The Affordance of Online Multiuser Virtual Environments (MUVE) for Creative Collaboration

by

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A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Architecture

and the Designated Emphasis

in

New Media

in the

Graduate Division

of the

University of California, Berkeley

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Spring 2013

Abstract

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Creativity is an important criterion for evaluating conceptual and design abilities of architects and their praxis. However, in recent years, the world has grown more complex. New problems have emerged that are often outside the architect's capacity. Given this challenge, architects collaborate with colleagues from architecture and other related disciplines, bringing more creative minds to participate in the process of producing creative solutions. In many cases collaboration can enhance creativity. Yet, at the same time it can create significant problems, including miscommunication, and conflicts.

New Media, particularly immersive, three-dimensional Online Multiuser Virtual Environments (MUVE) offer a possible solution to this problem by providing designers with immersive experiences in the designed environment, a synchronous and shared collaboration environment, presence of others, represented by avatars, and manipulability of a three-dimensional representation. These characteristics of MUVE can facilitate collaborators' intra- and extra-processes of communication, reflection-in-action, and socio-psychological mechanisms that can help achieve creativity.

The aforementioned potential of MUVE to assist creative collaboration rests mostly on theoretical assumptions rather than results based on empirical studies. Therefore, this dissertation investigates empirically the affordance of MUVE for creative collaboration in architectural design and attempts to answer two main questions: (1) What is the affordance of MUVE for creative collaboration in architecture? (2) In what ways does MUVE influence creative collaboration in architecture? To achieve this goal, this study has conducted comparative experiments in creative collaboration using two modes of creative collaboration: MUVE and sketching, in face-to-face collaboration, and in remote collaboration. For the purpose of the experiments, creativity is evaluated in terms of novelty and appropriateness of the results by the participants and by external judges.

The empirical experiments showed that statistically MUVE and sketching have equivalent affordances for creativity in face-to-face collaboration, but when participants collaborate

remotely, MUVE facilitates more creative outcome of exterior form than Online Sketch does. Based on interviews and observation, I verified the reasons of those statistical results. In face-to-face collaboration, the characteristics of MUVE, which are the immersive experiences in the three-dimensional environment, a synchronously shared collaboration environment, and co-presence of other partners, have equivalent impacts on the production of creative solutions when compared to the two-dimensional and non-immersive representation in face-to-face sketching.

In brief, the aforementioned characteristics of MUVE allowed participants to experience design solutions in search of creative solutions, and thus helped them to evaluate the usability of any new synthesized forms, whereas sketching media's characteristics enabled participants to track and reason their problem-solving processes, and helped problem analysis and initial solution synthesis, based on knowledge that designers already have.

In contrast, in remote collaboration, the characteristics of MUVE supported collaborative search for creative solutions, communication, and interdependency, like the feeling of working together amongst collaborators regardless of the remote distance. Online sketching, on the other hand, lacked communication cues, such as gesture, and collaboration mood. Therefore, participants misinterpreted their partners' representations and strained to communicate with each other. Those misinterpretation and miscommunication obstructed their creative attempts and problem-solving abilities.

The general purpose of this research is to contribute to the development of creative collaboration methods using MUVE to foster creativity in architectural design.

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Acknowledgments

If you are reading this dissertation, it is probably because you are a future student, a research colleague, or a newspaper reporter. I want to clearly stress that my dissertation would be impossible without the support, advice, inspiration, and encouragement of some remarkable people. First of all, I send my full respect to my dissertation committee. Professor Yehuda E. Kalay, the chair, helped me see further through his insights and wisdom. I promise that his legacy will be passed to my future students, as his grand students. I also appreciate the intellectual discussions with Professor Galen Cranz. She is a remarkable and thoughtful researcher. Professor Maria-Paz Gutierrez's knowledge of both design research and practice guided me to develop a reliable research methodology. Professor Kaiping Peng provided psychological lens to investigate creativity in architectural design.

Professor Charles (Chip) Sullivan encouraged my research and shared his experience in visual representation. The collaboration with D. Roger Hay, Principal of RHO Architect, was also a great experience. Professor Kimoko Ryokai, a member of my qualifying exam committee, inspired me to explore the potential of New Media. I also sincerely appreciate the supports of Professor Nezar AlSayyad throughout my Ph.D. study. My previous M. Arch. advisor, Professor Malcolm McCullough at University of Michigan, Ann Arbor, and M.S. advisor, professor Kwang-Hee Lee at University of Ulsan, Korea, also encouraged me to run the long trip.

I must thank the Digital Design Research Group (DDRG) family: Jaewook Lee, Yongwook Jeong, Seungwook Kim, Emelie Cheng, Bauni Hamid, Cecilia Kim, Gokce Kinayoglu, Selina Lam, Yael Perez, Hsin-Hsien Chiu, Kartikeya Date, Paul Kim, and especially, Ahmed El Antably. I never forget his faithful friendship throughout all my Ph.D. life. I am also grateful for the intellectual discussions with the visiting scholars: Yungil Lee, Armando Trento, and Gianluigi Loffreda, and the collaborative research with Davide Simeone and Davide Schaumann. Other Ph.D. students, DongMin Park, Hyungkyoo Kim, Jihira Yun, Rosie Han, and M.Arch students, GunWook Nam, YunIl Kim, YoungSeok Ju, were also excellent discussion mates. I cannot forget the pleasant memories with Korean visiting professors, Sung Ah Kim, KhilChae Kim, UooSang Yoo, and ChangGeun Yoo, and the Hybrid Ideation Space (HIS) research with Professor Tomas Dorta. ChangYeon Cho, my Michigan friend, and Seung-Yup Shin, my cousin, supported my research. I am also deeply thankful for the friendship of my high school friend, Sung Bo Sim. He always encouraged me to go further, and I will never forget the Alaska trip with him. GyungRak Sumin is also a wise and reliable mentor and supporter.

Finally, I send my best, indescribable thank, love, respect to my late father MyungShin Hong and my mother JungSoon Shin. I am sure that my father commends my achievement from Heaven. I always feel sorry for my mother. I could not spend much time with her due to my international study. Her endless love and devotion completed my dissertation. I dedicate this dissertation to my parents.

Chapter I Introduction

1.1. Problem Statement

Creativity is defined as an ability to produce a product that is both novel – original or possessing a new quality which people have not experienced before - and appropriate - useful and adaptive to some task constraints (Amabile, 1983, 1996; Csikszentmihalyi, 1996; Sternberg & Lubart 1999;2010; Paletz & Peng, 2008, 2009, Plucker & Makel, 2010; Runco & Jaeger, 2012).

Creativity is an important criterion for evaluating the design ability of architects and the quality of their products. Novelty as a component of creativity, defines identity, provides self-fulfillment, and even creates job opportunities for architects. Throughout history, patrons and clients have regarded distinctive novelty as one of the most important criteria for hiring architects (Bourdieu, 1984; Gans, 1999). Other components of creativity such as producing appropriate and useful designs in given contexts are equally important for architects to fulfill their role as professionals.

Creativity is also significantly related to architects' problem-solving and puzzle-making skills. Architects' problem-solving requires rational and appropriate analysis of given constraints, synthesis of novel and useful solutions, and rational evaluation (Gregory, 1966; Broadbent, 1973). The ability of architects to modify their initial solution to fit stated goals and needs, known as Puzzle Making, also requires creative abilities to compose given parts into new and unique whole solutions (Archea, 1987; Kalay, 2004). For these reasons, creativity has been long discussed in architectural professional and educational circles. *Accademia dells Arti del Disegno*, the first design school of architecture founded in 1563 in Italy, emphasized novelty in order to distinguish buildings designed by architects from buildings made by masons (Perez-Gomez & Pelletier, 2000). Whereas masons construct buildings based on practices learned from building precedents, architects plan not-yet actualized buildings. Such planning necessarily requires representation for both design development and communication with clients. Representation methods and media are not just a means to an end, but rather influence architects' ideation and communication in the search for creative solutions.

Creative solutions have become more difficult to achieve as the world has grown more complex (Schön, 1983; Cuff, 1996). An architect, as a professional, arranges complex variables and situations to propose novel and appropriate solutions. Rapid growth in the complexity of the world in recent years has produced many and diverse variables, such as new and specialized knowledge, technology, and market trends. Such complexity potentially provides architects with opportunities for producing creative solutions. However, the search for creative solution requires complex, professional, and specialized knowledge in domains that are often outside of one architect's capacity.

In order to respond to the complex problems and challenges, architects often collaborate with colleagues and other related professions and disciplines to bring more creative minds into the development of solutions. Collaboration is defined as an action or interpersonal relationship between experts or professionals to achieve a specific purpose such as solving a problem and creating or discovering something new (Schrage, 1999). In many cases, collaboration can help architectural creativity. Unique mechanisms of collaboration - sharing and converging of participants' different opinions – can facilitate appropriate problem-solving and synthesis of novel solution (Osborn, 1963; Schön. 1983; Schrage, 1995; John-Steiner). In particular, interdisciplinary collaboration between architects, clients, and consultants (i.e. structural engineers and contractors) leads to novel design products and appropriate problem solving, as the case of Meier, an architect, and Michetti , an engineer, for resolving construction problems of the curved walls of the Millennium Church, in Italy (Kalay ,2004). Pioneering collaboration models, including collaborative research developed in pursuit of new technologies, are progressively more common to architecture. For instance, to propose a new intelligent building facade that interacts with temperature and climate like a membrane, architects need the knowledge in bio and mechanical engineering, and collaborative research with the relevant experts for applying the knowledge to architecture (Gutierrez, 2009).

In what ways does collaboration facilitate producing creative solutions? By applying reflection-in-action for problem-solving (Schön, 1983; Kalay, 2004), idea productivity for creativity (Osborn, 1963), reliable decision-making (Goldschmidt, 1995; John-Steiner, 2000), and interdependency for encouragement and emotional reliability (John-Steiner 2000), collaborators can ultimately achieve a creative solution. To get the advantages of collaboration for creativity, the process of shared understanding, which means a deep reflection about other collaborators' world-views and visions, is essential (Kalay, 2004). In addition, communication and joint decision-making are required for creative collaboration (John-Steiner, 2000; Kalay, 2004; Nijstad, 2009).

The aforementioned mechanism of creative collaboration is challenging due to communication hurdles and conflicts (Kalay, 2004; Nijstad, 2009). Collaborators have their own different opinions and world-views, developed through training, education, and social and cultural backgrounds (Kuhn, 1968). Although architects use visual representations, such as sketches and physical models to communicate with other professionals and clients, different perspectives and values amongst collaborators can create arbitrary interpretation of any given representation. This misinterpretation causes communication barriers and conflicts (Cuff, 1996; Amabile, 2000).

As one solution to this problem, previous collaboration studies suggest the use of New Media[1] and Information Technology (Schrage, 1999; Dourish, 2001; Kalay, 2006; Lahti & Hakkarainen, 2004, Gu, Kim, & Maher, 2011, Koutsabasis, Vosinakis, Malisova, & Paparounas, 2011). They

[1] In New Media: A Critical Introduction, Martin Lister and co-authors introduce the definition of New Media in media studies as follows: a means of communication which are digitalized, networked, and interactive (Lister, Dovery, Giddings, Grant, & Kelly, 2003). New Media are exemplified in the following technological applications: computer mediated communication (e.g. email, online chat, and personal profile blog), simulated and alternative environment (e.g. immersive online virtual environments and 3-dimensional online games), and electronic devices for sharing information that produce human and computer interactions.

assume that New Media's communication and representation abilities can help creative collaboration. Additionally, recent advances in New Media, particularly Online Multiuser Virtual Environments (MUVE), such as *World of Warcraft* and *Second Life* - have the potential to support creative collaboration in architecture (Ijsselstejin & Riva, 2003)

First, MUVE provides immersive experiences that produce the feeling of "being in the designed environment." The immersion in MUVE is initialized by a first or third person view of avatars in a three-dimensional environment, and it may facilitate participants' exploration in the design, and thereby possibly help the search for new solution. Second, the immersion in MUVE is promoted by social and co-presence of others, the feeling of "being together in a shared environment" (Ijsselsteijin & Riva, 2003). In MUVE, users can be aware of other users' presence and interact with them. The anthropomorphic representations of others, called avatars, produce the awareness and interactions. I assume that the awareness of the presence of others and interactions with them may create unexpected and serendipitous events, which in turn inspire new ideas. In addition, in MUVE users can synchronously share the designed outputs with others. This may help communication, reflection-in-action, and joint decision-making amongst users for proposing creative solutions.

I assume that shared activities, objects, and contexts in MUVE may influence not only communication amongst users, but also psychological and social aspects, such as the feeling of working together and partners' reliability, which can encourage creative collaboration. Moreover, MUVE is able to reduce the complexity of three-dimensional representation. MUVE provides three-dimensional geometries, and thus collaborators can combine, manipulate, and deform those geometries to represent buildings' structure and necessary details, without high effort for representation. Therefore, a great number of creative feedback and design iterations among collaborators cab be expected. The above characteristics of MUVE can possibly facilitate collaborators' internal-design processes, and external-communication with other collaborators to achieve creative solutions.

To address my research questions about MUVE, I examined two cases of collaborative design studios held in the Department of Architecture, University of California, Berkeley, in which I introduced the use of MUVE in support of creative collaboration. Both studios targeted the design of a Virtual Smithsonian Museum using *Second Life*, a commercial MUVE platform, and other media. The first design studio was held in the Fall semester of 2008, and 4 students participated in the studio. The second design studio was held in the Spring semester of 2010, and 10 students joined the project. In both design studios, students took charge of 4 theme museums and ultimately proposed one unified Virtual Smithsonian Museum. In those studios, I collected students' design products and observed their collaborative processes. After completing the classes, I interviewed students and asked in what ways did MUVE influenced the production of creative solutions and the performance of collaboration. I summarize the results of the above mentioned case studies below. The authentic design studio analysis is a pilot study before conducting specific and systematic experiments in this dissertation research (see p. 10).

First, MUVE's immersive environment, which emphasizes the feeling of being in the designed environment, allows students to experience (i.e. examine and use) their own and others' design outputs in relation to their avatars' body perception. Such immersion probably influences students' design processes and the search for designs proposals and novel solutions. In interview, students stated that the immersion in the first person view enables them to develop and organize interior exhibition spaces and thus helps them produce useful and appropriate design solutions. However, if any designed space was not in range of the first person view, for example, the entire form of one theme museum, students struggled to perceive their collaborative design outputs and collaborators' design processes. In other words, students' perception of their own or other collaborators' designs is often limited by the immersion. Therefore, in the studios, instructors let students use supplementary media, such as physical study models, and hand and body gestures in order to organize and integrate the different theme museums within the museum.

Second, students were aware of other students' designed objects in MUVE's synchronously shared environment. This helped them understand each other's design intentions and ideas. They were also inspired by each other's design outputs. I assume that the synchronously shared environment possibly facilitates creativity.

Third, students stated that the presence and activity of avatars help them produce useful designs, one component of creativity. The scale and activities of avatars were used to evaluate the scale and function of their design output. Students also reported that co-presence of others evaluates usability of the built environment and provides unexpected feedback. In remote collaboration, social presence of classmates' avatars and co-presence with them visualized classmates' participation and work progress. This possibly may affect psychological and interpersonal aspects of creative collaboration, such as encouragement and comradeship.

In addition, in the design development phase, I observed that MUVE's three-dimensional representation helps students generate new forms and spaces. In addition, the accessibility to MUVE in the remote distance possibly facilitates students' feedback and search for new designs.

