pattern with historical maps of the city, developmental characteristics are uncovered, how, for instance, train infrastructures, affect the development of urban structures. Figure 3.6 shows an superposition from downtown Pittsburgh onto Shadyside, one of its suburbs, to illustrate an urban intervention/conflict.

Expanding from a two-dimensional (footprint) to a three-dimensional (volumetric) form dataset, Rhee and Veloso [5] designed an experiment for investigating

Fig. 3.6 Implanted downtown Pittsburgh urban fabric onto a typical low-rise residential area of Shadyside

high-rise building types across the world instead of a specific geolocation. For this, the pipeline used in the above research was modified to include a feature extraction step using deep learning from 3D building form data. 3D high-rise building forms from 33 cities over the world were collected. Much like computed tomography (CT) scans, each building is represented by stacked images of the building form's contoured boundaries. The entire dataset includes 4595 high-rise buildings in total. A deep neural network was trained to extract morphological features from the dataset. The high-rise building form types were identified by clustering features, tagging differently composited building elements such as podiums, towers, and roof shapes (Fig. 3.7).

As these examples suggest, latent space can be used to generate new architectural forms and to analyze extant urban forms. However, transitioning between latent space with abstracted feature embeddings and geo-space of three-dimensional forms remains unexplored. In this respect, in this paper, we describe an experiment integrating the two spaces in virtual reality thereby providing a basis for speculating on the potential of latent space intervening in digital space through architectural, urban, or cultural properties from any geo-physical world.

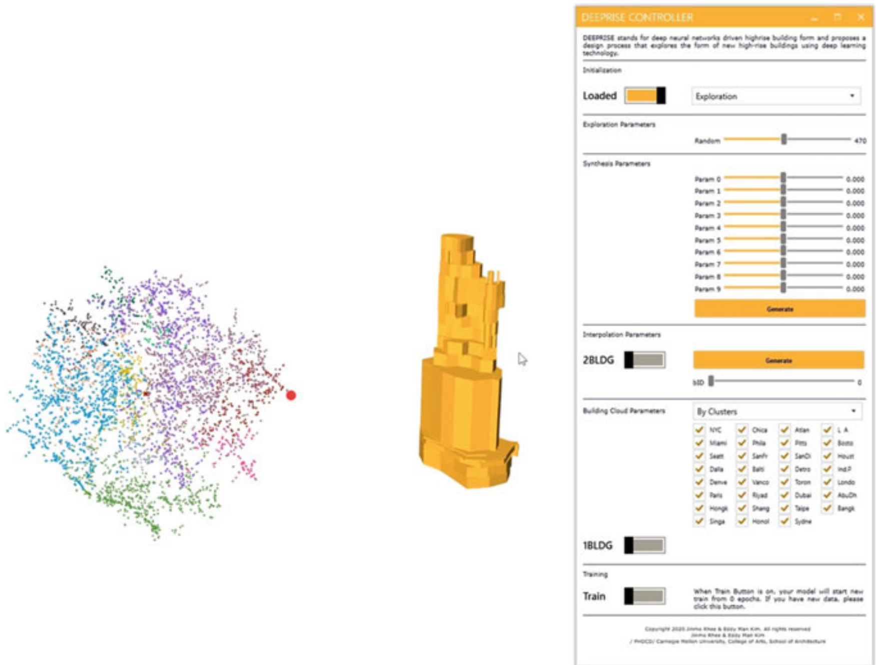

Fig. 3.7 Color schemed point cloud (left) represents clustered high-rise building forms, working as data interface for synthesizing a new high-rise building form (middle) with a controller (right)

3.3 Method

3.3.1 Combining Geo-space and Latent Space in Digital Space

The experiment has two steps. The first step is to construct the latent space of building form data; the second is to combine the latent space and geo-space in digital space. For this experiment, data on buildings in Montreal in Canada were collected to construct a form dataset. The building form data was provided by Montreal Open Data [6] which publishes diverse urban data produced for the city's internal operations for purposes of reuse in different ways. The raw data are given in seventy-three 3DM files [7] containing more than 70,000 building forms, each as a polygonal mesh. The data relate to six neighborhoods in Montreal: Côte-des-Neiges–Notre-Dame-de-Grâce, Outremont, Plateau Mont-Royal, Sud-Ouest, Verdun, and Ville-Marie.

Each 3DM file contains, on average, 980 building forms. A building form is defined as closed polygonal meshes of footprint, walls, and roofs. An algorithm was developed to extract individual building forms from the merged polygonal meshes. This algorithm loops through footprints, identifying corresponding walls and roofs, and generating new polygonal meshes. The algorithm also normalizes each polygonal mesh to an origin which are then saved as an OBJ file [8]. There is a total of 72,165 OBJ files.

OBJ files are converted to voxels, a volumetric representation of form. A voxel represents a value on a regular 3D grid, which is represented as a regular two-valued 3D-array of dimension r, the voxel resolution. A voxel occupied by the form has value 1, and 0 otherwise. The higher the resolution, the more detailed the representation of the building form. However, higher resolutions exponentially increase file size and processing time. See Table 3.1. At voxel resolution 32, a total of 3853 broken, open, or overlapping meshes were filtered out—that is, only about 5% of the entire data are discarded.

It was possible to improve on the voxel representation by using continuous representation—that is, using sign distance functions (SDF) instead of binary numbers in the voxel representation of form [9, 10] (see Fig. 3.8). This impacts on the efficiency of neural networks. According to Park et al., binary discretization tends to lose form detail and lowers prediction accuracy in a neural network. On the other hand, an SDF-voxel is a float number based on distance representing continuous space. SDF-voxels

Table 3.1 Trade-off between resolution, error rate, file size, and processing time

Resolution	Voxel file size (KB)	Error rate (%)	Dataset size (GB)	Processing time (h)
8	3	8.8	0.1	1
16	17	7.1	1.1	6
32	129	5.3	8.9	19
64	1025	4.8	70.4	42

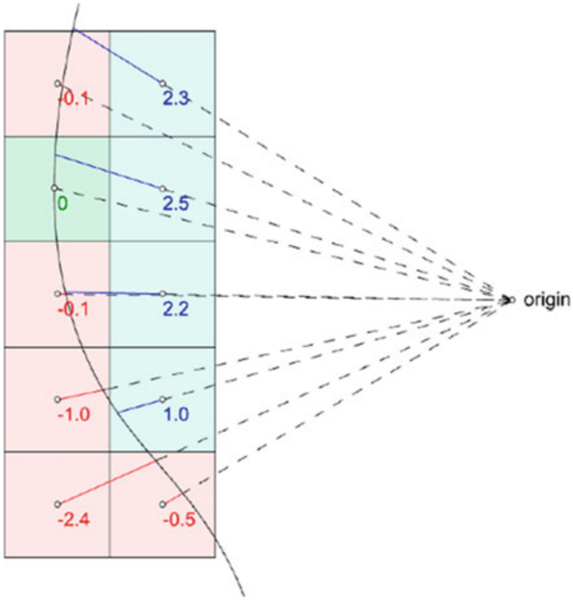

Fig. 3.8 Example of voxel representation using sign distance functions

increase prediction accuracy and compensate for the lack of detail from the limited number of voxel grids [9]. Each building is represented as an SDF-voxel file; 32,768 floats arranged in a 3D grid with resolution 32. The total number of SDF-voxel data is 68,312.

A deep neural network is trained to include an encoder that abstracts the 32-resolution voxel dataset into 256-size vectors by capturing morphological features. That is, a building is represented by 32,768 (= 323) floats, and the neural network abstracts these numbers into a 256-size vector, which is termed a feature embedding or latent vector. t-SNE reduces the dimensionality of the latent vectors into visualizable space, that is, two dimensions, establishing a latent space where the building forms can be topologically placed according to their features.

A point in latent space represents a building form and the point the point location represents its morphological characteristics. Distance between points represents the degree of morphological resemblance—the shorter the distance, the more similar the building forms. By focusing on the topological traits of latent space in which similarities are indicated by distance, we can use a clustering algorithm such as density-based spatial clustering of applications with noise (DBSCAN) [11] to classify building form types. We discovered a total of sixty types by finding core samples of high density from the data points. With further processing, the sixty types are compressed into twenty by merging smaller clusters with their nearest larger cluster. The urban pattern emerges by mapping clustering information onto map space and visually describing the distribution of each type (Fig. 3.9).

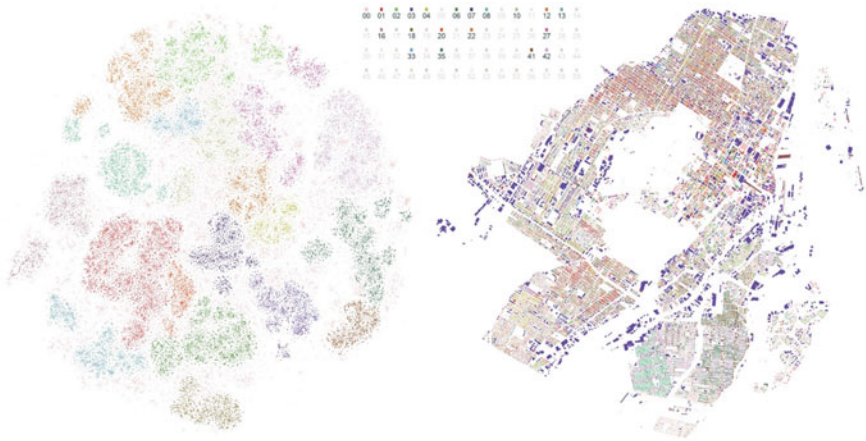

Fig. 3.9 Reduced visual latent space (left) and the urban patterns (right)

3.3.2 Combining Geo-space and Latent Space in Digital Space

Digital space was created in Unity [12]—a virtual reality software—for experimenting how virtual exploration of building forms distributed in the latent space can augment and enrich the spatial understanding of a city. The space is a combination of geo- and latent spaces. Building forms are imported into the modeling space and placed on the corresponding positions of both spaces. Scaling and re-centering the coordinates in latent spaces, a single digital space can have two sets of building forms one from each of geo- and latent space. That is, two different types of location data are imported into the digital space—coordinates of building forms in geo- and latent spaces (Fig. 3.10).

The digital space is compiled in a virtual reality software to provide users with a walk-through of building forms in geo-space, that is, in our experiment, a simulated virtual tour of Montreal. During a walk, users can select a building form in geo-space and move their perspective to latent space for the chosen building form. Users may then search in latent space for building forms similar to the one selected. The mapping of a building form in geo-space coordinates to latent space coordinates serves as a dictionary for finding similar building forms in the simulation of city space.

Likewise, users can select a building form in latent space and move their perspective to geo-space. Using color coded textures, buildings can be painted according to their type colors. From this color coding, users can understand how the urban space around a selected building form is organized; either as an assembled space where similar buildings are grouped, or as a collaged space where different buildings are clustered together. Users can observe how similar and different buildings compose the urban fabric in terms of their configuration and arrangements.

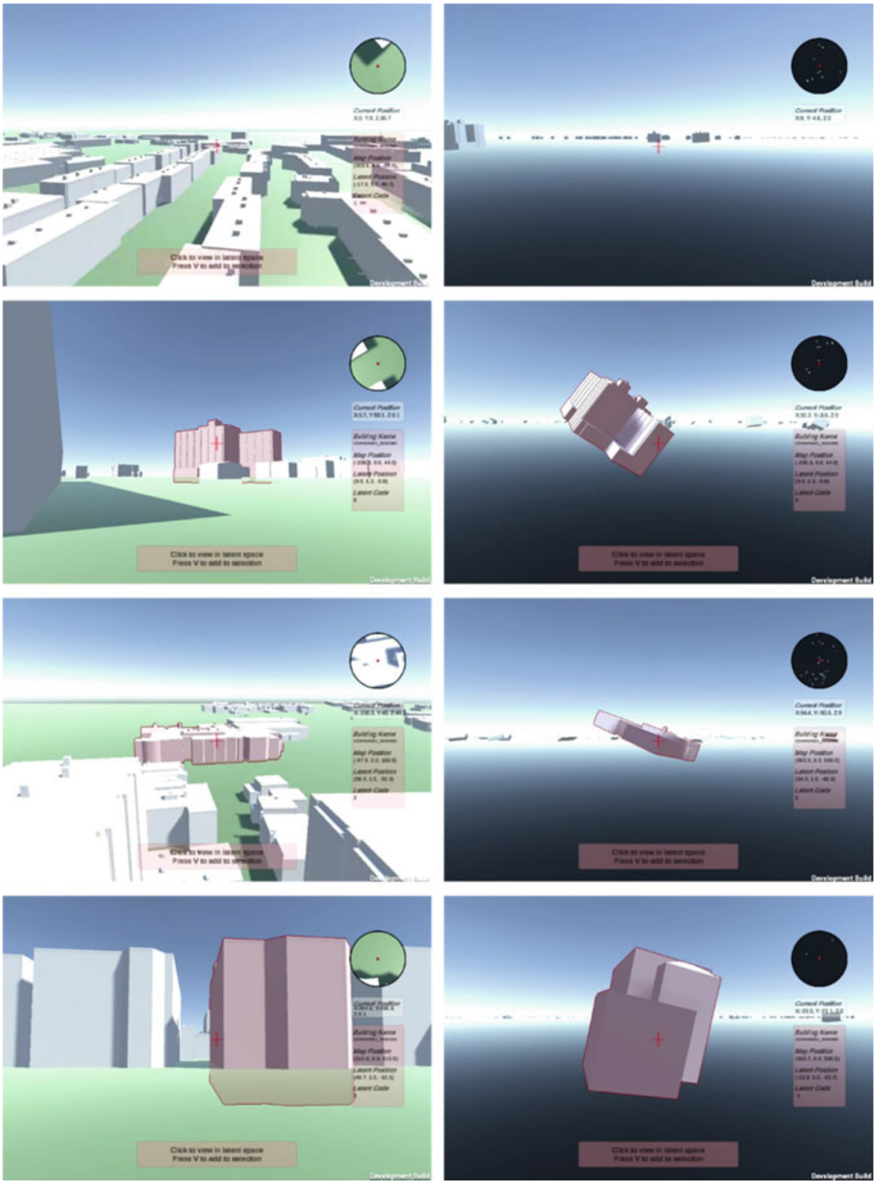

Fig. 3.10 Combined digital space in unity [Images from a walk in latent city shown tell, by Mitchell Foo (reproduced with permission)]

Transitions in the software enable seamless virtual walks and fly-through in the two spaces. Using the software, we can qualitatively and visually access building typo-morphological traits along with other variations and the fabric of urban space that they compose. Combining and referencing typo-morphological information in latent space to building forms in geo-space increases the complexity of modeling data in virtual reality. It is expected that such increased complexity expands the breadth of urban space analysis in virtual spaces beyond imitating, reproducing, and reconstructing urban models in digital space.

3.4 Conclusion

Latent space has variously been used for generation and analysis in architectural and urban studies. When latent space corresponds to geo-physical space, it was possible to create new architectural forms or expand on existing urban understandings. Extending this correspondence into a perspective experience, we implemented a transition between the geo- and latent space of building forms in a virtual urban space to explore the potential of latent space.

This implementation shows eye-level interaction between the two spaces, which is differentiated from the top-view patterns mapped with latent space information. In the interaction, we can seamlessly observe building types in both spaces, their other variations existing at short distances in latent space, and how buildings compose urban spaces in geo-space. Interweaving information in latent space with virtual or augmented reality demonstrates the potential for enriching analytical instruments for urban studies.

The experiment was conducted mainly on building form without including specific urban elements such as topography or street networks. Such detailed data of urban elements would reveal various and unexplored interactions of latent space with virtual urban space. We expect that in future studies in urban studies, incorporating and integrating digital twins, augmented reality, and remote sensing technologies with latent space would contribute greatly to the role of latent space accompanied by materiality and tangibility.

Acknowledgements We are indebted to Mitchell Foo in Computational Design Laboratory at the School of Architecture at Carnegie Mellon University for his implementation of virtual space integrating the geo- and latent space. Jinmo Rhee thanks Ardavan Bigdoli and Pedro Veloso for their many-faceted support as fellow graduate students and for insights into using deep neural networks.

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Chapter 4
Universal Design of Signage Through Virtual Human Simulation

Brandon Haworth, Colin Johnson, and Mathew Schwartz

Abstract Intuition behind sign placement and wayfinding features of architectural design can rarely encompass the needs of a wide range of building users. To help in automating sign placement, recent research has combined the use of agent-based simulation with optimization algorithms for maximizing visibility and wayfinding throughout a building model. As with many instances of machine learning applications, these too have unfortunately been dominated by an assumed young, healthy, and perfectly sighted virtual human. In this paper, we present an analysis of virtual human agents exploring a digital space using a combined vision and modified A* algorithm across multiple postures and visual impairments common amongst building occupants. We show how the inclusion of head angle and limited sights can change the results of what may be considered an optimal sign location.

Keywords Crowd simulation · Computer-aided design · Physiological modelling · Wayfinding

4.1 Introduction

While design often relies on intuition and experience, this can cause great difficulties when it comes to designing with respect to an experience the designer has and cannot have—such is often the case with many disabilities. While simulation and automated evaluation tools can improve efficiency in the design process, as well as provide opportunities for creative exploration and formfinding, one the greatest benefits to

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_4

designers is the ability to leverage scientific knowledge and quantitative data that they may not even realize has a place in their design.

Although past work has looked at the evaluation of the built environment for physical accessibility [1], and others have considered visibility for signage [2], there is still much work to be done for improving visual accessibility through improved analysis techniques of wayfinding and signage. In this work, we make use of a layered agent-based model with real-time *Parametric Saliency Map* (PSM) driving the gaze of synthetic vision that accounts for visibility at distance, visibility in relation to resolving text, and cognition of the environment. Using this framework, we demonstrate how varying the attention model on a sign through simulation of visual disabilities can cause agents to travel in the wrong direction (through missing the sign). We extend the work of Johnson and Haworth [3] to demonstrate how a localized agent-based approach to spatial analysis and the probability of understanding signage can be used to improve accessibility and incorporate Universal Design principles. Our work provides two important discussion points for the field—visibility-based analysis can be misleading as it excludes vital visual physiological properties and visual disabilities are greatly underrepresented in automated analysis literature.

4.2 Background

Our collaborative work intersects the computer graphics agent-based modelling field with the research area spatial analysis for the built environment. Importantly, we take this approach to emphasize the value of Universal Design—a set of guiding principles for ensuring environments are usable by all people, to the greatest extent possible [4]. Under this set of principles [5], the concept of `Perceptible Information` is directly related, while we will also show how the principle `Tolerance for Error` can be included in an agent-simulation approach.

4.2.1 Spatial Analysis

We leverage existing spatial analysis methods from the built-environment literature, which we use as an overall environmental affordance and evaluation map, with an agent-based local steering and behaviour tree decision-making system. This method of spatial analysis is commonly found in the literature, often represented in a graph of sparse network lines used for path planning for indoor (e.g. Refs. [6–8]) and outdoor (e.g. Refs. [9, 10]) environments. While other works further study how to define accessible locations of the environment, e.g. with surfaces [11, 12], grid points [13, 14] or both [15], our work assumes the accessible regions have been found.

Isovists [16] (polygons representing a field of view from a given location) are an early form of spatial evaluation, which is concurrently introduced alongside visibility graphs [17] (an undirected graph using line of sight between nodes in a geometry).

The use of visibility graphs for path planning was repurposed for evaluation of built environments by Turner et al. [18], and the evaluation metrics extrapolated from a visibility graph and from isovists are similar. Both methods have continued to be developed, including additional metrics (see Ref. [19] for metrics on isovist arrays). Traditionally, isovists are used for calculating min/max/mean extents (i.e. radial length), while general methods for visibility analysis have incorporated distance as a metric for spatial analysis (e.g. Refs. [20–23]). Visibility graphs have also been extended to include a more accurate 3D representation of views such as the 3D visual integration metric by Varoudis and Psarra [24] and the 3D visibility graph of [22], which includes POIs.

Static analysis methods such as isovists and visibility graphs have often been limited to course-grained metrics such as the general spatial characteristics. However, more direct influence of the visible connections throughout a space has been demonstrated, such as the impact of a window, which provides a view to a location without it being accessible [25]. At a more fine-grained approach, Fisher-Gewirtzman [20] uses a rendered depth map to produce distance metrics of certain objects from a viewpoint. Our work incorporates some aspects of many of these various techniques, providing a rendered view of an *agent* perspective, calculating a visibility graph for spatial analysis, and then using these two sources of information to help guide an agents decision–which in turn influences our wayfinding-based evaluation metric.

4.2.2 Signage and Wayfinding

Signage and wayfinding are inherently linked to how wells someone is able to comprehend navigational information. Although visibility graphs provide information on the direct lines of sight between locations, they lack a more individualistic understanding of comprehension in the space. In a need for standardization, some guidelines propose the size of signs based on certain zones. However, these often assume a *normal* vision, which is often seen as *20/20 vision* (the ability to resolve a target a 1 min arc that is corrected to normal vision). For example, given 20/20 vision, a "normal" vision would be understanding text at 20 ft., while 20/10 vision would be understanding text at 10 ft. while "normal" vision would be able to see that same text at 20 ft. While this is an important measure to understand what an average person can see at what distance, it is nearly the opposite of what Universal Design principles would consider a good metric. Recently, Schwartz et al. [26] incorporated attenuation into visibility graphs, which more accurately models the visual relationships between space. However, this method is still a generalization of spatial distances with line of sight and ignores cognitive complexities of understanding a space.

A more human-centric approach to visibility analysis is the use of *saliency* maps. This method provides a better approximation of how a person *understands* a view, not just what is in that view [27, 28]. We integrate the use of saliency maps with global wayfinding behaviour that uses visibility graphs to represent a general exploration.

4.2.3 *Agent Steering*

In contrast to the built-environment evaluation methods discussed previously, steering algorithms for agent-based simulation aim to provide local decision-making strategies that guide individuals through an environment. While not necessarily part of steering behaviour, the movements and resultant trajectories created by the steering algorithms can be used as metrics in evaluating the environment. Naturally, there are a wide variety of algorithms, although many share similar roots [29–31]. Some of the most studied and traditional methods of steering involves the use of forces [32–34] and velocities [35–38]. In these approaches, people are reduced to point-mass particles with limited physical attributes (e.g. mass, radius, desired speed). In aggregate, the people simulated in this method are repelled or attracted to other agents (i.e. forces) or use velocities of the particles to predict future movements in order to guarantee collision-free movements (i.e. velocities).

More recent is the introduction of human-centric models for agent-based steering algorithms. These include the use of vision [39] and space–time planning through biomechanics [40, 41]. There are numerous additional methods, such as probabilistic/time-variant behaviours [42] and multi-phase methods that combine various steering models for a single output [43]. Our work makes use of vision-based methods with probabilistic decisions based on such views from the agent's perspective and pre-computed information about the environment.

4.3 Methods

4.3.1 *Agent-Based Model*

The agent model is a system of layered models combined using a parametric behaviour tree. Previous work developed the underpinnings of this model [3]; here, we elucidate the important elements for describing our work. The system focuses on enabling cognitive exploration of environments through saliency-based signage understanding, signage catchment areas, cognitive building information mapping, modified heuristic path planning, and visibility graph-driven space exploration. The behaviour tree connects these disparate models by ordering their importance in a navigation scenario, such that the agent prioritizes goal reaching, signage vision, goal visibility, navigation information, and exploration. This ensures agents with trivial goals (e.g. they enter a building and immediately can see their goal) complete the task promptly as expected. All layers of this behaviour model rely on steering to move the agent at every time step in a scenario of obstacles and other agents. The steering model uses a physical force-based particle model that accumulates avoidance forces from nearby obstacles and agents as well as a goal-reaching forces and anticipatory collision avoidance forces [34]. When combined, these cause the

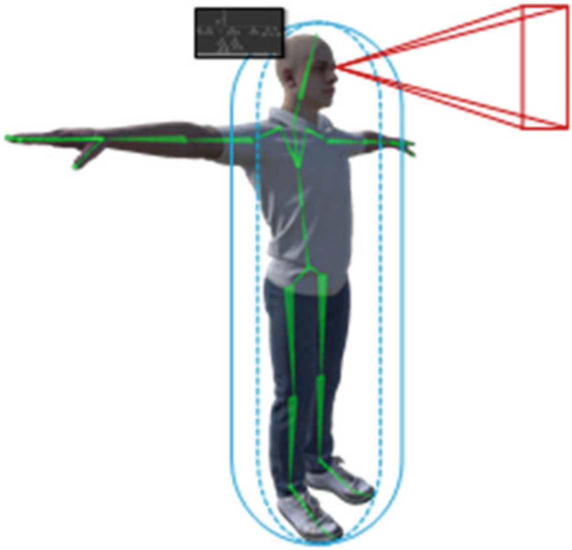

Fig. 4.1 Our agent model uses motion capture-driven skeletal animation with world target gaze control. A synthetic camera is attached to the head bone. The particle representation is a capsule for fast steering computation and robust manoeuvring over uneven terrain and steps. The agent is driven by an event-driven behaviour tree that integrates models for gaze control, signage saliency, distraction, and environment exploration [3]

particle to slide towards its current goal while avoiding static and dynamic obstacles in the scenario. In this work, we use a capsule-based particle taking advantage of the symmetric circular shape, like classic particle-based methods, as well as the low friction rounded bottom allowing the agent to slide over uneven terrain. When the agent can see its final goal or current intermediate goal (a goal along the long-term path plan), the agent simply steers towards it. Our skeletal animation-enabled particle-based agent with vision-based reasoning is pictured in Fig. 4.1.

4.3.2 Embedding Sign Information

The first step of the simulation configuration is labelling input geometry. Given a designer exploring the accessibility of signs in their space, they specify location and sizes of any sign they want to be considered by an agent (including semantic labels and parameters for each sign). For each sign, the parameters required are: path length (the length of path over which the signage information is attenuated), sign type, indicated direction, strength of information (how rapid the signage information attenuates), and goal location. There are various types of information that can be associated with a sign, corresponding to the “you are here” maps to locate one’s self in a space, and navigational signs containing an arrow with room numbers. These signs represent that required navigational cues for the agent, as each agent must have a specified start position and an end-goal location in the environment.

4.3.3 Environment Processing

To generate spatially relevant metrics through the accessible space, we generate an *obstacle grid* with a resolution of 1 m^2 that contains available cells for the agent to move within and use these spaces to store multiple metrics used by the agent as well as to store information about the simulation based on the agents decisions. One of these metrics is a visibility graph, generated at the start of the simulation through a ray cast between (all-to-all) cells from the height of an agents eye level. The cells are determined to be accessible if the square of a cell (and the agent height above the cell) is free from intersections with the environment (i.e. obstacle) geometry. As the environment is constant in our simulations, we avoid re-computation of the accessible space by sharing the stored cells across agents.

4.3.4 Agent Vision

Signage is "sensed" through a synthetic vision method that outputs a pseudo-saliency mapping called PSM [44, 45]. Each agent has its own synthetic perspective camera that is rooted on the head bone of the skeleton which renders the PSM via a fragment shader program on the GPU. The shader attenuates saliency for the peripheral vision such that objects outside the main focal region and nearer the extremes of the periphery have lower saliency. The method used in this paper greatly extends this pipeline to also encode the amount of information an object has as well as how that information cognitively maps to the environment [3]. In this way, we extend the capabilities such that attention is modelled, and gaze is changed to focus on signage, then signage is viewed until the information it contains is gained by the agent, without explicitly modelling the information itself. These steps are achieved as follows. We further process the output of the 2D saliency image from the shader to produce a clean binary image (first using a threshold to throw away spurious saliency information of extremely low values, the erosion and dilation to clean out noise, such as objects whose saliency values project to single pixels). We then use blob detection to identify the salient "blobs", or independent groups, of pixels associated with objects. We process these blobs and order the underlying objects in a sequence of importance based on their saliency and information. The shader output has multiple channels; on one channel, we store a unique object ID and on another the processed pseudo-saliency value. This allows us to store the objects seen in the world in a priority queue where the total saliency mass (the sum of saliency values in a blob) sorts the queue. We select the most salient object and project the screen coordinate of the relevant blob's centre of mass into the world to animate the upper spine and neck joints in the skeletal character control such that the agent looks towards objects of interest in world coordinates. In this way, the method combines the PSM model with 2D image processing to create a real-time saliency and information-based gaze controller.

4.3.5 Agent Cognition

Once vision is processed and the character is gazing at an object, the agent "gains" the information that the object imparts. In this way, we model this difference between different classes of signage and build a cognitive map of the information gained distributed over the environment. A user/designer can tune the amount of information, the type (global or directional), and its information fall-off. With these parameters, the heuristic value of the long-term path planner is modified by embedding the information directly in the navigation grid. Then any time long-term planning is needed it is directly affected by the newly gained information. If the information reveals the exact directions to the agent's actual goal (say with a global information map) and the information fall-off is low (or the goal is within the domain of the fall-off function), the agent's navigation defaults to the A* heuristic path planning method [46]. Otherwise, signage information, particularly from directional signage (like a sign pointing in the general direction of a washroom), will attenuate over the path towards the object of the signage. This process of gaining signage information and planning on top of attenuated information is visualized in Fig. 4.2.

If an agent follows this information, it may lead to more signage or perhaps an area with very low or no prior knowledge about the building. If an agent has never seen this area, the behaviour tree switches to exploration modelling. As the agent navigates the environment, grid cells are marked as "seen" if they are currently, or have been previously, visible. Only these cells are considered targets for exploration. Each exploration grid cell contains an *exploration heuristic* measuring the desirability of navigating to that location to gain additional information about the environment. This desirability metric favours open more organized areas which are likely to lead to maximizing information about the building layout. The exploration process and details are visualized in Fig. 4.3.