Recent research on the use of MUVE in support of creative collaboration investigates the collaborative design processes in face-to-face sketching, remote MUVE, and online sketching (Gu, Kim, & Maher, 2011). Another study discusses authentic design cases in MUVE (Koutsabasis, Vosinakis, Malisova, & Paparounas 2011). The value of those studies is that they introduce designers' collaborative patterns and behaviors in MUVE. However, they mainly investigate designers' information-processing and observable behaviors during collaboration in MUVE, while they ignore creativity, and psychological and interpersonal aspects of creative collaboration in MUVE. The research on the affordance[2] of MUVE for creative collaboration is

[2] In my dissertation, the term "affordance" means "the capacity of a medium" to allow a particular behavior or mechanism. This term is coined by James J. Gibson (1986) in his book, The Ecological Approach to Visual Perception. Gibson uses the term to explain humans' visual perception in the search for a capacity of the perceived object. For example, if an object is flat, humans perceive the object as sit-on-able. In the book Architecture's New Media, Yehuda E. Kalay (2004) expands its original meaning to denote the capacity of the architecture's media to allow or disallow certain behaviors or mechanisms during the design process.

still lacking. Furthermore, architectural research does not have a solid and standardized methodology regarding creative collaboration. Current methodologies for creative collaboration rely on architects' individual practices rather than objective research data and systematic case studies.

In this research, I aim to investigate the affordance of MUVE for creative collaboration. The goal is specified as the following research questions, and it is represented as figure 1.1.

(1) What is the affordance of MUVE for creative collaboration in architectural design?
(2) In what ways does MUVE influence creative collaboration in architectural design?

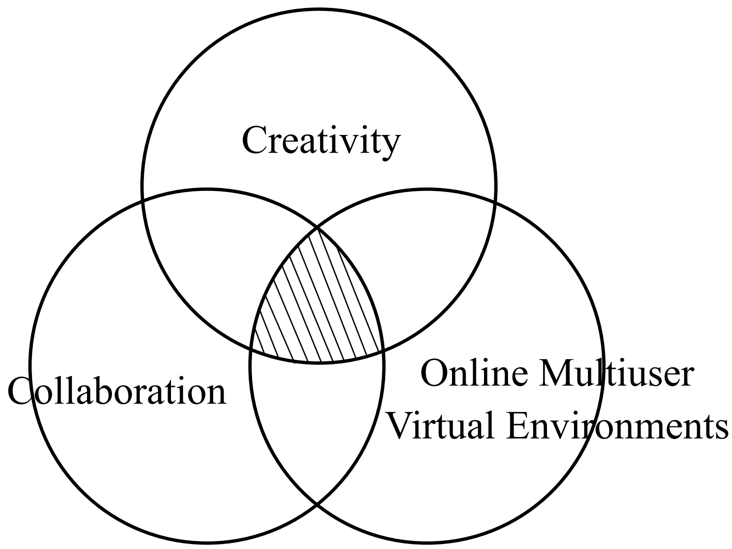


Figure 1.1 Fields of Research

1.2. Structure of Dissertation

In Chapter II, I investigate the definition of creativity in psychology and architecture fields, and the relevant creativity assessment methods. I also review the nature of creative collaboration in architecture as well as its benefits and challenges, the relationship amongst design tools, representation, and creative collaboration. In addition, I review recent studies that investigate the affordance of New Media, including MUVE, for collaboration.

In Chapter III, I discuss the research methodology for conducting the experiments, which includes experiment schema and procedure, data collection tools, and assessment methods for creative collaboration. I also introduce the quantitative and qualitative data analysis methods used in this research.

In Chapter IV, I investigate the affordance of MUVE for creativity in face-to-face collaboration. In this chapter, I analyze the creativity assessment data, collected in face-to-face collaboration. Both participants' self-assessment and external judges' consensual assessment are used for the analysis. In addition, I also evaluate the results of the statistical analysis of data on the basis of interviews and video observation to scrutinize the ways MUVE influences creativity in face-to-face collaboration.

MUVE and sketching media support synchronous collaboration in both face-to-face and remote modes of collaboration. While in face-to-face mode, participants can be aware of partners' verbal and gestural communication cues in the physical place. In remote mode, they work in a computer mediated environment and cannot directly perceive partners' communication cues stemmed from their physical presence. Therefore, the chapter on face-to-face collaboration aims to investigate the ways in which MUVE influences creativity when participants can perceive partners' communication cues in the physical place, compared to habitual sketching. Meanwhile, the chapter on remote collaboration focuses on MUVE's influence on creativity when participants can be aware of partners' communication cues only in MUVE's computer-mediated environment, compared to the mediated environment in online sketching.

In Chapter V, I focus on the affordance of MUVE for creativity in remote collaboration. As in the previous chapter IV, in this chapter I analyze the self- and consensual creativity assessment data collected in remote collaboration. Interviews and observations are also used for evaluating the statistical analysis results to investigate the impacts of MUVE on creativity in remote collaboration.

In Chapter VI, I summarize the affordance of MUVE on creative collaboration. In addition I also discuss the ways that the characteristics of MUVE influence creative collaboration with critical evaluation.

Chapter II Theoretical Background

To initiate this research on the affordance of MUVE for creative collaboration, in Chapter II, I investigate the definition of creativity in psychology and architecture, and creativity assessment methods. In addition, I also review the literature on the nature of creative collaboration in architecture, the relationship amongst design tools, representation, and creative collaboration, and the theoretical argumentations on the affordance of MUVE for creative collaboration and the relevant studies on collaboration using New Media. This chapter's literature reviews help in evaluating the statistical analysis in Chapter IV and V.

2.1. Creativity

2.1.1. Definition of Creativity

In psychology, creativity is defined as a combination of novelty (i.e. original, unexpected) and appropriateness (i.e. useful, adaptive concerning task constraints) (Runco & Charles, 1993; Runco & Jaeger, 2012; Lubart 1994, Amabile 1983, 1996; Sterberg & Kaufman, 1999, 2000; Paletz & Peng 2008; Plucker & Makel, 2010). Creativity is a person's capacity to create new actions, processes, or products in response to pre-existing conditions (Venon, 1989; Csikszentmihalyi, 1996). At the same time, creative actions, processes, and products are also appropriate and useful to suit the purpose and context of their production (Mednick, 1962; Amabile, 1983, 1996). Society and culture have the capacity to influence creative production, in that society and its culture will accept or deny the production (Amabile, 1983; Csikszentmihalyi, 1996).

Given these definitions, creativity can be measured through a product or response that reflects the creators' new ideas, acts, or processes as well as their appropriateness. The tangible products of creativity need to be evaluated by appropriate observers who are familiar with the domain in which the product or response was created. The appropriate observers mean expert judges who have knowledge and experience in the field where creative outputs produced (Kaufman, Plucker, & Baer 2008). For example, for assessing the creativity of children's pictures, art class teachers and researchers in the area of children's art projects and child development could be considered as the appropriate observers. The product or response will be judged by the appropriate observers as creative to the extent that it is both novel and appropriate, useful, correct or valuable to the task at hand (Amabile, 1983, 1996; Paletz & Peng, 2008). The appropriate observers can relate an individual's creativity to society and culture.

Creativity can be defined by cognitive processes and personal traits - unrelated "matrices of thought" that produce a new insight, productive ideation, and novel and unconventional problem-solving activity (Koestler, 1964; Guilford, 1950). However, these definitions of creativity are limited compared to the consensual definition of creativity that is based on group assessment about creative products. Creativity is an explicit concept in a social and cultural group rather than implicit individual ideation process and problem-solving activity (Bruner, 1962; Amabile, 1982, 1996). This study assumes that qualifying design products in terms of novelty and appropriateness is the more valid approach to evaluate creativity.

2.1.2. Creativity in Architecture

The importance of creativity initially arises due to patrons or clients' needs for uniqueness. Since the Renaissance, architects have generated distinctively different ideas and solutions compared to master-builders and ordinary people (Broadbent, 1973; Jones, 1992). Patrons and clients have hired architects due to this distinctiveness of architectural solutions in order to represent their social status, wealth, and power; one representative case is the Medici family in Renaissance Florence, the patron of De Vinci, Michelangelo, and other remarkable architects. Even contemporary clients want architectural distinctiveness in order to announce their identity (Bourdieu, 1984; Gans, 1999); governments want to express their nations' power and identity through unique museums, and rich clients and companies want to represent their success through distinctive skyscrapers. Novel architecture, which others have not owned or experienced before, surely satisfies such clients' needs of distinctiveness.

The other importance of creativity rests on architects' competency of problem-solving. In *Design in Architecture*, Geoffrey Broadbent (1973) mentions that architectural creativity contains both novelty of artistic expression and appropriate rationality for the problem-solving. Architects handle artistic levels such as forms of buildings, but at the same time, they have to consider reality including clients, sites, and construction technologies. Broadbent's notion of architectural creativity mostly rests on the creativity definition of Donald MacKinnon (1962), a well-known psychologist who studies architects' creativity. Broadbent introduces MacKinnon's definition of creativity as follows;

> Creativity involves a response or an idea that is novel or at the very least statistically infrequent. But novelty or originality of thought or action, while a necessary aspect of creativity, is not sufficient. If a response is to lay claim to being part of the creative process, it must to some extent be adaptive to, or of reality. It must serve to solve a problem, fit a situation, or accomplish some recognizable goal. Last, true creativity involves a sustaining of the original insight, evaluation, elaboration of it, and a developing to the full (MacKinnon, 1962).

Novelty of Spatial Conception and Organization

In *Space, Time, and Architecture*, Sigfried Gideon (1967) mentions three major changes of spatial conception in the history of western architecture. These changes show the most important criterion of architectural creativity: novelty of spatial conception and organization. In ancient Egypt, Sumer, and even Greece, the most important concept of architecture was exterior spaces and volumes such as buildings' forms, shapes, and sculptures. During the last two millennia, from the midst of the Roman to Baroque architecture, vaulting interior spaces consisting of walls and vaults were considered the most important. In modern architecture, an organic integration of exterior forms and interior spaces are the most significant conception in architecture.

These spatial conceptions are related to architects' novel attempts of existing architectural conventions. For example, when Le Corbusier proposes his five points of architecture, namely (1) freestanding pillars, (2) open floor plan that is independent from the supports, (3) vertical façade that is free from the supports, (4) long horizontal sliding windows, and (5) roof gardens, his novel and radical spatial conception stems from a critical view of the conventional retaining-wall based spaces. Novel spatial conception and organization also include rational analysis about design constraints, such as realization methods, client needs, and social and cultural contexts. For example, Rome's novel vaulting interior space appropriately satisfies the need for huge public spaces in order to respond to the expansion of Rome.

Appropriateness of Building Performances

As Broadbent mentions, appropriateness and usefulness of a building is one important component of architectural creativity. In particular, appropriate problem-solving about given constraints and contexts can be reflected in the performance of the building. In *Evaluating Methods To Measure The Performance Of Buildings*, Horst Rittel (1996, 1971) suggests social factors, physical factors, and economic factors are useful for evaluating architectural appropriateness related to the building performance. More specifically, social factors include numbers of people occupying a building, behavior of the inhabitants or users, and behavior of neighbors. Physical factors includes dimension of building, location of building, orientation of building, stability of structure, building materials, light, temperature, ventilation, and sound transmission. Economic factors are provision of facilities and maintenance. In *De Architectura, Ten Books on Architecture,* Marcus Vitruvius Pollio argues that a good building should satisfy the following three principles: *firmitas, utilitas, venustas,* which mean, respectively, solid (durability or stability), useful (utility or functionality), and beautiful (aesthetic). Amongst those principals, the meaning of *utilitas* indicates appropriateness and usefulness of a building. The statement of Vitruvius shows that appropriateness of a building has long been considered one of the important principles in architectural design

2.1.3. Creativity Assessment in Architecture

In contemporary psychology, the most popular way of assessing a creative product is the consensual assessment technique (CAT) (Amabile, 1983, 1996; Kaufman, Pluker, & Baer 2008; Paletz & Peng, 2008). In the consensual assessment, expert judges rate novelty and appropriateness of actual products and tangible responses, for example, answers and solutions about the given mathematical and scientific problems. These experts independently evaluate the degree of creativity of the products and responses, then based on integration of the judges' evaluation, creativity of those products and responses are decided. All of the judges are familiar with the domain of the creative products and responses. For example, in the case of museum design, appropriate experts can be architectural design theorists who are studying museums, professional architects who have broad design experience on museums, museum managers, and curators. The judges should be instructed to rate those products relatively, rather than rating them against some absolute standard they might have for work in their domain (Amabile, 1983, 1996).

The consensual assessment is also applied in the evaluation of design creativity. In "Variance in the Impact of Visual Stimuli on Design Problem Solving Performance", Gabriela Goldschmidt (2006) asked three external judges to assess originality and functionality of design products when participants are exposed to visual stimuli and not. In another study "Inspiring Design Ideas with Texts", she also used the same assessment method (Goldschmidt, 2010).

About the reliability and validity of the consensual assessment, in *Essentials of Creativity Assessment*, Kaufman, Plucker, and Baer (2008) state that in the consensual assessment, experts do tend to agree on which artifacts are highly creative and which are not. As evidence, the authors cite Teresa Amabile (1983, 1996) who assesses how much the agreement rates amongst experts is reliable in art collage creativity evaluations, and she finds the reliability range of experts' agreement rate is from 0.72 to 0.93 (1 is maximum). Other researchers also find the reliability range is between 0.7 and 0.9 (Baer, 1993,1997; Baer, Kaufman, & Gentile, 2004).

Kaufman et al. also state that the use of rating criteria in the consensual assessment is useful for separating technical goodness from creativity assessments, and they cite Amabile's artistic creativity evaluation in collage-making (1982, 1983). Besides, they mention that in reality, there are no other valid and objective methods to substitute for the consensual assessment method (Kaufman, Plucker, & Baer 2008).

However, in consensual assessment, the evaluation gaps amongst judges should be explored, especially where the products being judged are in relatively new domains or represent truly pioneering works (Kaufman, Plucker, & Baer, 2008). This assessment also needs more extensive work on the identification of appropriate judges for particular types of product, and the influence of judges' characteristics (Ambile, 1996; Kaufman, Plucker, & Baer 2008). In architectural creativity assessment, a judge's design and representation preferences should be considered in particular.

Aside from the limitations from the evaluation gap amongst judges, consensual assessment is still reliable for evaluating architectural creativity compared to other creativity assessments. In recent design studies, objective assessment of creative process is used for investigating brain activity and ideation process. Assessments of the idea of flow, optimal experience, and design protocols are representative examples in previous studies (Csikszentmihalyi, 1996). The objective assessment is applied to investigating the roles of sketching for internal ideation (Suwa & Tversky, 1997; Purcell & Gero, 1998; Hong & Lee, 2005). However, it is still questionable that productive ideation flow can be sufficiently qualified as creativity. Qualification of creativity requires an appropriate comparison of existing ideas and products in society and culture beyond personal ideation experiences. In many cases, the design process is a black box that is too complex to evaluate by objective methods.

2.2. Collaboration

Collaboration is defined as a relationship or an action between experts or professionals to achieve a specific target, such as solving a problem and creating or discovering something new (Schrage, 1999). The purpose of collaboration rests on (1) the limits of individual abilities which prevent completing a given task and (2) the expectation that collaboration can help people complete the task more quickly and more effectively as well as produce better quality than they could otherwise (Hobbs, 1996; Kalay, 1999). In architecture, the need of collaboration is increasingly important as the complexity and uncertainty of the world grows, and as both the problems architects must solve and clients' desires become more complex and more diverse. Architects need both specific and broad knowledge, command of more than one discipline, and experiences across multiple professions (Schön, 1983).

2.2.1. Creative Collaboration

Creative collaboration is a process of shared creation where the exchange of ideas among the participants helps to stimulate and enrich their own creativity to the extent that the solution they arrive at is novel and appropriate. It rests on interdependent, complementary, and integrative relationships among participants. For example, Watson and Crick discovered a DNA structure through interdependent collaboration and Picasso and Braque created Cubism through complementary and integrative collaboration (John-Steiner, 2000). Creative collaboration has the following characteristics: unique tasks, unpredictable results, shared understanding, communication, and joint decision-making (Kalay, 2004). It also supports complementariness and interdependency amongst collaborators (John-Steiner, 2000).

Exactly how does collaboration help creativity? Collaboration can facilitate participants' appropriate and rational problem-solving and novel solution synthesis via reflection in-action[1]. Donald Schön (1983) mentions that designs are based on reflective actions to find better solutions. Yehuda Kalay (2004) applies Schön's theory to collaboration. He describes collaboration as reflection-in-action where each of the participating professionals is attentive to the emerging solution and to the intents and actions of fellow collaborators, which are reflected upon and critiqued. The input received from fellow collaborators may trigger new innovative solutions or combinations that might have been missed earlier. Alex F. Osborn (1963) mentions that idea production among collaborators can facilitate creative solution because the ideation can provide collaborators with opportunities to discover unexpected novel synthesis among those diverse ideas.

Collaboration's distinct mechanism, shared understanding of other collaborators' world-views and knowledge, communication, and joint decision-making, may help creativity. Shared understanding allows each participant to comprehend, critique, debate, adopt, or incorporate the propositions made by other participants into the emerging collective creation. It also includes deeper cognitive states and critical reflections on other participants' social and educational backgrounds, world-views, and unshakable beliefs than just knowing their specialized

[1] Donald Schön (1983) defines reflection-in-action as the ability of professionals to "think what they are doing while they are doing it". The ability indicates that professionals analyze their reactions to the given situations and explores the reasons around and the consequences of their actions.

knowledge. Without shared understanding disagreements among participants may lead to conflicts. In contrast, disagreements based on shared understanding have the potential to produce novel solutions (Nijstad et al 2003; Kalay, 2004). Communication permits each participant to exchange ideas interactively. This may enrich and contribute to the shared understanding of the problems and to its creative resolution. Joint decision-making process may lead to converged novel resolution and reduce risks of failure if there is an embedded review process.

2.2.2. Creative Collaboration in Architecture

In architectural practice creative collaboration has four particular characteristics: (1) creative collaboration frequently happens in the pre-design, schematic design, and design development phases rather than the documentation phases, (2) architects usually collaborate with clients and other consultants rather than architects. Dana Cuff maps the relative levels of interaction experienced by architects throughout design and construction of a project (Cuff, 1996; Figure 2.1), (3) in these design phases clients and other collaborators bring improvisational suggestions and feedback, and (4) visual representation is significant in creative collaboration in architecture (Kalay, 1999).

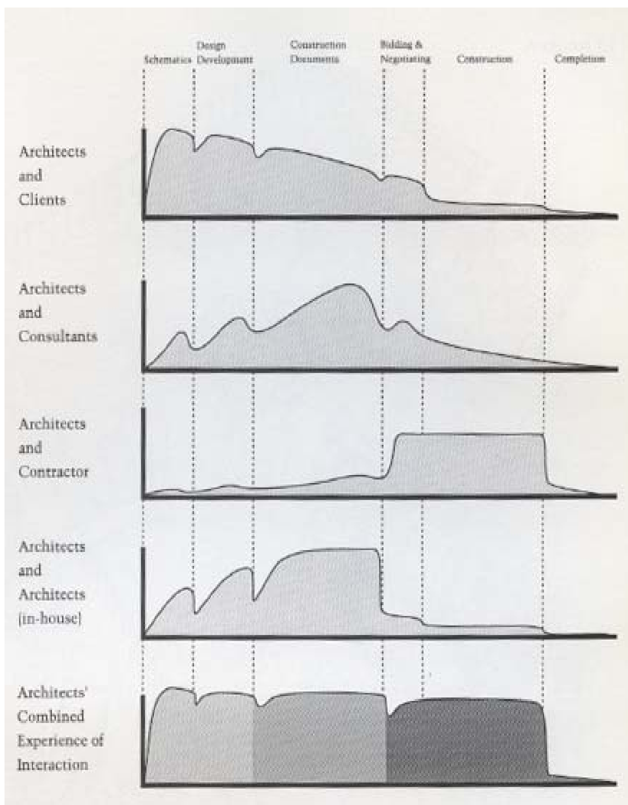


Figure 2.2 Relative levels of interaction experienced by architects in design and construction of a project, Cuff ,1996

In the cases of creative collaboration in architectural design, clients help architects know their exact quality demands and they inform the architect of local contexts and constraints. These quality demands and local information simplify decision-making and problem-solving for architects (Cuff, 1996). Other professions, particularly structural engineering can complement an architect's knowledge, helping them achieve unique architecture (Kalay, 2004). The cases of creative collaboration between an architect and multiple types of engineers are well documented. The Dives in Misericordia church near Rome, Italy is the result of creative collaboration between architect Richard Meier, who designed its curved shape, and structural engineer Antonio Michetti, who designed a double-stressed concrete structure that made the shape possible, and Italcementi, the Italian construction company, which developed a special concrete mix and a construction robot to realize it (Kalay, 2004). In this case, the engineer, construction company and architect solved tectonic problems through complementary collaboration to achieve its unique form.

Occasionally, architects collaborate with other design professionals to aim for better aesthetic quality and artistic argumentation of their building. This collaboration between artists and architects is complementary and at the same time integrative. For instance, architects provide spatial and functional plans whereas artists develop visual and aesthetic effects of the spaces through his unique artistic schemes. In *Two Minds: Artists and Architects in Collaboration*, Jes Fernie introduces cases of collaboration between architects and artists. For architects, collaboration aims to achieve better aesthetic quality and artistic argumentation of buildings, whereas, for artists, collaboration is useful to bring artistic argumentation to a public beyond the limits of the art world (Fernie & Ursprung, 2006).

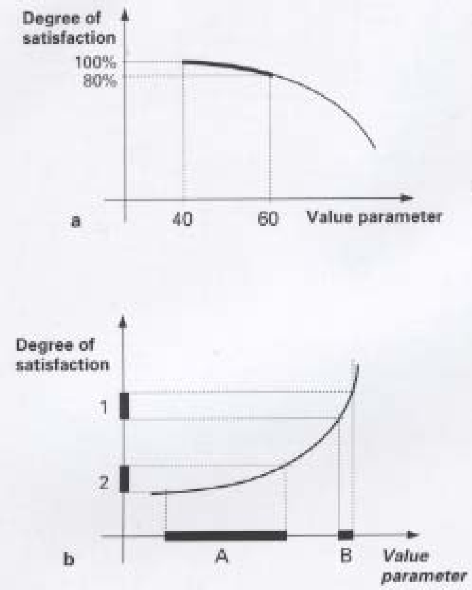
For example, for the Laban dance center in Deptford, London Jacques Herzog and his firm's architects knew they wanted to use color as a defining feature of the building. Most of their buildings to date had been constructed using natural materials such as wood, concrete and stone. They felt color was an element that would benefit the design so they collaborated with artist, Craig Martin. Martin suggested they integrate solid interior surfaces of the building with translucent effects from the exterior surfaces. Three corridors of the building were painted in a single tone of vibrant Craig Martin green, magenta or turquoise. Martin's color scheme satisfied Herzog's aim of creating a sense that the exterior of the building is blurred and soft while the interior is sharp and vibrant. This collaboration between Herzog and Martin is complementary and at the same time integrative. The architect provided spatial and functional plans, and the artist developed visual and aesthetic effects of the spaces through his unique artistic schemes. Their ideas were seamlessly integrated to create new valued architecture.

In *From Craft to Profession: The Practices of Architecture in Nineteenth-Century America*, Mary N. Woods (1999) also introduces the architects' multidisciplinary collaboration in the nineteenth-century America. In the late nineteenth and early twentieth centuries, new materials and mechanical systems are introduced, and the market for building services grow increasingly specialized and fragmented. In addition, specifications for drawings, coordinated supervision, and logistics become critical. Such complexity makes it hard for professional architects to direct all aspects of design and construction. Wood states that to manage such given complexity, architects collaborate with numbers of other professionals such as professional draftsmen, contractors, civil engineers, and other mechanical engineers. Woods adds that another reason for architects' multidisciplinary collaboration in the nineteenth-century America rests on the search for distinctive and pioneering architectural models such as skyscrapers and new types of urban offices. To build a new type of skyscraper, which other architects have not tried yet, architects require specialized knowledge from other professionals, such as civil and mechanical engineers.

2.2.3. Challenges of Creative Collaboration in Architecture

Conflicts and communication hurdles often happen in creative collaboration making collaboration challenging. Conflicts are caused by participants' different world-views developed through training, education, and social and cultural backgrounds (Kuhn, 1962; Nijstad et al ,2003). In creative collaboration in architecture, the participation of clients and consultants, who have different world-views from architects, frequently brings communication hurdles and conflicts. For example, in cases of collaboration between architects and artists, Jes Fernie mentions architects are interested in creating a solid form, managing various types of representation, and completing projects, while artists are interested in creating an experience, concentrating one type of representation's quality, and following open-ending ideas (Fernie, 2006).

To communicate with clients and other professions architects have used various forms of visual representation, such as sketches, drawings, and physical models. However, in many cases, clients and consultants arbitrarily interpret architects' representation via their own world-views and needs (Cuff, 1996). Musso and Rittel (1967) offer a way to visualize conflicts amongst collaborators , namely, satisfaction curves that represent the correlation between the degree of change in the value of some design parameter and the satisfaction it elicits (Figure 2.2). The goal of each participant is to find a design solution that optimally satisfies all issues of concern within the acceptable range of satisfactions and at the highest possible end of that range.



6.10 Satisfaction curves represent the correlation between the degree of change in the value of some design parameter and the satisfaction it elicits.

Figure 2.3 Satisfaction curves, Musso and Rittel 1967

When collaborators use traditional representation and visual communication methods, like free-hand sketches and graphs, they need to share appropriate level of knowledge for interpreting the represented messages. In addition, sufficient verbal and gestural communications are required to prevent misinterpretation. However, in the case of collaboration at remote distance, the communication cues and atmospheres, which exist when participants use traditional representation media, are inevitably reduced by computer mediation. Therefore, sharing those different worlds amongst collaborators becomes difficult.

In addition, communication hurdle is a general problem in both face-to-face and remote collaborations. Communication hurdle is also related to the limited affordance of design tools for communication, insufficient communication skills, both verbal and visual, and time constraints. Communication hurdle brings misunderstanding and lack of shared understanding, hampers joint decision-making, blocks the flow of ideas, and results in pre-mature convergence on less than optimal solutions (Bernard et al, 2003; Kalay, 2004).

2.3. Design tools and Design Environments

2.3.1. Design Tools

Characteristics of Design Tools

A tool is a moving entity whose use is initiated and actively guided by a human being for whom it acts as an extension toward a specific purpose: the entity may be physical or conceptual; the motion may be manual or machine powered; the guidance may be manual or by indirect control (McCullough, 1996). Design tools are defined as physical devices or conceptual instruments for implementing or representing design thinking and aiding the four processes of design: problem analysis, solution synthesis, evaluation, communication (Gregory, 1966; Broadbent, 1973).

How can design tools influence creativity and collaboration? Design tools produce representation and determine the properties of represented products. Representation by design tools can influence ideation, intra-processes of communication, and extra-process of communication with other collaborators for creativity. Representation also influences shared information, shared understanding, and conflict management for collaboration (Kalay, 2004).

Design tools can also influence creativity and collaboration through supporting evaluation and communication. Evaluation is a process that compares the proposed solution to the goals, constraints, and includes qualitative criteria such as creativity, aesthetics, and human behaviors (Kalay, 2004). Evaluation provides feedback that can facilitate ideation for producing novel and appropriate alternatives. Design tools also support verbal and visual communication. Communication allows all participants in the design process to become informed about the evolving goals and solutions in order to help generate solutions and evaluate them. Communication stimulates participants' reflective feedback for ideation, shared information and understanding, and negotiation for conflict management.

What are the characteristics of design tools for creativity and collaboration? Design tools for creative collaboration are easy to manipulate for visual representation (Scharge, 1999). Tools' manipulability of visual representations facilitates feedback for ideation, evaluation, and communication. These tools support verbal communication as well as visual representation. The integration of verbal communication and visual representation stimulates clear shared information, understanding, and negotiation (John-Steiner, 1997). Design tools for creative collaboration are also seamlessly interlinked with the collaboration environment (Scharge, 1999). For example, a whiteboard and markers are a set of tools for supporting easy representation, evaluation, and communication. At the same time, the whiteboard is a part of a collaboration environment: it records and displays collaborative process and outputs.

Design tools and Representation

One important role of design tools is representation. The verb "to represent" has the following meanings: (1) "to describe as having a specified character or quality by some term, character, symbol, or the like" and (2) "to form an image or representation of in the mind" (Akin, 1982).

According to these definitions, representation can be products that "designate or express," such as, a drawing, a tune, or a word. In other words, representation is a form of communication to one's mind or to the minds of one's co-worker, client, or user-group (Kalay, 2004).

Representation is an abstraction of a reality or a concept. Abstraction is the act of considering something as a general quality or characteristic apart from concrete realities, specific objects, or actual instances (Arheim, 1969). The abstraction can take place in two different forms: as extraction or aggregation of the characteristics of the represented reality (Akin, 1982, Kalay, 2004). An appropriate representation contains a suitable level of abstraction to convey information for its intended purpose. Symbols and arbitrary codes, such as floor plans, are efficient means to support communication among collaborators who share knowledge about the symbols and codes, whereas, photo-realistic renderings are a more effective means to support communication with clients who need more pictorial description.

Influences of Representation on Creativity and Collaboration

How can representation influence creativity and collaboration? Representation is a form of communication. Communication has two distinct roles: intra-process, when a designer communicates with him or herself during the search for and formation of design ideas; and extra-process, when a designer communicates with other members of the design team (Kalay, 2004).
Both roles of representation can help creativity. Intra-process between a designer's mental images and represented products helps the designer know how to decompose the problem, determine salient issues to consider, determine when closure is reached, and determine the appropriate criteria for evaluating the final product (Akin, 1982; Kalay, 2004). The intra-process is known as ideation: it is used for searching or discovering the best design alternative and problem solution. Ideation can provide designers with an opportunity to produce novel and appropriate ideas. The extra-process, which is based on proposals, observations, and criticism made by other collaborators, can also stimulate ideation (Kalay, 2004). Both can stimulate designers' creative cognition in terms of discovering novel forms and shapes.

Representation helps collaboration by facilitating shared information, shared understanding, and negotiation for conflict management. Collaborators can share necessary information to achieve their goal through representations, such as sketches, scale drawings, and scale models. Representation also aids shared understanding. Each collaborator has his or her own world-views that have been constructed by education, social, and cultural backgrounds. The different world-views often prevent collaborators from forming a shared, objective basis and converging opinions. Representation is a means for conveying collaborators' professional world-views and shared understanding (Kalay, 2004). Representation is also useful for negotiation and conflict management. Representing the argumentation process and decision-making process reduces conflicts (Tufte, 1990).

2.3.2. Design Environments

The definition of environment is the circumstance, objects, or conditions by which one is surrounded. It includes not only physical conditions, but also social and cultural conditions that influence the life of individual and community. A design environment in this context is defined as an environment for the task of designing a physical and social circumstance, objects, or conditions for proceeding with the design process.

How can a design environment influence creativity and collaboration? First, design products in the environment can stimulate ideation for searching novel and appropriate solutions. Particularly, rich displays of represented objects, which suit the goal of design, can facilitate creative solution (Goldschmidt, 2004). The display of design products and objects also stimulates communication amongst collaborators in order to evaluate and share information.