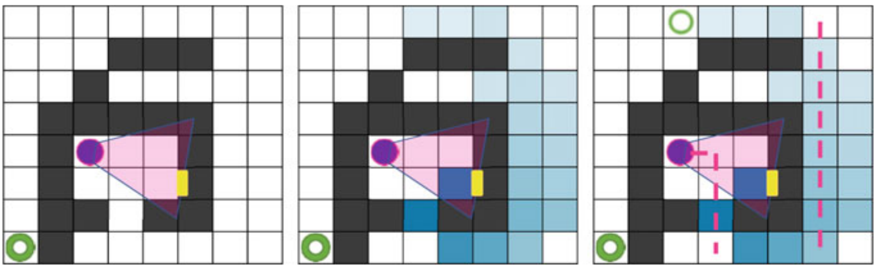

Fig. 4.2 Our agent model encodes attenuated signage information over a discretized environment representation [3]. Using this information value as a heuristic in a global path planner (A*), the agent can plan up the threshold at which information dissipates. Here, the dark grey cells are structures or obstacles, the green circle is a known world goal that the agent does not know the path to, and the agent (purple) sees (transparent frustum) a sign (yellow) with information (attenuated blue cell values). Once the agent has gained the signage information, the planner leads the agent up to the threshold between knowledge and uncertainty

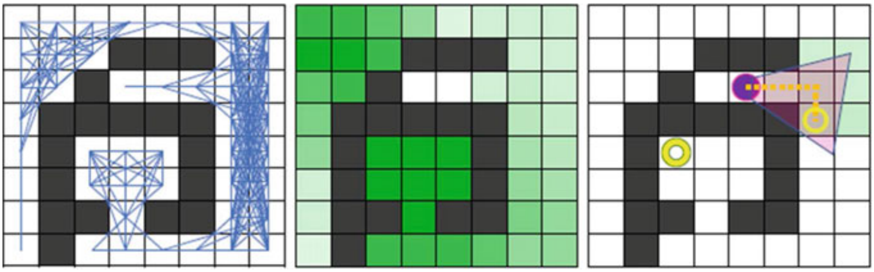

Fig. 4.3 Our agent model encodes visibility graph metrics information over a discretized environment representation [3]. The agent can overlap their isovist (egocentric visible space) with this information value as a heuristic in a global path planner (A*). Here, the dark grey cells are structures or obstacles, the blue lines represent the visibility graph, and the agent (purple) sees (transparent frustum) the value of the environment configuration (green cells) on which the planner returns an intermediate goal (blurry yellow). Once the agent sees this exploration value of the local environment configuration, the planner leads the agent towards higher values areas

4.3.6 Disability Modelling

By making use of a multi-layered vision-based steering and cognition model with skeletal animation, we can take advantage of the many affordances in bio-inspired systems that the layered models mimic to create representations of humans with a variety of disabilities. The skeletal animation system has two key impacts on our approach. First, the agent's perspective is a synthetic camera that is a child of the head bone in the skeletal rigging. This means that the camera's perspective is not only translated through the world but also undergoes the myriad of rotation and translation transformations of a natural viewpoint caused by natural gait. Our character is animated using publicly available motion capture data. Thus, we can also swap out this skeletal motion capture data for clinical data that captures disabilities that impact gait or mobility. This includes wheelchair users and, generally, users of mobility aids. We can also impose joint-level constraints on the skeletal animation system. This allows us to take existing motion capture data and modify it in real-time to model effects like spinal deformities or postural changes, for example, curving caused by ageing. The effect of this on view can be seen between the rightmost columns of Fig. 4.4 where the viewpoint of a character with a spinal postural constraint is rendered next to the normative viewpoint.

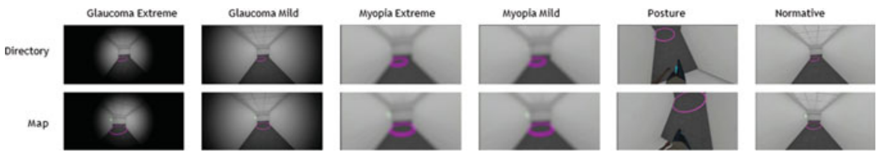

Fig. 4.4 Twelve user cases taken as screenshots at the start of the simulation

Importantly, because our approach is vision-based and makes use of the real-time programmable shader pipeline, we can model visual impairments directly on both the rendered image and the processed PSM. For this work, we focus on just two disabilities which directly impact the visual processing of signage in two different ways. First, we model glaucoma via vignette shading, a technique for the darkening of the outer region of the visual field. We apply a fragment-based vignette shader tuned to represent the characteristic visual field loss across a range of severities. Rendered levels of these severities can be seen at two extremes, Glaucoma Extreme and Glaucoma Mild, in the first and second columns of Fig. 4.4. Similarly, we can make use of a fragment-based shader for modelling myopia. Myopia has two components a blurring and a fall-off of useful visual information. We model this with exponential distance fall-off to black (zero saliency) in the PSM shader and a depth of field tuned to corresponding focal lengths and apertures in both the PSM and visual fragment shaders. Rendered levels of these severities can be seen at two extremes, Myopia Extreme and Myopia Mild, in the third and fourth columns of Fig. 4.4.

4.4 Evaluation and Results

We split our evaluation into two experiments. First, a preliminary experiment exploring the interaction between signage designs and various types of disability modelling within our simulation framework. Second, a look at the impact of modelling across the spectrum of two our disability conditions. These details of the experiments are elucidated below.

4.4.1 Environment Configuration

A simple interior mass model for basic layouts was created to mimic the sixth floor of NJITs architecture building. The starting point of the agent was defined at the staircase doorway leading onto the floor. Using this configuration, two different signs were implemented, one larger than the other.

As the metric for weighting direction when an agent is in exploration mode is based on the visibility graph metrics related to the openness of an environment, we selected this particular floor as there is a large open space towards the right side which the agent will search through when signage is missed.

4.4.2 Preliminary Experiment

To provide a variety of cases and human variation, we perform simulations using multiple visual and physical impairments. Two of the most common visual impairments are Myopia and Glaucoma, modelled as described in Sect. 3.6. We also use a reduced posture which simulates a person using a walking crutch in which their head is largely facing towards their feet. Example agent views are shown in Fig. 4.4.

We run simulations on a virtual human with (1) no impairments, (2) myopia, (3) glaucoma, and (4) reduced posture. For the visual impairments, we sample a high and low value of influence and for each experiment provide a map and directory sign as two environmental conditions. The map is a large sign with highly specific information and significant salient features like pictures, bright colouring, and stand out text. The directory is a small sign with little saliency and mostly textual features.

The saliency map is shown for two sample conditions (myopia and normative), with the agent view it was derived from in Fig. 4.5, respectively. This illustrates the key functioning of the saliency map, as the parameters for saliency of the map object are estimated from known saliency algorithms [45]. All other spaces in the environment have zero values in the rendered frame. However, as can be seen in the myopia mild condition, the boundary of these saliency values is extended by the blur caused by the aperture settings in the shader modelling myopia. The value of individual pixels is also significantly lower (grey as opposed to white) than in the normative condition and effect of the distance attenuated fall-off to black (zero values).

The two conditions for wayfinding in our sample scenario are (1) the agent correctly identifies and notices the signage, leading to the correct path (turning left) and (2) the agent does not notice the signage and travels to the most visually open area (turning right). These metrics and examples of the effect of agent decisions are detailed in Fig. 4.6.

In our case study, we were able to demonstrate the use of a more salient map was able to help localize the agent in all cases, while the less salient directory was missed by all agents except for the normative one (Table 4.1).

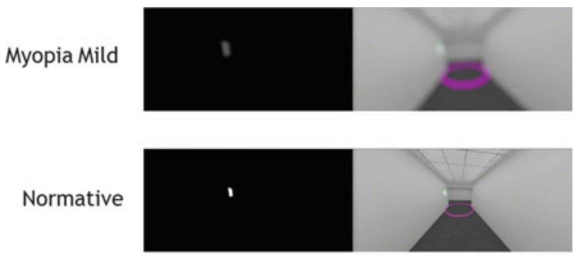

Fig. 4.5 Visual rendering (right column) and saliency maps (left column) of two example conditions

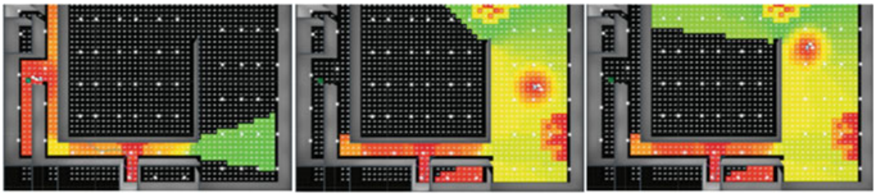

Fig. 4.6 Affordance map based on visibility graph of the environment under different conditions. In all images, the agent originally begins in the centre bottom of the environment in a hallway where the signage is displayed on the left wall (as seen in Fig. 4.5). In the left image, the agent has seen the sign and navigated to the left towards the thinner hallways there. Note the large swatch of high (green values) for the visibility graph metrics to the right. In the right two images, the agent has not seen the sign and instead followed the high exploration values. The right-most image shows the same exploration situation but with a later agent position. The agent is surrounded by an attenuated field of low exploration values when exploring to avoid local extrema in the exploration values of spaces in the immediate vicinity

Table 4.1 Conditions in which the agent noticed the sign or not

	Glaucoma high	Glaucoma mild	Myopia high	Myopia mild	Posture	Normative
Directory	x	x	x	x	x	○
Map	○	○	○	○	○	○

A missed sign is denoted by an x

4.4.3 Condition Intensity Experiment

In this experiment, we explore the spectrum of two of our conditions myopia and glaucoma. We continue the use of the environment in Sect. 4.1, however, we use one signage type, the large map. This sign is generally only missed when conditions are severe, as the sign is large and has numerous salient features. In this experiment, we show that even under these conditions there exists a spectrum over which users experience the environment differently.

In both conditions, glaucoma and myopia, we find the range of parameter values around which the agent always sees the sign and always misses the sign. For glaucoma, this means setting the vignette fall-off intensity such that the left side vision (where the sign is in the visual field) is not disrupted enough to miss the sign during the gait cycles of the few strides made before exiting to the hallways. The interaction of this radial field attenuation and the movement of the character is essential; as the intensity increases, there is not a hard threshold at which the agent switches from seeing to not seeing the sign. Similarly, the myopia condition is modelled over several intensity steps where the distance-based fall-off is increased. The effect is that there is a passing distance at which the left side vision (where the sign is in the visual field) is not far enough to miss the sign during the gait cycles of the few strides

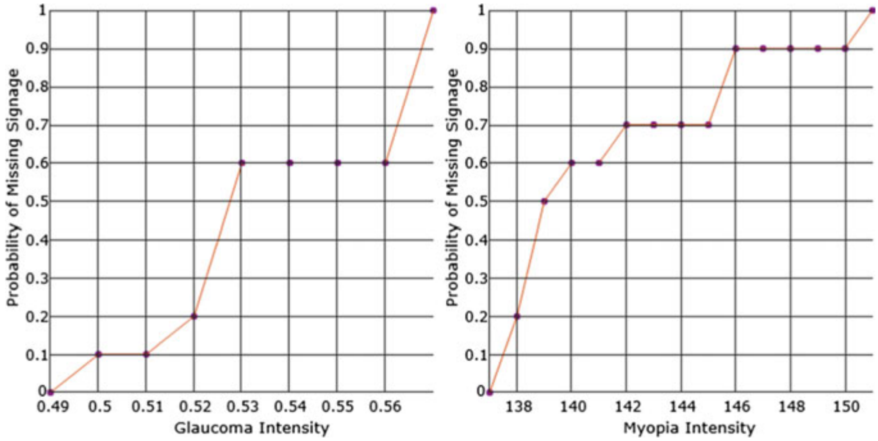

Fig. 4.7 Dense sampling of simulations of two conditions, glaucoma and myopia, across a spectrum of severities. On the left, we show that the probability of missing a sign in our environment increases with the intensity of the glaucoma condition. Similarly, on the right, we show that the probability of missing a sign increases with the intensity of the myopia condition. However, the shape and nature of this increasing probability are dependent on the condition

made before exiting to the hallways. Note how the subtle coronal sway in a gait cycle can bring the agent momentarily closer to the sign on the left.

For both conditions, we densely sample the intensity values (parameter values of the fragment shaders) several times in the interval of intensities between when the agent always sees the sign and when the agent always misses the sign. For each sample, we run ten simulations to estimate the probability the agent will miss the sign. The results of this experiment are shown in Fig. 4.7.

4.5 Discussion

Our results demonstrate the need for inclusive parameters when using agent-based modelling. Through slight variations in the virtual humans ability, signage was missed due to either distance or saliency of the environment, leading the agent to regions that space syntax considers more *integrated*. Notably, our studies show a nonlinear relationship between fall-offs of vision and the impact it has on the probability of missing a sign. Moreover, these nonlinear trends are different amongst the simulated vision deficiencies.

While our results are in a sample environment, the aim is not to evaluate this particular layout but rather illustrate how agent-based models (even advanced ones such as this) can lead a designer to miss vital considerations relating to human variation. In future work, we aim to extend this model to generative placement options parameterized on a wide variety of human abilities. We believe such an approach can further the design field to a universal approach in which people of greater physical variation can be included in the pre-built evaluation stages.

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Chapter 5
A Study on UX Design Guidelines and Visitor Profiling for Virtual Museum

Joosun Yum, Garyoung Kim, and Ji-Hyun Lee

Abstract Following the changes in the museum environment in Korea and abroad owing to COVID-19, this study examines how visitors behave and react in a virtual museum that has appeared frequently in recent years. In this study, we aim to profile categorized museum visitors, present usability evaluation tools and UX design guidelines for improving virtual museums. To achieve this, it was first necessary to classify the viewers of the virtual museum into several types. Next, the usability, affection, and presence of the virtual exhibition space of the participants who visited the 360-degree VR and 3D VR museums were measured. Finally, we attempted to derive needs, pain points, and insights through affinity diagram. We suggest a virtual museum UX design guideline by deriving what is lacking for each virtual museum and suggesting what needs to be supplemented in the future.

Keywords Virtual museum · Visitor studies · UX design guideline · K-means clustering · 3D VR museum · 360-degree VR museum

5.1 Introduction

To prevent the spread of infectious diseases caused by COVID-19 and owing to social distancing, many museums and art galleries in Korea have been closed, resulting in a significant decrease in visitors and sales. As a result, interest in realistic content technology has grown; in particular, the demand for viewing online collections and virtual exhibitions has increased. As the need for digitization of artworks and exhibition spaces has emerged, many art galleries and museums are actively introducing virtual reality (VR) exhibition platforms and services.

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_5

Following the changes in the museum environment in Korea and abroad owing to COVID-19, we tried to determine how the audience behaves and reacts in a virtual museum that has appeared frequently in recent years. To achieve this, it was first necessary to classify the visitors of the virtual museum into several types. Next, the usability, affection, and presence of the virtual exhibition space of the participants who visited the 360-degree VR and 3D VR museums were measured. Finally, we attempted to derive needs, pain points, and insights through affinity diagram.

First, based on literature review, evaluation items (System Usability Scale, Questionnaire for User Interface Satisfaction, Presence Questionnaire) for important indicators of web-based virtual exhibition measurement were created. Museum curators and UX experts then verified the completed evaluation items. Second, to evaluate the UX of the existing web-based 360-degree VR and 3D VR museums, the experiment with an eye-tracker and think-aloud protocol was conducted with the 30 subjects after filling out the pre-questionnaire, including their demographic data and virtual and real museum experiences. Third, subjects were evaluated and interviewed for each VR museum they saw with the evaluation items previously constructed. Fourth, after the experiment, we applied the K-means clustering technique to classify visitor groups based on pre-questionnaire and behavior data in two different environments. Besides, SUS, QUIS, and PQ were analyzed through SPSS to see if there is a difference in the usability, affection, and presence of 360-degree VR and 3D VR. Finally, we established a virtual museum UX design guideline by deriving what is lacking for each virtual museum through affinity diagram and suggesting what needs to be supplemented in the future.

5.2 Related Works

5.2.1 360-Degree VR and 3D VR in Museum

Many museums and art galleries have built 360-degree VR or 3D VR museums, allowing people to visit virtual exhibitions without the time and space constraints. 360-degree VR is a relatively higher-definition image created by picking up, filming, and connecting only the necessary parts, and it has various customizable features. In 3D VR, the entire space can be moved and viewed as a game through a 3D stereoscopic scan, which allows the creation and measurement of 3D floor plans [1]. In terms of mobility, 3D VR is an immersive world in which people can walk around; that is, they have a 360-degree view from the camera's perspective but are limited to the cinematographer's camera movements. In terms of the story, the 3D VR director does not control the viewer's physical location in the built environment but does control the camera's physical location and, as such, must capture the attention of and motivate the user to travel in the direction of the events of the story [2].

5.2.2 Cluster Analysis in Museum Study

Museum studies often employ cluster analysis to enhance user experience. These studies, as part of visitor studies, mainly focus on classifying museum visitors' traits by categorizing, and profiling their backgrounds or experiences [3, 4]. Apart from studies profiling visitors, cluster analysis has been applied in numerous other contexts in the museum domain. For instance, Zafiropoulous et al. investigated how museums manage Facebook and Twitter using principal component analysis and cluster analysis, and discovered that top museum groups show better use of the two social media [5].

Other recent studies have dealt beyond real museums. Trunfio et al. indicated that visitor studies in augmented reality (AR) and VR environments remain uninvestigated [6]. With this awareness, they explored museum services that include AR and VR. However, in their study, the cluster analysis relied on visitors' behavioral traits in general exhibition sites, rather than reflecting AR or VR environment-specific factors. In this regard, Errichiello et al. conducted an encouraging cluster analysis that profiled museum visitors based on their attitudes toward using wearable VR applications [7]. Following this strain of research, we attempt to conduct cluster analysis but focus on a more accessible web-based VR museum environment, which does not require wearable tools.

5.2.3 User Experience Evaluation in VR Museum Research

Researchers mainly measured usability, presence, immersion, and cybersickness evaluation measures to measure user experience in a virtual museum and tourism area. Takeuchi et al. [8] compared a developed VR museum and a screen-based VR museum to maximize the virtual museum user experience using Oculus Rift and Unity Game Engine. The four aspects of "freedom of operation," "immersion," "comfort of play," and "picture quality" were analyzed to clarify which type of virtual museum would be appropriate for the user's needs. Only two people participated in the experiment, including the researcher. Therefore, conducting an evaluation experiment with many people is essential to determine the type of VR environment that is suitable for users. Bessa et al. [9] measured the sense of presence and cybersickness by comparing 63 participants by gender; the participants were made to experience a VR application composed of 360 and 3D-360 video using an HMD. The authors utilized the Igroup Presence Questionnaire and Simulator Sickness Questionnaire and found no statistical differences between the 2D and 3D videos. Fang and Lin [10] compared the usability differences of VR travel softwares (Google Street View, Veer VR, and Sites in VR) for mobile devices using the Questionnaires for User Interaction Satisfaction (QUIS), the System Usability Scale (SUS), and semi-structured interviews. To create and evaluate virtual museums, Cecotti et al. [11] proposed a VR museum developed with Unity and tested it with the Valve Index to provide an immersive learning environment for students and instructors in art history. Twenty-five users measured the workload and system usability using the NASA-TLX and system usability evaluation. Pifel et al. [12] studied a VR application that allows visitors to curate their virtual museums. The authors focused on the usability of the application, task load, and cybersickness. Therefore, through SUS, NASA-RTLX, and cybersickness measurement, the design of experiential VR applications for tourism must consider user-centered development.

5.3 Experiment

5.3.1 Selection of Virtual Museums

We chose a web-based 3D and 360-degree VR museum, the two most frequently provided formats by national and private museums. To unify the characteristics of the artworks provided in the virtual exhibition space, two art museums with a similar number of artworks were selected, with most of the artworks on display being paintings. A special exhibition, "The Way of Drawing Scenery" of the Museum of Modern and Contemporary Art using Matterport software, was selected as the 3D VR museum [13]. For a 360-degree VR museum, a special exhibition, "Skin of Time" of Savina Art Museum, which uses a 360-degree camera, was chosen [14]. The 360-degree VR museum has a low degree of freedom because the places where users can move are fixed, while the 3D VR museum has a high degree of freedom because the places where users can move are not limited. In addition, the ways to view artworks and wall texts, move space, and provide videos and maps are different (Fig. 5.1).

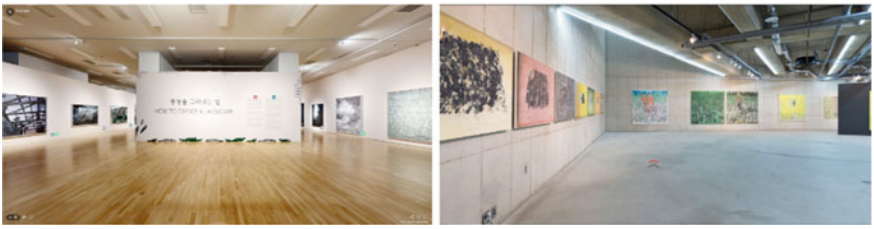

Fig. 5.1 3D VR and 360-degree VR (*Source* MMCA, Savina Museum)

5.3.2 Experiment Design

This study explored how 3D VR and 360-degree VR affects the virtual museum viewing experience of 30 participants. To build visitor-centered UX design guidelines of the virtual museum, we must categorize the visitor groups beforehand as an additional step. Therefore, we selected 3D VR experience cases exclusively and conducted K-means clustering based on visitors' interest and importance in textual information. Next, we analyzed the traits of each group, considering the tendency to utilize informative and navigating tools in VR museums. For the eye-tracking analysis, we chose the "Live-Observation and Video" method, in which the researcher can watch the subjects' gaze in combination with the screen that the test user looks at. When participants performed a think-aloud protocol while using a web-based VR museum, we can track their eyes in real time against their speech.

5.3.3 Measures

We made three hypotheses regarding the differences in *usability, affection*, and *presence* between 360-degree VR and 3D VR museums. First, we measured participants' usability using the System Usability Scale [15]. The SUS is the most commonly used questionnaire scale to evaluate the ease of use of a system and has been widely used in fast tests of system interfaces, desktop programs, and website interfaces. SUS is a standardized index consisting of ten items measuring different usability aspects, using positive and negative formulations, resulting in an index out of 100. We measured the participants' affection with the Qusetionnaire for User Interface Satisfaction, which measures a computer user's subjective satisfaction with the human–computer interface [16]. QUIS contains a measure of overall system satisfaction and specific interface factors such as screen visibility, terminology and system information, learning factors, and system capabilities. Finally, we measured the participants' presence using a Presence Questionnaire (PQ) [17]. Initially, 32 items were used, and we decided to use 25 suitable items for the web-based VR museum.

5.3.4 Participants

Thirty participants (16 males, 14 females) aged 22–33 years ($M = 27.77$, SD = 2.41) from the Korea Advanced Institute of Science and Technology (KAIST) were recruited. To subdivide the types of visitors, participants' demographic data (age, gender, major, and occupation) and real and virtual museum experiences were investigated in advance. In addition, the 30 subjects were compensated with 20,000 won for participating in approximately 1.5 h of study. Institutional review board approval was obtained before the experiment. However, we filtered eight participants at the

Table 5.1 Experiment procedure

Timeline		Events
Pre-session	10 min	Introduction and pre-questionnaire
Main-session	5 min	Eye-tracking calibration
	20 min	Using 3D VR with think-aloud protocol
	10 min	Survey (SUS, QUIS, PQ)
	5 min	Eye-tracking calibration
	20 min	Using 360-degree VR with think-aloud protocol
	10 min	Survey (SUS, QUIS, PQ)
Post-session	10 min	Semi-structured interview
Total	90 min	

clustering analysis stage because of unclear survey results. Therefore, 22 participants were included only for cluster analysis.

5.3.5 Procedures

Our experiment consisted of a pre-session, a main session, and a post-session. We briefly explained the overall experimental process in the pre-session to the participants and asked them to fill out the pre-questionnaire, including their demographic data and virtual and real museum experiences. Next, in the main session, eye-tracking calibration was conducted before visiting each virtual museum for accurate eye-tracking using GazePoint. Eye-tracking was then conducted while watching the 3D and 360-degree VR exhibitions. Finally, a think-aloud protocol was used to discuss the emotions and reactions in the VR environment and the operation method. After viewing each VR museum, the SUS, QUIS, and PQ questionnaires are administered. Finally, in the post-session, an interview was conducted regarding the pros and cons of each virtual exhibition space, differences in operation methods, and points to be improved in the future. All questions were provided in both Korean and English and were modified to fit the context of the web-based virtual museum based on verification by experts (Professor of the Department of Living Design at Yonsei University, Curators of the National Museum of Modern and Contemporary Art, National Museum of Korea) (Table 5.1).

5.3.6 Data Collection for Clustering

Cluster analysis is based on the following two hypotheses: (1) Each participant can be classified according to his or her opinion on the textual information, and (2) each cluster can represent a different tendency to use informative and navigating tools and attitudes toward VR museum environments. Therefore, we intended to yield at least two clustering groups according to the participants' survey responses, which helped evaluate their opinions about textual information. The following five-point rating scale statements were used for the first step: In real and virtual museums, "How important is textual information in your opinion?" and "What is your level of interest in textual information?" Meanwhile, in the profiling stage, we decided to perform qualitative analysis using descriptive response data to compensate for the small sample size and perform qualitative analysis subordinately using data such as using additional tools in natural museum environments and navigating informative tools in the VR museum.

5.4 Results

5.4.1 Cluster Analysis

In this study, we used the K-means clustering method. To compensate for the uncertainty inherent in the methodology, we applied the elbow method and silhouette score to calculate the best k. According to these results, the best k value in our study was 3. Figure 5.2. visualizes the three cluster groups using principal component analysis in Python.

As the data were less than 30, additional normality tests were needed. According to the results of the descriptive statistics, our skewness and kurtosis values do not exceed the level of condition (thresholds of 2.0 for skewness, 7.0, kurtosis, [18]), which means that our data are sufficient to establish normality (Table 5.2).

The cluster of *physical museum lover* (cluster 0, $N = 5$) represents high textual importance and interest in real museums, whereas low textual importance and interest in virtual museums. The cluster of *information seeker* (cluster 1, $N = 12$) shows an overall high score in both real and virtual situations. The cluster of *indifference*

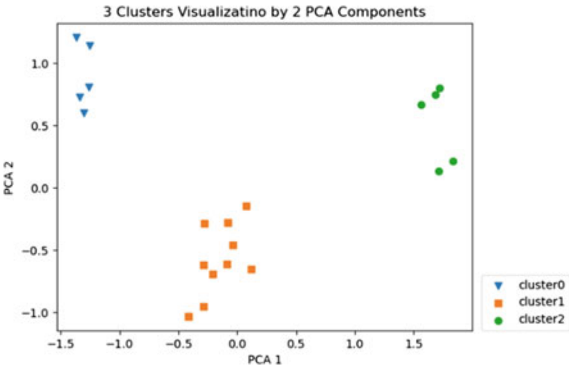

Fig. 5.2 Visualization of three clusters by two principal component analysis components

Table 5.2 Normality tests using skewness and kurtosis

		N statistic	Mean statistic	Std. deviation statistic	Skewness		Kurtosis	
					Statistic	Std. error	Statistic	Std. error
Real museum	Textual importance	22	0.54545454545	0.31782086308	− 0.611	0.491	− 0.431	0.953
	Textual interest	22	0.63636363636	0.33976479429	− 0.694	0.491	− 0.438	0.953
Virtual museum	Textual importance	22	0.53030303030	0.39385613506	− 0.239	0.491	− 1.443	0.953
	Textual interest	22	0.6250	0.34287	− 0.305	0.491	− 1.503	0.953

(cluster 2, $N = 5$), as opposed to the result of *information seeker*, had low scores in both real and virtual circumstances. Regarding demographic characteristics, 80% of the *physical museum lover* cluster was female and 67% of the *information seeker* cluster was male (Table 5.3).

Here, we used responses to two questions: "How many days do you visit a museum per month?" and "How many exhibits do you visit on a museum day?" For convenience, we will write the former questions as "museum visits," and the latter as "exhibit visits."

In the real world, visitors from the *physical museum lover* cluster visit museums for 1.8 days (sd = 0.8367) per month, and their "museum visits" are also relatively high. The average number of "museum visits" for the *indifference* cluster is less than one; however, we assume some binge watchers according to the results of "exhibit visits" (Table 5.4).

According to Table 5.5, most of the participants in the *physical museum lover* and *information seeker* clusters use caption information. Leaflet, which is widely used regardless of clusters, is the second preferred supplementary tool by the *physical museum lover* and the *information seeker* clusters, whereas the *indifference* cluster shows a tendency to seldom use supplementary tools that do not exist inside the exhibition hall or ask for extra efforts such as program reservation or finding reading material outside the exhibit site.

Table 5.3 Demographic (gender) characteristics of cluster

	Cluster 0		Cluster 1		Cluster 2	
	Female	Male	Female	Male	Female	Male
Frequency	4	1	4	8	3	2
Percent	80.0	20.0	33.3	66.7	60.0	40.0
Cumulative percent	80.0	100.0	33.3	100.0	60.0	100.0

Table 5.4 Frequency of museum visit in real

		Minimum	Maximum	Mean	Std. deviation
Cluster 0	How many days do you visit museum (per month)?	0.2	3.0	1.300	1.1916
	How many exhibits do you visit on a museum day?	1.0	3.0	1.800	0.8367
Cluster 1	How many days do you visit museum (per month)?	0.0	1.0	0.483	0.4130
	How many exhibits do you visit on a museum day?	0.0	3.0	1.083	0.9962
Cluster 2	How many days do you visit museum (per month)?	0.0	1.0	0.460	0.4980
	How many exhibits do you visit on a museum day?	1.0	4.0	2.400	1.2942

Table 5.5 Frequency analysis: usage of supplementary tools in the real museum

	Cluster 0		Cluster 1		Cluster 2	
	Mean	Std. deviation	Mean	Std. deviation	Mean	Std. deviation
Wall text	0.800	0.4472	0.500	0.5222	0.400	0.5477
Caption	1.000	0.0000	0.917	0.2887	0.600	0.5477
Leaflet	0.800	0.4472	0.750	0.4523	0.800	0.4472
Floor plan	0.000	0.0000	0.500	0.5222	0.200	0.4472
Book	0.400	0.5477	0.583	0.5149	0.200	0.4472
Audio guide	0.400	0.5477	0.417	0.5149	0.000	0.0000
Tour program	0.000	0.0000	0.250	0.4523	0.000	0.0000
Mobile search	0.600	0.5477	0.333	0.4924	0.600	0.5477

The virtual museum environment also serves functions similar to those listed in Table 5.5. For instance, navigating tools such as virtual tour, 3D miniature, and floor plan provide almost the same functional support to tour program and floor plan. In a virtual environment, more than half of each cluster uses floor plan and 3D miniature functions. This is interesting because, in the real museum, only the *information seeker* cluster used the floor plan at a similar level (Table 5.6). The following response illuminates this result: “Because the quality of visual experience (in the virtual environment) is lower than in the real museum” (Participant no. 2), and “fatigue exists in the virtual world. I think it is always difficult to concentrate under such circumstances” (Participant no. 15).

The number of captions used and the number of descriptions used show that the *information seeker* cluster’s own evaluations relating to textual interest and importance were trustworthy (Table 5.7). However, their low number of wall text use results is unusual compared with their own results, as well as to other clusters. The *physical museum lover* cluster’s low level of caption and description uses results can be explained through the following responses: “I feel I am hard put to read text in the virtual” (Participant no. 8) and “Because of dizziness, I pay more attention to other experiences than the textual one” (Participant no. 16).