Second, the people in a design environment can influence creativity and collaboration by stimulating feedback for ideation as well as sharing information. The social presence of collaborators also influences creativity and collaboration by creating a “climate” in work places such as competition (Osborn, 1967; Amabile, 1983, 2000). Third, the context and goal of design can be shared in the design environment. The displays of represented products, communication, and evaluation of collaborators remind collaborators about the shared context and goals of design. The shared context and goals are useful for producing novel and appropriate solutions, confirming the purpose of collaboration, and adjusting different world-views of collaborators (Kalay, 2004).

These characteristics of design environments can be extended to the concept of place. A place is the result of relationship between activities of peoples, physical attributes of objects or the built environment, and conception, such as the context and meaning of the place (Canter, 1977; Kalay & Marx, 2001, 2004). The three elements can be shared among people who are involved in a place. Sociological studies indicate the people who are involved in the place also share strong emotional bonds and social relationships that may help support shared information, shared understanding and conflict management of collaborators (Oldenburg, 1999). In the case of creative collaboration places, collaborators can share (1) their activities for communication, evaluation, and representation, (2) objects and products, which come from collaborative process, (3) the context and goal of design, and (4) emotional bonds and intensive social relationships.

In “Re-Place-ing Space: The Roles of Place and Space in Collaborative System”, Steven Harrison and Paul Dourish (1996) also argued that a notion of place, which frames interactive behaviors, is valuable to support Computer Supported Cooperative Work (CSCW). They stated that “a place is a space which is invested with understanding of behavioral appropriateness, cultural expectation, and so forth. A place is generally a space with something added like social meaning, convention, cultural understanding about role, function and nature and so on.” Based on the concept of a place, the authors recommended that to support ongoing management activities amongst collaborators, CSCW design refers to the emergent patterns of human behaviors and social interactions like a place rather than the mimicry of three-dimensional metaphors in a space.

2.4. Online Multiuser Virtual Environments (MUVE)

2.4.1. Characteristics of Online Multiuser Virtual Environments (MUVE)

Online Multiuser Virtual Environments (MUVE) are online, immersive 3D environments based on anthropomorphic avatars and synchronous multiuser access. In terms of representation, in MUVE, participants are immersed in the three-dimensionally represented environment. The representation of self, called an avatar, is located in the three-dimensional environment, and users are able to perceive and experience (e.g. walk, sit, and touch) the environment based on the avatars' first or third person view[2] and body activities. The immersive experiences in the designed environment, based on the representation of self, promote the feeling of being there.

In addition, the representation of self and others probably promotes the social and psychological relationship amongst users. In "Being There: The Experience of Presence in Mediated Environments", Wijnand Ijsselsteijn and Giuseppe Riva (2003) introduced three types of presence for multi-user collaborative virtual environment (CVEs): (1) physical presence, (2) social presence, and (3) co-presence. The authors defined physical presence as "the sense of being physically located in mediated space," whereas social presence refers to the feeling of being together, of social interactions with a virtual or remotely located communication partners. At the intersection of these two categories, is co-presence, that sense of being together in a shared space, combining significant characteristics of both the representation of self and social presence. The authors also argued that co-presence plays a critical important in CVE design, to support users' social interactions such as a process of negotiation and community creation.

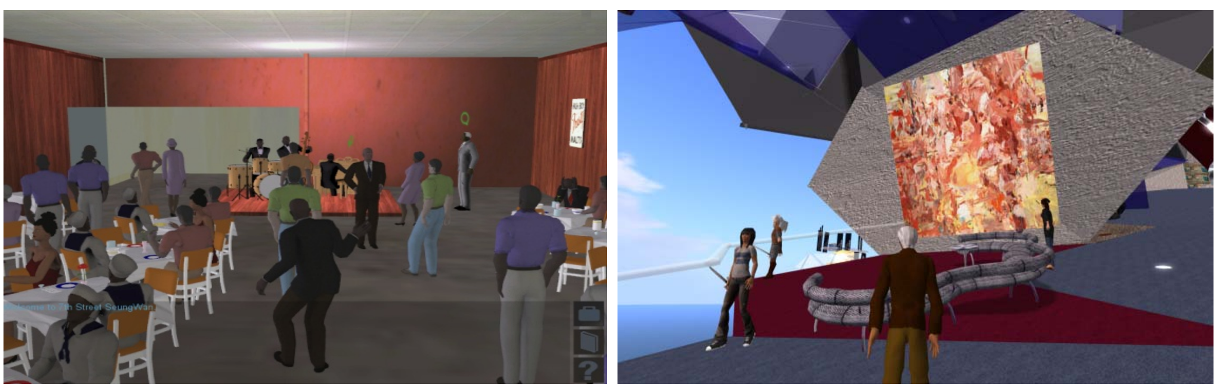


Figure 2.4 Examples of MUVE, Virtual Oakland Jazz and Blues (left), Virtual Design Studio 101 (right): in MUVE, users are able to perceive and experience the designed 3D environment using their avatars' activities and views. In addition, they can be aware of the presence of other users and interact with them. These characteristics of MUVE provide not only the immersive representation, but also the social and psychological relationship amongst users.

The feeling of social and co-presence could be emphasized by synchronously shared objects and contexts in MUVE. Co-presence satisfies the concept of "Virtual Place", and possibly promotes

[2] In the immersion in MUVE, participants perceive the designed environment from either eye level of their avatar, called first person view, or behind their avatars, called third person view.

social and psychological relationships amongst users. Regarding social and psychological aspects of Virtual Place, Yehuda E. Kalay (2004, 2006) defined the concept of Virtual Place as follows: "A place is as much a psychological phenomenon as it is a physical one. It is rooted in human social actions and cultural conception, and it is a space activated by social interactions and invested with culturally based understanding of behavioral appropriateness." He built on David Canter's principles of place-making (1979) as follows "Place-making is the conscious process of arranging or appropriating objects and spaces to create an environment that supports desired activities, while conveying the social and cultural conception of the actors." In extending the concept of place, Kalay argued that one premise of a Virtual Place, a technological platform to support online, multi-users' access, is to support the sense of other people's presence and the ongoing awareness of their activities, which allow users to structure their own activities and to integrate them with those of others. The aforementioned theoretical framing of a collaborative system, proposed by Harrison and Dourish (1996), is also probably extended to co-presence in MUVE's synchronously shared environment and its social and psychological aspects.

In the extension of aforementioned theories, I assume that the theoretical relationship between MUVE's representational, social and psychological aspects and mechanisms of creative collaboration are as follows. (1) The immersion in the three-dimensional environment, using physical presence of self, probably influences personal ideations and feedback in the search for creative solutions. Since participants feel being in the designed environment,, they have opportunities to explore the environment from a personal, immersed point of view.

(2) In addition, in MUVE, users can be aware of other users' social presence, design outputs, and collaborative contexts. They also can interact with other users and environmental elements like a place. I assume that such co-presence in a shared environment probably creates unexpected and serendipitous events which inspire new ideas. The co-presence in the same environment also may facilitate communication, reflection-in-action, and complementariness amongst users for proposing creative solutions. Social and co-presence of collaborators perhaps influence not only ideation and communication amongst users, but also psychological and social aspects of creative collaboration, such as the feeling of working together and reliability about partners, which encourage creative attempts.

(3) An additional representation aspect is that MUVE is probably able to reduce the difficulty of three-dimensional representation. MUVE provides three-dimensional geometries, and thus collaborators can combine, manipulate, and deform those geometries to represent buildings structure and necessary details, without the high cost of representation. Therefore, a great number of creative feedback and design iterations among collaborators are expected.

2.4.2. Research on New Media and MUVE in Collaboration

In this section, I evaluate the recent literature that investigates the use of New Media in collaboration. The literature targets the following three areas of research: (1) online sketching and collaboration, (2) tangible user interface and collaboration, and (3) MUVE and collaboration. Based on the literature review, I explain the ways in which my research is different from previous work on the subject.

Research on the Use of Online Sketching in Collaboration

Henna Lahti et al. (2004) investigated the effectiveness of a computer supported collaborative environment, called FLE Tools, which allows participants to post their sketches and images remotely, for sharing and building knowledge amongst collaborators. They asked teachers, undergraduate students, and clients to use FLE Tools for sharing knowledge and ideas in an authentic design studio. Then, they analyzed textual messages and sketches posted to the FLE Tool's database using criteria of degree of organizing (sharing) knowledge. In conclusion, Lahti et al. stated that a networked collaborative learning environment facilitates students' engagement in sharing design problems, knowledge, and collaborators' ideas. In addition, they argued that shared visual and technical sketches induce joint-decision making amongst collaborators.

This research shows that a networked collaborative environment based on shared sketches influences sharing of knowledge and design constraints. However, this research is based on a single use of FLE Tools. A comparison between networked and non-networked collaboration environment is required to understand the affordances of the tool for sharing knowledge among collaborators. In addition, Lahti et al. regard collaboration as simply knowledge-building. They miss the psychological and interpersonal aspects of collaboration.

In another research, H. H. Tang, Y. Y. Lee, and J. S. Gero (2010) compared the design processes of designers in both digital (online) and traditional (habitual) sketching environments. Based on design protocol analysis, classified by Gero as these three categories: the user's needs (Function), the design performances (Behavior), and the final forms of the designed objects (Structure), they concluded that the design processes in those two environments are not statistically different in terms of personal ideation and collaborative ideation. Nevertheless, the authors argued that traditional sketching has advantages over digital media in the perception of visual-spatial features in collaborative environments, and in the reasoning of design problems. However, they do not sufficiently interpret the affordance of online sketching for collaboration. This research is valuable for having established that online and traditional sketching has equivalent affordances for collaborative processes. However, as in the case Lahti's et al. work, this research also regards collaboration as only information-processing.

Research on Tangible User Interfaces (TUI) in Collaboration

In order to clarify the impact of Tangible User Interfaces (TUI) on collaboration, Mi Jeong Kim, and Mary Lou Maher (2006) compared the design protocol of collaborative design sessions using a tabletop system integrated with 3D blocks and a typical keyboard/mouse/display Graphical User Interfaces (GUI). In TUI, the movement of 3D blocks is tracked by the tabletop system, including camera detection, and displayed as building elements in the LCD screen. In this research, collaboration is defined as cognitive synchronization (i.e. proposal, argument, question, resolution, and specification), and gesture actions (i.e. design gesture, general gesture, touch gesture, and point gesture). Using protocol analysis, the researchers argued that the use of TUI influences designers' spatial awareness about design objects, and the cognitive changes facilitate designers' problem-finding, which means the formulation of problems and alternative ideas for producing a solution, and collaborative behaviors.

The importance of Kim and Maher's research is that they have demonstrated that spatial cognition using TUI, and potentially other immersive media, influences collaborative design processes and behaviors. However, like other protocol analysis studies, this research defines collaboration as cognitive processing and observable behaviors, and creativity as idea production. Therefore, this research does not reflect the influence of media on the psychological aspects of collaboration.

Research on Online Multiuser Virtual Environments (MUVE) in Collaboration

Ning Gu, Mi Jeong Kim, and Mary Lou Maher (2011) investigated the effectiveness of 3D Virtual Worlds, the same technology as MUVE, in architectural design collaboration.. They compared collaborative design protocols produced in habitual sketching in face-to-face collaboration, online sketching in remote collaboration, and MUVE in remote collaboration. They analyzed collaboration in criteria of communication contents, design process, operation on external representation, function-structure, and working modes. In conclusion, Gu et al. found that (1) there are no insignificant differences amongst those three tools in terms of communication content and operations, (2) the design process and function-structure protocol percentages of face-to-face sketching are higher than those in remote MUVE and online sketching. Gu et al. argued that this conclusion is important because it indicates that 3D Virtual Worlds are able to support design communication and representation during collaboration even when the designers are remotely located.

The value of this research rests on the introduction of collaborative behaviors using MUVE, face-to-face and online sketching. Gu et al. describe the work distribution pattern in MUVE like this:

In 3D virtual Worlds, an average 40% of the duration was for individual design activities where different designers worked on different tasks or different parts of the design representations. They often came together after an individual phase to review each others' outcome or swap tasks. During these individual design phases, participants reduced and some pairs even stopped verbal communications, which is evident in the decrease of the communication contents for the 3D world session. (Gu, Kim, & Maher, 2011).

They also found that MUVE facilitates communication about the awareness of the other designers, visual analysis for design development, and manipulation of objects (change-related activities) rather than creation of new proposals (creation-related activities).

However, like other protocol analysis studies, this research focuses on only observable behaviors and information-processing in collaboration. In addition, Gu et al. do not explain why the collaboration processes in face-to-face sketching, remote MUVE, and online sketching's collaboration are not different.

In another research, Panayiotis Koutsabasis et al. (2012) investigated three authentic design cases using 3D Virtual Worlds. Using qualitative methods, they evaluated design cases in criteria of the quality of communication (complexity of design changes, numbers of use), situation awareness, problem-based collaborative learning. In conclusion, Koutsabasis and colleagues argued that "the collaborative design in 3D Virtual Worlds is a very engaging experience for remote participants and can add values to the activities of conceptual design and/or design review."

The researchers state that while designers are immersed in MUVE environment, they produce more complex outputs by adding new content and by instantly manipulating and arranging 3D objects. In addition, they argue that MUVE effectively supports design review and customer-centered evaluation of conceptual design, active communication and awareness of others for satisfactory collaboration. The research values rest on the introduction of the above collaboration behaviors in MUVE. However, the research is limited to the investigation of the ways in which MUVE influences such results. The limitation perhaps stems from the fact that the research relies on authentic design cases. Authentic design cases are easily influenced by variables other than MUVE, for example, the use of supplementary tools. In addition, since this research is based on a single use of MUVE rather than a systematic comparison with other synchronous collaboration tools, it is hard to reach conclusive results regarding the affordances and the degrees of effectiveness of MUVE in collaboration. Furthermore, as per other recent studies, the research also targets observable behaviors and interface/tool operations in MUVE rather than other aspects of collaboration.

General Criticism

The above research precedents show that MUVE can potentially support creative collaboration. They also introduce unknown collaboration patterns using New Media. However, the criticism of the former studies is as follows. (1) Most research precedents focus mainly on information-processing, observable behaviors, and interface operations in collaboration using New Media, whereas creative collaboration involves interpersonal and psychological relationships among collaborators. (2) Research precedents have not yet considered the quality of collaborative results, creativity in particular. (3) Some former studies do not sufficiently interpret the results, so conclusive results for the affordances and effects of New Media on design collaboration cannot be reached. (4) Those studies do not employ systematic comparisons between characteristics of New Media and other media.

Parting from research precedents on collaboration in New Media, my research focuses on (1) the affordances of MUVE for a consensual concept of creativity in collaborative outputs, (2) the affordances of MUVE for the psychological and interpersonal aspects of creative collaboration. I also systematically investigate (3) in what ways characteristics of MUVE, for example 3D immersion, influence creative collaboration when compared to other media that support synchronous collaboration, such as face-to-face and online sketching. The rationale of the comparison is described in detail in Chapter III.

Chapter III Methodology

In the previous chapter, I introduced the definition of creativity and collaboration in psychology and architecture, and the relevant creativity assessment methods. I also stated the relationship between design tools and creative collaboration, and the impact of MUVE on creative collaboration in literature. In Chapter III, I develop research questions and hypotheses, experiment schema and procedure, and assessment methods for creative collaboration. In this chapter I also introduce the statistical data analysis and qualitative methods for this study.

3.1. Research Questions and Hypotheses

As discussed in Chapter I, this research poses two main questions: (1)What is the affordance of Multi-user Virtual Environments (MUVE) for creative collaboration in architectural design? (2) In what ways does MUVE influence creative collaboration in architectural design? To investigate those inquiries, I compare MUVE and sketching[1] in terms of the criteria of creativity and collaboration. Those research questions are specified as the following hypothesis.