Table 5.6 Frequency analysis: usage of navigating functions in the virtual museum

	Cluster 0		Cluster 1		Cluster 2	
	Mean	Std. deviation	Mean	Std. deviation	Mean	Std. deviation
Search	0.40	0.548	0.25	0.452	0.40	0.548
Virtual tour	0.20	0.447	0.42	0.515	0.20	0.447
Highlight reel	0.80	0.447	0.33	0.492	0.40	0.548
3D miniature	0.80	0.447	0.83	0.389	0.60	0.548
Floor plan	0.60	0.548	0.50	0.522	0.60	0.548

Table 5.7 Usage of informative functions in the virtual museum

		Minimum	Maximum	Mean	Std. deviation
Cluster 0	Number of wall text buttons used	0.0	1.0	0.700	0.4472
	Number of caption buttons used	0.05882352	0.56862745	0.27058823	0.20158922
	Number of description buttons used	0.16666667	0.83333333	0.35555556	0.28218722
	Number of film buttons used	0.0	0.75	0.3000	0.27386
	Number of supplement reading buttons used	0.0	1.0	0.700	0.4472
Cluster 1	Number of wall text buttons used	0.0	0.5	0.375	0.2261
	Number of caption buttons used	0.21568627	1.0196078	0.61437908	0.31509653
	Number of description buttons used	0.16666667	1.0555556	0.65277778	0.34664093
	Number of film buttons used	0.0	1.00	0.4792	0.36084
	Number of supplement reading buttons used	0.0	1.0	0.667	0.3892
Cluster 2	Number of wall text buttons used	0.0	2.0	0.700	0.8367
	Number of caption buttons used	0.0	0.96078431	0.39607843	0.37701146
	Number of description buttons used	0.0	0.44444444	0.22222222	0.16197089
	Number of film buttons used	0.0	1.50	0.4000	0.62750
	Number of supplement reading buttons used	0.0	1.0	0.300	0.4472

5.4.2 Survey Analysis

Statistical analysis of the survey data was performed using SPSS software. First, the average values of SUS, QUIS, and PQ of the National Museum of Modern and Contemporary Art's (MMCA) 3D VR and Savina's 360-degree VR were derived, and the difference in mean scores was derived. Next, a paired t-test was performed to determine whether there were differences in *usability*, *affection*, and *presence* between 360-degree VR and 3D VR. Paired t-test is an analysis that verifies the difference of one paired value, and compares the difference between two numbers from the same group, and not the difference between different groups. Because the

Table 5.8 Paired samples statistics

		Mean	*N*	Std. deviation	Std. error mean
Pair 1	SUS_3D	3.9350	30	1.38737	0.25330
	SUS_360	4.4010	30	1.26537	0.23102
Pair 2	QUIS_3D	4.2257	30	0.86730	0.15835
	QUIS_360	4.7083	30	0.75701	0.13821
Pair 3	PQ_3D	4.2020	30	0.58624	0.10703
	PQ_360	4.2357	30	0.58841	0.10743

sample of two variables appears to be more than 30 people, a paired sample t-test, one of the parametric tests, is possible (Table 5.8).

A paired sample test table is a result table that tests the three hypotheses we want to see (Table 5.9). The t distribution values between the two variables, 360-degree VR and 3D VR, were − 1.445 for SUS, − 3.203 for QUIS, and − 0.326 for PQ, and the significance probabilities were 0.159 for SUS, 0.003 for QUIS, and 0.747 for PQ. Clearly, there was a difference between 360-degree VR and 3D VR only in terms of *affection.* The paired sample test was performed as follows.

H1: There is a difference between 360-degree VR and 3D VR in the *usability* of subjects
→ rejected
H2: There is a difference between 360-degree VR and 3D VR in the *affection* of subjects
→ adopted
H3: There is a difference between 360-degree VR and 3D VR in the *presence* of subjects
→ rejected

5.4.3 Think-Aloud and Interview with Eye-Tracking Analysis

In this study, the think-aloud protocol and interview data with eye-tracking were analyzed using the affinity diagram method to improve the virtual museum user experience. Affinity diagram is a grouping technique for discovering meaningful rules among vast amounts of data and are mainly used to classify and organize qualitative data. Initially, the needs and problems of the participants were listed using yellow posts. Second, we grouped the most relevant data and named the group using the blue post. Third, similar groups were combined, and the derived insights were created using pink posts. Through the affinity diagram, the problems and needs of the virtual museum were identified, and seven insights were derived for the UX design guidelines of the virtual museum. Through the affinity diagram, seven important factors were derived: a way of providing artwork, grasping the location and exhibition flow, manipulation of movement and viewpoint, text size adjustment and caption

Table 5.9 Paired samples test

		Paired differences					*t*	df	Significance	
		Mean	Std.deviation	Std. error mean	95% confidence interval of the difference				One-sided p	Two-sided p
					Lower	Upper				
Pair 1	SUS 3D-360	− 0.46600	1.76599	0.32242	− 1.12543	0.19343	− 1.445	29	0.080	0.159
Pair 2	QUIS 3D-360	− 0.48267	0.82529	0.15068	− 0.79083	− 0.17450	− 3.203	29	0.002	0.003
Pair 3	PQ 3D-360	− 0.03367	0.56635	0.10340	− 0.24515	0.17781	− 0.326	29	0.374	0.747

placement, providing a catalog of artwork, intuitive icon's color and shape, and dialogue function and sound for a sense of reality. The three most essential elements in the main text are addressed, and the remaining four elements are attached to the appendix (Fig. 5.3; Table 5.10).

The Way of Providing Artworks

Three factors can be considered to provide artwork in a virtual exhibition space. First the resolution of the artwork provided in the virtual exhibition space is shallow, and the texture is still being determined. As a result, people did not have a virtual viewing experience in the exhibition. In particular, in the case of 3D VR (MMCA) collections, there were many artworks that used various materials because there were works by various artists, but it was not easy to know the texture of the artworks.

> P9: In this case, the texture is essential, so I want to see it in detail, but I need help to see the details even if I zoom in.
> P13: It was regrettable that the artwork's quality could have been improved if it had been expanded to a certain extent.
> P29: The artist worked with unique materials, but I did not feel any physical property (Fig. 5.4).

After appreciating the 360-degree VR (Savina) and 3D VR (MMCA) exhibition, the subjects' opinions suggested a technical method to determine the artwork's texture and view it with high resolution.

> P27: To observe the material's properties, it would be nice to have a high-definition shot through Reflection Transformation Imaging (RTI) or light reflectance. There are shiny and thick ones, but it is a shame that it looks like a picture.
> P29: The material of the work is challenging to see; therefore, the feeling of the work itself is low. There is a game and movie called *Uncharted*, and people can see all ancient artworks or objects stolen in the game 360 degrees in 3D. People can also zoom in to see it. Therefore, it is better to scan the works in 3D.

In a virtual exhibition space, it is not easy to know the texture of paintings and sculptures; therefore, 3D scanning is needed so that users can feel the texture virtually as they see the work in reality.

Second, both 360-degree VR (Savina) and 3D VR (MMCA) filmed the exhibition space as it was and uploaded it to the virtual space, causing inconvenience to users. In the case of works protected by glass, the artwork or cameras on the other side were reflected, interfering with the exhibition's appreciation.

Most of the artwork provided by the 3D VR (MMCA) was in a protected form of glass; accordingly, other objects were reflected in the glass, causing inconvenience.

> P4: When I look at the work, the picture on the other side is reflected through the glass, so I lose my immersion.
> P5: It is not easy to fully appreciate this work. When looking at the work, the objects behind them are reflected.

Fig. 5.3 Affinity diagram analysis by Miro [19]

Table 5.10 Problems, needs, and insights through affinity diagram

Keyword	Problem and needs	İnsights
Way of providing artworks	The artworks' resolution is low and hard to know the precise texture	Artworks must be 3D scanned with precision and presented separately from the exhibition space
	Complaints about the reflection of other objects if the picture is protected by glass	
	Clicking on a video links to another website or provides a separate video player	The video should be provided within the exhibition space or video overlays should be applied
Grasping the location and exhibition flow	Difficult to quickly identify the location of artwork and user in a space	Maps should be provided along with an exhibition to facilitate the location of artworks and viewers in real time
	Hard to grasp the flow of the exhibition, so users don't know the order in which to view the artworks	Motion path should be provided, and the exhibition space section should be classified into different colors
Manipulation of movement and viewpoint	Moving with a mouse click has too low or too high a degree of freedom	Allows users to move the space with a direction key or WASD key with a mouse
	Like FPS games, users want to move with arrow keys or WASD	
	Need to set the optimal viewing location for painting works	It is necessary to allow viewers to appreciate artworks from various eye levels and viewpoints
	Lack diverse perspectives for viewing 3D sculptures	
	Limited eye level for viewing eye works	
Text size adjustment and caption placement	The text size of the caption is small, so it is not readable	Provide a function to adjust the text size of the caption
	Feeling discomfort when position of the caption is vertically on the right side	Place caption close to artwork and provide a horizontally explanation
Providing a catalog of artworks	Satisfy with providing a list of artworks in the form of an archive	Provide a list of artworks on display as an archive, along with titles
Intuitive icon's color and shape	Improper location of supplied icons	Icons' intuition and visibility should be highly improved
	Difficulty understanding the meaning of icons	The color or shape should be intuitive for understanding the icons easily
Dialogue and sound for a sense of reality	Want to talk or chat with other users, or avatars	Enable simultaneous access to VR museum and set the NPC or chat function
	Want to see the exhibition with music or ambient sound	Provide music or ambient sound to match the exhibition space

Fig. 5.4. 3D VR (P24, P29)

Fig. 5.5. 3D VR (P16, P28)

P6: The camera for filming the space is reflected on the glass protecting the artwork, so I do not know what to look at, and I cannot concentrate well.
P9: The entire exhibition environment is reflected by the glass used in this work. For example, one can see all the tripods, and the lights are also reflected, which hinders the appreciation of the work.
P28: It was uncomfortable because other works were reflected on the glass.

Therefore, artwork must be filmed separately from the exhibition space and uploaded to the virtual exhibition space (Fig. 5.5).

However, nothing was reflected when there was no glass on the work, so it was easy to appreciate the exhibition. In the case of 360-degree VR (Savina), most artworks were provided without being protected by glass. Therefore, it maintains a sense of immersion in viewing.

P9: Most importantly, there is no glass in the work, so there are no objects that are reflected, so it seems to be less obstructive to viewing the exhibition.
P11: Here, too, the camera is often reflected on the glass, so it would be nice if it were not there.

Third, if users play video-type work, immersion is broken when they go to an external site. For example, when the artist's interview video provided by the 360-degree VR was played, it was linked to a YouTube site, and the subjects complained of inconvenience.

P2: When I played the video, it was linked to a YouTube site, and it felt like I was watching it on my phone, so my immersion broke.

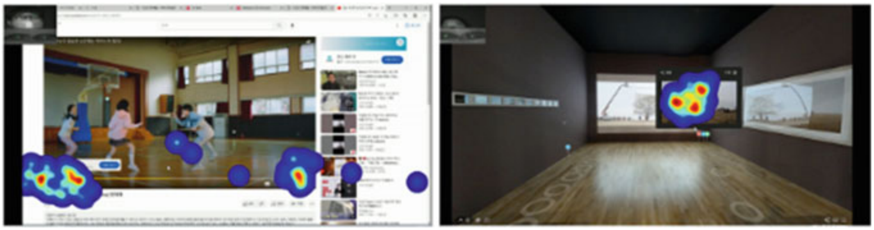

Fig. 5.6 360-degree VR (P30), 3D VR (P22)

P18: When I played the video, it was challenging to link it to YouTube.
P22: As the provided video is linked to YouTube and advertisements appear together, the sense of immersion is broken.

However, in the case of 3D VR (MMCA), because the video is played separately in the exhibition space rather than being transferred to YouTube, people can immerse themselves without any burden. However, there was a preference for overlaid videos than videos provided separately.

P18: This museum was okay because it was not burdensome to show the videos separately.
P22: This is a form of showing videos directly in the exhibition space; therefore, immersion continues.
P27: If it were a virtual museum, it would be possible to provide sufficient video overlays, but this is a pity.

Therefore, we recommend playing the video immediately in a virtual exhibition space, and this video should be overlaid on the screen rather than provided on a separate window (Fig. 5.6).

Grasping the Location and Exhibition Flow

In a virtual exhibition space, it is essential to understand the location of the artwork people are looking at while appreciating the work and to facilitate the identification of the flow of the exhibition. First, it is vital to facilitate the identification of one's current position in the exhibition hall and the position of the work being viewed by viewing the map in real time. The 360-degree VR (Savina) informs the viewer of his or her current location in real time through a map as well as the titles without images of which works are placed.

P10: It is good to see the work title on the map view, but it is hard to know what kind of painting it is. When I watch an exhibition, I usually look at the picture first and then at the title. Therefore, would it not be nice to show a small picture on the map?
P14: This exhibition hall has a simple structure, so there is little confusion but even if it becomes slightly complicated, a mini-map needs to be displayed continuously in the exhibition space.

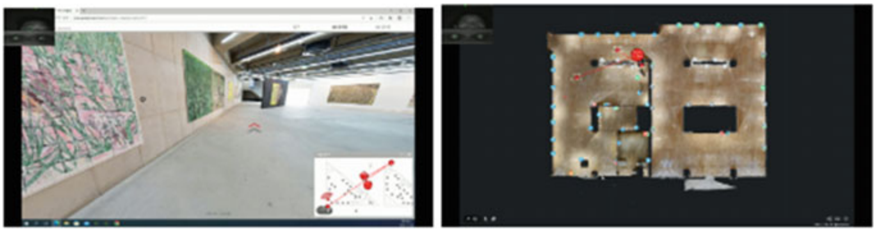

Fig. 5.7 3D VR (P14), 360-degree VR (P20)

P18: It was good to know my current location when my location was displayed as a dot in the map view.

The 3D VR (MMCA) provides a map in the form of a floor plan, and it does not show the map in real time. Thus, participants had to open the map to check their location.

P27: It is hard to figure out the line of view, so I hope that the mini-map remains visible on the screen.
P30: It would be better to display a mini-map next to the screen. Because I have a high degree of freedom, I do not know where I am or where to go, so it would have been better if the map had been fixed (Fig. 5.7).

Second, it is difficult to grasp the flow of the virtual exhibition, unlike the real exhibition space. Thus, it is necessary to provide movement lines or classify exhibition sections differently by color or number.

P5: It took considerable time to see the flow of the exhibition space. 3D VR marked exhibition hall sections 1 and 2, but 360-degree VR was uncomfortable because there were no section numbers.
P13: I like to see the works in the exhibition hall in order. It was tricky to see the order.
P2: The spatial structure of 3D VR could have been more straightforward, so it was not easy to see in which order I should look.
P20: I was hoping you could tell me where to look at the exhibition and the direction of movement because it seemed slower than the actual location. I want you to know where to start watching.
P25: You can see where to start in real space but cannot determine which order to move on the monitor screen (Fig. 5.8).

Therefore, visitors made the following suggestions to understand the flow and movement of exhibitions.

P15: In the case of the Naver map view, there are cases where it moves along the path, so it will be beneficial to have a viewing route and be more intuitive.

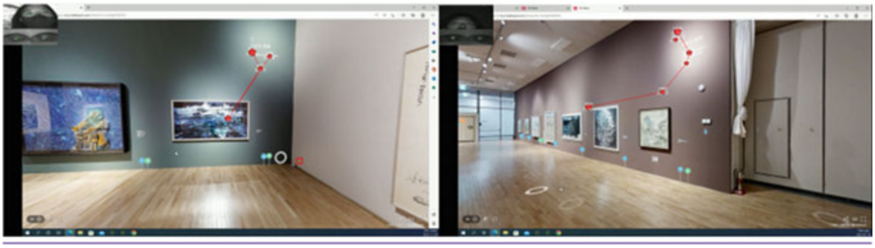

Fig. 5.8. 3D VR (P5, P29)

P17: In real exhibition halls, people's movements and order of view are considered, but I think the limitation is that these things are not considered in virtual exhibitions.
P19: For the section division of the exhibition space to exist in a virtual exhibition, it would be nice to have guided movement.

Manipulation of Movement and Viewpoint

In a virtual exhibition space, users have to move with a mouse or keyboard, unlike walking, therefore natural movement is significant. However, there were difficulties in positioning and viewpoint control for viewing the artworks and wall text. In the case of 360-degree VR (Savina), participants complained about the low degree of freedom because it was possible to move only to a place set by clicking with a mouse.

P24: It is unnatural because I do not walk around myself but move only with arrows.
P26: I feel like the 360-degree VR has a uniform path, so I cannot move freely.
P30: Because the path that can be moved is minimal, it cannot be viewed from the desired location or direction.

In the case of 3D VR (MMCA), viewers can move to most places with a mouse and a keyboard using the ↑ and ↓ keys, allowing a high degree of freedom. However, participants complained that the movement was different from what they expected.

P10: It is good to go where I click, but it goes where I did not mean.
P12: I could see the work from different perspectives, but it was difficult to control.
P14: There were many places to move, so I moved incorrectly many times. It was uncomfortable because I made a mistake and moved far away (Fig. 5.9).

Therefore, there is a strong need for visitors to move to the direction key or WASD, as in a first-person shooter game. However, in the case of 360-degree VR, users complained of discomfort because the direction keys would not move but instead would adjust the field of view.

P17: Walking like an avatar with a WASD key would be nice. It would have been nice to look at with mouse.
P23: In Savina, the direction keys change the angle of view, which was unexpected.

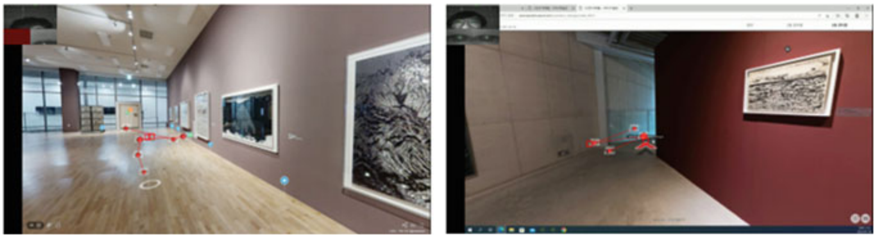

Fig. 5.9 3D VR (P14), 360-degree VR (P26)

P28: The arrow keys change the view, but not help me to move.

3D VR (MMCA) provides direction keys, but the keys ← and → were caused discomfort because they controlled the field of view rather than moving left and right.

P7: It was inconvenient to move because the keyboard could only move back and forth, and it was disappointing that the left and right keyboards only switched views.
P17: It would be comfortable if the keyboard moved like in a first-person shooter game, but it needed to be more intuitive.
P29: I used direction keys like a first-person shooter game, but when I pressed the left and right keys, I thought it was strange because the view turned around, and I was disappointed that it did not work like a standard interface.

Next, more work is required to set and adjust the viewpoint for viewing the artwork. For example, in the case of painting, participants wanted an optimal viewing position from the front; in the case of a 3D sculpture, they wanted to appreciate it from various angles. In the case of the 360-degree VR (Savina), most exhibited works consisted of paintings, so there was a solid need to see the works from the front.

P6: It was easy to see because the viewing point was designated such that it could be viewed from the best position.
P8: It was good that the point of view did not move autonomously, but after moving, I went in front of the artwork and focused on it without shaking my eyes.

3D VR (MMCA) provides 3D artworks and paintings, and the subjects wanted to look at the 3D sculptures from various angles, not just the front.

P9: It is difficult to see the bottom of the sculpture in the actual exhibition hall, so it would be nice to have a 3D capture, so that it can be rotated and viewed.
P13: There were many sculptures in 3D VR, but they might look different depending on the location, which was not possible (Fig. 5.10).

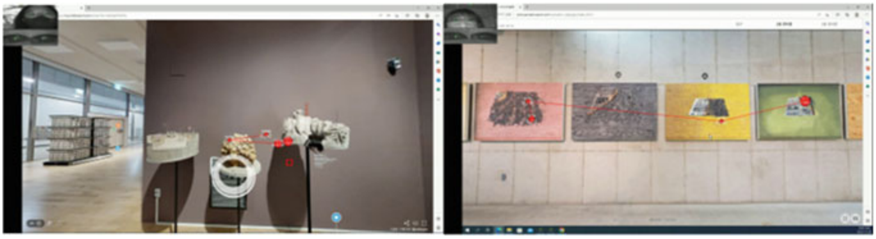

Fig. 5.10 3D VR (P5), 360-degree VR (P6)

In addition, they wanted to adjust their eye level to view the work. Because each person is different in height, the eye level for viewing the works in the actual exhibition space is different, but in the virtual exhibition space, the eye level is fixed.

P13: Everyone's height is different in the real space, so the eye level is different, but in the virtual space, the eye level is the same, so it is different from the real thing.
P23: It would be nice if it could be adjusted according to the viewer's height. Viewers' experiences can be personalized.

5.5 Discussion

This study aims to establish UX design guidelines and visitor profiling in a virtual museum environment.

Based on the cluster analysis above, we propose three visitor profiles: *physical museum lover*, *information seeker*, and *indifference*. The *physical museum lover* cluster is most influenced by the physical museum in the real world and the experience there. Their attitudes toward physical and virtual museum environments are contrary to each other. We speculate that this trend is due to the poor readability of virtual museums. The *information seeker* cluster includes viewers whose interests and positive attitudes toward text information have a significant effect on appreciation, regardless of the influence of the environment. Finally, the *indifference* cluster refers to those viewers for whom the influence of the text is not significant.

This result can be linked to the UX design guidelines of the virtual environment. Motion sickness and dizziness, which occur owing to the nature of the virtual environment, are commonly noted regardless of the cluster. As a result, appreciation is greatly affected by this phenomenon except for the *information seeker* cluster, which has a basic interest in the text. In particular, in the case of a cluster of *physical museum lover*, environmental difficulties were a barrier, despite the possibility of a similarly positive attitude toward virtual exhibitions based on their positive attitude toward museums and exhibitions. This fact requires us to reconsider how text information is presented in a virtual environment.

The SUS, QUIS, and PQ questionnaires were used to determine the differences in *usability, affection,* and *presence* in 3D VR and 360-degree VR environments. As a result of checking whether there was a difference in the two environments through a paired t-test, significant results were obtained only for affection. Because there was no difference in usability and presence between 360-degree VR and 3D VR, we tried to determine how they differ by analyzing the affinity diagram. Accordingly, participants' actions and reactions were examined according to the 3D VR and 360 VR environments and the user interface provided. It was possible to understand the needs and pain points of art museums in each environment First, in the way of providing aspects, artworks must be 3D scanned and presented separately from the exhibition space. In case of video content, it should be provided within the exhibition space or video overlays should be applied. Second, for grasping the location and exhibition flow, the map should be provided along with an exhibition to facilitate the location of artworks and viewers in real time. Besides, the motion path should be provided, and the exhibition space section should be classified into different colors. Third, for manipulation of movement and viewpoints, allowing users to move the space with a direction key or WASD key with a mouse is essential. Furthermore, it is necessary to allow viewers to appreciate artworks from various eye levels and viewpoints. The factors to be considered when constructing a virtual museum are thus presented. We hope that these insights provide appropriate UX design guidelines for museum officials and virtual space designers seeking to create virtual museum experiences.

5.6 Conclusion

This study is important as a prior attempt to build new UX guidelines and visitor profiles for the VR museum environment. We propose two hypotheses regarding the clustering analysis in this study: (1) Depending on the degree of textual importance and interest evaluated by the visitor that can be obtained in the virtual environment, different clusters of tendencies can be divided; and (2) each cluster will have a different aspect of using information or navigation functions while viewing the exhibition in a virtual environment.

Through K-means cluster analysis, we identified a total of three clusters. Each cluster has a different attitude toward textual information: (1) important in the real environment, not important in the virtual environment; (2) important in both real and virtual environments; and (3) not important in both real and virtual environments. The difference in attitudes by cluster was also linked to a slight difference in the tendency of function selection. This finding is judged to influence visitor profiles during the development of UX guidelines.

First, in terms of *usability, affection,* and *presence* of 360 VR and 3D VR, only affection was significant, indicating a difference between the two virtual museum environments. Second, through thinking aloud, interviews, and eye-tracking, seven needs, pain points, and insights were derived as follows: way of providing artwork, grasping the location and exhibition flow, manipulation of movement and view point, text size adjustment and caption placement, providing catalog of artwork, intuitive icon's color and shape, and dialogue function and sound for sense of reality.

However, we must remark upon some limitations to study:

- The overall sample size ($N = 30$) was relatively small. Among them, only 22 data points were available for cluster analysis. However, in this case, because the number of clusters was three, the data size should have been at least 60 to achieve statistically valid results [20].
- Our clustering results mainly focused on the textual aspects. Comprehensive data collection and analysis, including opinions regarding image information, are required.
- In this study, usability, immersion, and affection were evaluated to compare user experiences in 360-degree VR and 3D VR environments, but significant results were found only in affection. This is because the number of visitors is insufficient, and most of the subjects were KAIST students. In addition, the user interface may have affected the user experience rather than the difference in the virtual environment (360-degree VR and 3D VR).

Nevertheless, we derived some new research questions based on the limitations mentioned above. The directions for future research are as follows:

- How many clusters can be classified according to visitors' opinions on the textual and image information?
- In addition, how can each group be explained based on their behavior in the VR environment?
- In the future study, to develop user experience studies in 360-degree VR and 3D VR environments, we would recruit people from various backgrounds and ages to conduct experiments. In addition, to see the pure difference between 360-degree VR and 3D VR environments, we intend to design a virtual exhibition space by unifying the content and user interface as much as possible.

Appendix

In addition to the main consideration factors covered in the main text, there were four other consideration factors: text size adjustment and caption placement, providing a catalog of artworks, intuitive icon's color and shape, dialogue and sound for sense of reality.

Text Size Adjustment and Caption Placement

First, there was an opinion on the size of the wall text provided by the 3D VR and 360-degree VR. There were opinions that the text size provided by the work was too small at the 360-degree VR.

P10: I wish the text size was bigger.
P16: Text size is small.
P18: The text provided by the Savina Museum is too small. The text was small, so I did not have time to look at the work because I got motion sickness.

Some participants stated that the size of the text provided by the 3D VR was small, but others said that it could be seen well because the size was appropriate.

P16: It was nice to see the caption clearly.
P18: It was easy to see because it stood out even if you did not zoom in to see the caption.
P27: I think the text is a little smaller when I look at the text more.

Because each person feels differently about the size of the text, it is necessary to make it possible to adjust the size of the text as if zooming in on the artwork.

Second, the 360-degree VR provided the wall text horizontally at the bottom of the painting, and 3D VR provided the wall text vertically to the right of the work. In the case of 360-degree VR, participants noted that this was more comfortable because the explanation was displayed horizontally at the bottom. However, overlapping text in the painting was a hindrance to appreciation and wanted to be provided separately.

P14: I like the caption, because it is intuitive. I think it is okay because the caption does not interfere with the appreciation of the work.
P23: I think it is more comfortable because the description for each work is organized based on images, not on the right side.
P29: I cannot even see the text properly because it is overlaid on the picture.

In the case of 3D VR, the wall text was displayed vertically on the right side next to the work, complaining of inconveniences.

P10: If the caption appears at the bottom, it is okay, but when it appears on the right, immersion is reduced.
P19: First, I didn't like the text on the right.
P27: I think there is another way in which the text does not appear on the right.

When providing a caption, it is better to place it close to the work and provide a horizontal rather than vertically long explanation (Fig. 5.11).

Providing a Catalog of Artworks

In the case of 360-degree VR, unlike 3D VR, works are listed and provided. These archives are good at checking what works people have seen.

P6: It was good to have an archive in which you could see each work. If I miss anything, I can check.

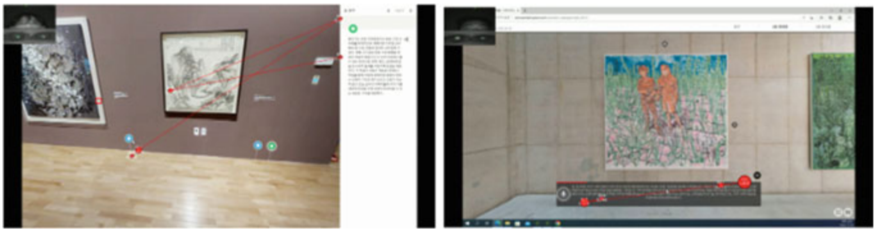

Fig. 5.11 3D VR (P10), 360-degree VR (P14)

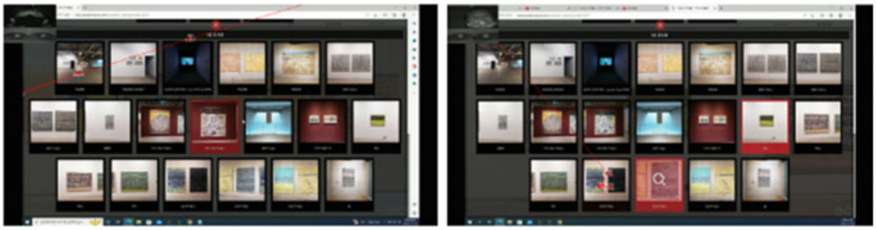

Fig. 5.12 360-degree VR (P4, P21)

P23: It is good that the image and description are displayed together in the archive. When I go to the actual exhibition hall, I want to see all the artworks, but I have to move them one by one to check if I have already seen them, but I think it's good because I can check with my eyes if I missed anything in the virtual space.
P25: It is good to check if you have seen all of the works in the archive (Fig. 5.12).

Intuitive Icon's Color and Shape

Each virtual museum and art gallery has slightly different forms of icons, but because the meaning of icons provided is important in virtual exhibition spaces, it is necessary to clarify the reason for the existence of icons.

In the case of 3D VR, captions, wall texts, and video icons all had the same circular shape and were differentiated only by color, so it was difficult to know what the difference between the icons was.

P27: In the case of a video, it is a red circle icon, but it would be nice if the video were more intuitive, such as using the play button.

Also, in the case of the 360-degree VR, although the shapes of the icons are different, the colors are all provided in achromatic colors, making it difficult to notice.

P27: The UI color is not suitable for visibility. The icons are nice, but I wish that the colors were more visible.

Moreover, in the case of the 360-degree VR, it can be seen that it is difficult to find the arrow icon for movement.

> P2: The 360-degree VR had three floors of exhibition space, but it was a shame that I did not know how to get up there. I found the arrow late.
> P27: The direction keys are not intuitive. It would be better if the icon blinks because it does not stand out at once.

Therefore, when providing icons to provide explanations, directions, and videos in a virtual space, intuition and visibility should be highly improved.

Dialogue and Sound for a Sense of Reality

In the two experimental virtual exhibition spaces, there was a need for communication, because it was impossible to talk or chat with other users. In addition, because an avatar exists in the virtual space, they wanted to feel as if they were with someone, even if they visited alone. Therefore, there is a need to simultaneously provide user access, NPC, and chat functions.

> P21: I prefer to go to the exhibition hall with someone, so watching and sharing opinions together is more fun than simply watching. However, it is a pity that I cannot share the conversation in real time because I am watching it alone here.
> P28: It would be nice to have a chat function at the VR Museum of Art to create a communication channel where you can talk to other people.
> P11: I wish there were some characters other than me.
> P27: I also think it would be nice to have a virtual avatar.

Therefore, a virtual museum should enable simultaneous access to the virtual exhibition space of other visitors and place NPC such as docents or helpers in the exhibition space to ask questions.

In addition, there was an auditory need to feel realism in the virtual exhibition space.

> P5: There is some noise in the real space, but there is no noise here, so I feel a sense of heterogeneity.
> P8: It would be nice to provide ambient sounds. I think it will turn out very well.
> P10: I wish there was an auditory element. There are things like music or white noise in an actual exhibition space, but I thought it would be nice to have one.
> P11: I wish there was something like a white noise. Would it not be nice to play in a virtual space?
> P23: There are sounds that this space gives, but if there are footsteps or ambient sounds, I think you can feel the experience of a real exhibition hall.