Hypothesis: Online Multiuser Virtual Environments (MUVE) better facilitates architectural design creativity, including novelty and appropriateness as its components, than sketching in face-to-face collaboration, and Online Sketch in remote collaboration.

The rationales of the comparison between MUVE and sketching media in face-to-face and remote collaboration rest on the following assumptions. First, while sketching is based on two-dimensional and non-immersive representation, MUVE is a three-dimensional and immersive environment with anthropomorphic avatars. In MUVE, participants feel that they are in the designed three-dimensional environments using their avatars' immersive view and body activities. I assume that such immersion allows participants to experience the designed three-dimensional forms and spaces, thus it probably facilitates the search for more novel and unexpected solutions and feedback, called reflection-in-action processes, than sketching's two-dimensional and non-immersive representation does. The immersive experiences in MUVE also can allow participants to assess the dimension and scale of their design outputs using avatars' activities. Therefore, the hypothesis assumes that the immersion in MUVE is more effective for producing appropriate and useful design solutions than sketching.

[1] In this research, I use the term "sketching" to mean a medium for free-hand drawings. In face-to-face collaboration, I provide pens, pencils, color pencils, and tracing paper. In remote collaboration, I provide a digital pen, tablet, and mouse.

Both MUVE and sketching support a synchronous and shared collaboration environment.While MUVE's synchronous collaboration environment rests on the immersive experiences in three-dimensional objects and presence of avatars, the representation of partners, the synchronous collaboration in sketching is based on two-dimensional and static representation.

In addition, in MUVE, participants can be aware of collaborators' design processes, represented by avatars' activities and three-dimensional objects, and they can experience each other' design proposal using avatars' immersive view and activity. Therefore, I assume that participants can precisely share each other's ideas without misinterpretation and miscommunication compared to sketching media's two-dimensional and static representation.

Third, I also assume that the presence and activities of avatars in MUVE can not only prompt the feeling of immersion and communication, but also enhance psychological and social aspects of creative collaboration, such as interdependency amongst collaborators. In MUVE, participants can be aware of partners' presence, represented as avatars, and interact with them. Such social presence, the feeling of being together, and co-presence, the feeling of being together in a shared environment, probably leads to the feeling of working together and a comfortable collaboration mood. Particularly, in remote collaboration, I assume that the awareness of collaborators' avatars in the designed environment better promotes such comradeship and mood than the awareness of collaborators' drawing processes in online sketching, and thus probably encourage participants' attempts for proposing creative solutions.

Although I generally hypothesize that MUVE better facilitates creativity in collaboration than sketching media do, I also assume that MUVE and sketching possibly have the equivalent impacts on the production of creative solutions. While the immersive representation in MUVE allows designers to experience the new designed environment, the designers perceive differently the same environment depending on their own immersive experiences. Therefore, when a designer wants to share information about a building, she needs to explain the location and details of the building to her partner, and the partner also needs to spend time and effort to experience it. In contrast, static and non-immersive representation is probably more efficient to share overall information because designers can directly see the partners' sketches. However, sketching does not allow them to experience the new design. Therefore, both representations in MUVE and face-to-face sketching possibly have equivalent merits and limitations for supporting the communication, joint in decision-making processes, and complementing each participant's competence for proposing creative solutions.

In MUVE's synchronously shared environment, participants can be aware of his or her partner's presence, represented by anthropomorphic avatars in the three-dimensional environment, and interact with him or her. Those social presence and co-presence possibly facilitate the psychological and interpersonal aspects of creative collaboration, such as comradeship. However, face-to-face sketching also can promote the comradeship because designers sit together and look at each other's sketches and physical gestures. While the comradeship in MUVE probably emerges from working together inside the design, the feeling in face-to-face sketching is possibly generated by being together outside the design, but at the same physical work place.

3.2. Experiments

To test the aforementioned hypotheses, this research designs two sets of comparative experiments. The first set of experiments compared *Second Life*, a popular commercial MUVE, to freehand sketching in habitual face-to-face collaboration. The second set aimed at comparing the same media in the context of remote collaboration. Senior undergraduates and M. Arch students in the Department of Architecture at the University of California, Berkeley participated in the experiments. From a pool of 220 students, 40 joined my experiments, 24 senior architecture-major students and 16 M. Arch students. I teamed up participants at the same academic level in groups of two.

In the first set of experiments, face-to-face collaboration, participants worked together in the same room for designing two bus stops. First, participants were required to design one bus stop in *Second Life*. After one hour break, they were asked to design the other bus stop using freehand Sketching. They were required to complete each task within two hours (Figure 3.1). The two tasks had different site conditions, but they had similar complexity and requirements. The design studio instructors at UC Berkeley checked the complexity and requirements between those two design tasks (Table 3.1). The second set of experiments address remote collaboration. Participants were separated in different rooms. They were required to work together using *Second Life* and *Group Board*, a commercial online sketching environment, with voice and text chat. The design tasks were two street exhibition booths. Like in face-to-face collaboration, the two design tasks were located on different sites, but have similar difficulty and requirements (Table 3.1). Participants started by designing an exhibition booth via *Second Life*, then after a one-hour break, they designed the other exhibition booth via *Group Board*. Each design task required a maximum of two hours (Figure 3.2). The experiment results, produced in the two sets of experiments, are sampled in Table 3.2 (Table 3.2). In the above experiments, participants used site photographs for both MUVE and sketching tasks. Additionally, participants used a three-dimensional site model with adjacent buildings and street elements for the MUVE task, and they used a two-dimensional site plan drawing. Participants' *Second Life* skills were trained in either a prior class "Designing Virtual Worlds" or in tutorial sessions with a simple assignment for practice.

In pilot experiments, I noticed that a participant's skills and experiences in a particular medium affected her feelings of ease or exhaustion using such a medium. In other words, a participant who was not skilled in *Second Life* may find the design task that employed *Second Life* exhausting. Thus, in both sets of experiments, I systemically swapped the order of experiments for the neutralization: one time I started in *Second Life*, the other time I started by sketching. After participants completed the two design tasks in each set of experiments, I separated the two participants in different rooms, and then interviewed them for one hour.

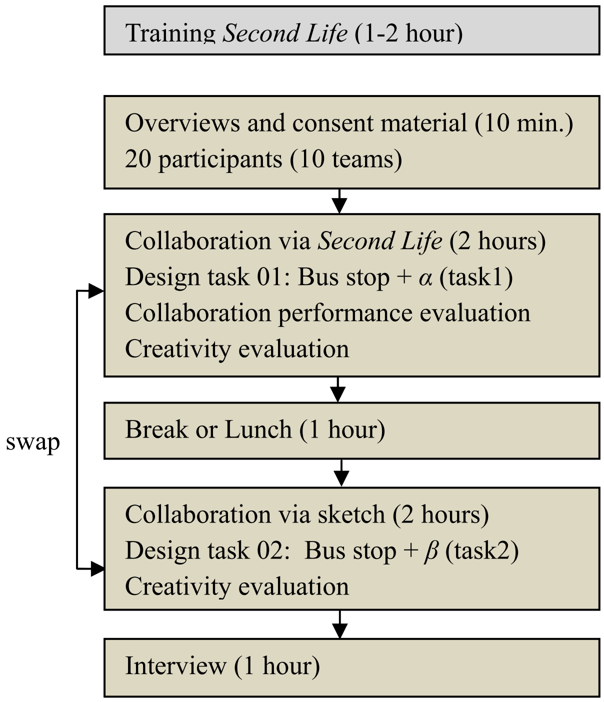


Figure 3.1 Face-to-face collaboration experiment procedure

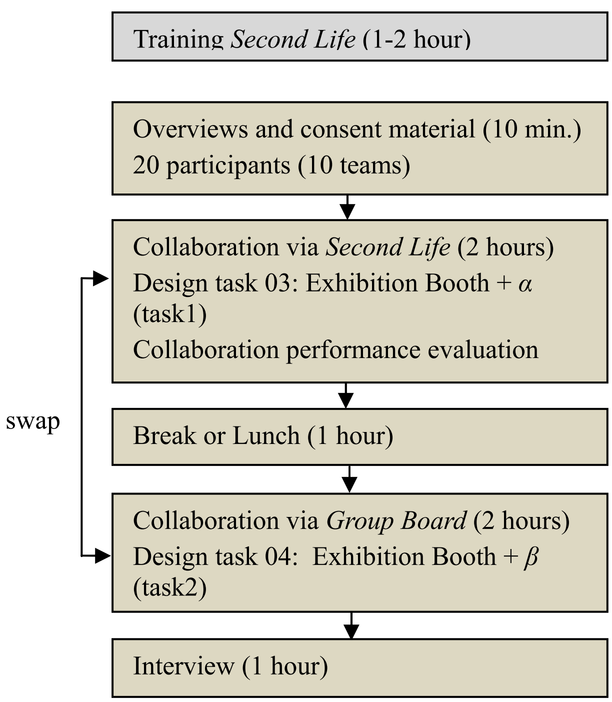


Figure 3.2 Remote collaboration experiment procedure

Experiments	Design Tasks	Site and Size	Requirements	Time
Face-to-Face Collaboration	Bus Stop + α (task1)	Next to Berkeley Bart Station, 19 x 49 feet	Part I: Schematic Design (1) A landmark of the City of Berkeley to invite visitors (2) An architectural space (3) Seating/waiting area for family unit passengers with children (4) A bus stop sign (5) A roof to the bus stop Part II: Design Development (1) Schemes for ventilation, materials, lighting, shading, and rain protection (designated areas) (2) Safe landing area (4' perpendicular from bus X 15' parallel form bus) (3) At least one wheelchair lots (60"x60") (4) Seats and tables for at least 10 passengers	Total 2 hours
	Bus Stop + β (task2)	At the right corner from the cross of Bancroft way and Telegraph Ave, 34 x 35 feet	Part I: Schematic Design (1) A landmark of UC Berkeley which responds to Sather Road and Sather Gate (2) Seating/waiting area for students Part II: Design Development (1) Safe landing area (6' perpendicular from bus X 20' parallel form bus) (2) At least five bicycle lots (18" x 30" per one lot) (3) Seats and tables for at least 15 passengers *The other requirements are the same with Bus Stop + α	Total 2 hours

Remote Collaboration	Street Exhibition Booth + α (task1)	Next to Berkeley Bart Station, 28 x 72 feet	Part I: Schematic Design (1) A landmark of the City of Berkeley to represent the communication between artists and citizens (2) An architectural space (3) Exhibition area for paintings and sculptures (4) Staying/Seating area for one exhibition manager (5) A small café area (6) A roof /canopy to the partial or whole exhibition booth Part II: Design Development (1) Schemes for ventilation, materials, lighting, shading, and rain protection (designated areas) (2) A space to display 3 big sized paintings (5'X6') and 1 big sculpture (6'X6'X9') (3) One desk and chair for the manager (the minimum size of the desk: 24"X72" and the minimum size of the chair: 18"X18") (4) Seats and tables for 6 persons	Total 2 hours
	Street Exhibition Booth + β (task2)	At the right side of Sather road, UC Berkeley, 24 x 83 feet	Part I: Schematic Design (1) A landmark of UC Berkeley to represent academic achievement of UC Berkeley students (2) Exhibition area for painting/drawings and models Part II: Design Development (1) 3 big sized paintings/drawings (5'X6') and 2 big sized models (4'X4'X5') (2) Seats and tables for 4 persons *The other requirements are the same with Exhibition Booth + α	Total 2 hours

Table 3.1 Design tasks for face-to-face and remote collaborations

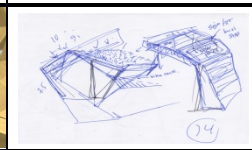
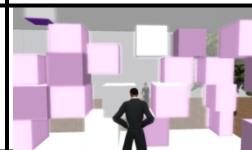
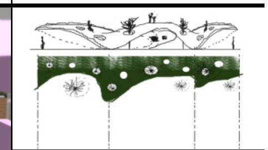
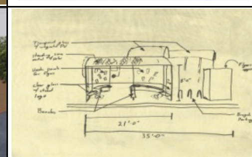
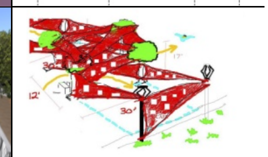
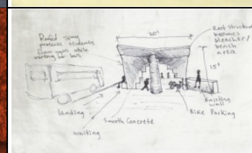
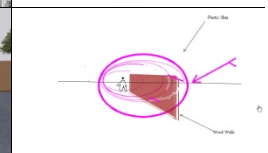
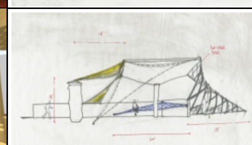
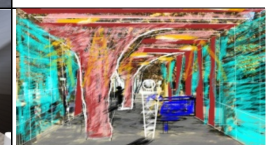
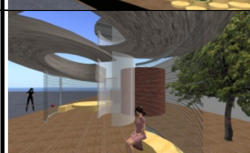
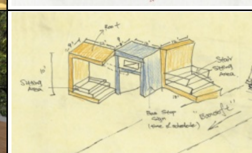
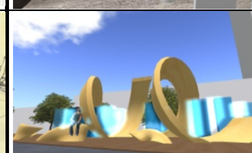
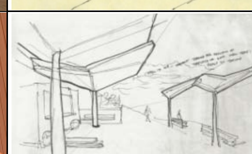
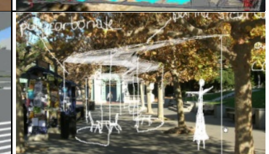
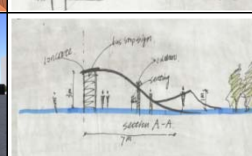
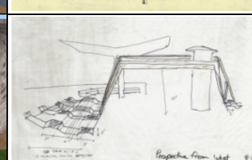
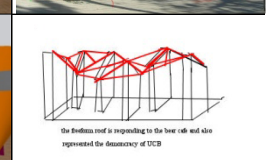
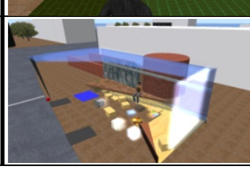
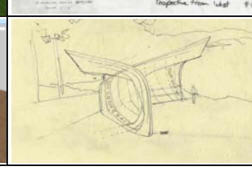
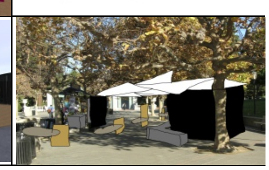
Teams	Face-to-Face Collaboration Results		Remote Collaboration Results	
	MUVE	Sketching	MUVE	Online Sketching
Team 01				
Team 02				
Team 03				
Team 04				
Team 05				
Team 06				
Team 07				
Team 08				
Team 09				
Team 10				

Table 3.2 Experiment result samples

3.3. Assessments

3.3.1. Quantitative Methods

This research relies on the definition of creativity in psychology (creativity = novelty X appropriateness, or creativity = novelty + appropriateness. In *The Cambridge Handbook of Creativity*, Robert J. Sternberg (2010) states that creativity is an integrated concept of novelty and appropriateness and he states that this definition is widely accepted in psychology. In *The Standard Definition of Creativity*, Mark A. Runco and Garrett J. Jaeger (2012) also mention that novelty is vital for creativity, but must be balanced with fit and appropriateness. Their assertion relies on the literature reviews advanced in previous creativity research. In addition, in another study, Runco investigates the statistical correlation between creativity and its two components, novelty and appropriateness. The result indicates that when both novelty and appropriateness increase, creativity ratings increase significantly. Runco (1992) suggests that although it is not necessary for a novel idea to be appropriate, to be viewed as creative, novel ideas are not valued less by being appropriate. Research in design methods sometimes refers to the definition of creativity in psychology in order to investigate the affordance of design media (Goldschmidt, 2006, 2010; Acuna & Sosa, 2010).