Thus, if music that matches the exhibition or ambient sound is provided, people can become more immersed into the VR exhibitions.

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Part III
Smart Architecture

Chapter 6
Merging Augmented-Reality Interface with Smart Building Controls: Considerations for the Building User Interface

Andrzej Zarzycki

Abstract This paper looks at how emerging interactive extended reality (XR) technologies are being integrated with smart systems and the IoT in the context of the built environment. Specifically, it investigates the ways to extend this interoperability between AR and IoT into areas of construction, building use, facility management, and post-occupancy evaluation. The synergy between augmented reality (AR) and the Internet of Things (IoT) technologies has a potential to go beyond mere visualization of captured data and provide active controls of building services in a user-specific context/perspective. These controls together with building environmental data overlays can serve as a building user interface connecting virtual and physical assets as well as users and building construction professionals.

Keywords Augmented reality · User interface · Building user interface · The Internet of Things · Smart buildings

6.1 Introduction

Augmented reality (AR) increasingly occupies an important place in transportation, branding, tourism, manufacturing with applications in a diverse range of activities, from remote collaboration and navigation to interactive print, data visualization, and digital heritage [1, 2]. Unlike virtual reality (VR), which is fully immersed in nonphysical datascapes, AR closely correlates the virtual and physical assets by making them highly interconnected and interdependent through location awareness, enhanced data overlays, and user-focused content. It enhances the users' experience and provides a unique opportunity to seamlessly extend physical environments with virtual interfaces, real-time data feeds, and user feedback mechanisms.

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_6

Similarly, embedded systems—smart devices, buildings, and cities—emerge as a primary approach to enhanced user interactions, high-performance architecture [3], and safer environments. Environmental sensing not only provides actionable data to improve building operations [4, 5] but also empowers users by giving them access to data and controls.

This paper looks at how XR emerging interactive technologies are being integrated with smart systems and the Internet of Things (IoT) in the context of the built environment. Specifically, it investigates the ways to extend this interoperability between AR and IoT into areas of construction, building use, facility management, and post-occupancy evaluation.

6.2 Augmented Reality: Key Concepts

The AR framework is defined through key concepts and functionalities, such as location awareness, context awareness (CA), points of interest (POIs), data filters, and user profiles. The goal of these functionalities is to make human–computer interaction, natural, seamless, and effective. New technologies make it easy for products, both hardware and software, to have a large number of features. While each new feature could be seen as desirable, the abundance of options can make a product's use difficult and overwhelming to consumers [6]. This condition is propagated not only through the simplicity of new feature implementations but also through the attempt to offer a versatile product attractive to a wide range of consumers. Furthermore, many users may not know which available feature or information provided by a product could be relevant to their particular situation and personal preferences. CA is one of the approaches to contextualize information and activities available to users and to define ways these can be announced. It also could help users to navigate the abundance of choices presented by new technologies with just-in-place and just-in-time filtering. The filtering is based not only on the physical context of the user but also on past activities and personal choices.

There is a wide range of definitions and interpretations of what constitutes CA. In general, CA is the ability of a system or a device to collect and analyze data about its environment in order to adapt to it in real time. The Active Badge Location System [7] developed by the Olivetti Research Laboratory (ORL) is generally considered the earliest context-aware computing research. Schilit and Theimer [8] first introduced the term "context-aware," referring to context as location, as the identities of nearby people and objects, and as changes to those objects. Their work was further extended by Ryan et al. [9] to consider context as the user's location, environment, identity, and time and by Dey [10] to include a user's emotional state and focus of attention. Similarly, Brown et al. [11] defined context as location, identities of the people around the user, time of day, season, and temperature. Furthermore, Schilit et al. [12] observe that the context is constantly changing and that its key characteristics include where users are, whom they are with, and what resources are around them. Schilit et al. also organize contextual data in three categories: (1) computing environment with electronic networks and devices accessible for user inputs; (2) user environment, understanding the location, social situations, and adjacencies/nearby people; and (3) physical environment, such as temperature, lighting, and noise levels. Abowd et al. [13] combined multiple CA taxonomies and proposed three types of features that context-aware applications would need to support: (1) presentation (visualization) of data and services to users, (2) automatic execution of a service (controls), and (3) tagging of context information for future retrieval (contributing and authoring). These three functionalities not only represent basic user interactions within AR environments but also integrate well with smart buildings and cities as well as IoT devices and systems.

6.2.1 Geofencing

Geofencing, one of the implementations of location awareness, allows for geographic event triggering (announcements) based on the virtual boundary defined by the Global Positioning System (GPS) or radio-frequency identification (RFID) technology. Once a mobile GPS- or RFID-tracked device enters a designated geofence zone, the system notifies users and executes relevant actions. Mobile apps that use this technology commonly correlate users' physical location with their calendars and task schedules, such as reminding about grocery shopping when in the proximity of a store while considering time availability.

Geofencing is already used for automobile entry and ignition. Starting a car can be done with a push of the button as long as the car key is in close proximity to the car. When a driver walks far enough from the car, the engine will shut off and doors will lock. Similar functionalities are being implemented in connection to smart buildings, appliances, and devices as well as security systems.

AR and IoT are direct beneficiaries of location awareness capabilities. The spatial relation of a user in the context of a city or a building can be used as data filters for enhanced built environment interactions. Users can gain an access to various spaces, track physical assets within a building, and manage their environmental control systems. AR and IoT devices can also serve as data collection of building occupants and their activities. This data combined with machine learning algorithms can serve as a user-based predictive component of building systems and operations.

6.2.2 Types of AR Sensing

Traditionally, AR environments employ two distinct ways of spatially registering data. Marker-based AR uses computer vision (CV) technology with distinct markers or image targets to locate virtual data within the physical world. Targets can be two-dimensional (2D) images or three-dimensional (3D) objects and spaces with distinct natural features. Marker-based technology provides high-precision registration (localization) for data overlays while maintaining extended tracking with only partially visible markers. This technology also allows for various interactions with targets, such as virtual buttons, triggered by intentionally obscuring parts of the image. However, for AR registration to work effectively, marker targets cannot be symmetrical (i.e., must differentiate left from right or top from bottom) and must possess a necessary level of unique features within the target image. Also, low illumination levels can significantly impact readability of visual markers.

A second, markerless approach associated with mobile AR involves the GPS, digital compass, and accelerometer sensors to position users and the virtual content around them. The GPS location and compass direction are checked against a database for location associations. If any dataset point meets user-defined criteria, such as proximity or thematic interests (filters), the visual reference to the data set is displayed on a mobile device as a POI. Markerless AR is limited to areas with good GPS reception and tracking precision. It generally can locate with 3- to 6-m (10- to 20-foot) precision [14]. This makes this type of AR more effective in outdoor and open urban areas, where access to GPS satellites is unobscured (e.g., is not blocked, does not reflect signals) and high-dimensional tolerances for POI tracking are acceptable. While less common, spatial localization can also be achieved with Bluetooth Low Energy (BLE) [15] utilizing Bluetooth beacons. This is particularly useful inside building where GPS reception is weak.

Early implementations of AR relied on less appealing fiducial markers with visually distinct geometric patterns reminiscent of bar and quick-response (QR) codes (Fig. 6.1). Current technology can recognize and track a wide range of 2D images and everyday objects, such as industrial products (e.g., shoes). This removes an explicit marker as an intermediate step for data access with images and objects that may not always be perceived as explicit portals to AR environments. Aesthetically, this improves the clarity of communications, since it directly links an image/object to a data set. In this instance, an image or object becomes a clearly recognizable physical avatar of digital content as compared to a marker that visually does not communicate actual content of the virtual data link. On the other hand, the benefit of QR codes or markers is that they are easily identifiable as links to virtual information, since they do not by themselves present any other visually meaningful content.

The current trend deploys image, object, and spatial targets in lieu of markers as a more user-friendly and direct interface. AR development platforms, such as Vuforia [16] have already discontinued marker functionalities they offered in the past. This switch from markers to image and object targets, while generally beneficial, poses an important user interface (UI) consideration: how to make users aware of extended data connections and capabilities that may be associated with 2D graphics and 3D objects surrounding them in the physical world. This need for the UI to inform users of possible AR interactions becomes an important part of interaction design strategies. It is even more relevant to AR applications that deal with a wide range of users and a high number of data sets, as would be the case when interfacing with IoT devices and systems.

Fig. 6.1 Early examples of the augmented reality fiducial markers (left and center: ARToolkit and right: ARTag)

6.3 Emerging Marker Technologies

What are often perceived as limitations in the integration of AR technology with IoT—such as the need for a large number of markers corresponding to a number of smart devices, their relative proximity to the user, and aesthetics considerations [17] could be addressed with emerging cholesteric liquid crystal shell (CLCS) marker tracking proposed by Schwartz et al. [18]. CLCS markers are invisible to the human eye, so their appearance does not contribute to additional visual information clutter. However, they are readable to mobile device-based cameras, since they can be seen in infrared light. Their precise visibility wavelength (e.g., 750 nm) could be customized for a narrow spectrum, effectively allowing layering of multiple markers on top of each other, each marker tuned to a different light frequency. Furthermore, these narrow infrared light frequencies could be assigned to different users or levels of authentication, allowing users to tune in only to a particular wavelength and record only information for a given channel, not unlike conventional TV and radio channels. Finally, an important part of CLCS technology is a unique visual signature of each marker. Since these technologies rely on the configuration of crystal shells, they cannot be replicated.

6.4 Data Overlays: Commonality of the Public Realm

Augmented reality is also a bespoke realty. AR technology shifts the explicit nature of interactions and meanings found in real-world environments to customizable, user dependent, and privileged. Who can see (be aware of) and control what is the key differentiation between AR-enhanced environments and their physical counterparts. Since AR is usually interfaced with personal devices, such as smartphones or headsets, it brings with it not only particularities of each device (location and position) but also user characteristics and preferences (profile, contacts, history, or filters). This undermines socially and culturally established expectations about the collective

Fig. 6.2 Augmented reality provides users with highly customized context- and location-aware functionalities

perception and shared experiences of the environment. Unlike the physical environment (an object, building, or city), which by its shared experiential nature could be collectively agreed upon—what you see is what you get (WYSIWYG)—an AR interface provides users with highly customized information and functionalities. This on-and-off data layering associated with WYSIWYG and non-WYSIWYG worlds is characteristic of electronic networks and online culture in general (Fig. 6.2). While it breaks the consensus on what is collectively perceived, it also allows for setting various levels of information access and controls necessary for effective interactions with IoT technologies.

6.5 Emerging AR Interface

The combination of geofencing with customizable and user-dependent content open opportunities for on-demand UI functionalities and recommendation systems. With information overflow typical for electronic systems and associated user fatigue, an effective UI needs to provide users with only those choices that are meaningful at a given moment, without unnecessary additional features. Choices need to be presented in a similar way as with software providing contextualized menus corresponding to the right mouse button (RMB)—only viable commands linked with a particular action are shown as possible. The contextualized UI can be further enhanced with predictive capabilities powered by a recommendation system. Product recommendation systems are commonly used in e-commerce and data-driven marketing. For example, Amazon's "Frequently bought together" and "Customers who bought this item also bought" aim to cross-sell and upsell products by providing suggestions based on the items in a customer's shopping cart or reviewed during online shopping. While these systems correlate products and their features, they do not necessarily consider individual customer characteristics. Similar data-filtering tools could be deployed to tailor AR UI experience and recommend the most relevant system functionalities to each user. Information and controls in AR/IoT systems could be correlated in a similar way to products and services in e-commerce. When combined with user-specific data—past activities and user intent behind the interaction session—applications could also provide predictive capabilities and establish intent awareness [19, 20].

6.6 Internet of Things: Concepts and Opportunities

The IoT is the network of interconnected devices, appliances, and elements of infrastructure with embedded sensors and actuators, which allow for data sharing and management. IoT extends Internet connectivity beyond standard electronic devices, such as personal computers, smartphones, and tablets, to a wide range of traditionally unconnected technologies and services, physical devices, and everyday objects. Examples of IoT-enabled devices include thermostats, door locks, security systems, and home appliances. Remote controls and sensory data acquisitions can be accessed over the Internet, managed, and fed to online monitoring systems. IoT applications extend to a broad range of markets, including consumer products, infrastructure, and commercial and industrial systems. In the context of the built environment, IoT technologies are part of home automation controlling heating and cooling, lighting, and security systems. They are also incorporated into assistive technology to accommodate the needs of elderly people and people with disabilities as well as to encourage healthy living and to monitor patient data. An important part of IoT communication is reciprocity: sending data and enabling controls bidirectionally. Voice controls, such as Amazon Alexa or Google Home, are one strategy to provide easy and immediate control interface with home automation and personal wearable devices. They complement and can be incorporated into mobile devices and smart appliances.

Smart infrastructure and smart cities are other areas of high impact for IoT technologies within the built environment. Distributed sensing and actuation are critical for operations, maintenance, and controls of large infrastructure projects, such as roads and bridges. City of Santander [21] in Spain is one pioneer in developing a sensor-rich (over 10,000-sensor) smart-city test bed measuring everything from air pollution levels and traffic conditions to the amount of trash in containers, number of pedestrians on sidewalks, and available parking spaces. The sensor data are used by the local government and shared publicly via the open application program interface (API) [22]. Open API allows for programmers to develop third-party applications to capitalize on implemented smart infrastructure and provide new citizen-focused services [23]. Some early applications, including those with location awareness, have begun taking advantage of this opportunity. For example, Pulse of the City [24] not only locates environmental sensor data within the city but also serves as a participatory platform for citizens to share information about the city. The latter is a reoccurring functionality for many city-sponsored citizen-engagement mobile apps, such as *BOS:311* (previously *Citizen Connect*) [25]. *BOS:311* gives Boston residents a venue to inform the city administration about broken streetlights, street potholes, or uncollected trash. The app allows users to share a photo and message together with the geolocation to situate the event. While *BOS:311* provides one-directional communication with no visibility of information shared by other residents, it is still an important step in combining environmental data with the citizen participatory culture.

6.7 Digital Twins

The interdependency of the physical world and digital data assets' characteristic of AR applications is even more evident in the industrial implementations of digital twins. A digital twin is a virtual duplicate of a physical asset (physical twin), which yields a data-rich and simulation-ready digital model. Both twins share real-time reciprocal connection with data updates and knowledge exchanges. The digital model is continuously aware of its physical counterpart monitoring and analyzing its activities, performing simulations, and making recommendations to respond to changes in physical asset conditions [26].

Smart buildings and smart cities provide opportunities for application of the digital twin framework. Specifically, building information models (BIMs) can start playing a significant role as a component of the digital twin [27] and facilitate real-time data. This would allow for extending digital models developed as part of the design process into post-occupancy. Current implementations of BIM are usually out of synch with the physical counterpart by the time a newly erected building is conditioned and occupied. There is no connection between a building's equipment inventories and digital BIM assets or even specifications. Such an incomplete model cannot be used for integration with IoT, not to mention that current BIM formats and conventions do not support interoperability between these possible twins.

While IoT applications in the built environment have increased significantly and gained developer interest, there still exists a gap in incorporating IoT data-rich assets with BIM platforms in ways that would meet or exceed the digital twin framework discussed earlier. This convergence should also integrate with building automation system (BAS) and building management system (BMS) dashboards to bring data-generating and data-managing platforms together.

The enhanced BIM framework, referred to in this paper as BIM+, would be necessary for the development of user-end services and user-oriented smart applications. It would also allow for life-cycle modeling over the entire life span of a building and across the entire fleet of buildings. The key to successful implementation of BIM+ would be a join framework with open standards allowing for interoperability and easy utilization of data [28].

6.8 IoT Application Layer

While IoT encompasses a wide range of data-generating and data-consuming objects, the Web of Things (WoT) is the application layer collecting, processing, and acting upon data from IoT devices. It is middleware between individual smart objects and users. The AR platform is a prime contender for the WoT applications that would interface between IoT devices and data consumers and managers.

The current market for IoT-enabled devices, particularly on the consumer level, involves a myriad of mobile apps and other middleware to connect to a narrow range of products. Although several smart thermostats are available on the market, such as Nest or Honeywell, each of them comes with a separate app and closed proprietary ecosystem. While this could be acceptable for personal controls in the context of a private home, it is not scalable to the broader participatory nature of public facilities and infrastructure. Jean-Louis Gassée's analogy of the current state of the IoT with a "basket of remotes," [29] each controlling a separate system and each speaking its own language, frames the goals for the future WoT applications that need to provide universal and transparent access to shared data resources.

A number of platforms, such as Amazon Alexa, Google Home, or If This Then That (IFTTT), interact with a wide range of smart devices. They provide dashboards that connect with individual product APIs. In many cases, smart device and appliance manufactures develop custom connections for one or more of these services. However, at present they merely scale up the proprietary nature of individual smart devices, not opening them for true interoperability.

The points raised by Gassée set the stage for AR as a promising IoT application layer forming WoT. Particularly at the consumer level, AR UI could provide a direct and low-threshold access to IoT platforms, both increasing consumer exposure to available environmental data and providing venues for data sharing and content authoring. The AR platform may help in the democratization of IoT data, as argued by scholars and new media activists. Howard [30] sees the IoT as a way to create new models of civic engagement, assuming that device networks would be open to user interactions and control. He sees IoT as an intimate and constant feedback loop between users and the government.

6.9 AR and IoT Integration

The IoT platform, utilizing distributed sensing, actuators, and microcontrollers, allows for direct integration between embedded objects or buildings and users. Used for security access and controls, building data monitoring, or content authoring, mobile devices effectively extend spatially and conceptually what is considered a building and its perimeter. A mobile interface connects directly to what is often hidden within and defined as a private realm. Smartphones also provide opportunities for greater public participation in authoring media contents, in a similar way to the D-Tower project by artist Q. S. Serafijn and architect Lars Spuybroek (NOX).

Digital twins provide a good example of potential functionalities of AR-based WoT applications. While digital twins are in service of physical assets such as cars and industrial machinery, their framework could be extended beyond data collection and simulations into system controls.

Building operations and maintenance schedules can be informed by data gathered from enabled devices. Similarly, the equipment inventory would be kept current with the digital twin framework between BIM+ assets and IoT-enabled physical building components. Equipment and machinery taken off service would immediately register as being offline, or decommissioned, with the BIM+ model automatically updating new equipment specifications and data channels. The update could utilize one of several localization technologies, such as RFID, WiFi, or Bluetooth Low Energy (BLE) beacons. A maintenance target can be easily positioned with AR sensor-based localization or with CV abilities.

At the same time, building repairs and maintenance could be enhanced by service staff's access to information on equipment, including its location and guidance on how it should be serviced. The instruction could be fed on an as-needed and just-in-time basis. This information could also be associated with technical drawings and be linked to video of the last servicing procedure. Localization and service guidance with the help of AR technology are already practiced in other industries, including the automotive industry [31], and could be easily ported into construction and building contexts. Added benefits of this approach would be the lower level of expertise required for specific operations, the ability to engage more complex tasks, and the expedited knowledge sharing between users [32].

AR UI is particularly effective in merging on-site activities with telepresence by allowing for sharing visual data and integrating remote experts on an as-needed basis. This can lead to combining training with the on-site maintenance work.

An important part of AR UI is the ability to share captured images and videos with remote collaborators. As pointed out earlier, this lowers the expertise threshold required to maintain complex assemblies. However, it can also improve quality assurance through CV and image overlays to see if the assembly conforms to the design specification [33]. The same strategies become even more relevant in construction, where a significant amount of work is performed on-site, with a lower level of quality controls and oversight. The consistency of quality and craftsmanship could be tracked over extended periods of time with IoT technology and compared between different work crews and conditions.

The quality assurance, particularly automated and CV based, opens an AR–IoT platform for augmented intelligence and artificial intelligence (AI) applications. Augmented intelligence emphasizes AI's assistive role, as it is intended to enhance human intelligence and effectively leverage human expertise rather than replace it. This goes back to previous points about how AR combined with IoT could elevate the skill set of a worker as well as provide customized and just-in-time UI options.

Two important aspects of the digital twins are predictive models and machine learning-based recommendation systems [34]. These are the same capabilities that would allow for enhanced UI in AR applications for IoT. An additional aspect of predictive modeling used by digital twins, as in GE's example, is the ability to collect and compare data across the entire fleet of similar smart assets. In the case of AR IoT apps, these data collection and comparison could include surveying both users with their profiles (context awareness) and similar conditions across the same class of smart objects functioning outside that context.

6.10 Public Assets with Public Access

SmartSantander projects set an important precedent for open IoT data, both as a public resource for environmental data awareness and as a style of transparent governance. However, key to successful dissemination and utilization of open data are applications that can make data and knowledge coming out of the data, easily readable and actionable for users. AR apps, with their dual physical and virtual highly correlated contents tagged with user filters and geolocalized, seem to be prime candidates for effective WoT applications. The democratization of environmental data through open-source sensor networks could also be seen in the crowdsourced movement that emerged after the Fukoshima Daiichi nuclear plant disaster in March 2011. Government efforts to contain radioactive spills and to understand the actual impact on the environment were inconsistent and caused serious concerns about the reliability of official reports. A number of activists developed an independent platform for environmental monitoring, specifically focusing on the deployment of Geiger counters throughout Japan. While this particular initiative originated from local concerns regarding the nuclear power plant radiation, it quickly acquired global relevance in the current climate-change context by developing a platform to share findings and "empower people with data about their environments" [35]. This platform—Safecast—followed a framework already established for similar data infrastructure and community initiatives for the IoT, such as Pachube/Cosm/Xively.

6.11 Collaborative Systems

The empowerment of users starts with their perception and acceptance of smart systems. The quality of user interactions is the main driver in the IoT asset quality perception [36]. This is the primary motivation behind the development of UIs that use natural interactions that users are already familiar with, such as a smartphone or tablet, instead of the traditional keyboard and mouse [37]. AR applications with CA are a meaningful step in reducing interaction barriers and making them more effortless. However, users not only need to interact naturally with IoT assets but also should be able to configure smart-object behavior and author the content.

6.12 Multi-user Interactions

While user controls and system overrides are essential components of smart systems, with multiple occupants, there is a strong possibility of conflicting requests. This raises the question of who has the ultimate control and whose authority should prevail. There is little research devoted to the specifics of multiuser conflicts which is smart building controls; however, a well-implemented CA module should potentially address conflict protocols by considering user privileges and profiles. Ultimately, there will also be occasions where building automation would execute predefined scenarios for conflict resolution. These scenarios would need to be associated with adaptive decision systems powered by a machine learning module.

6.13 Emerging AR-IoT Frameworks

A number of research studies utilize VR platforms for data visualization and communication. Bartosh and Krietemeyer [38] use the Oculus Rift and Unity3D game engine to investigate the connection between indoor environmental comfort and energy data (Fig. 6.3). The authors claim that VR environments can have a positive impact on design decision-making when correlating solar irradiation with VR tools. The same approach could also be applied to AR environments and interfaced via AR headsets, such as Microsoft HoloLens, or smartphones. Furthermore, this example speaks to the universality and scalability of this approach between various media and interfaces.

6.13.1 FRERE-NETRE

The project [39] exemplifies the class of interactive AR apps that extend physical 2D design representation by 3D assets and real-time simulations. While this particular

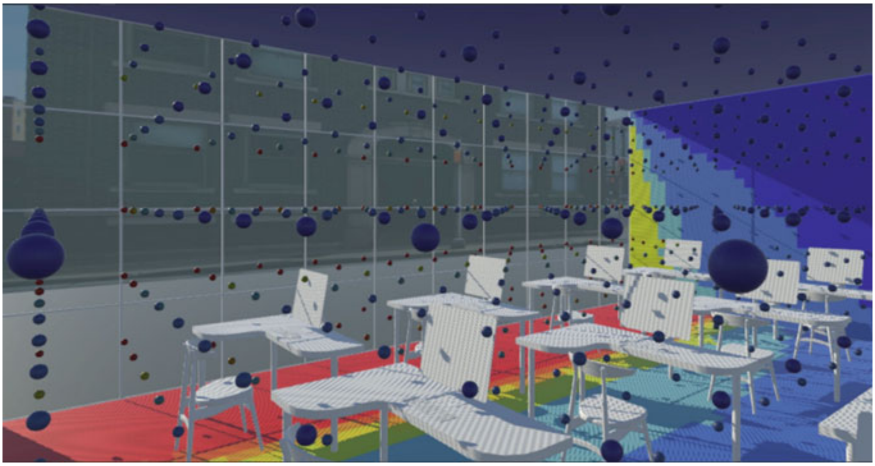

Fig. 6.3 VR interface showing environment and energy data in virtual space. *Image credit* Amber Bartosh and Bess Krietemeyer

project does not actively connect to IoT assets, it provides an effective prototype for the AR interaction layer for BIM+ and BAS/BMS platforms. It also can serve as UI for the digital twin framework. The project used design drawings as a base navigation map for interactions with the virtual content. With this AR app, audience is able to (1) access and manipulate 3D detail models, (2) control the layering and visibility of the construction detail data, and (3) interact with simulation infographics showing building environmental performance (Fig. 6.4). This information is contextualized through image targets (computer vision) and NFC technologies. The app allows not only for accessing non-printable and dynamically changing information but also for real-time feedback and commenting of design. As such, it could also function as a collaborative platform for building design, construction, and management. Its AR interface provides not only contextualized but also up-to-data and multimodal information.

Research by Jo and Kim [40] proposes an example of AR-based framework that interfaces IoT infrastructure called ARIoT. It provides a user-friendly environment for controls of home appliances, such as refrigerator, microwave, and electric kettle. It uses Bluetooth BLE communication for spatial localization. While it focuses primarily on the dedicated appliance controls in form of the virtualized remote control, it could be extended into a collaborative platform.

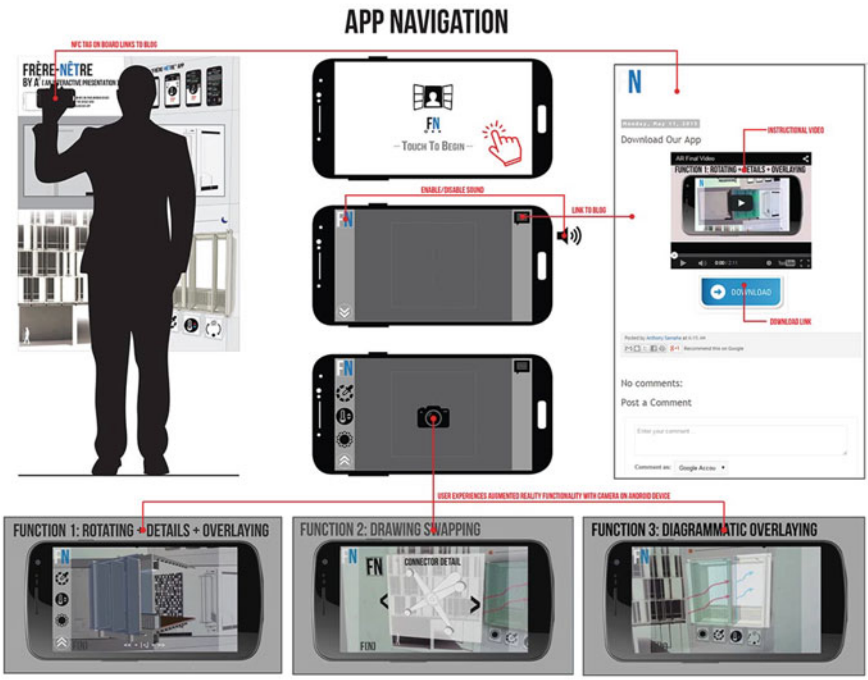

Fig. 6.4 AR app user interface and navigation tree. *Image credit* Anthony Samaha and Anthony Morrello

6.14 Building–User Interface

With the AR as localized data access and controls, WoT applications in the built environment can acquire an even greater role both as management tools and as user controls. With the combined platform of BIM+ knowledge-generating capabilities with AR-contextualized knowledge-sharing interface, there is an opportunity for a highly targeted and comprehensive building–user interface (BUI). The key components of an effective BUI include BIM+, which encapsulates a wide range of capabilities, such as (1) BIM, (2) IoT asset interoperabilities, (3) building performance simulations models (digital twins), and (4) BAS/BMS. There is also the need to interface this combined platform with (5) users and broader public interests. The question of what constitutes an effective front end for BIM+, giving direct access to users and allowing further access to other devices, programs, or databases, can be answered with an AR interface (Fig. 6.5).

AR leverages context awareness with IoT to collect information about the environment and share it with users. It also could bring a number of functionalities relevant to smart building: (1) user auto detection and tracking with understanding of past histories, (2) access to building controls with levels of security and authentication as with traditional computer networks, and (3) an adaptive and suggestive interface

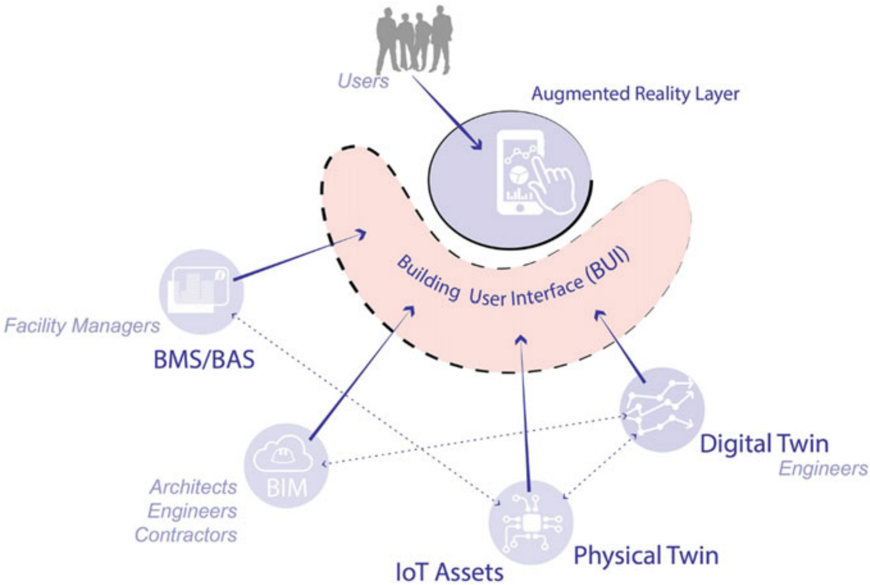

Fig. 6.5 Augmented reality (AR) as the Web of Things (WoT) application layer for the building user interface (BUI). AR layer provides users a single access point for data interactions and controls

utilizing advanced recommendation systems. Point 2 above directly connects to the non-WYSIWYG nature of AR environments, with data overlays customizable for context, location, and user characteristics.

Looking at a broad class of smart, enabled, IoT-connected, digitally twinned objects, certain shared characteristics emerge as consistent features informing ways to interface and control IoT assets. Localization with context awareness, including IoT assets as well as user characteristics and preferences, provides opportunities not only for broadcasting sensed environment to broader constituencies but also forms bases for computer-based contextual reasoning. The reasoning enhances the users' ability to process incoming information and, consequently, act on it. Data derived from IoT assets often speaks to broader societal needs and interests and offers an insight to how the built environment could be collectively shaped and improved. As such, it needs to be democratized—accessible and shared—while maintaining privacy and public safety. Providing an intuitive and transparent interface, such as AR discussed in this paper, seems to be a prerequisite to any framework that makes this data and controls an effective tool. Furthermore, AR is perhaps the most multimodal interaction interface currently used allowing for both data inputs and outputs as well as the use of multiple modalities, such as voice, text, and image.

6.15 Conclusions

Currently, IoT devices are being accessed and controlled through BAS/BMA platforms, web-based dashboards, or user-grade mobile applications, such as Nest or Honeywell thermostat apps. These services function as self-contained proprietary systems that allow for remote controls and data analytics but restrict access to only authorized users. While this is understandable from a building safety and operations perspective, there are also controls and data sets that could and should be made available to a broader public. With the IoT technologies reaching a broader consumer base and increasingly being seen as a public utility, as in the case of the SmartSantander project, there is a need to develop a public user access and interaction approach to IoT interfaces. This is particularly relevant in the context of the built environment, since buildings and cities always to some extent function as public domains serving citizens' collective interests. This public access and authorship of smart buildings and cities seem to be best addressed with AR-based applications that can front-end IoT, BIM, and BAS/BMS technologies to share their assets. The key concern is how to design an effective interplay of public, private, and environmental interests. The examples discussed in this paper start defining possible scenarios and technologies necessary for their effective implementation.

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Chapter 7
Narrative and Experiential Qualities of Architecture and Places in Video Games' Virtual Environments

Danilo Di Mascio

Abstract The research presented in this chapter focuses on a preliminary investigation of narrative and experiential qualities of architecture and places in the virtual environments of video games. This writing shares information from a research study in progress and other reflections based on parallel research studies and publications. This research investigates a selection of case studies through direct experience of their virtual environments. During these virtual explorations and analyses, concepts and definitions from both the architectural and video games' fields, and from previous research and publications in this area, are used. The tradition of designing imaginary architectures and places has expanded from architecture into other fields, and video games have added a new dimension to this. Video games allow users a freedom of movement that cannot be experienced in any other media. Thanks to the continuous artistic and technological progress accompanying video games, titles published in recent years present architectural and spatial characteristics that can compete with real-world buildings and places, and VR technologies bring these experiences to a new level. The conclusions describe possible relationships between virtual environments and reality.

Keywords Architecture and narrative · Experiential qualities · Imaginary architectures and places · Experiential qualities · Narrative qualities · Narrative architecture · Narrative urban environments · Video games' virtual environments · Virtual environments · Virtual experiences

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_7

7.1 Introduction

The research presented in this chapter focuses on a preliminary investigation of narrative and experiential qualities of architecture and places in the virtual environments of video games. This writing shares information from a research study still in progress and other reflections based on parallel research studies and publications.

In recent years, we have witnessed an increasing interest in academic studies related to the design of interactive virtual environments. This is partly due to the availability of more affordable and user-friendly advanced software (for example, real-time 3D immersion software such as Twinmotion [1] or Unreal Engine [2]), VR technologies and headsets. Another reason is the increasing popularity of the video games' industry, which has developed many creative ways of using these available digital devices and technologies.

The revenue of the video games' industry (including PC, console and mobile games) is now double the combined revenues of cinema and music [3]. However, in architecture and related fields, the number of research studies on video games is still quite limited. The majority of such research seems to focus on technical aspects linked to visualisation and overlooks several other elements that could inform and enrich areas of architecture connected to architectural theory and design. By contrast, several theories and tools used in the architecture field have been applied in video games' design. As mentioned in an earlier publication [4], this situation might be caused by various factors. One of them is the fact that if academics and professionals want to understand, study and analyse the characteristics and values of video games, they need to play them, and this is an aspect that should not be underestimated [4].

Another factor is that it takes time to recognise the cultural and artistic values of a new form of expression. The same has happened with other art forms including cinema, for example, and has recently happened with comic books. However, things are slowly changing. For instance, international museums such as the British Museum and the Louvre have started adding Japanese manga to their collections, and in 2019, the British Museum organised the most extensive exhibition of these comics outside Japan [5]. In a similar way, the artistic and cultural values of video games are increasingly being recognised, as demonstrated by the exhibition entitled "Videogames: Design/Play/Disrupt", shown first at the Victoria and Albert Museum in London [6] and then in Dundee [7]. All these exhibitions were organised in museums with an international reputation, and the latter was the first to explore and showcase the design process behind video games. It was very successful.

Furthermore, thanks to all the ongoing conversations around the metaverse, as well as various research projects and reflections on the positive effects of video games on people's well-being during the pandemic [8], a greater interest in video games and their virtual environments is now being generated.

7.2 Imaginary Architectures and Places and Their Interdisciplinary Expressions

7.2.1 Fantasy Architecture

Throughout architectural history and theory, there have been various examples of architects interested in exploring imaginary architectures and places. Piranesi (1720–1778), Etienne-Louis Boullée (1728–1799) and Francois Garas (1866–1925) are some of the many architects who designed imaginary, visionary and evocative projects. According to Bingham [9], the area of study related to fantasy architecture has started in early 1960 and has grown continuously since then. All these imaginary architectures and places go beyond the limits imposed by standard real-life architecture.

This tradition of designing imaginary places has also been expanded in other fields and through the use of new media including cinema and, today, video games. Each of these media has added a new dimension to the usage of these imaginary architectures and places. Cinema added the impression of moving through them along pre-defined and pre-recorded paths. By contrast, video games allow users a freedom of movement that is incomparable to any other media, as well as the facility to explore vast and immersive environments. People are very interested in exploring these virtual environments, as demonstrated by the many online rankings for features such as the "best video game cities" [10].

7.2.2 Exploring Digital 3D Virtual Environments

Similarly to cinema, comics and literature, video games can be classified into different genres; there are simulations and sports, strategy games, platforms and so on. Obviously, video games pertaining to these various genres are very different on multiple levels. It is evident that there are many differences between video games like Tetris, football games and games like Assassin's Creed [11] or The Last of Us [12] (Fig. 7.1). This research focuses on video games with a strong narrative component, which allow explorations of their virtual environments and which present first- and third-person points of view. The first-person point of view is the most immersive because it gives the player the impression of seeing the game world through his/her own eyes. The third-person point of view shows the 3D game environment through a camera positioned at a selected distance behind the shoulders of the controlled virtual character.

Fig. 7.1 The Last of US, a video game with a strong narrative component. *Source* Author's personal archive

7.2.3 Evolution of Digital 3D Environments

The true potential of 3D virtual navigable environments became evident after the publication of the video game Doom by ID Software [13]. This game allowed players to explore a complex and detailed 3D environment for the first time. The higher degree of immersion compared to all previously published video games was immediately evident. This game also generated a remarkable phenomenon of mods or users' modifications. Many of these mods were new levels, demonstrating people's interest in designing and playing/experiencing 3D virtual environments [14]. Since then, thanks to more powerful computers, technological advancements and new digital tools, the spatial complexity, aesthetic richness (in terms of quality and level of detail) and size of these virtual places have been constantly increasing. Other video games published after Doom improved some of its aspects and introduced new ones. For example, Quake [15] (also developed by ID Software) was the first game with full 3D levels instead of the 2.5D used in previous video games. Unreal [16] (by Epic Games) presented vast outdoor spaces and Half-Life [17] (by Valve) showed a strong narrative component.

7.3 Methodology

This research investigates a selection of case studies through direct experience of their virtual environments. During these virtual explorations and analyses, concepts and definitions from both the architectural and video games' fields, and from previous research and publications in this area, are used. The process of using direct experience to analyse architectures and places in video games' virtual environments is very similar to the way architects analyse real buildings and places. In the real world, it is possible to take photos to document some aspects. The equivalent recording process in virtual environments is taking screenshots. On the list of selected video games are included the following titles and series: Assassin's Creed Unity [18] and Syndicate [19], Bioshock [20], Dishonored [21], Half-Life [17], the Last of Us [12], The Order: 1886 [22] and Bloodborne [23]. Most of these provide the ability to free-roam around large virtual cities or places. This research is also informed by the study and analysis of several sources, including academic publications, art books of the selected video games, online websites and documentaries. Moreover, personal experience in the field of level design for video games constitutes further supporting knowledge. The research presented here continues a research path started in 2010 with a paper entitled "Learning from Video Games Level Design: an education point of view for architecture" [24] and developed further through other presentations and publications including [4, 14, 25].

7.4 Architectures and Places in Video Games' Virtual Environments

Thanks to the continuous artistic and technological progress accompanying video games, titles published in recent years present architectural and spatial characteristics that can compete with real-world buildings and places. The increased freedom to design these complex virtual environments has also allowed game designers, level designers and concept and environment artists to take greater inspiration from various architectural styles and from real architectures and places. The design of each virtual architecture and place is usually informed by an in-depth precedents study and field trips to explore real locations. For example, this process has been used to design the fictional cities of City17 in the video game Half-Life and Dunwall in Dishonored (Fig. 7.2). This kind of design process shares many common elements with the design process in architecture and urban design. In-depth historical research has also informed the design of the historical cities in the Assassin's Creed Series [25].

7.5 Narrative and Experiential Qualities of Architecture and Places

Architecture and places in first- and third-person video games present several interesting characteristics, and two of the most relevant ones are related to their narrative and experiential qualities.

Fig. 7.2 In-game screenshot taken during the exploration of Dunwall in Dishonored. *Source* Author's personal archive

7.5.1 Narrative Qualities

In relation to video games (though this is also valid in several other fields), the word narrative can be interpreted in a wide range of ways. The idea of conveying narrative through the environment is at the centre of environmental storytelling [26], also used in theme park design (for example, in Disney Theme Parks). However, architecture has always communicated stories and meanings both intentionally and unintentionally. For instance, in Gothic cathedrals, spaces and decorations communicate several meanings and stories (Fig. 7.3) and usually translate textual descriptions such as those included in religious texts into an architectural, physical form. Two examples are the stained-glass windows and statues positioned inside and outside these mediaeval constructions.

In his essay "Narrative Spaces" [27], Jenkins identifies four narrative experiences triggered by environmental storytelling in video game spaces, namely, evocative spaces, enacting stories, embedded narratives and emergent narratives [27]. However, each of these expressions can in turn be interpreted by each scholar in different ways. For instance, Jenkins uses the expression "evocative spaces" to refer to spaces that are reminiscent of locations presented in other media such as books, and he uses as an example American McGee's Alice [28]. This game presents a dark version of Wonderland described by Lewis Carroll in his famous novel [29]. In this research, the use of the word evocative in reference to architecture and spaces in video games is connected to their capacity to evoke emotions, a quality that architectures and spaces also have in real life. Further interpretations of video games' spaces are included in the publication "Toward a Ludic Architecture: The Space of Play and Games" [30].

Fig. 7.3 Detail of York Minster (York, UK), a narrative architecture. *Source* Author's personal archive

For the purposes of the current study, narrative is mainly considered in relation to characteristics of architectures and places. Previous publications have described how the identification of a number of narrative layers can support the analysis of virtual cities in video games [4, 25]. The main plot/storyline affects the background setting, the main setting and the architecture and urban representations. Similarly to the real world, architectures and places in video games tell stories through their characteristics. Interiors and exteriors of buildings, and public spaces such as streets and squares, can present details about specific fictional past events, shed light on the current situation and/or indicate something about who inhabits or uses them. Moreover, they also suggest how the player can interact with them. These can be defined as virtual narrative environments. A specific time of day and weather conditions can further strengthen a particular narrative and atmosphere and support a specific moment in the story.

Places in video games are also informed by specific storylines. Whereas newly designed and built architecture presents only the narrative carefully planned by the architect(s), the passage of time, its users and other events will add several other narrative layers on top of this. Thus, embedding virtual architectures and places with narrative elements increases the immersion and the perception of visiting believable locations. Players often explore these virtual environments in the same way as they would explore real places, with a similar level of curiosity. Specific details can trigger questions and encourage players/explorers to fill gaps. Moreover, spaces are enriched by various smaller narrative elements that might be related to architectural and spatial details or activities performed by Non-Player Characters (NPCs). For instance, in Assassin's Creed Unity, it is possible to visit courtyards that present collections of classical statues (Fig. 7.4—above). These might be part of small quests/narratives or can simply be admired in the same way as statues located in any city with a specific artistic and historical past. These courtyards also host people concentrating on various activities, including conversations while enjoying some tea, or painting at an easel (Fig. 7.4—below). Hence, the place presents a variety of narratives similar to those that can be found in many real-life places.

7.5.2 Experiential Qualities

As mentioned before, compared to the representations of architectures and places in other media, including cinema, video games allow users/players to actively experience these places with freedom of movement and choice. Hence, the sense of immersion is much higher than that experienced through any other medium, as the players are not merely passive viewers but are constantly asked to make active decisions and move dynamically in real time through various locations. This kind of experience, involving the user's active role and dynamic movement, has never previously been provided in media. Moreover, the narrative layers previously described enrich players' experiences. Video games' environments allow players to experience many locations, and thanks to their narrative qualities, the entire process of exploration and discovery is very often engaging and rewarding. Each street, passage, corner or doorway could hide a surprising location. The sense of wonder and discovery that accompanies these explorations is constant, and this is one of the reasons why these game environments are so successful.

In The Last of Us [12], for example, the two protagonists explore several locations including areas and buildings within big cities such as Boston, small and isolated houses in the woods, a small town and a lakeside resort in Colorado. Along the journey, the player is constantly asking himself/herself what the next location might be, and there are always opportunities to be amazed.

This also explains why players constantly desire new virtual architectures and places to explore and why there is such a remarkable variety of virtual locations. It is possible to explore places and interact with them in many ways, for example, by walking, running, climbing and so forth. Despite the possibility of using other transportation means in specific locations, for example, a buggy in Half-Life 2 [17], horses in The Last of Us [12] and carriages in Assassin's Creed Syndicate [19], the main way to move through and explore these virtual environments is by walking, an activity that allows players to appreciate the quality of the virtual architectures and places and their narrative elements. Moreover, walking often allows a seamless experience of movement, for example, from street level to rooftops in the Assassin's Creed series. In the first Dishonored video game [21], which presents a semi-open

Fig. 7.4 In-game screenshots collected during the exploration of Paris in Assassin's Creed Unity: (above) courtyard with several classical statues which are part of a quest; (below) on the right-hand side of the main character, there are people engaged in several activities, from conversations while enjoying tea to painting at an easel. *Source* Author's personal archive

world, the player can reach locations relevant to the story by using various paths. The game gives the player the opportunity to perform the role of an assassin who can, with his physical and magical skills, furtively move through and experience a variety of locations such as rooftops, houses with big interior spaces, jails, bridges. By moving through these locations, the player can experience the narrative of these places and their characteristics, including scale, atmosphere, decorations and materials (Fig. 7.5). As the whole experience moves closer to the experience of real places and architecture, it also becomes possible to apply some of the approaches

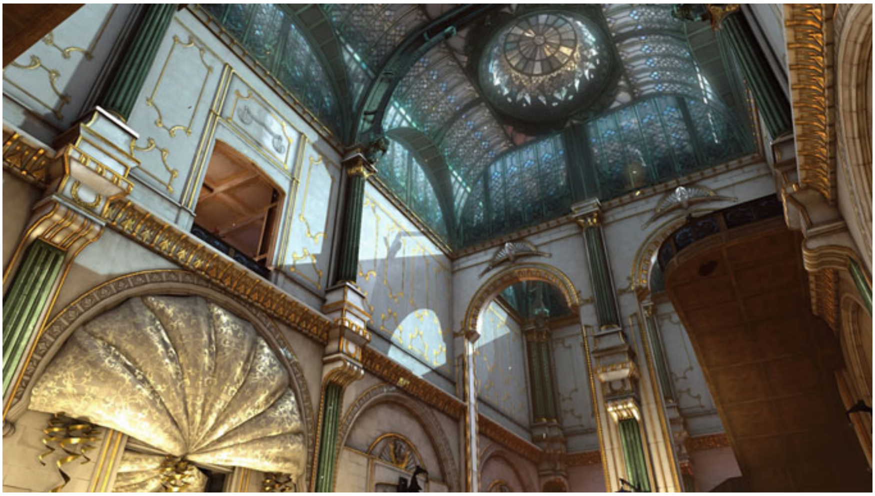

Fig. 7.5 In-game screenshot collected during exploration of the Boyle Estate in Dishonored. The sumptuous interior spaces tell something about their owners. *Source* Author's personal archive

to perceiving and understanding architectures and spaces available in publications such as "Experiencing Architecture" [31].

7.6 Towards New Virtual Experiences

In 2020, Valve finally published a new, long-awaited chapter of the Half-Life series, Half-Life Alyx [32]. This game was published 13 years after Half-Life 2: Episode Two [33], which had previously been the latest episode of the series. Compared to the previous episodes, Half-Life Alyx introduced VR technologies which, together with more detailed and carefully designed narrative virtual environments, provide a sense of immersion and interaction never experienced before. Moving around a more detailed version of City17, and interacting with virtual objects by using wireless controllers, is an experience difficult to describe and understand without trying it in person (Fig. 7.6). This highlights the point that in order to understand the narrative and experiential qualities of architecture and places in City17, it is essential to explore the city directly with a VR headset. No images or pre-recorded gameplay videos can communicate or provide the same information and emotions. Moreover, there is a clear difference between experiencing City17 on a TV or computer screen and experiencing it through a VR Headset. With this latest technology, there is the impression of "being there". Even though the three senses involved (sight, touch and hearing) are the same as when playing a video game without VR, the sense of involvement is different. This is largely because the scale of objects is 1:1 and the interaction with these objects, as well as the player's movement via the controllers,

Fig. 7.6 Two in-game screenshots of City17 taken from Half-Life: Alyx. *Source* Author's personal archive

is closer to experiences available in real life. It is not uncommon to linger on even the smallest, most unimportant detail, for example, a simple handrail.

7.7 Relationships Between Virtual Environments in Video Games and Reality

Thanks to technological advancements and more affordable prices of computers and consoles (for example, PlayStation, Xbox and Nintendo), many people can now explore the imaginary worlds of video games. Computers and consoles could be considered as doors to other worlds, similar to Narnia's wardrobe door [34]. Moreover, the complexity and size of the architecture and places in these virtual worlds are constantly increasing. There are obviously some interesting questions to be considered. Why do people want to spend hours exploring imaginary places? Why do they prefer to spend more time in virtual environments than in real places? For many years, it has been possible to note that the amount of work, care and detail going into the design and creation of video game virtual worlds is increasing, and the results are obviously more exciting and engaging, while many new interventions in the real world continue to lack detail for a variety of reasons. As mentioned in other publications, it is essential to design architectures and places which, in addition to their purely functional elements, provide users with interesting and enriching narratives and experiences. This has also been highlighted by the COVID pandemic, when people were constrained in their homes, neighbourhoods and cities [35]. Interestingly, playing video games based on exploration and complex narratives was found to have a positive effect on people's well-being during the pandemic, because it allowed players to escape into other worlds where they could feel immersed, relaxed and engaged [8].

One of the sources of inspiration for the modern movement was abstract art. However, it is not surprising that several spaces inspired by abstract art are alienating and lack a variety of exciting details. Moreover, many abstract representations in today's architecture fail to communicate interesting spatial and narrative experiences for people, or even any spatial experiences at all. Also, the smart city movement has not communicated places with interesting narratives and experiences, but rather, places where efficiency seems more important than providing people with desirable lifestyles. This is clearly confirmed by the online article "Toronto wants to kill the smart city forever" [36] and by listening to the experiences of people living in these smart cities, including Songdo, one of the most technologically advanced smart cities in the world [37]. The narrative and experiential qualities of many architectures and places in video games could enable us to re-evaluate how we design in the real world. It is clear that there is a need to develop projects which present and trigger such engaging narratives and experiences. The sense of discovery and wonder people feel while exploring these virtual environments should also be present in our urban environments. Indeed, architecture is not the only field that could benefit from a consideration of video games; as mentioned in Jane McGonigal's book "Reality is Broken" [39], video games provide a sense of engagement and other positive characteristics that are often missing in the real world. A look at the numerous residential complexes around the world constituted by repetition of the same high-rise buildings makes it clear why many people living there enjoy spending hours roaming inside virtual places.

7.8 Conclusions and Future Developments

This chapter has presented reflections and information developed during ongoing research, in combination with information and findings from other parallel projects. It is clear that more studies on the narrative and experiential qualities of architecture and places are needed and that the virtual environments in games can provide many sources of inspiration and study. Understanding why so many people are willing to invest many hours exploring imaginary architectures, cities and places could also help architects, urban designers and related professionals to understand how to improve real places.

It can be argued that three main relationships with video game virtual environments are possible. Firstly, they can inspire and inform the way we design the narratives and experiences of real architectures and places. They can also complement real architectures and places by providing narratives and experiences that cannot be provided in the same way or with the same freedom and complexity in the real world. Finally, once the necessary technologies are available in the distant future, they could almost substitute reality and provide fully immersive narratives and experiences. Obviously, a combination of the first two relationships would be preferable. This research will be further developed through future projects and publications.

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Part IV
Communication and Cultural Value

Chapter 8
Spatial Behavior Data in Virtual Conference: Proximity and Network Analysis

Gi-bbeum Lee, Mi Chang, Ji-Young Yun, and Ji-Hyun Lee

Abstract Recent advances in virtual environments have extended real-life activities to virtual spaces, thereby generating enormous amounts of data on spatial behaviors. Spatial behaviors in physical spaces have been extensively studied; however, in virtual spaces, it is limited to measuring proxemic distances or visualizing spatial diffusion. Therefore, to understand users' spatial behaviors in virtual spaces, a novel network approach that connects users and spaces is proposed in this study. Using a proxemics dataset from a virtual conference, positional connectivity between users and spatial units was measured using Euclidean and temporal measurements. A bipartite network and projections were used to extract Close-Proximity Interactions. The proposed method quantified user activities using topological features. In addition, log analysis revealed observations of spatial interactions in virtual spaces without a dedicated tool, such as an eye tracker. The results of this study can improve the understanding of remote-learning activities in virtual spaces. Its application can help education managers, designers, and marketers to assess user interactions based on specific contexts in virtual spaces.

Keywords Spatial behavior · Proximity · Bipartite network · Virtual conference · Log analysis

8.1 Introduction

Social activities in virtual environments (VEs), including academic conferences, have increased owing to recent advances in virtual reality technology and global pandemic issues. The increased use of VEs has produced enormous amounts of data that can be used to quantify and analyze spatial behaviors of users. Thus, research on

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_8

spatial behaviors in virtual spaces is both possible and necessary. However, previous studies on spatial behavior in virtual spaces have been limited. For example, many studies have focused on heatmap visualization of spatial diffusion and proxemic distance measurement based on user characteristics. On the other hand, spatial behaviors in physical spaces have been extensively studied from various perspectives and methodologies [1].

The assumption in this study is that understanding spatial behaviors in virtual spaces can be deepened by further analyzing spatial behaviors in physical spaces. Therefore, we propose a novel network approach to understand users' spatial behaviors in virtual spaces in terms of spatial interactions. As a preliminary study, we applied our network approach to a proxemics dataset from a virtual conference [2]. We developed bipartite networks of users and spatial units. The temporal frequencies of consistent distances are represented as accumulative edge weights. The spatial interaction and social networks of conference participants were extracted using bipartite network projections [3]. We compared these networks according to conference sessions based on the topological features—node degree, centrality, and modularity.

Further, we designed a virtual conference for the fourth Cultural DNA Workshop. This workshop was held virtually using the metaverse platform—Gather Town. The spaces were implemented in a similar structure and image as the third workshop venue. The elements in the spaces were organized to facilitate presentation and socializing.

Preliminary results showed that our method could quantify user activities using topological features. The results also provide evidence for expansion of the understanding of remote learner activities to virtual spaces. Academia and practitioners can use applications of this method to assess user activities based on specific contexts in virtual spaces. Through further studies, we will look deeper into users' socio-spatial activities in the context of virtual education.

8.2 Related Works

8.2.1 Spatial Behaviors in Physical and Virtual Spaces

Researchers have attempted to understand the context and behavior of physical spaces using various types of data and methods. Recent spatial data include logs (GPS) and user-generated content (PPGIS). Some studies have used such data to analyze spatial behaviors and understand spatial processes, such as diffusion, interaction, impact, and segmentation [1]. The various tools and approaches for analysis include network, clustering, pattern extraction, simulation, psychometrics, overlay, and proximity measures. In particular, social studies have utilized proximity measures to assess the spatial behavior of subjects. Hall [4] developed the representative concept of proxemics. In addition, Close-Proximity Interactions (CPIs) at different distances have been measured to simulate disease diffusion among social networks [5]. Regarding proximity of humans and space, people understand behaviors in a specific location as an information source and descriptive norm and then try to align with the information to maximize social norms [6, 7]. Thus, the information that people receive from close spaces is essential to composing a social place.

In virtual spaces, spatial data, such as GPS and PPGIS data, can be automatically obtained using the VE system. Avatars ground the user behaviors to VEs by expressing their intentions automatically or semi-automatically according to their interfaces [8]. In addition, the users interact with the virtual space using the position and direction of the avatars to receive spatial information [9]. Moreover, social norms in physical proxemics appear similar to spatial behaviors in virtual spaces [10]. Furthermore, position and direction provide social cues to the other users [11, 12]. While most VEs enable peer communication when two users get closer, users tend to control their avatars and create social formations and face a peer for communication [11]. Although several studies have used hybrid tools to analyze spatial processes [13, 14], methodologies to expand the understanding of virtual spatial behaviors still require progress.

8.2.2 Proxemics in Virtual Education

Educational and academic events have been one of the active uses of collaborative learning environments, and the study of remote learner experiences is becoming important. Videoconference applications, such as Zoom and Skype, have been widely used for this purpose. However, some social VEs—such as Gather Town, Mozilla Hubs, and Second Life—have recently increased in use.

Most studies on educational events have used videoconference environments [7]. Although these environments showed advancement in information exchanger, they did not facilitate socializing among learners [15]. Moreover, videoconference environments have shown limitations in collaborative learning in which the exchange of social resources through private talks and presentations/lectures is an essential activity for learner communities [16].

Recent studies have focused on environments that provide virtual spaces and virtual bodies (i.e., avatars). These studies gathered spatial social data to analyze remote learner activities in the environments [2, 15]. The feedback from student experiences proved that socializing and feeling a sense of place were facilitated in Gather Town [15]. When learners socialized and presented in virtual spaces, their avatars maintained proxemic zones in a manner very similar to physical spaces [2]. Immersive virtual environments support people in paying attention to a talker when they converse [12]. However, there is still a lack of research on socio-spatial analysis in the context of virtual education. In the following section, we describe our network approach to spatial behavior using virtual conference data.

8.3 Network Approach to Virtual Proxemics Data

8.3.1 Dataset

In the preliminary study, we used Williamson et al.'s [2] proxemics dataset extracted from user logs of a virtual academic conference. The conference was held in a 3D virtual environment platform, Mozilla Hubs.[1] Most conference participants joined the venue using a web browser, whereas a few used a head-mounted display. The open-source platform was implemented on the web using the A-Frame and three.js framework. The researchers customized the client to track logs on ticks and opening of scripts and datasets.[2]

From the log data, we utilized the main-room logs. The main-room activities were conducted in the program order—keynote session, the first break, short presentations, and the second break. These activities took approximately 95 min in total. The main room was an outdoor lecture hall equipped with large and small screens called *Outdoor Meetup* by Mozilla Hubs.

The dataset contained user positional data according to time and space, and our main focus was on the position and direction of the avatars. Specifically, we used the values of the timestamp, UUID, room, and coordinates (x, y, z). Table 8.1 shows example data with the columns that we used from the dataset. Data sampling was analogous to the method used by the researchers in their article. We performed 0.167 fps sampling, which was the result of ten frames of extraction per minute. Rows that contained missing values were dropped. In total, 8657 event rows from 18 participants in the main room were retained.

8.3.2 Methods

For the analysis, we produced bipartite graphs (Fig. 1b) of users and spatial units that compose the virtual space (Fig. 1a). In the graphs, the edges are drawn by the positional connectivities of user–spatial unit pairs. First, the direct interaction between the user and space was measured by positional connectivity. We measured the Euclidean distance between the coordinates of the avatars and the spatial units. If the distance was within a certain range and connected the two nodes, it was counted as an interaction. The edge weights were increased based on the temporal scale and the number of frames in which interactions were counted.

Spatial and social interactions were extracted by projection on bipartite graphs of positional connectivity. Social connections were analyzed using social networks (Fig. 1c) based on CPI. To produce social networks, direct interactions were counted if the user and spatial units were within each proxemic zone. Concerning the size of

[1] https://hubs.mozilla.com.

[2] https://github.com/ayman/hubs-research-acm-chi-2021.

Table 8.1 Virtual proxemics data

Timestamp	UUID	Room	*X*	*Y*	*Z*	*fX*	*fY*	*fZ*	*fW*
1.588147e+09	e66510f1-5be6-49d3-b453-d6c4c06fc90c	/x5Dw6Dp/ social-xr-workshop	12.514999	9.039499	38.039475	− 0.218455	0.388116	0.0	0.895345
1.588147e+09	e66510f1-5be6-49d3-b453-d6c4c06fc90c	/x5Dw6Dp/ social-xr-workshop	13.634767	8.199674	36.919707	− 0.218455	0.388116	0.0	0.895345
1.588186e+09	4c94bc4d-f1d1-47f2-bfa3-7c80ecd04636	/x5Dw6Dp/ bleak-wide-nation	3.725364	1.615979	17.981550	− 0.022345	− 0.600723	0.0	0.799145

UUID Unique ID for users. Room: Unique ID for spaces. X, Y, Z: User coordinates. fX, fY, fZ, fW: User orientation (quaternion)

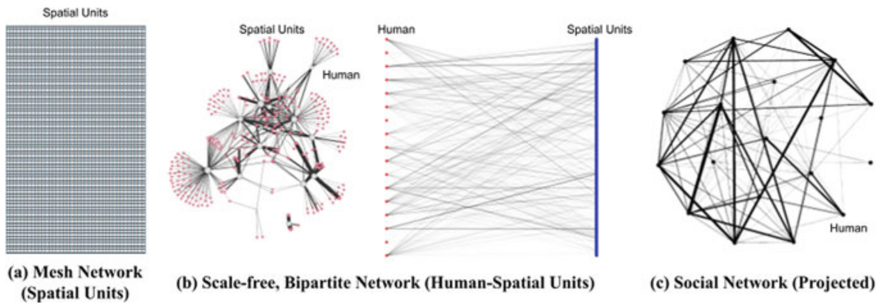

Fig. 8.1 Types of networks to investigate socio-spatial behaviors

the main room, only the personal zone (0–1.5 m) and social zone (1.5–3.6 m) were counted.

8.3.3 Results

The sequences of spatial interactions were visualized using projected graphs of the positional connectivities between spatial units (Fig. 8.2). Spatial units were arranged according to their coordinates in the main room. Different types of information were displayed and extracted from the same dataset using heatmaps and networks. Our approach provided additional information about its trajectories, while both approaches showed where they were crowded by participants.