In this research, creativity is assessed based on novelty and appropriateness by external judges: five design studio teachers and two professional architects. The evaluation method follows Consensual Assessment Technique (CAT) used in psychology, which means appropriate observers assess the creative products in terms of novelty and appropriateness. In scoring, the definition of creativity is formulized as either a multiplication of novelty and appropriateness scores, Creativity = Novelty X Appropriateness (Paletz & Peng, 2008), or a sum of novelty and appropriateness, Creativity = Novelty + Appropriateness (Finke, 1988; Goldschmidt, 2010). I preferred to use the addition formula for creativity analysis: Creativity score = Novelty score + Appropriateness score. because the multiplication formula: Creativity score = Novelty score X Appropriateness score, if both novelty and appropriateness scores are negative (both are banal and inappropriate), a product of those two negative scores produces a positive score of creativity: It makes a logical error. The evaluation score range is from -6 (very banal or very inappropriate) to 6 (very novel or very appropriate).

Each judge assesses 10 results using MUVE and sketching in face-to-face collaboration, MUVE and online sketching in remote collaboration. The total numbers of assessment cases per each design tool (N) are 70. The experiment results are shown in Table 3.2 (Table 3.2). The creativity assessments have 4 categories: (1) exterior form, (2) interior space, (3) material planning, and (4) miscellaneous requirements (site facilities), and contain 34 executable questions (Table 3.3).

The assessment questionnaire form has bar-like Likert scales from -6 (very negative) to 6 (very positive). Evaluators can mark anywhere in between those nodes (Figure 3.3). In addition to investigating how participants experience and communicate with design media for creative solutions, this research also asks participants to assess the creativity of their final solutions. The self-assessment form is the same as the external judges' assessment form.

Please assess <u>the appropriateness of the bus stop's roof and wall design (including shape and dimension)</u> to <u>support passengers' activities such as waiting (rest), accessibility, and visibility</u>.

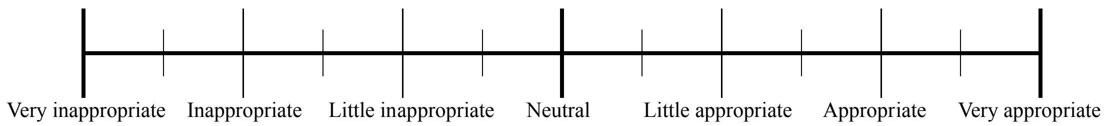


Figure 3.3 An assessment question sample (bar like-Likert scale)

Design Tools	Novelty and Appropriateness	Controlling variables
Face-to-face collaboration 1. Sketching 2. MUVE (*Second Life*) Remote collaboration 1. Online Sketching (*Group Board + Skepe*) 2. MUVE (*Second Life + Skepe*)	1. Exterior Form 1.1 Wall and roof design to support users' activities 1.2 Wall and roof design to support building performances 1.3 Wall and roof design as a landmark 1.4 Opening and entrance planning[2] to support users' activities 1.5 Opening and entrance planning to support building performances 2. Interior Waiting Space (face-to- face collaboration), Interior Exhibition Space (remote collaboration) 2.1 Interior space to support users' activities 2.2 Interior space to support building performances 2.3 Waiting and sitting space (face-to-face collaboration), Space for big-sized exhibits (remote collaboration) 3. Material Planning 3.1 Materials to support users' activities 3.2 Materials to support building performances 3.3 Materials to support a landmark 4. Misc. Requirements 4.1 Bus stop sign (face-to-face collaboration), 4.2 Landing area (face-to-face collaboration), a small café area (remote collaboration) 4.3 Wheel chair lots/bicycle lots (face-to-face collaboration), manager's seat (remote collaboration)	1. Participants' skills to use tools 2. Participants' design ability 3. Complexity of design tasks

Table 3.3 Experiment variables

As a statistics tool, *SPSS V 18.0* [3]analyzes the raw data which come from the creativity and collaboration performance assessments. The independent T-test compares means of two

[2] The opening and entrance planning factor means partitioning and organizing exterior and interior spaces

[3] Statistical Package for the Social Sciences, a static toolkit produced from WinWrap Basic.

independent groups, for instance, the means of the creativity scores in MUVE and face-to-face sketching, and it confirms the statistical significance of the mean difference between those two groups via testing p-value. P-value means the probability of obtaining a test statistic based on probability distribution. In statistical analysis, if p-value is higher than 0.05 (>95%), null hypotheses are accepted, which means that MUVE and sketching are not statistically different to enhance creativity and collaboration, and if p-value is less than 0.05 (<95%), the score between MUVE and sketching have statistical difference, and the comparison results are acceptable. However, in this research, sample numbers are too small to rely on the statistical analysis (the sample numbers for self-evaluation is 20, the numbers for consensual assessment is 70), so simple arithmetical mean comparison regardless of p-value is also appropriate to show how MUVE and sketching affect which creativity categories and factors.

3.3.2. Qualitative Methods

In this research, interview and video observation are the primary qualitative methods for interpreting statistical analysis results and to investigate the impact of MUVE on the mechanisms of creative collaboration. The interview questionnaire contains 21 questions in 5 categories: (1) The contents of design, (2) The relationship between creativity and design tools, (3) The relationship between collaboration and design tools, (4) The relationship between design process and design tools, (5) The relationship between creativity and collaboration (Table 3.4).

In addition, observation data are collected by video recording. In the sketching experiment, one camera records the sketching process, and another camera captures collaboration performances. In case of online sketching, two cameras capture each participant's collaboration performances, and a screen capture tool records the sketching process in *Group Board* (Figure 3.4).

In the MUVE experiment, one camera records collaboration performances in face-to-face collaboration, and two cameras capture each participant's performances in remote collaboration. Additionally, a screen capture tool records each participant's design process inside MUVE. In MUVE, since two participants experience the same design differently, video editing software synchronizes those two participants' different experiences to observe their collaborative behaviors and interactions in detail (Figure 3.5).

Figure 3.4 Recording observation data: sketching in face-to-face collaboration (left), online sketching in remote collaboration (right)

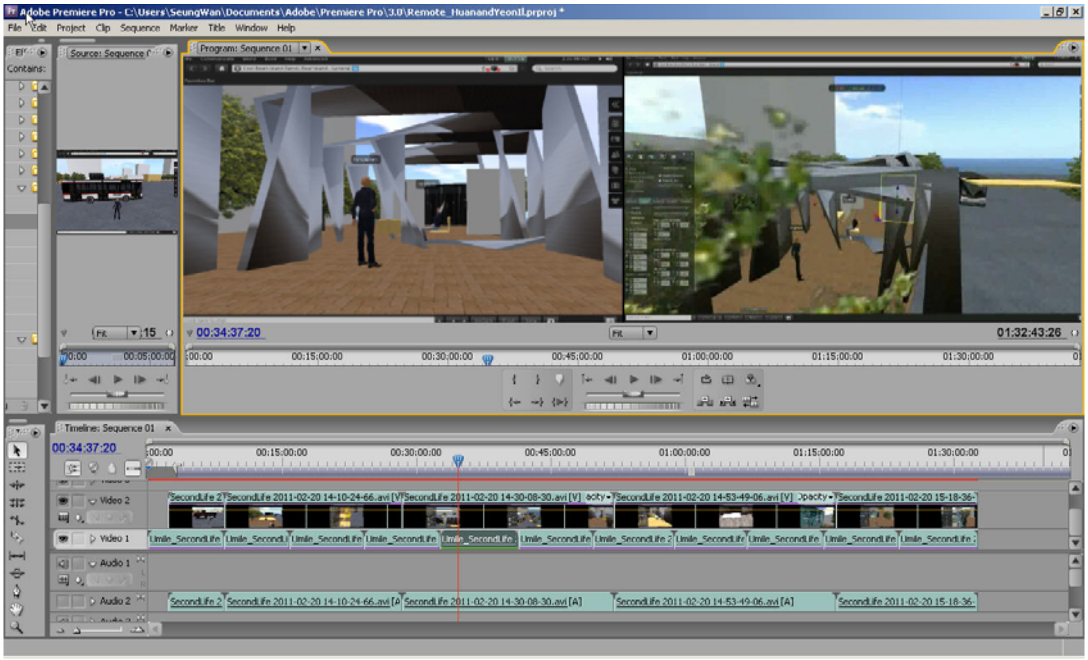


Figure 3.5 Synchronization of two participants' experiences in MUVE: While participant Y is working at the inside of the building (the left side window), partner H is observing its outside (the right side window). As the example, the software synchronizes such different experiences amongst participants in MUVE.

Categories	Questions
1. Contents of design	1-1. First of all, please explain the contents of your team's final design output. What are the important characteristics of the design output? 1-2. How did you understand the design problems of each design task? 1-3. Could you briefly explain design solution of each design task?
2. Relationship between creativity and design tools	2-1. Generally, do you think your team's final result is creative or not? Why do you think so, in what ways? 2-2. Do you think your design is novel or banal? Did sketching influence the novelty or banality of your team's collaborative results? (If no, then go to 2-3) In what ways? Did Second Life influence the novelty or banality of your team's collaborative results? In what ways? 2-3. Do you think your design is appropriate or inappropriate? Did sketching influence the appropriateness of your team's collaborative results? In what ways? Did Second Life influence the appropriateness of your team's collaborative results? In what ways? 2-4. What kinds of characteristics of sketching did particularly influence the novelty and appropriateness of your team's design what you mentioned? 2-5. What kinds of characteristics of Second Life did particularly influence the novelty and appropriateness of your team's design what you mentioned?

3. Relationship between collaboration and design tools	3-1. How did sketching influence your team's general collaboration? Is it negative or positive or not influenced? In what ways? 3-2. What characteristics of sketching particularly positively or negatively influenced your team's collaboration? In what ways? 3-3. How did Second Life influence your team's general collaboration? Is it negative or positive or not influenced? In what ways? 3-4. What characteristics of Second Life specifically positively or negatively influenced your team's collaboration? In what ways?
4. Relationship between design process and design tools	4-1. Can you explain your problem analysis process in the first design task? How did sketching and Second Life influence your problem analysis of the given constraints? (i.e. ,data generation, data collection) Was it helpful, or not for problem analysis? In what ways? 4-2. Can you explain your design process in the first design task? How did sketching and Second Life influence this process? solution integration and synthesis (i.e., data juxtaposition, editing and looping) Was it helpful, or not for design process? In what ways? 4-3. Can you explain your design evaluation process in the first design task? How did sketching and Second Life influence your evaluation? (i.e., data modification through iteration and testing) Was it helpful, or not for evaluation of design results? In what ways?
5. Relationship between creativity and collaboration	5-1. Did collaboration have a positive, negative or no influence on your team's result? In what ways? How did collaboration influence the general creativity of your team's result? Was it helpful, or not? In what ways? 5-2. How did collaboration influence the novelty of your team's result? Was it helpful, or not? In what ways? 5-3. How did collaboration influence the appropriateness of your team's result? Was it helpful, or not? In what ways? 5-4. How did collaboration influence your problem-analysis process about given constraints? Was it helpful, or not? In what ways? 5-5. How did collaboration influence your design process or solution synthesis? Was it helpful, or not? In what ways? 5-6. How did collaboration influence your evaluation process? Was it helpful, or not? In what ways?

Table 3.4 Interview questionnaire

Chapter IV The Affordance of Online Multiuser Virtual Environments (MUVE) for Creativity in Face-to-Face Collaboration

In Chapter IV, I analyze the statistical data collected in creativity assessments. The creativity assessments are based on both participants' self-assessment and external judges' consensual assessment. In typical creativity evaluation, Consensual Assessment Technique (CAT) is sufficient, but this research also uses participants' self-evaluation to examine the intra-processes of communication between designers and media and the ways in which the medium influence the production of creative solutions. In addition, I evaluate the statistical analysis results in light of interview questionnaires and video observations to find out the impact of MUVE's on creativity in both face-to-face and remote collaborations.

4.1. Statistical Analysis: The Affordance of MUVE for Creativity in Face-to-Face Collaboration

In Section 4.1, I discuss the statistical analysis on the self-creativity and consensual creativity assessments in face-to-face collaboration, and in Section 4.2, I evaluate the statistical analysis results based on interviews and observations ultimately in order to investigate in what ways MUVE influences creativity in face-to-face collaboration.

4.1.1. Creativity Analysis

In the statistical analysis[4] based on participants' self-assessments, I find that (1) there is no statistically meaningful difference between MUVE and sketching for creativity[5] (N: numbers of participants = 20, p-value>0.05) [Appendix Figure 1, Appendix Table 1]. More specifically, (2) MUVE's creativity scores for exterior form, interior waiting space, material planning, and misc. requirements are not statistically different from those of sketching (N=20, p-value>0.05) [Appendix: Figure 4, Appendix Table 1].

[4] As discussed in Chapter III, Independent T-test is used for the analysis and the statistics software is SPSS V. 18.0. The independent T-test is a statistical analysis method to compare two groups' means and determine the statistical significance of the two groups' mean difference based on probability calculation, called p-value. If p-value is less than 0.05 (the probability that the comparison results happen by coincidence is less than 5%), the two groups' mean difference is statistically significant.

[5] As discussed in the previous methodology chapter, the creativity score is the sum of novelty and appropriateness scores (Finke, 1998; Goldschmidt, 2010).

In the statistical analysis for judges' consensual assessments, another assessment, (1) there is no statistical difference between the use of MUVE and sketching on the score for creativity (N=70, p-value>0.05) [Appendix Figure 9, Appendix Table 3]. For this consensual assessment, 5 design studio teachers and 2 professional architects evaluate 10 collaboration results, so the total numbers of cases are 70 (7X10=70). In addition, (2) MUVE's creativity scores for exterior form, interior space, material planning, and misc. requirements are not statistically different from those in sketching (N=70, p-value>0.05) [Appendix Figure 12, Appendix Table 3].

4.1.2. Novelty Analysis

In self-assessment analysis, I find that (1) there is no statistically meaningful difference between MUVE and sketching for novelty (N: numbers of participants = 20, p-value>0.05) [Appendix Figure 2, Appendix Table 1]. (2) MUVE and sketching's scores have insignificant differences for exterior form, interior waiting space, material planning, and misc. requirements (N=20, p-value>0.05) [Appendix Figure 5, Appendix Table 1]. (3) More specifically, about 14 assessment factors[6] in the bus stop design, which is introduced in the Appendix table 3, MUVE and sketching also do have significant differences for the scores (N=20, p-value>0.05) [Appendix: Figure 7, Appendix Table 2].

In external judges' consensual assessments, statistical analysis indicates the following results: (1) there are no significant differences between the scores of MUVE and sketching for novelty (N=70, p-value>0.05) [Appendix Figure 10, Appendix Table 3]. (2) MUVE's novelty scores for exterior form, interior space, material planning, and misc. requirements are also not statistically different from those in sketching (N=70, p-value>0.05) [Appendix Figure 12, Appendix Table 3]. In addition, (3) MUVE's scores for 14 assessment factors in the bus stop design are not statistically different from those in sketching (N=70, p-value>0.05) [Appendix Figure 15, Appendix Table 4].

4.1.3. Appropriateness Analysis

The self-assessment analysis for appropriateness indicates the following results: (1) there is no statistically meaningful difference between MUVE and sketching for appropriateness (N: numbers of participants = 20, p-value>0.05) [Appendix Figure 3, Appendix Table 1]. More

[6] Exterior form category: 1) wall and roof design to support user's activities, 2) wall and roof design to support building performance (e.g. ventilation), 3) wall and roof design as a landmark, 4) opening and entrance planning to support user's activities, 5) opening and entrance planning to support building performance; Interior waiting category: 1) interior space to support user's activities, 2) interior space to support building performance, 3) waiting and sitting space and area; Material planning categories: 1) materials to support user's activities, 2) materials to support building performances, 3) materials to support a landmark; Misc. requirement category: 1) a bus stop, 2) a landing area, 3) a wheel chair lot

specifically, (2) MUVE and sketching's scores have insignificant differences for exterior form, interior waiting space, material planning, and misc. requirements (N=20, p-value>0.05) [Appendix Figure 6, Appendix Table 1]. In addition, (3) MUVE and sketching' scores are not statistically different for 14 assessment factors in the bus stop design [Appendix Figure 8, Appendix Table 2].