The CPI social networks revealed clear differences in topological features according to proxemic zones (Fig. 8.3). On an average, CPIs occurred between 6 and 10 users in social-distance networks and 1and 2 users in personal-distance networks. Every user was connected to a giant-connected component (GCC) in a social-distance network. By contrast, the users were clustered with moderate modularities (0.34–0.54) for community detection in personal-distance networks. Personal-distance networks always showed a GCC and 2–5 isolated users. Although the clustering coefficient remained at a similar level over the same proxemic zones, the personal-distance network showed no triangle during the short presentation session.

8.3.4 Findings

From the results, we found evidence that expands the understanding of learner experience using topological features.

In bipartite graphs of users' spatial units, user node features can provide quantitative information about the spatial activity of the user. For example, user nodes with high degrees can be interpreted as conference participants who visit many spaces in

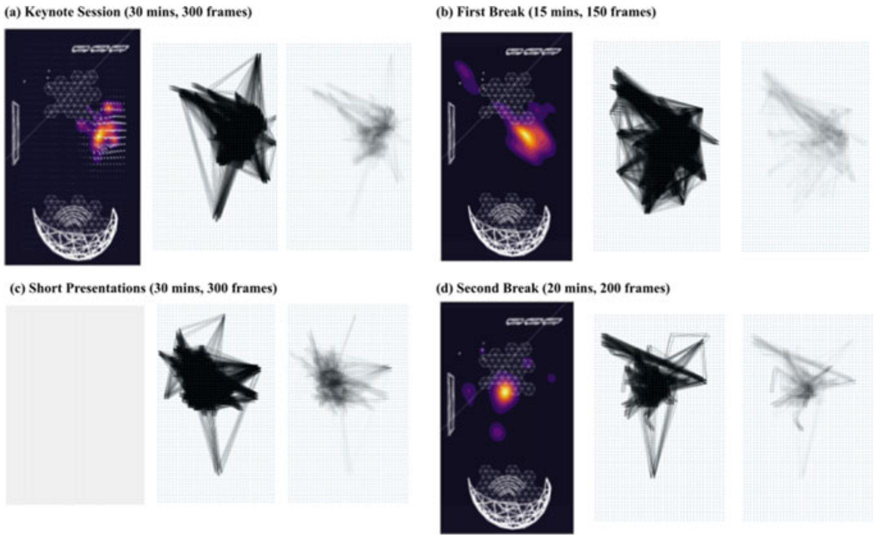

Fig. 8.2 Spatial diffusions visualized in heatmaps (Williams et al.) and networks (ours). Networks were drawn in unweighted (left) and weighted (right) forms

a venue. Because network nodes can accept neighbor information, they are expected to be exposed to a large amount of spatial information. In addition, these participants were expected to have a number of social interactions with other participants. Similarly, user nodes with high degrees in CPI networks can indicate active collaborators in a learning community.

By contrast, user nodes with low degrees showed high weights on their edges. The high weights between users and spatial units represent the intensity of visits to a point. The participants were expected to accept information from spatial units. These highly weighted edges were compressed into *strong ties* between participants in the projected CPI networks.

Virtual proxemic zones between two users are represented as edges in the bipartite graphs. With this view, researchers can identify the number of proxemic zones generated in the virtual space and the location of the spatial centroids of social interactions. This method can provide richer information about the "wheres" and "whos" in socio-spatial activities in VEs. Eigenvector centralities of the nodes can be read as the mainstream points of the event.

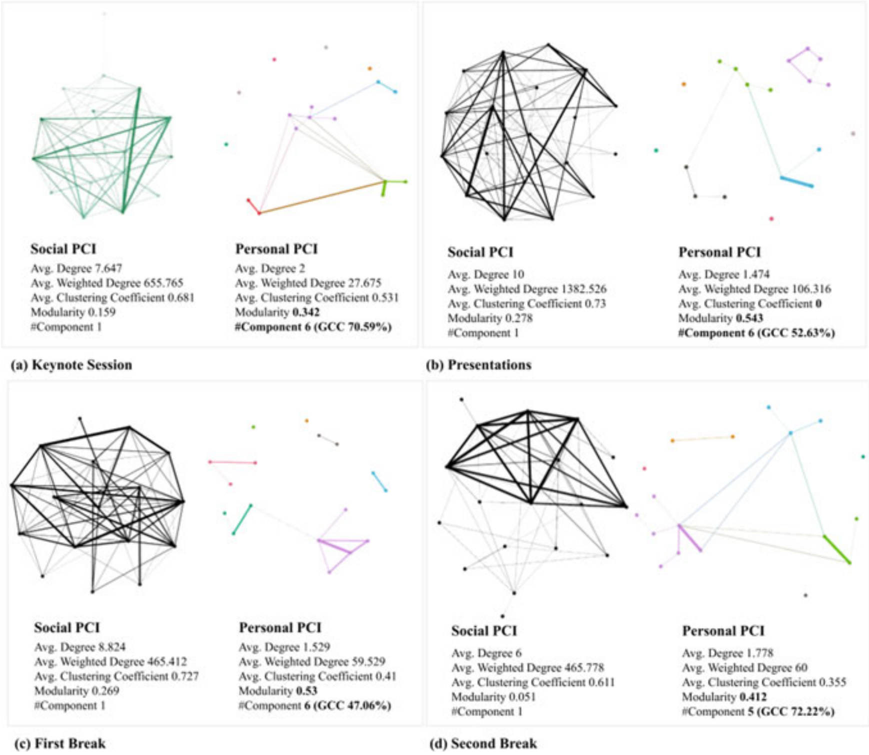

Fig. 8.3 Close-proximity interactions (CPIs) between participants

8.4 Design of the Fourth Cultural DNA Workshop

8.4.1 Environment

The fourth Cultural DNA Workshop was designed to be held virtually using the well-known VE platform, Gather Town.[3] Gather Town is a web-based metaverse of two-dimensional virtual spaces that provides various communication methods, such as proximity chats, text chats, and private areas. This platform has been used for educational events, conferences, social meetups, etc., by a wide age range of users. Presumably, the participants of this workshop have seen a picture of it or have experienced it.

We designed the workshop spaces based on the venue of the 2019 Cultural DNA Workshop at the Graduate School of Culture Technology in KAIST, South Korea. We replicated most of the spatial structures, such as walls, windows, and desks. The

[3] https://gather.town.

conjunctions and orientation of spaces were altered so that participants could clearly see the spaces and navigate in this two-dimensional platform.

Our main focus during data collection was the position, direction, and communication of the participants. For this purpose, our logging system tracked the following user events.

- User joins and exits.
- Avatar movements and direction changes.
- Object interactions.
- Proximity chats.
- Text chats.
- In/out conversation.
- Emojis.
- Bubble chats.
- Username changes.

For privacy, no content of chats was gathered by the system. Only the ringing activity, which is a function of ringing an inactive user, is collected by text chats. For example, if a user rings the bell of an inactive user, text such as '[is ringing you]' is typed automatically. User identifiers are gathered as UUIDs such that a participant identity is not obtained in the data.

8.4.2 Space and Settings

Workshop spaces were created as realistically as possible to track the spatial behaviors of participants in virtual spaces. There were four different types of places in the virtual workshop—the CT garden, corridor, seminar room, and our lab (Fig. 8.4).

As studies have shown, participants' proficiency in manipulating VEs is an important factor in user experiments [17–19]. Thus, to prevent confusions, such as unintentionally tentative movement and malfunctioning, we provided a manual on some important functions of the service.

The *CT Garden* is first point of access for participants in the virtual workshop. This place comprises interaction objects that include information about the workshop; thus, participants can easily access such information. For example, through poster objects, participants could check the fourth cultural DNA poster, schedule, and program. Banner objects with each symbol of the university were linked to the lab websites of the presenters. In Gather Town, people can talk to other users by approaching them. Floating video streams appeared when people were within 5 m. For those who wanted a private place, we utilized a catering territory. Outside a private area, users can talk to each other freely, but inside a private area, only those who are in the same area tiles can communicate.

We also issued an NFT as a reward to commemorate the virtual workshop. An ATM-shaped object was deposited in the CT Garden so that participants could check

Fig. 8.4 Aerial view of spaces for this workshop

their NFT wallets. We paid close attention to recreating the CT Garden because many participants had visited the place previously.

The *Corridor* connects the CT Garden, N25 Seminar Room, and the lab. Past Cultural DNA posters were hung on the wall of the corridor; therefore, participants could check the poster images by interacting with the poster objects. In addition, a door object showed the host's greeting when a participant interacts with the object. An ATM was also placed in the corridor in consideration of the crowds of people in the CT Garden.

A formal presentation was held in *Paik Nam June Hall (Seminar Room)*. This room is a representation of a room where we had a presentation at the third Cultural DNA Workshop. Interactive objects for checking the fourth Cultural DNA poster and its schedule were deposited in the room. In addition, there was a survey object that is linked to the website for a post-workshop survey.

Finally, the *lab* is a room to introduce the authors' lab. Additionally, the room could be used to provide casual conversations among participants. Through this room, participants could indirectly experience what the lab looks like. In addition, a computer-shaped interactive object was linked to the laboratory website.

8.4.3 Program

Based on the space described, the workshop was held for two days, as shown in Table 8.2. There were four sessions in total; the first day included two sessions, a total of six presentations, and tutorials of virtual workshops were introduced; and the second day included five presentations, a social networking break time, and an announcement of the workshop winner(s) throughout the remaining two sessions.

Table 8.2 Schedule of the fourth cultural DNA workshop

Date	Time (KST)	Programs	Presenter
Day 1 (August 11)	21:00–21:10	Workshop introduction	Ji-Hyun Lee
	21:10–21:30	Spatial behavior data in virtual conference: proximity and network analysis	Gi-bbeum Lee
	Session 1		
	21:30–22:00	Future learning in the metaverse—an exploration of virtual architectural design studios	Rongrong Yu and Ning Gu
	22:00–22:30	Designing in online, diverse teams: a study using protocol analysis	Ju Hyun Lee
	22:30–22:40	Break time	
	Session 2		
	22:40–23:10	Capturing the customer experience culture of high-end motorcycle helmets through the cyberspace	Kai-Ti Wang
	23:10–23:40	Universal design of signage through virtual human simulation	Matthew Schwartz
Day 2 (August 12)	Session 3		
	19:00–19:30	Panopticon of virtual classroom: evolution on teacher-student relationship in distance education	Tse-Wei Hsu
	19:30–20:00	Narrative and experiential qualities of architecture and places in video games virtual environments	Danilo Di Mascio
	20:00–21:00	Break time—networking and activity	
	Session 4		
	21:00–21:30	Latent space to support virtual 3D models	Jinmo Rhee and Ramesh Krishnamurti
	21:30–22:00	Merging augmented-reality interface with smart building controls: considerations for the building user interface	Andrzej Zarzycki
	22:00–22:20	Closing	Ji-Hyun Lee

8.5 Conclusion

Approaches for handling the increased data on spatial behaviors in virtual spaces have high potential for growth. This study demonstrated a novel network approach using positional connectivity between users and virtual spaces. The method was preliminarily tested on a proxemics dataset of a virtual conference. We demonstrated the utilization of topological features to describe remote participants' activities related to the virtual spaces. With this potential, we designed the fourth Cultural DNA Workshop to gather more spatial behavior data in the same educational context.

In our next study on this virtual workshop, we will apply the proposed method to new data and improve our approach. This preliminary study did not analyze spatial information in spatial units. Therefore, further studies should investigate spatial information. Although this study reported the early results from our first approach, we believe that this will support advances in the methods for understanding learner activity in VEs.

Acknowledgements We thank Juhyun Lee, Marvin Lee, and Ho Kim for their support in designing the spaces and in developing the logging system. This study was supported by Korea Advanced Institute of Science and Technology (KAIST) [Project Number: A0601003029].

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Chapter 9
Design Team Cognition Across Spaces and Cultures: An Exploratory Protocol Study

Ju Hyun Lee, Michael J. Ostwald, and Samaneh Arasteh

Abstract While historically the design team was almost always co-located, physically sharing the same space, tools, and systems, over the last few decades, advances in information and communication technology (ICT) have broadened the definitions of collaboration and teamwork, to include a range of Computer-Supported Collaborative Workplaces (CSCW). Such CSCWs have become core to the cognitive and communicative operations of design teams around the world. Furthermore, architectural design education and practice are increasingly reliant on multilingual and multicultural teamwork. Design team cognition (DTC) is central to design teamwork, particularly in a synchronous or asynchronous, distributed environment. However, DTC in remote, diverse collaboration processes is still largely uncharted territory. Thus, this exploratory protocol study (i) captures in-depth cognitive activities related to four DTC levels of online collaboration (visual communication, verbal communication, design coordination, and task coordination), (ii) compares the DTC results of two cultural teams (mono-cultural and cross-cultural) and their patterns over time, and through this, (iii) develops fundamental knowledge about the ways distributed, diverse teamwork settings, enable designers to effectively contribute to a changing global environment.

Keywords Remote teamwork · Computer-supported collaborative workplace (CSCW) · Design team cognition (DTC) · Protocol analysis · Online collaboration · Design communication

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_9

9.1 Introduction

The combination of *online* and *diverse* teams has posed a significant and increasing challenge across the Architecture, Engineering, and Construction (AEC) industry. At the same time, there has been growing awareness that competent multicultural collaboration is critical to success in a globalised creative economy [1]. Conventionally, design teams have been co-located, relying on the use of visual representations, physical cues, and multimodal communications that simply do not work in the same way when using technology to connect remote sites [2]. The use of different design environments or digital design technologies can also lead to different characteristics in the design process [3]. Particularly, remote design teamwork has inherently limited cues and representations (e.g. lost possibilities of instant sketches and models), undermining both standard design and communication processes. Further complicating this situation, multicultural studies have identified social and behavioural differences across nations and cultures, revealing that people from different countries have different value orientations [1]. For these reasons, misunderstandings between designers working in international teams can be costly and time consuming to correct, making it more difficult to solve complex problems and meet the requirement of different markets [4, 5]. That is, designers in culturally and geographically distributed teams face a significant challenge sustaining successful design collaboration. Past research on remote design teamwork is, however, limited to creating innovative digital environments for collaboration and supporting synchronous/asynchronous design communication [6–9]. In contrast, due to advances in information and communication technology (ICT), and specifically the Internet and Virtual Reality (VR), multiple studies have dealt with remote design teamwork in 'architectural design' [10–13], 'industrial design' [14–16], 'engineering design' [17, 18], and 'urban design' [19]. Their hypotheses, however, mostly address collaborative and/or design processes in different digital design platforms, for example, a comparison between traditional and remote or VR environments. In contrast, design team cognition (DTC)—interactive and collective design thinking—in remote teams is still lacking systematic investigation. Moreover, there is a clear knowledge gap between empirical evidence and practice in the cognitive operations of remote multicultural teams.

Past research has identified deep social and behavioural differences across cultures, confirming that people from different countries have different values and habits [1, 20]. Psychological, social, and semiotic researchers repeatedly observed that ideas were intrinsically tied to the language in which it was both constructed and expressed [21, 22]. It is, however, standard practice to assume that international design communication is conducted in English and that various forms of representation (diagrams, drawings, models) function as a type of 'universal' language, which overcomes any other linguistic, collaborative, and cultural barriers [5]. In contrast, design teamwork using remote communication has inherently reduced cues and relies on a limited representation and/or a shared screen. The question that this raises for many educators and practitioners is: *how do designers work in an online, diverse team?*

To address this knowledge gap and research question, this paper explores remote collaborative processes between distributed designers and across cultures. Multiple empirical and ethnographic methods, e.g. protocol analysis [23], qualitative content analysis [24], dialogue analysis [25], and video ethnography [26], have been used in the past to develop data from design communication, in an attempt to analyse or classify cognitive characteristics. In particular, protocol analysis has become the most widely accepted cognitive research technique in the design domain [5, 27]. In order to conduct the first investigation into cognitive activities in an online, diverse team, this paper presents an exploratory protocol study established upon the theoretical foundation of a DTC model [5], exploring both (1) visual and verbal *communication* [3, 28] and (2) *coordination* activities defining design and social relationships. Collaborative design is basically communicating and sharing 'expertise, ideas, resources and responsibilities' by coordinating design information and tasks between diverse participants [6]. Core to this activity is the concept of a mental model (MM), a 'mechanism whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states' [29]. A shared mental model (SMM), which represents 'shared cognition among dyads of individuals' [30], enables team members to develop consistent and coordinated teamwork [31] and to predict their actions without formal communication [32]. That is, the desire for 'shared design thinking' drives *communication* [33], along with interactions and information collection. Conversely, *coordination* develops correct relationships between team members, tasks, and design processes, integrating heterogeneous information. In summary, successful design collaboration should be caused by effective *communication* and *coordination.* In this context, this paper hypothesises that a mono-cultural team may have an existing SMM and easily develop it, while a cross-cultural team may need additional assistance to develop a SMM. To examine this idea, this paper reports the results of a protocol analysis study of two sets of remote design protocols.

9.2 Methodology

9.2.1 Protocol Data Collection

Two sets of design protocols were collected in a course at UNSW, Sydney on Building Information Modelling (BIM). This course was delivered in an online mode during the COVID-19 pandemic. Masters-level architecture students undertook a collaborative design assignment, 'mixed-use development (MXD)' in a real site (their own choice), using online conceptual design tools such as *Miro*, as well as BIM tools (*REVIT* and *BIM 360*). Each team, consisting of four designers, determined its own design concept and/or project goal(s) for a massing and planning design for four functional buildings (e.g. convention centre, residential, commercial, and hotel) and a bridging element (e.g. basement, ground floor, or skybridge). Importantly, designers

Fig. 9.1 Final design outcomes

were requested to record their online meetings (at least four 30-min team meetings) via an appropriate virtual collaboration tool (e.g. *MS Teams* or *Zoom*) over seven weeks. After the final submission of their assignments, students were contacted by the research coordinator to seek their consent for the authors to collect and use their recordings for research purposes and follow-up interviews. This exploratory research reports the results of two teams' remote collaborations (Team 1—Indian nationality and culture only and Team 2—Australian and Jordanian nationality and culture). These teams provided four and five recordings, respectively, but for the present analysis, the first, introductory and task allocation meeting and other very long meetings over 60 min were excluded. Thus, this study presents two protocols per team that were on design development and final stages for the assignment, respectively. Figure 9.1 illustrates the final designs produced by the two teams.

9.2.2 Coding Procedure

Each remote design meeting developed a concurrent, think-aloud recording. Collected recordings were automatically segmented and transcribed by an online application and then refined by the researchers. Since these protocols were design conversations, the automatic segmentation was largely dependent on changing speakers or long pauses. If a segment was encoded by more than one code (or episode) in the coding scheme (Table 9.1), then it was further divided. Some unnecessary segments caused by long pauses were also merged into a single segment.

The coding scheme in Table 9.1 consists of four DTC levels of collaborative activities—visual communication, verbal communication, design coordination, and task coordination. In addition to these collaborative levels, trivial 'chat' was used to encode casual conversation. Each code was selectively adapted from past studies, e.g. communication content, operations on external representations, design processes

Table 9.1 DTC coding scheme, partly adapted from [3, 28]

DTC level	Code	Description
	Chat	*Casual conversation*
Visual communication	Creating	Creating a design element
	Modifying	Changing object properties
	Inspecting	Looking at design brief or design representation
	Analysing	Analysing a proposed solution or design
	Evaluating	Evaluating a proposed solution or design
Verbal communication	Naming	The current focus of the design activity
	Proposing	The expression of an idea
	Constraining	The formulation of limits, or requirements
	Questioning	Raising potential issues of an idea or clarification
	Discussing	Discussing/explaining about an idea or question
	Reacting	Short agreement or disagreement on an idea
	Deciding	Making a choice or resolution
	Moving	Moving forward/backward
Design coordination	Collecting	Collecting individual designs in a team space
	Positioning	Positioning individual designs in a team space
	Detecting	Detecting clashes or issues between drawings or models in a team space
	Resolving	Resolving clashes or issues between drawings or models in a team space
Task coordination	Planning	Creating tasks, roles, or shared goals
	Reminding	Reminding tasks or situations
	Assigning	Assigning tasks or roles
	Negotiating	Negotiating tasks, roles, or goals
	Accepting	Accepting tasks, roles, or goals

[3], and a design conversation framework [28]. The first DTC level, visual communication, addresses a shared visual representation in remote design collaboration, while verbal communication is more related to a shared idea in the design process. As such, design coordination deals with drawings or models in a team space, linking to *BIM 360* or other remote design tools, while task coordination focuses on 'team-MM and task-MM' [34]. Compared to task coordination, verbal communication is close to individual cognitive operations in design process, i.e. 'process-MM' [34] or a 'distributed mental model (DMM)' [35].

This research involved two stages of encoding processes. In the first stage, a coder encoded each protocol twice over a three-month period. The coder commenced with the automatically segmented transcription and then revised it while reviewing the video recording. In contrast, the second stage used a pair of arbitration processes in which the first author and coder reviewed the encoded data together and resolved identified conflicts between them. To resolve some issues, three codes ('discussing', 'reacting', and 'planning') were added to the coding scheme. Lastly, the coder then encoded it once more, developing the final data.

9.3 Results

Excluding the first meeting, this protocol analysis used the second or third meeting and the last meeting of each team. Table 9.2 describes the results of segmentation and the final protocol data. The last meeting of Team 1 was relatively short (17.45 min) but produced relatively long segments (18.37 s), because there were some lengthy casual conversations. Since the second meeting of Team 2 (about 110 min) exceeded the length limit, this research instead reports the results of the third meeting. The last meeting of Team 2 also took about one hour but, after excluding a conversation with a tutor, it was 51.48 min long. Interestingly, the 'time per segment' results of Team 2 were shorter than those of Team 1.

9.3.1 Coding Results

Table 9.3 reports the coding results of DTC activities (codes) for remote design collaboration (the percentage of the frequency weighted by time). In the four team meetings, the dominant DTC level that the meetings produced was 'verbal communication', while they developed the smallest volume of 'design coordination'. Notably, the average coding coverage of 'Chat' was 24.08%. Both meetings of Team 2 produced a significant number of casual talks (40.13% and 35.80%, respectively). Thus, this paper describes DTC levels with/without 'Chat'. On average, the 'visual communication' level accounts for 16.19% with three dominant codes ('Analysing': 6.21%, 'Inspecting': 5.27%, 'Modifying': 4.96%); the 'verbal communication' for 30.68% with three dominant codes ('Discussing': 9.41%, 'Questioning': 9.24%, 'Reacting': 4.91%); the 'design coordination' for 9.86% ('Collecting': 7.94%, 'Resolving': 5.23%, 'Detecting': 2.63%); the 'task coordination' for 19.20% with three dominant codes ('Reminding': 7.31%, 'Negotiating': 6.67%, 'Assigning': 3.40%).

Table 9.2 Results of segmentation

	Mono-cultural team (team 1)		Cross-cultural team (team 2)	
	Second meeting	Last meeting	Third meeting	Last meeting
Time duration (min)	38.48	17.45	46.68	51.48
Num. of segments	270	57	375	367
Time per segment (s)	8.55	18.37	7.47	8.42

Table 9.3 Coding results (the percentage of time duration)

	Mono-cultural team (team 1)		Cross-cultural team (team 2)			
	Second meeting	Last meeting	Third meeting	Last meeting	Mean	SD
Chat	0.69	19.68	40.13	35.80	24.08	17.90
Visual communication						
Creating	1.69	–	0.43	1.23	1.12	0.64
Modifying	7.32	2.29	4.36	5.86	4.96	2.15
Inspecting	0.52	10.03	–	–	5.27	6.72
Analysing	11.74	5.35	2.61	5.15	6.21	3.89
Evaluating	1.86	–	1.86	2.46	2.06	0.35
Verbal communication						
Naming	0.95	–	4.00	2.20	2.38	1.53
Proposing	5.76	–	2.32	1.04	3.04	2.44
Constraining	2.43	–	0.21	–	1.32	1.56
Questioning	9.01	9.55	7.43	10.97	9.24	1.47
Discussing	18.28	6.69	6.82	5.86	9.41	5.93
Reacting	0.69	4.97	6.46	7.51	4.91	3.00
Deciding	0.09	–	2.82	4.08	2.33	2.04
Moving	1.86	–	0.07	0.65	0.86	0.91
Design coordination						
Collecting	0.13	15.76	–	–	7.94	11.05
Positioning	0.35	2.20	–	–	1.27	1.31
Detecting	0.13	7.45	1.50	1.46	2.63	3.27
Resolving	–	10.32	0.14	–	5.23	7.19
Task coordination						
Planning	–	–	5.36	3.69	4.52	1.18
Reminding	13.78	5.54	5.46	4.47	7.31	4.34
Assigning	6.33	0.19	3.57	3.50	3.40	2.51
Negotiating	12.39	–	3.96	3.66	6.67	4.96
Accepting	3.99	–	0.50	0.42	1.64	2.04
Sum	100.00	100.00	100.00	100.00	100.00	–

Excluding the 'Chat' code, the 'verbal communication' level accounts for 41.60%. Interestingly, the dominant DTC level in Team 2's meetings accounts for over 50%. This indicates that both teams tended to produce many 'visual communication' activities, although their allocations of DTC levels are quite different. Thereafter, 'task coordination' accounts for 24.97%, 'visual communication' for 20.91%, and 'design coordination' for 12.52%.

During the second of Team 1's meetings, four team members talked about the site of the MXD, various building levels of design, the bridging floor, and *REVIT*

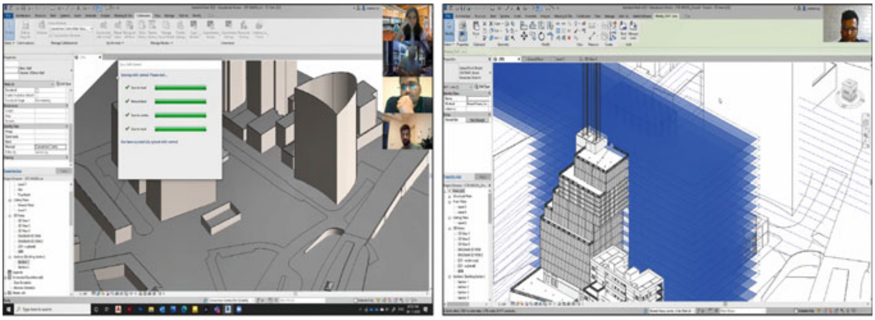


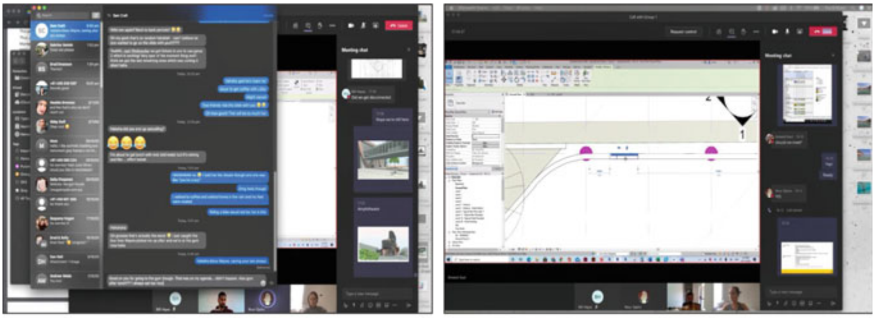
Fig. 9.2 Team 1's videoconferencing screenshots

models, producing the highest percentage of 'task coordination' (36.48%). At the same time, the meeting also developed the highest percentage of 'verbal communication' (39.08%). Both results indicate that the team addressed the development of SMM, because the meeting was still at the early stage of design collaboration, focusing on the site analysis (see Fig. 2a). In contrast, in the last meeting (17.45 min), one team member clearly led the team meeting, saying:

> … as I was saying, we can finalise the central model right now, I'm just going to sync it because we made some changes while we were working. And you've got the central model set up on the BIM 360 file, and we've got all of our individual models in folders and that once we're done with this, I'm just going to show how it's organized in BIM 360. So, each of us have individual access, cloud access to each of our buildings, and we're all working in different work sets as well in our individual files. Just so we have a file … that we can navigate easily and that does not crash multiple times … (Team 1, last meeting)

Likewise, designers at the final stage focused on coordinating the central model for *BIM 360* and individual models, producing the highest percentage of 'design coordination' (35.72%) (see Fig. 2b). The coding results, including the lowest percentage of 'task coordination' (5.73%) in the last meeting, reveal that their focus was on the coordination of their model, and they had already established a SMM. In addition, there was no 'Planning' code in Team 1, which might imply that this mono-cultural team had already distributed tasks and roles or shared goals before its final meeting.

In contrast, the cross-cultural team required a significant amount of 'verbal communication' activities and 'task coordination' until the final meeting. During the third meeting of Team 2, the four team members largely talked about general design issues and individual modelling techniques like *REVIT Families* as well the site and landscaping, which indicates that they were at the similar design stage to Team 1's second meeting. Interestingly, they also discussed using a group chat application to improve their communication (see Fig. 3a). However, they had a high proportion of casual conversations (40.13%). As such, the last meeting of Team 2 produced large amounts of 'chat', 'verbal communication', and 'task coordination' activities (35.80%, 32.31%, and 15.73%, respectively). Excluding 'chat', the cross-cultural team produced the highest percentage of 'verbal communication' (41.60%).



a. 3rd Meeting b. Last meeting

Fig. 9.3 Team 2's videoconferencing screenshots

Even during the final meeting, cross-cultural team members still required significant effort to develop a SMM (see Fig. 3b), producing the largest volume of 'questioning' (10.97%):

> I noticed that one of our requirements is to include on the cover page our design aims and stuff. Do you want me to do that? Or, I don't know if someone else wants to do it…. Cool. And then that BIM management plan, I feel like every single week we're told something different about that. … Did we agree what we're actually doing? Is it the combined one combined? … Yeah. But in terms of which template we use, is it the combined container? (Team 2, last meeting)

In summary, compared to Team 1's results, Team 2 tended to produce more 'chat' as well as 'verbal communication' activities. Importantly, Team 1's DTC coding results had dramatically changed over time, while Team 2's meetings developed similar DTC allocations. Because the mono-cultural team might easily form a SMM or clearly assign individual tasks or roles, the last meeting could focus on the 'design coordination' and produce less 'task coordination' activities. However, the nature of cross-cultural teamwork might require clearer or more frequent 'planning' and 'reminding' activities in the 'task coordination' level. Similarly, excluding 'chat', both the cross-cultural team members contributed relatively higher percentages of their time to 'questioning' activities (12.40% and 17.10%, respectively).

9.3.2 Cognitive Patterns Over Time

Figure 9.4 illustrates the four DTC levels of collaborative activities and 'chat' of Team 1's meetings over time. Like the coding results in Table 9.3, the primary differences are that in the second meeting, the 'task coordination' activities were dominant in volume and occurred more consistently, while in the last meeting, 'design coordination' was more consistent over time. In addition, the 'design coordination'

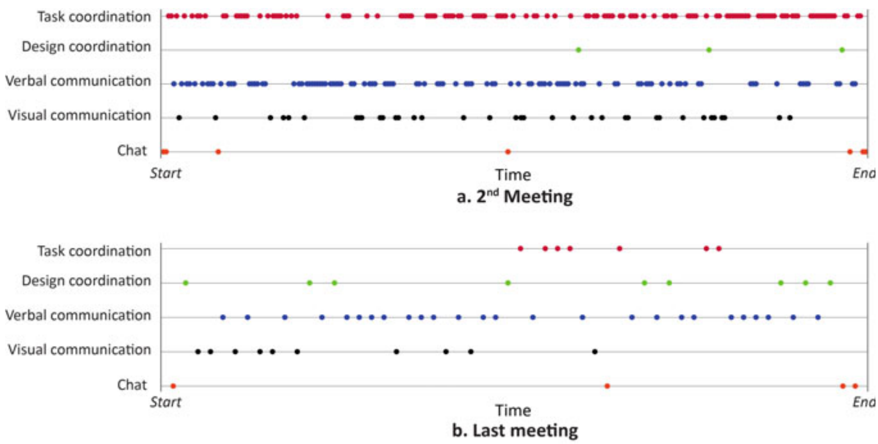


Fig. 9.4 Design team cognition (DTC) levels of Team 1's meetings over time

activities appeared at the late stage of the 2nd meeting, while the 'task coordination' activities started halfway through the last meeting. The 'verbal communication' and 'visual communication' activities were dominant and consistent in the second meeting, while codes for the 'visual communication' activities were less consistent in the last meeting. That is, compared to the second meeting, the last meeting in Fig. 9.4 developed the different DTC pattern over time. The casual talks rarely interrupted these meetings.

Figure 9.5 illustrates the four DTC levels and 'chat' of Team 2's meetings over time. Compared to the mono-cultural team's meeting, Team 2's meetings were often interrupted by 'chat'. The 'verbal communication' codes also appear regularly in the third and last meeting in Fig. 9.5. In the third meeting, team members tended to discuss tasks, roles, or shared goals, highlighting both 'task coordination' and 'verbal communication' activities. In contrast, at the early stage of final meeting, the team tended to focus on both 'verbal communication' and 'visual communication' activities. Except for that visualisation moments, the last protocol shows the regular use of 'task coordination' with a small number of 'design coordination' activities. In summary, compared to Team 1, the cross-cultural team developed different DTC patterns over time. This result may be caused by differences in communicating ideas [4], cultural experiences and preferences [36], or collaborative, conversational strategies [37]. Nonetheless, the shared understanding of tasks and goals should be critical in the formation of certain DTC patterns in online teamwork.

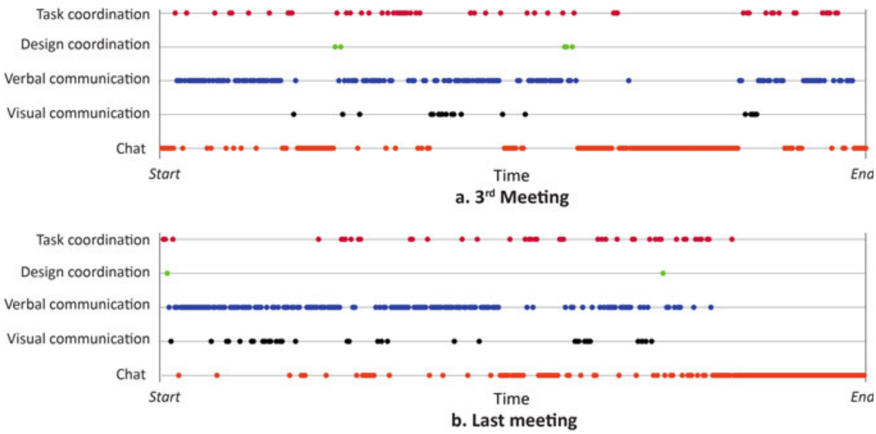


Fig. 9.5 Design team cognition (DTC) levels of Team 2's meetings over time

9.4 Discussion

This study has focused on communicative and coordination aspects of online design teamwork. Specifically, it was evident that the mono-cultural team more easily developed a SMM and a straightforward teamwork process from the second meeting to the last meeting. In contrast, the cross-cultural team required repeated 'team coordination' and 'verbal communication' activities across the different stages of the process. However, according to Lee et al.'s DTC model [5], team cognition consists of both a SMM and a distributed mental model (DMM), accommodating different perspectives of team members [35]. In addition, transactive memory is used for encoding, storing, and retrieving both long-term memory (LTM) and short-term memory (STM). These additional DTC components should be addressed in a future study, along with general design collaboration issues such as creativity and productivity, and precisely capturing microscopic design processes.

Although the 'verbal communication' activities were dominant in the online meeting, this study did not address the ways design language might shape design itself, and vice versa [36, 38, 39]. The cultural, linguistic characteristics of design, and their relationship to design communication and process, remain a further gap in disciplinary knowledge. Considering language as a system that reflects the way people think and their sociocultural values [40, 41], future research on online, diverse design teamwork should deal with a bi-directional relationship between DTC and design language.

9.5 Conclusion

While limited to the results of a pilot study, this paper has revealed different cognitive allocations and patterns over time between the online meetings of mono-cultural and cross-cultural design teams. However, due to a small sample size, it is impossible to develop any major conclusions about cultural differences. In addition, because the participants voluntarily recorded their online meetings, the collected data were never controlled to minimise environmental effects and interferences. That is why the cross-cultural team developed many conversational codes. Uncontrolled experiments might have both advantages and disadvantages, but at least they reduce the inference of the coding results. Acknowledging these limitations, this paper has uncovered four DTC levels (visual communication, verbal communication, design coordination, and task coordination) in different online meetings as well as the cognitive patterns over time, which were successfully captured by the DTC coding scheme. This fundamental knowledge and methodological development contribute to understanding the process of design across cultures, particularly in the distributed global environment.

Acknowledgements This research was supported by the ARC (DP230100605), UNSW Scientia program, and an Australia-Korea Foundation grant from the Department of Foreign Affairs and Trade (AKF202119).

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Chapter 10
Capturing the Customer Experience Culture of High-End Motorcycle Helmets Through the Cyberspace

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Abstract The demand for premium full-face helmets is growing. To win the market, the pace of product development has to match the rapid change of customers' culture. As technologies are reshaping the ways we work, studying customer experience is no longer restricted to the real world. To this end, this research demonstrates the collection of data in and through the cyberspace to gain insight on customer experience culture: (1) helmet online reviews; (2) subject matter expert interviews through the web. We performed two consecutive studies: (1) analyzing 15-month online reviews to identify critical customer values and (2) conducting online semi-structured interviews with two domain experts to obtain a comprehensive understanding of the identified customer values. Results showed that collecting data in and through the cyberspace was effective in identifying customer experience culture. Customers of premium full-face helmets cared more about the comfort, the noise deduction, and the usability issues when wearing helmets. The outcomes of the study provide insight on conducting remote user experience studies via the cyberspace.

Keywords Cyberspace · Customer experience culture · High-end and full-face helmets

10.1 Introduction

For the past few years, the sales of motorcycle helmets have surged dramatically [1]; also, the sales and demand for full-face helmets continue to rise. According to grandviewresearch.com, the market share of full-face helmets reaches up to 70% in 2018, and the website predicted the sales will continue to rise until 2025. Furthermore, since people travel more frequently and sales for high-end motorcycles are

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_10

growing in the market, luxury full-face helmets are attracting customers' attention [2]. Nowadays, the majority of research focuses on the safety and comfort of helmets [3–5], yet there is little research that focuses on consumer needs. For example, the user experience when wearing a helmet, the vision when the user wearing a helmet, or the needs when the user riding motorcycle, these topics are not yet been deeply studied. Therefore, for a rapidly growing market like the full-face helmet, further research on capturing the customer experience culture is needed.

In order to understand consumer demand quickly, all areas of society are rushing to join the virtual world [6]. As the metaverse changes apace in our lifestyle and the way of interaction [7], the customers' needs for physical products are no longer limited to obtaining them from the physical world.

Studies were conducted to investigate methods for capturing customers' needs towards products through the Cyberspace [8]. This suggests that acquiring user experiences via Cyberspace has good potential in understanding users compared with traditional face-to-face interviews and focus groups. Collecting user data via Cyberspace could not only reduce product development time [9], but also obtain valuable data regarding customers' preferences and behavior on products. Online review is one of the most efficient and widely used methods for capturing the customer experience culture. For instance, on washing machine showed though online reviews, the customer satisfaction was influenced by drainage methods, noise, color, and capacity [10]. Besides that, they found that although consumers are concerned about noise, the actual noise is different from what consumers perceived, and this kind of consumer attitude information can also be found on online review. However, many studies have shown the difficulty on obtain integrated and in-depth customer needs from online reviews [11]. Thus, there is a need for additional research to make up for deficiencies of information overload and unreliable data [12, 13].

This research aims to capture the customer experience culture of high-end full-face helmets in cyberspace through online reviews and online expert interviews. A combination of both methods provides a comprehensive and in-depth understanding of customer needs. Online reviews provide various preferences and usage patterns of customers; expert interviews provide a thorough understanding of the culture of these preferences and behaviors of customers. This research purposes a method for capturing the customer experience culture that can assist designers in quickly making design decisions and rapidly generating design concepts. As the result, companies can reduce the development time of premium full-face helmet, which allow extend the marketing period and increase life cycle.

10.2 Literature Review

10.2.1 Understanding the Limitations of Customer Needs from Online Reviews

The design and direction of products can be obtained through online reviews [14], which is a way to quickly provide the needs of customers. Collecting online reviews to obtain customer needs has long been widely used in various industries, for example, product development, website design, web store, etc. However, although online reviews have certain reference value, there are still many obstacles and uncertainties [15, 16]. For example, online reviews are overloaded with information, and companies lack effective methods to extract features from review content [17]; and some reviews are accumulated over a long period of time. In terms of satisfaction and ranking, the reviews will be too old and invalid. The company needs to have another method to evaluate which reviews are recent and effective [18]. Coupled with the uneven quality of review content, ranging from detailed and complete reviews to unilateral product reviews, it may cause useful information to be ignored [16].

Online reviews cannot obtain more accurate and complete information than questionnaires or field research [9, 19]. Therefore, although the valuable voice of customers can be obtained from online customer reviews, it is necessary to cooperate with other methods or analysis to increase the reliability of online review information. For example, [20] first, customer preferences are extracted through online reviews, and then product features are evaluated with Kano model and prioritized according to emotional needs. It provides the company with the importance of customers to product features, improves the reliability of online comment results, and helps the company to obtain a more accurate customer experience. In addition, [11] in order to shorten the gap between online reviews and actual results, product designers are also referenced to actually perceive, define and evaluate the usefulness of product reviews. Finally, follow-up analysis is made according to the designer's suggestions. The above research shows that companies can obtain customer satisfaction and demand directions for products from online reviews, but more detailed information about products cannot be obtained from online reviews. Therefore, other methods are needed to support the results of online reviews.

10.2.2 The Importance of Getting Customer Experience Culture Quickly

With the rise of global competitive pressure and the shortening of product life cycles, many businesses are attempting to reduce their product development cycles [21]. The full-face helmet's product life cycle is shortened. In the past, helmet development required considerable time. In the past, the development of helmets was labor-intensive and time-consuming, requiring a significant amount of human resources. The majority of businesses collect customer data through questionnaires, field research, and laboratory research. For instance, [22] spent three months interviewing one hundred individuals at local two-wheeler shops, metro parking lots, and helmet shops. This research requires a significant amount of time and human resources to collect data and recruit participants in the field. Furthermore, [23] observed and measured the head size, helmet wearing position, adjustment mode, and stability of 216 motorcyclists over a period of one year. Complete the measurement, fill out the questionnaire regarding past motorcycle riding experience, and obtain additional information about helmet use. However, the preliminary experiments and questionnaires will not only lengthen the duration of development, but also incur substantial labor expenses. The aforementioned methods will result in the extension of the development schedule, place a significant burden on the company, and even cause the launch of the product to be delayed. When the full-face helmet's product life cycle becomes shorter, the helmet becomes a popular and fashionable product [24]. The company must accelerate data collection in order to keep up with fluctuating customer needs. The Internet can improve development efficiency, accelerate product development, and lengthen product life cycles [25]. However, Internet usage by consumers may vary by region or country. To obtain customer requirements from the Internet, businesses must adopt diverse strategies based on cultural factors [26]. Internet is the most efficient and rapid way to understand the customer experience of different cultures [27]. Barnes et al. [28] online survey on purchasing behavior, they recruited 1011 consumers. The respondents hailed from France, Germany, and three culturally distinct American nations. Not only can researchers obtain the customer characteristics of different countries and cultures without traveling to each respondent's location, but they can also obtain information that is extremely useful for developing online marketing. In addition, [29] obtained product innovations by holding idea competitions on the Internet. It successfully stimulated creativity among users from diverse cultural background. The company utilizes the Internet to gather users for collaborative thought. The company utilizes the Internet to collect thoughts from users, which rapidly generating numerous new product design directions. The preceding research demonstrates that the customer experiences of various cultures can be obtained quickly and effectively via the Internet. The above research demonstrates that the user experiences can be obtained quickly and effectively via the Internet. Thus, collecting user data through Cyberspace reduces product development time and benefits product development teams in organizations.

10.3 Method

Objective

To win the market, the rate of product development must match the rapid evolution of the culture of customer experience. This study provides a method for rapidly obtaining the customer experience culture through non-physical media, using the example of a high-end full-face helmet. We collect online reviews of high-end full-face helmets and recommendations from remote expert interviews over the Internet in order to quickly capture customers' experiences with high-end full-face helmets. The research consists of two phases: (1) obtaining customer value from online reviews and (2) gaining a comprehensive understanding of customer value through expert semi-structured online interviews. Phase one can rapidly ascertain more comprehensive customer requirements. The second phase entails conducting interviews based on the online customer needs gathered in the first phase, which can enrich the information gathered in the first phase. Described below are the two phases of the study.

10.3.1 Obtain Customer Value from Online Reviews

10.3.1.1 Participants

Participants included one marketing manager from a Taiwanese helmet manufacturer and two industrial design graduate students. The marketing manager has 7 years working experiences in the helmet manufacturing industry. As the marketing manager of a Taiwanese company and its Italian branch, he is very familiar with the European and Taiwanese sales markets. He participated in the design and development of full-face helmets on numerous occasions and was familiar with their design, structure, and accessories. In phase one, the information experiment that can obtain customer value via internet evaluation can contribute to the current market trend and various safety helmet knowledge.

Two graduate students with expertise in industrial design obtained training from a helmet manufacturer and became knowledgeable about full-face helmet design. During this phase, in addition to providing sales data and fashion trends for high-end full-face helmets, the marketing manager of the helmet company has contributed significantly to the manufacture of full-face helmets. In the first phase of the experiment, two graduate students will collect and categorize online reviews.

10.3.1.2 Description of the Website

Customers' opinions primarily originate from FC Moto.com, Amazon.com, and Revzella.com. Statista.com is one of the world's most popular online statistical databases. Statista.com expressed ecommerce DB which contains a database of more than 200,000 online stores, which can provide online sales data, pertinent KPIs, and company information. According to ecommerce DB Com statistics, FC moto.com's annual net sales are greater than $50 million. And it has continued to expand since 2017. FC Moto.com only sells bicycles and items related to motorcycles. Examples include helmets, tectile pants, textile jackets, and gloves. It is one of the most popular websites for purchasing motorcycle accessories in European nations. Amazon.com is among the largest online retail sites [30]. According to the statistics provided by ecommerce DB.com, revzella.com's global net sales are $220 million dollars and have been rising since 2016.

10.3.1.3 Procedure

The first phase, obtaining customer value from online reviews, consists of two parts. (1) Validate the model of a premium full-face helmet. From FC Moto.com Amazon.com and Revzell.com, nine popular full-face helmet brands were chosen, including Shoei, Scorpion, Caberg, HJC, Nolan, AGV, Arai, Shark, and Airoh. Set the search parameters and examine the filter conditions, such as bestsellers, price between 159 and 360 euros, fiberglass, touring helmet, and reviews from January 2019 to April 2020, in the filter item column of each website. Motorcycle riding in Europe is primarily a hobby. They are willing to invest a substantial sum in premium full-face helmets. Consequently, the searched helmets are priced above the high end of the price range. Summer is when the majority of these consumers ride long distances. Consequently, an effective shading function is required. In addition to the original visor, the Touring helmet is equipped with sunglasses, meeting the needs of the majority of consumers. This full-face helmet is primarily composed of glass fiber and is resistant to brittleness after prolonged exposure. Then, we tally the number of reviews for each model of each brand, remove models that have been discontinued from each brand's official website, and remove customer reviews that do not elaborate on the function or content of the helmet and are older than January 2019 to April 2020. Ensure that our statistical results will not be impacted by a large number of invalid reviews that have accumulated over time. And choose the premium full-face helmet with the highest number of reviews. Regardless of the color and size of the full-face helmet, if it is the same brand and model regardless of size, it will be classified as the same full-face helmet when reviewing statistics. (2) Categorization of negative customer reviews. First, researchers collected all negative customer reviews of the intended helmet. Then, classify all customer specifications as negative comments. Similar requirements mentioned in the reviews are grouped together. Goggles are difficult to operate while riding, difficult to disassemble, difficult to install, etc. They will be categorized in the same group. The categorization of comments will guide subsequent phase two semi-structured interviews.

10.3.2 Remote Semi-structured Interview

10.3.2.1 Participants

This study involved the participation of two experts, the marketing manager and the designer of full-face helmets. One of the participants is a French marketing manager with over three years of experience in the helmet industry who had extensive knowledge of the motorcycle helmet markets in Europe and customer requirements. Standard amusement consists of riding a heavy motorcycle. His riding experience exceeds five years, and each ride is longer than two hours. It has three heavy motorcycles and multiple full-face helmets for use in rotation. The second participant is a helmet designer from Italy who has five year working experiences in the helmet design industry. He also has more than three years of experiences in riding motorcycles. He has three large heavy motorcycles and multiple full-face helmets. Thus, he was very familiar with the design, the stucture, and the safety requirements of full-face helmets.

10.3.2.2 Procedure

We conducted online interview with the experts. We asked them to "think aloud" the processes and steps they would take in response to the tasks we gave. We simulate the events that will occur when using the helmet. Allow the experts to observe the researchers wearing safety helmets, simulating riding motorcycles, removing safety helmets, adjusting safety helmet accessories, installing accessories, etc., prior to the interview. In each step of the researchers' operation, the experts must discuss the emotions, methods, and issues associated with using the helmet. At this stage, the objective is to allow experts to recall their own issues and ideas regarding the use of full-face helmets. Regarding the classification of online reviews generated in phase one, interviews were conducted. For instance, during the interview with experts, we will inquire about the first stage of statistics and discover that a large number of online commenters complain about comfort. From the interview, we can quickly ascertain the underlying meaning of consumer comments, thereby guiding the design of future designers.

10.4 Results and Discussion

Through online reviews and expert interviews, this study aims to quickly capture the customer experience culture of high-end full-face helmets in cyberspace. We conducted two experiments to quickly ascertain the customer experience: (1) obtaining customer value from online reviews and (2) gaining a comprehensive understanding of customer value through expert semi-structured online interviews. The initial phase of online reviews can comprehend the diversity of customer preferences and usage patterns. The second phase of expert interviews illuminates the cultural context of these preferences and behaviors. The method proposed in this study for capturing the customer experience culture can help designers quickly enter the design phases of product development, which reduces the time required for developing high-end full-face helmets, as well as increases the time for market sales and company profits.

10.4.1 Obtaining Customer Value from Online Reviews

There were a total of 353 comments from FC Moto.com Amazon.com and Revzell.com. Delete the discontinued models from the official websites of various brands and customer reviews prior to 2019, and choose the six high-end full-face helmets with the most reviews. Table 10.1 shows the model names and the total # of comments for the six popular full-face helmets, which include: (1) Scorpion 1400 Air, (2) Airoh ST501, (3) HJC RPHA 70, (4) Caberg Drift evo, (5) Shoei Z7, and (6) AGV K5. Regardless of the color and size of the full-face helmet, if it is the same brand or model, it is categorized as the same full-face helmet for statistical purposes.

The negative reviews of the six premium full-face helmets selected in phase one were categorized. We received a total of eight requests for high-end full-face helmets from customers: factors influencing the purchase of helmet comfort, ease of wearing glasses, ease of operation of the visor, ease of use of vent switch, source of noise, the influence of ventilation, vision feeling with helmet, and ease of use of double D buckle. The subsequent is described separately.

1. **Influencing factors for helmet comfort purchase**: Due to the lengthy duration of riding, consumers place a premium on the comfort of full-face helmets, including head shape, pressure points, materials, and hot spots, which will affect the consumers' long-distance riding comfort.
2. **Ease of wearing glasses**: The design of the helmet slot is poor, making it difficult to put on and remove glasses.
3. **Ease of operation of the visor**: The visors are difficult to operate and are susceptible to noise issues while riding.
4. **Ease of use of vent switch**: The ventilation switch is difficult to operate while riding with gloves on.
5. **Noise source**: During riding, the predominant source of noise is the wind shear. The riding angle, ventilation system, and visor, among other factors, will generate loud noise.
6. **Influence of ventilation**: When riding for an extended period of time, the head will have hot points and will be unable to take in and expel wind, resulting in headaches and vertigo.

Table 10.1 Models and comments of the six full-face helmets

Helmets						
Brand	Scorpion	Airoh	HJC	Caberg	Shoei	AGV
Models	1400Air	ST501	RPHA 70	Drift evo	Z7	K5
Reviews	117	27	26	20	18	13

7. **The vision of wearing a helmet**: When riding a motorcycle, you must move your head from side to side or look down at the instrument panel. The helmet's accessories and chin may obstruct the rider's view.
8. **Double D buckle usability**: Double D buckles are difficult to button on and off. Poor design may cause the buckle to fall off during riding.

Summary

We discovered that consumers of premium full-face helmets have stringent comfort requirements. Other opinions regarding helmets were also mentioned. The glasses' slot and double D buckle are difficult to use when putting on and removing the helmet; the visor and vent switches are difficult to operate when riding a motorcycle; the noise generated during riding, ineffective ventilation, and the feeling of wearing sight will directly result in the physical discomfort of consumers. Nonetheless, due to the vast amount of data contained in online reviews, some customers' feedback lacks sufficient specificity, making it difficult to comprehend their complaints, their motivations, and the current use situation. Therefore, additional information is required to accurately represent the customer experience.

10.4.2 Semi-structured Online Interview

This study generates the following interview questions based on phase one's classification of eight customer experiences:

1. **Influencing factors for helmet comfort purchase**: How do you believe consumers determine if a helmet is suitable for them? How to decide? What is the issue with donning a helmet?
2. **Ease of wearing glasses**: What do you believe will occur when consumers don glasses or sunglasses?
3. **Ease of use of the visor**: How do you believe consumers utilize the visor? Do the goggles fog up after a while of riding? How was the circumstance? What is the motorcycle's speed? How do you feel about the visor's disassembly and reassembly process? Is it simple to install and replace?
4. **Ease of use of vent switch**: How is the vent switch operated? What do you think of the operation? When will it function?
5. **Noise source**: Where do you believe the noise has the most impact? What might be the reason?
6. **Influence of ventilation**: How warm is the rider's head? Where do you feel the hottest?
7. **The vision of wearing a helmet**: How does the field of vision feel when wearing a helmet while riding a bicycle? What helmet design may obstruct the view?
8. **Ease of use of the double D buckle**: What difficulties might you encounter when putting on and taking off the buckle?

Table 10.2 shows that more and more detailed consumer demand can be obtained through online interviews with experts of full-face helmets. Detailed requirements are as follows:

Summary

Through expert interviews, we gain a deeper understanding of customer needs and customers' experience culture. Due to the influence of different cultures, consumers of high-end full-face helmets will have unique needs in addition to their primary requirements. For instance, riding motorcycles in Europe is a popular activity, and consumers are willing to pay more for designs that resemble their motorcycle or are currently popular. In addition, it pays more attention to the design details and riding experience. Detailed information that consumers are unaware of can be obtained more precisely through the expertise of professionals. For instance, due to the new safety regulations, the wearing comfort will change, and consumers will also give priority to purchasing helmets that pass the new regulations; the directionality of switch operation will affect the usability of customers while riding; the vent should be designed with gloves in mind, etc.

10.5 Conclusions

This study's objective is to rapidly acquire cyberspace-based customer experience culture. This paper proposes a model that would allow companies to easily access the Internet-based needs of high-end full-face helmet customers. We spent a total of 3 weeks acquiring extensive customer knowledge, which is 50% less time than originally anticipated. We conducted two experiments to quickly ascertain the customer experience: (1) obtaining customer value from online reviews and (2) gaining a comprehensive understanding of customer value through expert semi-structured online interviews. Eight customer experiences were captured by the results of the initial phase. The results of the second phase indicate that expert interviews can provide insight into the culture and behavior of specific customer experiences. With the rapid development of metaverse technology, we can now acquire customer requirements from cyberspace, which is no longer restricted to physical means. The Internet is a significant source of customer interest and behavior [31]. However, the number of online comments provided in this study is relatively small, and a larger amount of online review data helps to more precisely identify customer needs. In the future, either the number of online reviews can be increased or a more comprehensive classification system for online reviews can be developed in order to meet consumers' needs in a more comprehensive manner. Our contribution to research is that we provide a method for companies to capture customer experience on the Internet and the customer experience of high-end full-face helmets. It can reduce the time required for preliminary market research and increase the company's revenue during the product life cycle.

Table 10.2 Customer values and domain expert comments

	Customer values	Expert comments
1	Influencing factors for helmet comfort purchase	**Suggestion**: When purchasing a full-face helmet, the salesperson should teach the user how to put on and take off the helmet. Many consumers are uncomfortable because of the wrong way of wearing. Moreover, consumers only care about the feeling of wearing helmets at the moment, and the real feeling can only be known when riding. In addition, when trying on a full-face helmet, you should put the accessories on to feel it and make sure that it meets your requirements for comfort and sight **Customer experience culture**: Most Europeans ride motocycles for leisure and entertainment purposes (especially in summer and fall). Who then riding for more than 1–2 h, the head may produce hot points and feel uncomfortable. Therefore, good ventilation and the correct location of the vents will increase the consumer's desire to buy. The new European regulation ECE22.06 will have a great impact on the size design of the helmet shell and internal polystyrene in the future. Consumers will give priority to buying helmets that conform to the new safety regulations and better fit their head shape
2	Ease of wearing glasses	**Suggestion**: Nowadays, more and more people wear glasses. It is very troublesome to wear glasses when wearing helmets. Obvious glasses slots should be provided **Customer experience culture**: Consumers ride mostly in summer and autumn. In addition to the new regulations of ECE 22.06, many helmets have canceled the design of inner sunglasses, and wearing sunglasses has become very common. Therefore, a good design of spectacle slots is very important for consumers, especially when wearing glasses and helmet at the same time, the head will not feel obvious pressure
3	Ease of operation of the visor	**Suggestion**: The visor has the functions of defogging, ventilation, and protection. The switch of goggles is generally designed on the left, because the right hand has to control the motorcycle. Many high-end full-face helmets will be designed in the middle, which can improve both aesthetics and operability. In addition, the mechanism design of the visor is also the cause of poor operability. Users often need to replace the visor or disassemble it for cleaning. The mechanism should consider the convenience of disassembly and assembly **Customer experience culture**: In addition to the basic protection function, the design of the visor must match the appearance design of the overall helmet. In addition to the helmet body, the visor is the largest accessory of the full-face helmet. Therefore, the modeling of the visor needs to capture the current popular elements

(continued)

Table 10.2 (continued)

	Customer values	Expert comments
4	Ease of use of vent switch	**Suggestion**: The location, size, and operation direction of the vent are the key points in the design. Too big a vent will cause mosquitoes to get stuck and produce harsh noise when riding, or the operation direction is inconsistent, which will lead to users' inability to identify the ventilation switch state when riding **Customer experience culture**: Most users ride in the suburbs. If the weather is too hot or rainy, the air vents will be turn on or off when riding. In Europe, most people wear gloves, which are hard and thick, so it is not easy to operate the ventilation switch. Therefore, the operability of wearing gloves should be considered in the design
5	Noise source	**Suggestion**: The size of the air vents must match the shape of the helmet, and any prominence on the helmet and gaps in the helmet may cause harsh noises. And noise is one of the main factors affecting consumer usage **Customer experience culture**: When riding, the noise will come from all parts of the helmet. The spoiler can effectively reduce the noise. The design of the spoiler is easily affected by the design of the popularity sports car, and consumers will pay special attention to it. Therefore, the safety helmet can be designed with reference to the popular sports car of the season
6	Influence of ventilation	**Suggestion**: Good ventilation in addition to effective vents, the Styrofoam inside the helmet is also relevant. The good air flow and air exhaust of air have become one of the most important factors affecting ventilation **Customer experience culture**: Because most of the riders' riding time is in summer and more than one hour. Ventilation is related to the diversion design of the helmet, and comprehensive consideration is required when designing the shape of the helmet
7	The vision of wearing a helmet	**Suggestion**: Before purchasing, consumers need to install the nose protector and chin deflector to test the comfort of the sight line. When riding, the rider will need to swing his head to check the oncoming cars and dashboard. These accessories may block the riding time sight **Customer experience culture**: The appearance of safety helmets has always been one of the factors that consumers pay attention to. Many designers design exaggerated or special shapes in order to make the appearance conform to the fashion, but the shape of the helmet shell will directly affect the wearing line of sight. Therefore, it is also necessary to design a unique appearance when it needs to conform to the good sight

(continued)

Table 10.2 (continued)

	Customer values	Expert comments
8	Ease of use of the double D buckle	**Suggestion**: The double D buckle is designed to ensure that the helmet can be effectively fixed on the rider's head to protect the head in case of collision. Most of the user will not untie the buckle when using it, because it is too troublesome to take on and off. Therefore, the double D buckle can be easily pulled forward to the front edge of the helmet when it is fastened, which is very important for the convenience of the knight to put on and off. In case of an accident, the rescue personnel can easily remove the safety helmet, which is one of the safety specifications **Customer experience culture**: The new ECE22.06 is on the market, there are many updates to the double D buckle, and consumers in Europe will give priority to buying helmets that pass ECE22.06

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Chapter 11
Analysis of Museum Social Media Posts for Effective Social Media Management

Ji-Young Yun and Ji-Hyun Lee

Abstract Understanding visitors' needs is important for museum management. For this purpose, many museums run social media platforms, such as Facebook and Instagram. Numerous studies have discussed whether museums currently manage social media efficiently through only the communication elements within social media, such as the number of comments and likes. However, to communicate with potential visitors, it is necessary to analyze the preferences of actual users on social media posts and the types the museum uploads. In addition to investigating the efficiency of museum Instagram using data envelopment analysis (DEA), this study analyzed users' preferences regarding types of museum Instagram posts. We determined what posts are effective for communicating with potential visitors when museums upload posts on Instagram. Effective communication for museum Instagram was discussed from various perspectives. This study also derived effective museum Instagram management strategies.

Keywords Social network analysis · Social network management · Museum social network · Data envelopment analysis · Instagram · Multidisciplinary research

11.1 Introduction

11.1.1 Motivation

Nowadays, there is a vast amount of arts and cultural content. Customer and visitor needs for the various arts and cultural content are also skyrocketing in Korea. Reflecting this tendency, and thanks to the active support of various subjects,

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J.-H. Lee (ed.), *Cultural Space on Metaverse*, KAIST Research Series,
https://doi.org/10.1007/978-981-99-2314-4_11

including the government, the number of museums in Korea has increased dramatically over the last 20 years [1]. As a result, the number of museums per capita has achieved remarkable growth, reaching the Organization for Economic Co-operation and Development (OECD) average. This dramatic quantitative growth in museums is undoubtedly a positive change; it can increase access to culture and arts in terms of people's cultural and artistic welfare and provide a stage for artists in various fields.