In consensual assessment analysis, as self-assessments, MUVE and sketching's scores do not have statistical differences for (1) appropriateness, and (2) appropriateness for exterior form, interior space, material planning, and misc. requirements, and (3) appropriateness for 14 assessment factors in the bus stop design (N=70, p-value>0.05) [Appendix Figure 11,14,16, Appendix Table 3, 4].

In sum, in face-to-face collaboration, MUVE and sketching do not have statistical differences regarding creativity and its two components, novelty and appropriateness. Therefore, I propose the following responses to the hypothesis of this research: In face-to-face collaboration, MUVE does not facilitate architectural design creativity, including novelty and appropriateness as its components more than sketching does. MUVE and sketching have the equivalent affordances for creativity and its two components, novelty and appropriateness.

4.2. Evaluation of Statistical Results: The Impact of MUVE on Creativity in Face-to-Face Collaboration

In this section, I evaluate the statistical analysis results in the previous section in order to investigate the impacts of MUVE on novelty and appropriateness in face-to-face collaboration. Interview and observation data are used for the evaluation. In statistical analysis, MUVE and sketching do not have statistically significant difference in criteria of novelty and appropriateness.

The statistical results probably rest on the fact that MUVE and sketching have equivalent impacts on creativity and its components in face-to-face collaboration. In brief, the immersion in MUVE's three-dimensional environment, the feeling of being in the designed environment, enables participants to experience new designs, produced by geometrical and parametric iterations, using first or third person view and senses of avatars' body. Thus, the immersion in MUVE facilitates reflection-in-action and feedback in the search for creative forms in particular. The immersive views and activities of avatars also allow participants to evaluate the dimensional assessment and usability of solutions.

In MUVE's synchronously shared environment, participants can be aware of his or her partner's presence, represented by anthropomorphic avatars in the three-dimensional environment, and interact with him or her. The awareness of the other's design processes, shared in MUVE, inspires unexpected solutions for proposing novel solutions. The different immersive experiences in a shared environment allow participants to collect more evaluation data and identify design errors in order to produce appropriate and useful designs.

In face-to-face collaboration, social presence, the feeling of being with others, and co-presence, the feeling of being with others in a shared environment, facilitate not only the aforementioned ideation, communication, and evaluation, but also psychological and interpersonal aspects of creative collaboration, such as working together, and comradeship.

In contrast, in sketching, participants' views are detached from representation. Sketching's two-dimensional and non-immersive representation allows participants to perceive overall information in sketches and organize them in the search for creative solutions. The perception of overall information facilitates site context analysis, design scheme establishment, site planning, and space allocation, relevant to the creativity for interior space and site facilities. In sketching, since participants cannot experience the inside of their solutions like they can in MUVE, they rely on pre-knowledge for reasoning the novelty and feasibility of their solutions. Based on sketching's static and non-immersive representation, participants can directly see partners' sketches and to collect information from them. Sketching's quick line drawing also helps participants accumulate and amalgamate each other's knowledge for proposing novel and useful solutions.

MUVE and sketching are equally limited in their influence on particular areas of creativity. In MUVE, if any spaces are not in avatars' immersive view and body ranges, participants struggle to perceive and develop the spaces. On the one hand, since each participant has his or her own different immersive experiences in one designed environment, it takes time and effort to track partner's different experiences for sharing necessary ideas.

In the case of sketching, its two-dimensional and non-immersive representation describes partial information about three-dimensional forms and spaces, thus participants strain to share the relevant knowledge and information. Since sketching's reasoning rests on participants' pre-knowledge, it is hard for them to propose unexpected novel solutions beyond such former knowledge.

As discussed before, in face-to-face collaboration, MUVE and sketching have equivalent advantages and limitations in facilitating the production of creative solutions. In the next section, I discuss the impacts of MUVE on novelty and appropriateness in face-to-face collaboration in detail.

4.2.1. The Impacts of MUVE on Novelty in Face-to-Face Collaboration

The effect of immersion in MUVE on novelty

In MUVE, participants doodle with geometries through parametric deformation and adjustment in search for novel and unexpected forms. While participants iteratively create new forms, they are immersed in the three-dimensional environment and the forms themselves, using their avatars' first or third person view[7]. The immersion in a newly generated forms enables participants to explore the spatial quality of the forms. At the same time, the avatars' body and activities (e.g. sit, walk, and stand) in the immersive environment allows them to search for and develop a potential usable form. The immersive experiences in the designed environment, with avatars' activities, help participants' reflection-in-action and feedbacks for proposing novel forms and spaces.

For instance, in the collaboration case between participant T and Y, while participant T deformed a cube searching for a new curved form, T was developing the shape. His avatar's immersive view enabled him to search for a new formal quality, while his avatar' activities (e.g. sit and stand) allowed him to examine the potential usability of the curved form. The third person view and activity of "sitting" of T's avatar aided him in developing the curved shape as "a seat". Based on the form iteration in MUVE's immersive environment, T iteratively designed and developed the new generated form until it had achieved both novelty and usability [Figure 4.1].

Figure 4.1 Face-to-face collaboration between T and Y in MUVE (sequences of participant T's design process, from left top to right bottom)

In another example, while participants J and H were designing the angle and proportion of the vertically curved objects, they were immersed in the designed objects and had the opportunity to experience the quality of the space using their avatar's view and activities. Their avatars stood, walked, and sat on the objects to examine the objects' potential usability as "walls" [Figure 4.2].

In the collaboration case between participant S and Y, S developed the giant curved object in the search for a unique roof shape. While modifying parameters of the object, S experienced its slope, scale, and height via her avatar's first person view and activities, such as walk-through, and proposed the object as "the sloped roof which starts from ground level" [Figure 4.3]. In addition, in the collaboration case of J and M, participant J wanted to create a shading device for his roof part. To achieve the goal, J changed iteratively the heights and radiuses of cylinder

[7] In the immersion in MUVE, participants perceive the designed environment from either eye level of their avatar, called first person view, or behind their avatars, called third person view.

objects and suggested the shading device, which consists of cylinders with different heights and diameters, in order to project varying amounts of light and shadow. While J develped the shading device, his avatar's immersive first person view examined the quality of the device. J's avatar stood or sat under the device and observed the results of his parametric iterations. This facilitated his search for the new roof shape [Figure 4.4].

Figure 4.2 Face-to-face collaboration between H and J in MUVE: participants H and J developed the wall objects in MUVE's immersive three-dimensional environment (sequences of participant J's design process, from left top to right bottom)

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Figure 4.3 Face-to-face collaboration between S and Y in MUVE: participant S and Y searched the scale of the roof form using their avatars' activities and immersive first person view (sequences of participant S's design process)

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Figure 4.4 Face-to-face collaboration between J and M in MUVE: participant M developed his roof's shading device and experienced the quality of the device using his avatar's first person view and activities (sequences of participant J's design process, from left top to right bottom)

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The aforementioned form iteration examples in MUVE are close to “puzzle making”. John Archea and Yehuda E. Kalay define the puzzle making paradigm as follows: “the search for the most appropriate effects that can be attained in unique spatiotemporal contexts through the manipulation of a set of components, following a set of combinational rules” (Archea, 1987; Kalay, 2004). In MUVE, participants set up and develop rules for form manipulation and combinations in the search for novel solutions.

However, in interivews, participants report that the immesion in MUVE is occasionally limited during the analysis of the overall site and the development of large scale design schemes, such as overall site planning, and space and site facility allocation. The reason is that in MUVE, paraticipants’ perceptions coincide with the immersive view and body ranges of their avatars. Therefore, if spaces and objects, for example - large-scale site elements - are not in the perceptual range of avatars, it becomes difficult to develop those spaces and objects. Although MUVE’s zoom-in/out views enable participants to see the spaces and objects from a distance, most of their experiences in MUVE rest on their avatars’ immersive views and body actions.

The effect of synchronsly shared environment in MUVE on novelty

MUVE’s synchronized and shared three-dimensional environment allows participants to be aware of their partner’s design processes, represented by their partner’s avatar and three-dimensional objects. The shared design processes evoke unexpected ideas that inspire further developments. Based on interviews, the co-presence of partners, which means being with others in a shared environment, in the shared design processes facilitates new attempts at developing forms in particular. For instance, in the collaboration between T and Y, Participant T was inspired by partner Y’s curved shape developments. Initially T explored a composition of boxes, whereas Y developed a curved shape to unify a wall and roof. Once T observed and experienced partner Y’s design progress, he borrowed partner Y’s design vocabulary, the curved shape, and explored its potential for proposing a more novel solution [Fig 4.5].

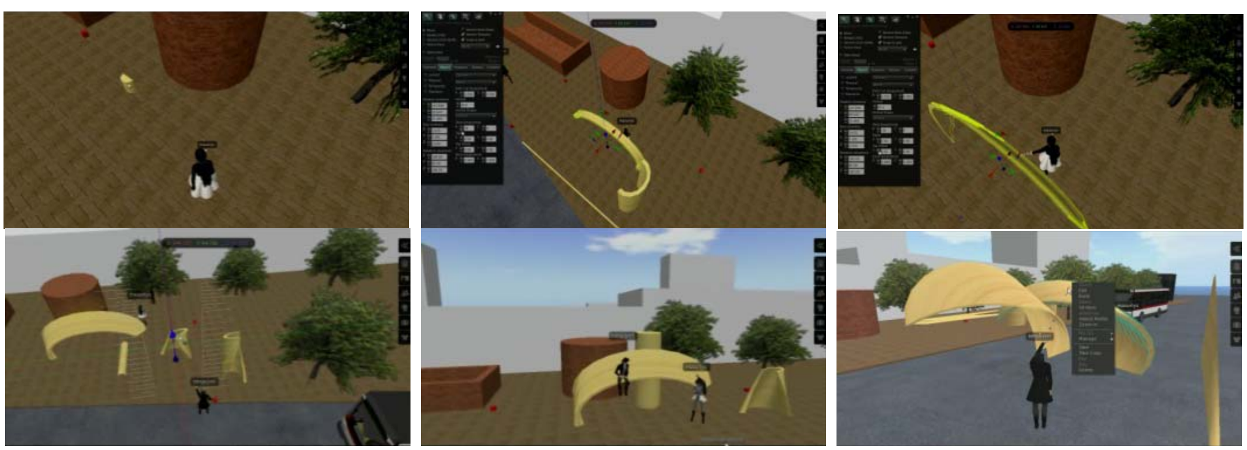


Figure 4.5 Face-to-face collaboration between T and Y in MUVE: participant Y’s design processes inspired partner T’s new attempts. Initially Y developed the curved shape (3 images on top). Partner T observed and sat on the shape, and he found the potential in the curved form for further development (3 images on bottom).

In addition, the synchronously shared environment in MUVE, partner's avatar created serendipitous events and the events inspire unexpected design approaches. The events happen when a partner interacts with any object in the design progress in ways that are different from the original creators' intentions. In many cases, the objects in design process do not have a solid meaning yet. Therefore, the serendipitous events, the partner's interactions with the designed objects, inspire additional new design approaches. For example, in the collaboration case between S and J, once J made a box and modified it, partner S sat on the box. Partner S interpreted the box as a bench, while the original creator J just changed the form of the box without a solid intention. The unexpected event - S sat on J's box - inspired J to develop the box as a street bench [Figure 4.6].

Figure 4.6 Face-to-face collaboration between J and S in MUVE: Once participant J developed a box, partner S sat on his box. The serendipitous event inspired creator J to develop the box as a street bench (sequences of participant J's design process, from left top to right bottom).

In the collaboration case between G and S, another example, when G created a group of small boxes for seats, his partner S examined the seats using his avatar's walking and sitting. G became aware of his partner's activities and was insired to search for new potentials of his seat design. G decided to develop his original seats as the scattered seats in order to support passenger's accessibility [Figure 4.7].

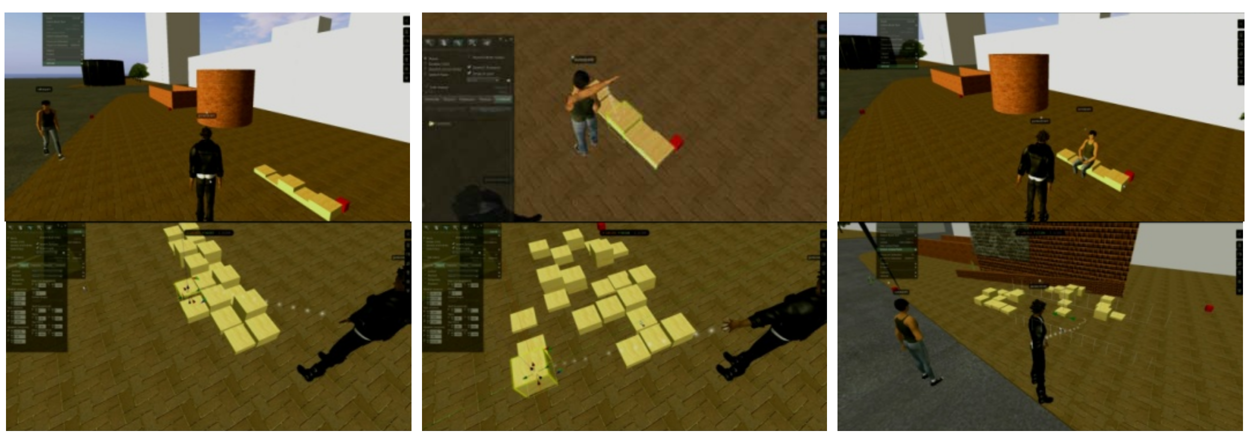


Figure 4.7 Face-to-face collaboration between G and S in MUVE: participant S examined partner G's seat design. This inspired G' s new attempts (sequences of participant S's design process, from left top to right bottom) .

As discussed before, in MUVE's synchronous and shared environment, partners' social presence, being together, and co-presence, being together in a shared environment, inspire unexpected solutions. They also enable participants to complement each other's design competence for proposing new solutions. In interviews, I found that the social presence and co-presence of partner facilitated not only the aforementioned reflection-in-action and communication amongst participants, but also psychological and interpersonal relationships, such as the feeling of working together, and comradeship. However, in face-to-face collaboration, participants can perceive not only the presence of partners' avatars in MUVE, but also the presence of partners in the physical place. Therefore, it is hard to say that the presence of partners' avatars in MUVE solely influences the psychological and interpersonal relationship amongst participants.

The Effect of two-dimensional and non-immersive represenation in sketching on novelty

Different from the three-dimensional and immersive environment in MUVE, in sketching, participants' views are detached from representation, thus participants cannot experience the inside of the designed environment. Instead, the non-immersive view in sketching enables participants to perceive overall and whole information in sketches. The sketching's non-immersive and static representation also allows participants to share each other's information in sketches and reason about site problems, design schemes, and solutions together. In sketching, since participants share one static and non-immersive view in the sketches, they easily read what partners think of, and directly draw new ideas on the partners' proposal to jump to yet more new solutions.

For example, in the collaboration case between Y and H, participant Y reasoned the location for seating and waiting spaces through drawing diagrams. Once Y represented the separated path between bus stop passengers and ordinary pedestrians, partner H observed Y's site plan and directly added his opinion on Y's sketches. Y and H reasoned users' movement patterns together in sharing Y's sketches and proposed the zigzagged seat location for satisfying both bus stop users and pedestrians [Figure 4.8].