However, to improve the quality and quantitative performance of museums, it is necessary to identify the diverse artistic needs of the public and consider how to meet them more effectively. To determine what the public wants from museums and meet their needs, museums use social media. Social media is an effective tool for communicating with museum visitors, potential visitors, and sharing information. In addition, social media has impacted museums' brand images. Martinus and Chaniago argue that visual storytelling through Instagram is a critical brand property [2]. They discovered that it enhances the formation of an emotional connection among visitors and improves recall and recognition of the brand [2].

Even though much research has proved that running social media is suitable for communicating with visitors, sharing information, and improving a museum's brand image, what kind of posts effectively attract Instagram users' attention has not been investigated in depth. Moreover, most studies on the efficiency of cultural facilities tend to analyze only the efficiency of the output factors for the input factors. For example, Lee, Kim, and Choi analyzed the factors affecting the efficiency of the museums' Instagram using data envelopment analysis (DEA). However, their results are only about operational efficiency [3].

To discover what types of posts are effective in communicating with potential visitors, it is necessary to investigate not only the efficiency of the functional communication elements of Instagram, such as likes, comments, and video views, but also the preferences of visitors for the types of posts and the relationship between them.

11.1.2 Research Questions

The following research questions were derived from the problems and limitations of previous research. First, we investigated which museum manages social media most efficiently in terms of using the functional communication elements of Instagram. Second, we determined what kinds of posts social media users prefer and why. Third, the relevance of preferences for social media posts and their efficiency are revealed. This sequence of research investigates what types of Instagram images users prefer beyond the efficiency of functional communication elements on Instagram and compares them to investigate an effective way to communicate with users more diversely than in previous studies.

11.1.3 Goal

The final goal of this study is to suggest an effective museum social media management strategy by analyzing the efficiency of the museum's Instagram, preference for the posts, and comparison between them. For this purpose, we analyzed museums and selected four museum Instagram pages for the DEA analysis and user experiments, which used an eye-tracker and preference survey. Lastly, we categorized each post related to exhibitions and compared the result with the analysis.

11.2 Related Work

11.2.1 Efficiency of Cultural and Arts Institutions

As mentioned in the introduction, the art museum market in Korea has achieved rapid quantitative growth over the past 20 years based on rich cultural and artistic content and diversified public cultural and artistic needs [4, 5]. As a result, the number of museums has grown significantly. Accordingly, museums have emerged as a crucial operational task for finding ways to satisfy the various tastes of the public effectively and efficiently.

In the case of art museums, Kim and Jung selected the building area, academic employees, planning exhibitions, and operating budget for 15 years as input factors to analyze the results of calculating the number of visitors and revisit rates [6]. Kim and Soh selected museums to compare and analyze the efficiency in terms of the number of employees, total area, collection status, and exhibition days [7]. Joo and Kim measured the efficiency of performance days, exhibition days, total users, and performance and rental income based on the number of employees and annual operating expenses of culture and arts centers in the Seoul metropolitan area (Seoul, Gyeonggi, Incheon) [8]. DEA techniques have been used to measure the operational efficiency of art galleries and museums, including cultural and artistic institutions with broader popularity such as multiplexes [9]. Numerous overseas studies have employed DEA techniques for cultural and artistic institutions [4, 10, 11]. As such, DEA techniques have been widely used to analyze the operational efficiency of various cultural and artistic institutions both domestically and abroad. However, other research tasks should be conducted together to understand, besides efficiency, reactions from social network users to each decision-making unit more deeply.

11.2.2 Use of Social Media in Cultural and Arts Institutions

As the contact point with the public has widened, cultural and artistic institutions have become aware of the influence and importance of social network services and social media [4]; they try to communicate with the public in various ways [5].

Various studies have been conducted on the use of social media in museums. Many have analyzed the current status and effects of the use of social media in art museums. Chung, Marketti, and Fiore analyzed SNS activities in art galleries in the Midwest of the United States. They found that SNS activities positively affect building awareness, community formation, and various networks [6]. Jang and Shin analyzed Facebook posts during a specific event held by the Daelim Museum of Art in Korea and found that the emotional factors included in the posts were related to the responses of information users [7].

As such, the importance of using SNS in operating cultural and artistic institutions is already widely understood. However, what kind of Instagram posts users prefer and their relationship with operational efficiency requires further investigation.

11.2.3 Use of Social Media in Branding Context

In the branding process context, a brand's social media page is a channel for communication and interaction with consumers. By uploading a post relevant to products, such as advertisements, campaigns, and user research, profit organizations can raise brand awareness and instant reactions from consumers [9]. In this branding context, many researchers have empirically analyzed the effect of social media. For example, De Vries, Gensler, and Leeflang extracted social media characteristics that correlate with the number of likes and comments that imply post popularity. They discovered that the vividness and interactivity of a brand affect the number of likes, and the number of comments can be boosted by the interactivity of the post [12]. Similarly, Cuevas-Molano, Matosas-López, and Bernal-Bravo (2021) and Schultz (2017) classified brand posts uploaded on social media fan pages according to the characteristics in De Vries, Gensler, and Leeflang's study and discovered that each characteristic affects social media engagement [11, 13].

Social media also plays a pivotal role in the branding process of non-profit organizations like museums. Vassiliadis and Belenioit discovered that by using social media, museums could strengthen the museum experience, communicate with visitors, and enhance visitor engagement. However, while there are diverse studies on social media effects on profit organizations, how social media characteristics impact the museum domain is yet to be established [10]. Thus, we classify posts by characteristics such as vividness, interactivity, and content type [11] and discover their relationship with users' preference for posts and operational efficiency.

11.3 Methodology

11.3.1 Selection of Museums and Exhibitions

Referring to previous research [3, 4, 10, 11], museums with the highest number of visitors per year were selected as the analysis target. Considering that, since 2019, the operation of cultural and artistic institutions has been temporarily suspended or intermittently operated owing to COVID-19, data from the "2019 Cultural Infrastructure General Survey" were utilized [1]. When comparing the statistics from 2019 and 2022, the ratio of the size of each museum and the number of visits after COVID-19 was similar to that before COVID-19 [1, 14]. Therefore, it was judged that the data were acceptable for his study.

According to statistics compiled from January 2018 to January 2019, a total of 1,508,271 people visited the Jeju Onggi Breath Museum, 1,185,168 visited the National Museum of Modern and Contemporary Art in Seoul, 911,179 visited the National Museum of Modern and Contemporary Art in Gwacheon, 830,000 visited Seoul Arts Center, 484,834 visited Daelim Museum, and 461,901 visited D-museum [1]. Among them, the art museums that have run an Instagram account were the National Museum of Modern and Contemporary Arts (Seoul Center, Gwacheon Center, and Cheongju Center Integrated), Seoul Arts Center, Busan Museum of Art, and Daelim Museum (Daelim Museum and D-Museum Integrated).

By comparing the number of Instagram followers at each museum, art museums with a high number of annual visitors were found to have a relatively large number of followers. Therefore, this study selected exhibitions held in these museums from January 2018 to January 2019 (Table 11.1).

To analyze the museum posts in detail, we selected exhibitions with similar periods. As a result, two to three exhibitions were selected for each museum (Table 11.2).

Table 11.1 Number of exhibitions and visitors of selected museums in 2019 and Instagram followers

Selected museums	The number of exhibitions held in 2019	The number of visitors in 2019	The number of followers
National Museums of Modern and Contemporary Art	23	2,451,701	213 K
The Daelim Museum	4	925,896	156 K
The Seoul Arts Center	185	1,230,000	19.3 K
The Busan Museum of Art	14	484,934	19.3 K

Table 11.2 Selected museums and exhibitions for analysis

Selected museums	Selected exhibitions	The number of posts	The number of pictures	The number of likes	The number of comments
National Museums of Modern and Contemporary Art	Akram Zataari	11	19	2129	13
	How Little You Know About Me	3	3	7300	74
The Daelim Museum	Mike, My Q	8	25	4191	51
	The Exit	7	23	5715	96
The Seoul Arts Center	Niki de Saint Phalle	6	17	1475	126
	John Lennon	3	18	1410	20
The Busan Museum of Art	New Acquisitions	1	1	29	0
	The Warmth of a Moment	1	1	19	0
	Kim Jong Sik	2	4	81	3

11.3.2 Data Collection

We conducted web crawling to collect images and the total number of posts, likes, and comments on Instagram. After excluding posts unrelated to the selected exhibitions, 42 posts and 111 pictures were collected. Python 3.10 and Selenium WebDriver were used for the experimental setting of web crawling. Details of the collected information and web crawling are presented in Table 11.2.

11.3.3 DEA Analysis

DEA was employed to determine the operational efficiency of each museum's Instagram. Such analysis reveals whether the input cost is being used more efficiently than other museums. We selected input and output factors related to the efficiency of Instagram operation for the four art museums. Referring to previous studies [3], we selected the number of posts, which indicates the museum's efforts to operate Instagram. The number of comments and likes were selected as output factors; these are users' responses to each Instagram post, so it can be a representative performance indicator for input factors.

CCR and BCC are representative DEA models. Suggested by Charnes et al. (1978), the CCR model assumes that output increases as a percentage of input. Suggested by Banker et al. (1984), the BBC model reinforces the CCR model [15, 16]; it assumes that the ratio of increase or decrease in output may vary as the input size changes. In particular, the BCC model reflects the economic logic that the initial input slows over a particular input point.

11.3.4 Post-classification

We classified each post to conduct a preference survey to discover Instagram users' preferences regarding types of posts and compared them to the results of the DEA analysis.

A post typology for this research follows Cvijikj and Michahelles and De Vries et al.; thus, content factors are indexed differently based on the interactivity degree [12, 17]. Since there is no content, including gifs, videos, and videos with sound in our data, we excluded them from the vividness list. We also counted post length in numeric and classified posts, and whether the purpose of each post was sharing information or entertaining users (see Tables 11.3 and 11.4). Definitions of information and entertainment in terms of content type follow Taylor et al. [18] and Pletikosa Cvijikj and Michahelles [17]. Post-topic typology follows Schultz (2017) [11].

Table 11.3 Instagram post types and level (left) and content type (right)

<table>
<tr><th>Level</th><th>Vividness</th><th>Interactivity</th><th>Content type</th></tr>
<tr><td rowspan="3">Low</td><td>Photo</td><td rowspan="3">Voting</td><td rowspan="4">Information</td></tr>
<tr><td>Graphic</td></tr>
<tr><td>Edited photo</td></tr>
<tr><td rowspan="3">Medium</td><td rowspan="3">Event</td><td>Hashtag</td></tr>
<tr><td>Contest</td><td rowspan="4">Entertainment</td></tr>
<tr><td>Call to act</td></tr>
<tr><td rowspan="2">High</td><td rowspan="2">Carousel</td><td>Mention</td></tr>
<tr><td>Question</td></tr>
</table>

Table 11.4 Instagram post topics

Topics	Description
Competition	Posts presenting a competition
Content	Informative posts not directly related to an exhibition (e.g., relevant workshop)
Holiday	Posts referring to a holiday, season, or weekend
Product	Posts related to a specific exhibition
Promotion	Promotional activities, such as discounts, sales, or exhibition openings

11.3.5 Preference and Eye-Tracking Analysis

Eye-tracking has been used to analyze how visitor gaze moves and which area a user is interested in while viewing an Instagram post. User studies using eye-tracking are associated mainly with images and are used to analyze regions of interest (ROI) in images such as paintings and photos. Walker et al. compared children and adults according to the main viewing area of artworks before and after using a salience map to provide information related to the artworks [8, 11]. They found that the suggested information greatly influenced children's interest. Thus, eye-tracking analysis has frequently been used to determine the interest in and concentration on images. We conducted eye-tracking analysis to discover the concentration hit map according to the differences in user preferences.

11.4 Implementation

11.4.1 Eye-Tracking and Preference Survey

We recruited 25 Instagram users aged 19 or older for the experiment. The experimental environment for eye-tracking is illustrated in Fig. 11.1. The left monitor is for the subjects; they can see each Instagram post through the monitor. Under the monitors, the eye-tracker detects pupil movement. The right monitor is for the researcher. We can control the monitor a subject watches and the eye-tracking analysis program. During the experiment, the subjects cannot see the researcher's monitor.

First, calibration was performed to trace a subject's pupil. Through a test set consisting of three Instagram posts, the subjects have time to familiarize themselves with the experiment. After that, the experiment is conducted with the seven sets of

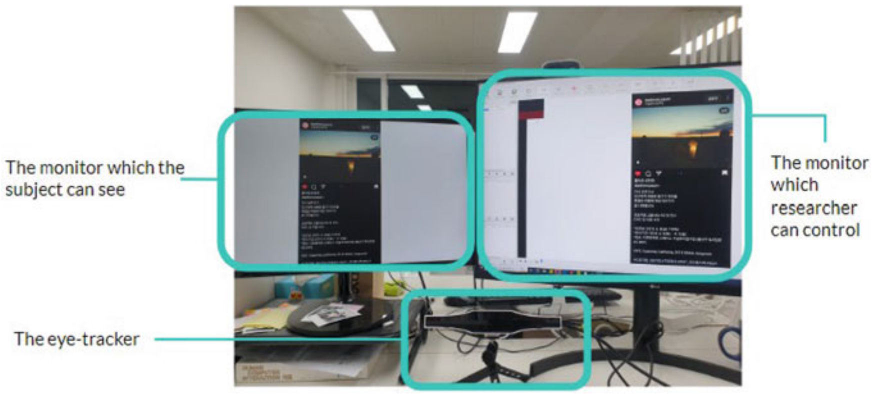

Fig. 11.1 Eye-tracking experiment environmental setting

Instagram posts. Each selected museum's posts are grouped into one set for each exhibition. Since there were only a small number of posts for each exhibition on Instagram of the Busan Museum of Art, we combined them into one set. Thus, there are seven sets of exhibition posts in total.

At the end of each set, participants were asked to indicate their preference for each post and the overall image of the group of posts for each exhibition on a five-point scale. A short interview was conducted after the experiment.

11.5 Results

11.5.1 DEA Analysis

The efficiencies of all exhibitions were calculated using the CCR and BBC models. The efficiency score for each of the nine exhibitions is reported in Table 11.5. In each model, 1 means that the exhibition's efficiency score reaches a peak, and the further away from 1, the less efficient.

Overall, the efficiency scores in the BCC model were higher than those in the CCR model for every decision-making unit. Only HA attained the highest score in both models. TE, NS, JL, and KJ score highest only in the BCC model. The lowest

Table 11.5 DEA efficiencies for exhibitions under CCR and BCC models

Museums	Exhibitions	Input	Output		CCR	BCC
		# of posts	#of likes	# of comments		
National Museums of Modern and Contemporary Art	Akram Zataari (AZ)	11	2129	13	0.08	0.56
	How Little You Know About Me (HA)	3	7300	74	1.0	1.0
The Daelim Museum	Mike, My Q (MQ)	8	4191	51	0.26	0.69
	The Exit (TE)	7	5715	96	0.56	1.0
The Seoul Arts Center	Niki de Saint Phalle (NS)	6	1475	126	0.85	1.0
	John Lennon (JL)	3	1410	20	0.27	1.0
The Busan Museum of Art	New Acquisitions (NA)	1	29	0	0.01	0.58
	The Warmth of a Moment (WM)	1	19	0	0.01	0.99
	Kim Jong Sik (KJ)	2	81	3	0.06	1.0

score in the CCR model is 0.01, which is NA and WM; the lowest score in the BCC model is 0.56, which is AZ.

To maximize the efficiency of each exhibition, the number of output factors needs to increase. To reveal what kind of posts generates more positive reactions from Instagram users, we classified the posts and conducted eye-tracking and preference analysis.

11.5.2 Post-classification

The number and types of posts most frequently posted by each museum were counted depending on vividness, interactivity, content type, and topic. Multiple photos can be posted on Instagram as a single post. However, each photo can be counted as a different kind of vividness and interactivity. Thus, when we classified posts, if there were multiple photos in a single post, we treated each as a single post. Therefore, a total of 111 posts were classified according to this system.

The National Museum of Modern and Contemporary Art (MMCA) uploaded 19 photos, 1 graphic, 1 edited photo, 5 events, and 11 carousels on the vividness side and used 0 votes, 22 hashtags, 0 contests, 0 calls to action, 2 mentions, and 0 questions on the interactivity side. They also uploaded 19 pieces of content for sharing information and 7 pieces for entertaining the users. Topics comprised 0 competition, 3 content, 0 holidays, 16 products, and 5 promotions. Daelim Museum (DM) uploaded 33 photos, 3 graphics, 12 edited photos, 30 events, and 43 carousels on the vividness side and used 0 votes, 48 hashtags, 0 contests, 2 calls to action, 21 mentions, and 2 questions on the interactivity side. They uploaded 35 pieces of content to share information and 32 pieces to entertain the users. Topics comprised 0 competition, 21 content, 0 holidays, 30 products, and 6 promotions. On the vividness side, the Seoul Arts Center (SAC) uploaded posts including 9 photos, 3 graphics, 23 edited photos, 6 events, and 35 carousels. On the interaction side, 0 votes, 31 hashtags, 10 contests, 18 calls for action, 20 mentions, and 3 questions were used for the posts they uploaded. The type of content consisted of 21 pieces of information and 23 pieces of entertainment. Topics comprised 8 competitions, 15 pieces of content, 0 holidays, 0 products, and 15 promotions. Busan Museum of Art (BA) uploaded 4 photos, 1 graphic, 1 edited photo, 0 events, and 4 carousels on the vividness side and used only 6 hashtags on the interactivity side. Additionally, all 6 posts were about information and products.

Overall, museums mostly uploaded photos, and carousels and graphics were hardly found. All museums used hashtags most frequently to interact with Instagram users. Only SAC used contests to interact. DM tried to interact with the users most frequently and used various types of interactivity. Most museums, except SAC, uploaded posts to share information rather than to entertain users. SAC uploaded entertaining posts more often than informative ones. Museums frequently uploaded topics about their products, but only SAC uploaded the same number of topics about content and promotion. Additionally, it is interesting to note that SAC was the only museum that held competitions.

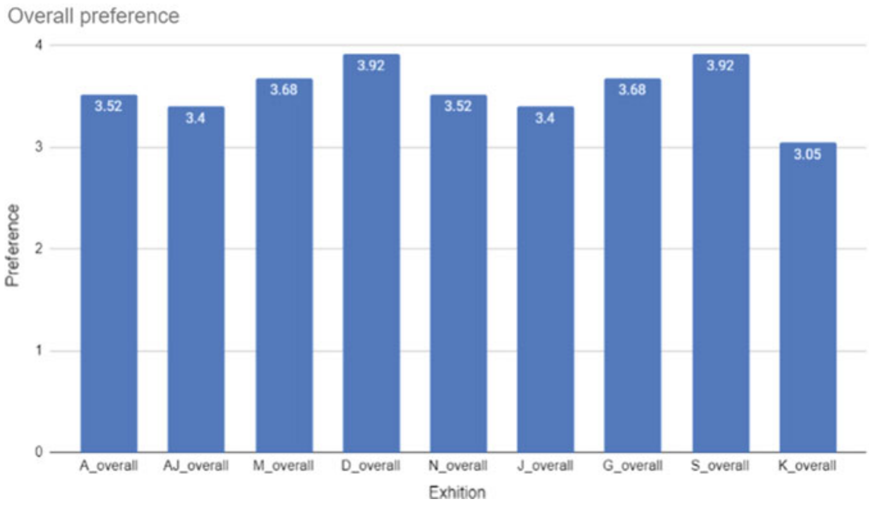

Fig. 11.2 Overall preference (sd. 0.259)

11.5.3 Preference Analysis

The results of the overall preference of each exhibition post group are illustrated in Fig. 11.2. The most preferred group of exhibition posts is The Exit from DM, and the least preferred is Kim Jong Sik from BM. The post type related to the two exhibitions is described in Table 11.6. The post content types of Exit consisted of 16 pieces of information and 17 pieces of entertainment. Moreover, most posts were about content. All four posts related to Kim Jong Sik contained information and were about products.

The types of the five most preferred posts, a single post from How Little You Know About Me held by MMCA, two and single posts from The Exit and Mike My Q each, held by DM, are illustrated in Fig. 11.3. The last was a single post from New Acquisition held by BM. There were no significant differences between the vividness level and topic of each post. The interactivity level of each post was medium, except for that by Mike My Q, which was higher than the others. However, the content type of all five posts was information.

We also analyzed commonly preferred and non-preferred posts based on the frequency of the preference scores for each post; the analysis is summarized in Fig. 11.4.

First, the two posts that scored five points most and did not one 1 point are from The Exit. Both had the same vividness and interactivity levels, content type (information), and topic (product). This corresponds to the fact that the type of post with highest preference was information.

Second, the posts that scored one point most and did not receive five points are from The Exit and Kim Jong Sik. Even though both have the same vividness and

Table 11.6 Types of post groups of most and least preferred exhibitions

Daelim Museum_The Exit										
Vividness					Interactivity					
Photo	Graphic	Edited photo	Event	Carousel	Voting	Hashtag	Contest	Call to act	Mention	Question
15	1	7	17	22	0	23	0	0	4	0
Content type					Topic					
Information	Entertainment	Competition		Content	Holiday		Product		Promotion	
16	17	0		17	0		13		2	
Busan Museum of Art _Kim Jong Sik										
Vividness					Interactivity					
Photo	Graphic	Edited photo	Event	Carousel	Voting	Hashtag	Contest	Call to act	Mention	Question
4	0	0	0	4	0	4	0	0	0	0
Content type					Topic					
Information	Entertainment	Competition		Content	Holiday		Product		Promotion	
4	0	0		0	0		4		0	

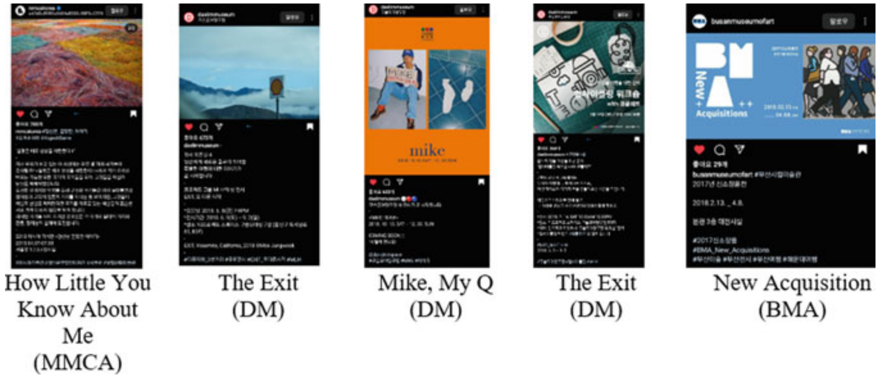

Fig. 11.3 Five most preferred posts

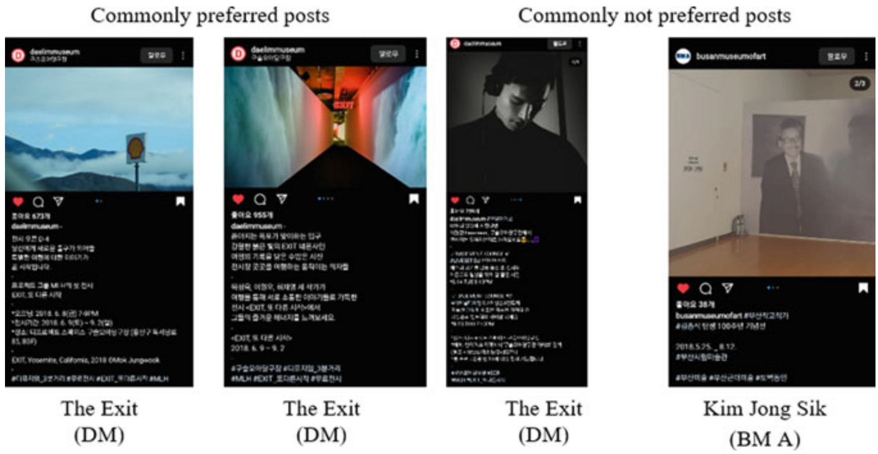

Fig. 11.4 Five commonly preferred and non-preferred posts

interactivity level, the content type and topic differ, that is entertainment and content from the post from The Exit and information and product from the post from Kim Jong Sik, respectively.

Finally, we conducted a Pearson correlation analysis between post length and each post's preference score, but there was no correlation between them.

11.6 Conclusion

This study examined and measured the efficiency of museum Instagram and scrutinized users' preferences by type of post to determine what kind should be uploaded when museums upload posts related to exhibitions to communicate with visitors effectively.

Interestingly, the content type of the five most preferred posts was all information. When we interviewed subjects about the commonalities of posts with high preference scores, subjects highlighted whether a post contained useful information related to the exhibition, such as date, place, and location, and so on, whether the information was correctly organized, and lastly, whether the information about the exhibition was easy to skim read. Some subjects state that this was because "museum Instagram is kind of an advertisement for the exhibition they hold." Given this, people prefer posts with information because subjects considered museum Instagram to be an exhibition promotional post and scored them based on such perceived characteristics (Fig. 11.5).

Another interesting point is the differences in content type when comparing the preference for each post and the posts grouped into exhibition units. Although informative content received high scores in the preference survey for each post, the Daelim Museum, which posted different contents than other museums, received high preference scores for posts grouped into exhibition units. From this perspective, subjects

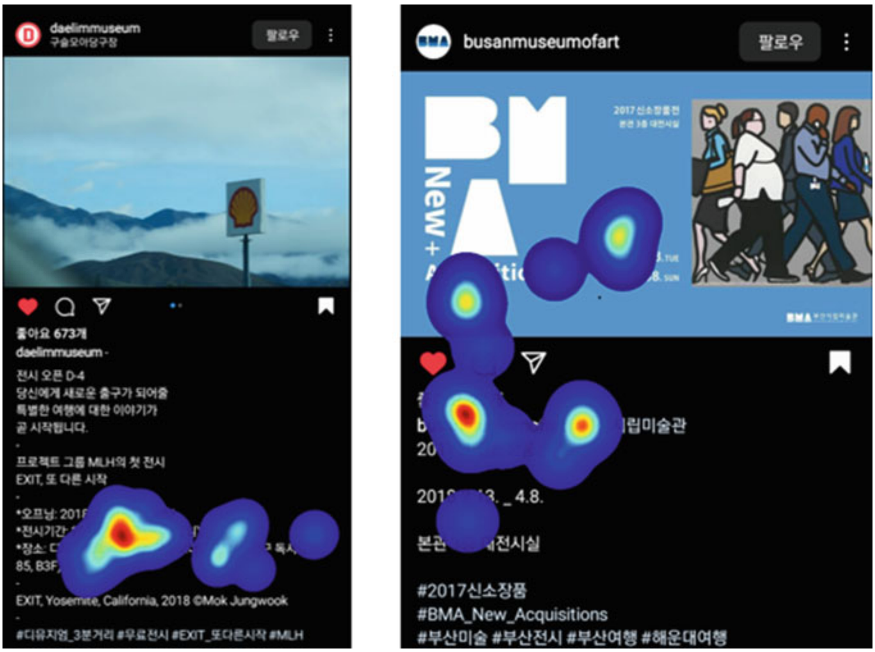

Fig. 11.5 Eye-tracking results of posts with information content type

value postings containing information but want to see different contents in a single collection of exhibition posts in the museum domain.

Moreover, 16 out of 25 participants answered that they considered images more than text when assigning preference scores. Regarding this, even though they uploaded the post with information and product, the post from Kim Jong Sik was selected as the commonly non-preferred post, because the quality of the image did not satisfy the subjects. Some subjects cited the post when they gave an example of the characteristics of a non-preferred post. P15 said, “I don’t like random photos of paintings without design elements.” P17 said, “I have no idea why they uploaded the photo at the exhibition’s entrance. It was taken too carelessly. I don’t want to see it.” P21 and 24 also mentioned the fire extinguisher in the photograph and stated that the composition of the photograph was terrible.

However, some subjects complained about the images of celebrities who visited the exhibition. P2 said, “Just post the face of a celebrity, and this person is doing something, and that’s it.” (they gave a low score). Other subjects also stated that they gave a low score if there was a photo of a celebrity’s visit because it was unrelated to the exhibition.

In this regard, when people look at a museum’s Instagram, they consider the quality of the image and its relationship with the exhibition, as well as whether the post includes information about the exhibition. For example, even though Kim Jong Sik post includes information content, participants more focused on unnecessary objects in the picture (Fig. 11.6).

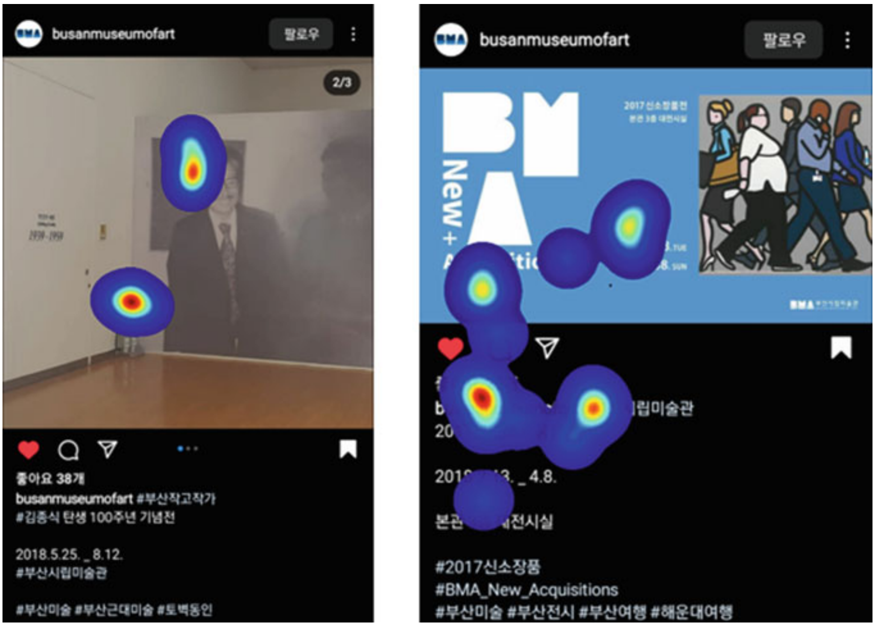

Fig. 11.6 Comparison of Kim Jong Sik and another information content post

11.7 Limitations and Future Work

This study has several limitations. More samples are required to generalize the results; our sample was composed of university students. Additionally, the results are limited to Instagram. Since each social media platform has different characteristics and different groups of users, the same experiment conducted on other platforms may reveal different results [19, 20]. Lastly, even though subjects mentioned that delivering information regarding exhibitions is essential, we could not scrutinize how and what kind of information should be uploaded; for example, summarized information in photos or detailed information in the text section. Therefore, follow-up studies should be conducted to address the aforementioned limitations.

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