Figure 4.8 Face-to-face collaboration between H and Y in sketching: Sketch's static and non-immersive representation allowed participants H and Y to share their ideas and reasoned the location of their bus stop's seats together (design process of participant H and Y, from left top to right bottom).

Sketching's static and non-immersive representation also aids participants in referring to ideas and knowledge in previous sketches. In sketching, since participants' views are detached from representation, they can watch and track previous sketches to rethink former ideas and improve on them. In addition, sketching's line-based two-dimensional representation also enables participants to list design problems in the given site and visualize design concepts and strategies quickly. Diagrams allows participants to record the sequences in a problem-solving process. Simple line sketching reduces efforts to visualize ideas and share them amongst collaborators, thus participants add more new ideas to partners' sketches and reason them together. This mechanism produces more branched ideas for design strategies in particular.

However, most participants describe sketching's impact on novelty like this: "In sketching, I produced ordinary designs that I have seen before, rather than merely novel ones. When I sketched an idea, the idea relies on my previous knowledge and memory, and it is hard to leap from them to an original idea." In sketching, the achievement of novel designs is due to participants' knowledge and competence rather than the design media's affordance. In contrast, the immersion in MUVE, as one affordance of the medium, allows participants to explore an unexpected potential in their design. Therefore, in sketching, participants refer to partners' knowledge and competence to improve novelty of their solutions. However, they report that it is hard for them to achieve unexpected new solutions beyond the knowledge and design competence that they already have.

In addition, participants also report that sketching's two-dimensional and non-immersive representation is useful for reasoning from fragmented information of one building, but they struggle to imagine a completed form of the building for the exploration of its potential. Sketching allows participants to represent static and partial information about three-dimensional forms and spaces (e.g. projective plans, perspective sketches, and orthographic form description). It takes much time and effort to share the three-dimensional forms and spaces using sketching's representation. In face-to-face collaboration, participants use body and hand gestures to reduce the time and effort for describing forms and spaces [Figure 4.9].

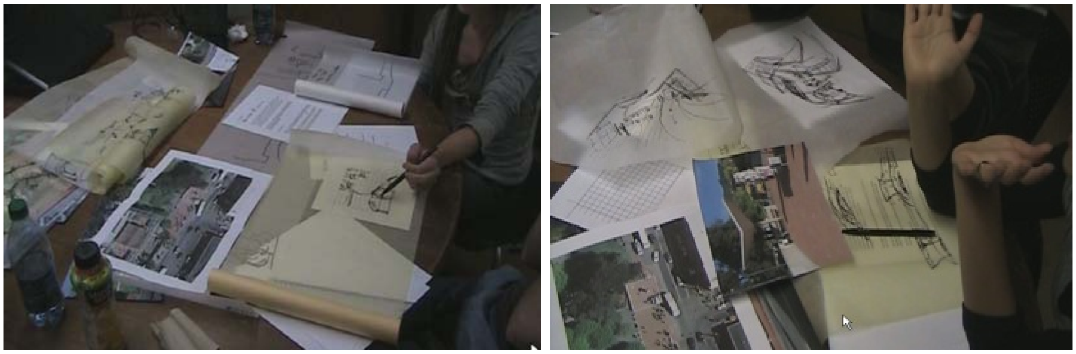


Figure 4.9 Face-to-face collaboration between A and D (left), and D and S (right): Due to sketching's static and non-immersive representation, participants spent much time and effort to represent three-dimensional forms and spaces. Therefore, in face-to-face collaboration, they used hand and body gestures for describing the ideas about forms.

4.2.2. The Impacts of MUVE on Appropriateness in Face-to-Face Collaboration

Immersive experience-based evaluation in MUVE for appropriateness

Unlike other media, MUVE allows participants to be immersed in the designed environment with a represented body, called an avatar, and directly experience the built environments in range of the avatar's body and view. Thus, the immersive experience of avatar is a means of assessing the appropriateness of a design. For instance, in the collaboration case between D and S, the avatar of participant S sat on the prisms and stacked them vertically. Her avatar's immersive view and activity, "sitting", helped S assess the scale of the prisms to fit the function of "a seat". At the same time, her avatar's immersive experiences, "walking and standing" in the stacked prisms were used for evaluating the proportion of the stacked prisms as "a wall". The original prisms, cubes, do not have the architectural meaning of a seat or a wall. Such immersive experiences of S's avatar specify the meaning of the prisms as a seat and wall in light of functionality [Figure 4.10]. In another example, in the collaboration case between H and Y, participant Y adjusted the height of the seat design using his avatars' activities "sitting" and immersive third person view [Figure 4.11]. In interviews, participants described the relationship between the immersive experiences of avatars and the appropriateness of a design like this: *"give a meaning to parametric objects via using them."*

Figure 4.10 Face-to-face collaboration between D and S in MUVE: avatars' immersive experiences assessed the scale and proportion of objects, thus it enhanced appropriateness of design.

Figure 4.11 Face-to-face collaboration between H and Y in MUVE: participant Y adjusted the height of the seat that Y was designing, while his avatar sat on it.

In addition, based on the avatars' immersive walk-through as pedestrians, participants evaluate the scales and details of interior spaces and iterate partitioning and organizing interior and exterior spaces. Besides, the immersive experiences in MUVE probably helps participants assess the appropriateness of material planning. MUVE allows participants to develop the properties of materials, such as photo-realistic textures, color, illumination, and transprancy in the search for new materials. At the same time, the immersion in MUVE enables them to assess the effects of such material planning applied to the three-dimensional objects. For example, in the collaboration case between G and S, while partner S developed his seat cubes' materials, he observed the effects of the materials in the designed, three-dimensional environment, such as texture's scale and brightness, using his avatars'immersive view [Figure 4.12].

Figure 4.12 Face-to-face collaboration between G and S in MUVE: participant S iterated the seat materials in designing and examined the materials' quality using his avatar's immersive view.

However, participants also state that the immersive experience-based evaluation of photo-realistic materials occasionally induces them to skip evaluating the feasibility of the materials. Participants feel that they can use the materials due to the immersive observation of the materials. In contrast, sketching allows participants to evaluate the feasibility, based on knowledge about the materials in reality.

The effect of synchronously shared collaboration environment in MUVE on appropriateness

In MUVE's synchronously shared environment, participants assess design outputs together using their own avatars' different experiences. Therefore, they can accumulate more evaluation data for enhancing the appropriateness of a design. For example, in the collaboration between A and D, when participant D developed his seat part, his avatar sat on the seat and assesses its usability. After a while, partner A joined in D's assessment. The avatars' activities of A and D assessed the usability of D's seats together [Figure 4.13].

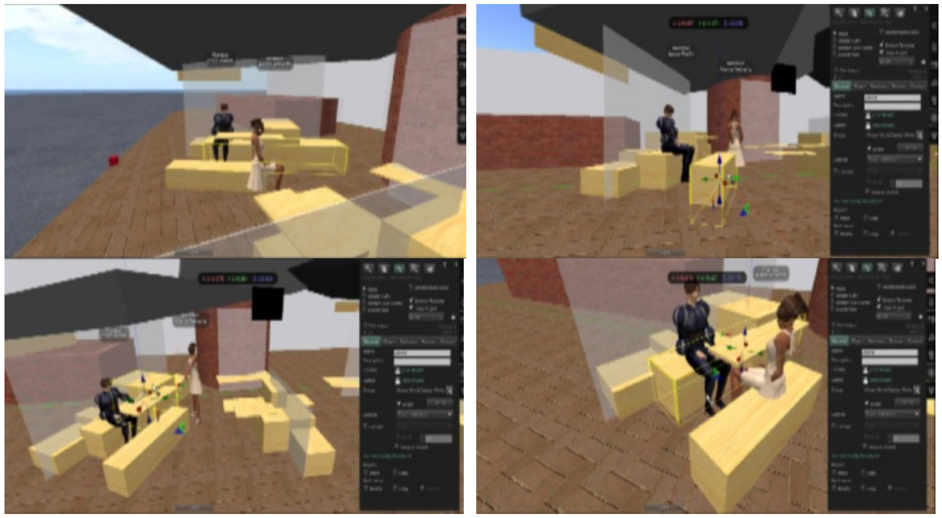


Figure 4.13 Face-to-face collaboration between A and D in MUVE: participant A and D assessed the dimension of D's seats together using their own avatars (sequences of participant A's design process, from left top to right bottom).

In addition, when participants observe their partners' avatars, they tend to discover unexpected design errors. In the collaboration case between H and J, while J sat on her seat design and adjusted its shape and scale, partner H sat next to J. The activity of H provides J with an opportunity to examine the seat's usability, such as the seat's height for tall passengers and the adequacy of its space for more than two users [Figure 4.14].

Figure 4.14 Face-to-face collaboration between H and J in MUVE, Participant H and J assessed the height and space of the seat in their bus stop together (sequences of participant H's design process, from left top to right bottom)..

In the aforementioned examples, in MUVE, the different immersive experiences amongst participants allow them to collect more evaluation data and search design errors, which facilitates appropriate and useful solutions. However, when a participant points out a particular building part, she has to explain where the part is, and partners also need to search and experience this part. When participants develop the designed objects which have larger scale than avatars' perceivable ranges, such as site facilities and interior spaces, they spend much time and effort tracking their partner's different immersive experiences in order to share their opinions.

The Effect of Knowledge-based reasoning in sketching on appropriateness

Different from MUVE, sketching's static and non-immersive representation does not allow participants to evaluate the dimensions and usability of solutions, based on their avatars' immersive views and activities. Instead, sketching enables them to reason about the feasibility of solutions based on prior knowledge. Most designs using sketching are initiated from prior knowledge and references that participants have already learned and experienced in reality. In experiments, participants refer to knowledge in existing architectural precedents, and they reason about the solutions based on such knowledge. The static and non-immersive representation facilitates participants' collection of information and problem analysis such as overall site contexts, pedestrians' movements, and location of site facilities. Based on the collected knowledge and information, participants reason about the feasibility of their solutions.

For instance, in the collaboration case between J and M, participants J and M observed and analyzed the given site context, and determined to change the existing shelter structure on the site. They planned to install a hammock seat and tensile membranes on the structure. When J and M developed the plan, they referred to the knowledge relevant to the existing structure's dimensions and determined by reason alone the location of the hammock seat and tensile membranes. The referred knowledge aided the participants in collecting meaningful problems and helped them propose a feasible solution to achieve usability and site suitability [Figure 4.15].

Figure 4.15 Face-to-face collaboration between J and M in sketching: participant J and M reasoned their solution through referring to site contexts and knowledge. The static and non-immersive representation in sketching influenced the reasoning.

The effect of static and non-immersive representation in face-to-face sketching

In addition, when participants use sketching, they can share one static view, for example, like the top view. In contrast, in MUVE, each participant experiences the same design differently depending on their own avatars' body range and point of view. Sketching's static views allow participants to easily to track their partner's problem solving process and thus helps them reason solutions together. Furthermore, since sketching records the reasoning processes, participants refer to former sketches in their problem solving. The referred former sketches allow participants to reason about the given proposals back and forth compared to their previous steps of problem solving, and helps the search for errors in the design processes.

Another reason why participants refer to former sketches probably rests on fragmented information in sketching. Sketching's two-dimensional and non-immersive representation can capture improvisational ideas and partial information about three-dimensional forms and spaces. In many cases, they are not linked to each other. Therefore, participants track and refer to former sketches for organizing such fragmented information.

In addition, sketching's quick and two-dimensional line representations, such as diagrams, enable participants to share such reasoning and problem solving processes with partners. Such collaborative reasoning amongst participants probably contributes to the production of appropriate designs. For instance, in the collaboration with A and D, when A developed her site plan part, she referred to partner D's former sketches. Based on D's sketches, A checked her design processes and logically deduced the solution for the multiple pedestrian pathways with partner D [Figure 4.16].

Figure 4.16 Face-to-face collaboration between A and D in sketching: participant A reasoned about partner D's design process through referring to his former sketches.

Besides, the static projective top view plan, one of sketching's habitual representations, helps participants to calculate site usage, including used and empty spaces. For example, participant S and Y designed their bus stop's form like the letters "CAL" and calculated the occupation of those forms on the top view plan with grids. Based on the dimensional calculation on the top view plan, participant S allocated seats to the "L" shaped form [Figure 4.17].

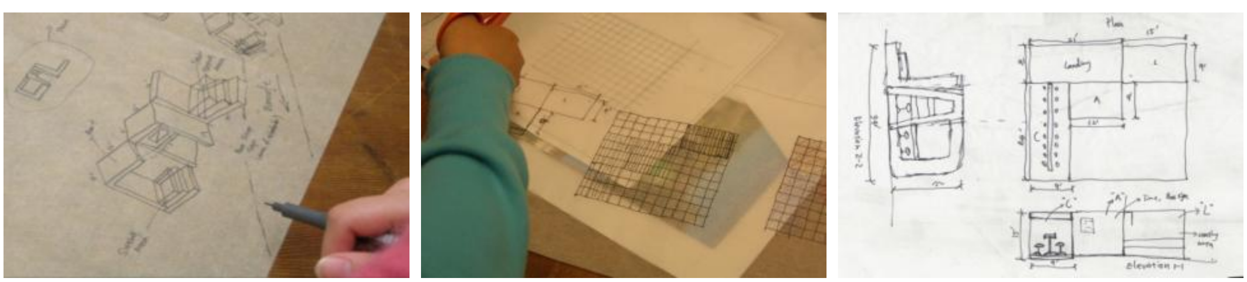


Figure 4.17 Face-to-face collaboration between S and Y in sketching: participant S calculated the dimension of "L" shaped volume on the top view plan.

4.3. Summary

In face-to-face collaboration, MUVE and sketching do not have statistical differences on creativity and its two components, novelty and appropriateness. Those two tools have equivalent affordances for creativity in the face-to-face collaboration mode. The reasons probably rest on the fact that the characteristics of MUVE and sketching have unique but equivalent impacts on creativity and its two components in face-to-face collaboration.

Regarding the impacts of MUVE and sketching on novelty, in MUVE the form iterations in the three-dimensional and immersive environment allows participants to experience the newly generated forms and spaces using their avatars' views and body activities. The immersive experiences in the designed environment facilitate participants' explorations about unexpected potentials in their solutions. The awareness of partner's design processes, based on social presence of the partner's avatar, and interaction with him or her in a collaborative process, called co-presence, also creates unexpected events and thus inspire novel solutions. In addition, the social- and co-presence of partner's promotes psychological and interpersonal interdependency amongst participants, the feeling of working together and comradeship, which encourages more new attempts.

In contrast, sketching's two-dimensional and non-immersive representation enables participants to perceive and orchestrate overall and whole information in sketches for improving novelty about overall site planning and space allocation, relevant to interior space and site facilities. In sketching, participants rely on prior knowledge for reasoning about novelty of their solutions. Sketching's static and non-immersive representation allows participants to refer to necessary knowledge from partners' sketches. Sketching's fast visualization capacity also helps participants share such knowledge.

Regarding the impacts of MUVE and sketching on appropriateness, MUVE allows participants to evaluate the appropriateness of solutions based on avatars' immersive experiences in the designed environment. The avatars' immersive view and activities have an advantage for evaluating the dimension and usability of newly generated forms interior. Since participants have different immersive experiences in one solution, depending on their own avatars' view and body ranges, they collect more evaluation data and design errors, thus complement each other's design competence.

Unlike MUVE, sketching enables participants to reason regarding the feasibility of solutions based on knowledge. Sketching's static and non-immersive representation allows participants to perceive their partner's sketches and refer to knowledge in sketches; thus, it enables them to collect and analyze meaningful knowledge and information for reliable reasoning.

Along with the aforementioned advantages of MUVE and sketching for creativity in face-to-face collaboration, both tools also have equivalent limitation in particular areas of creativity. The limitations of MUVE and sketching are also one reason why MUVE and sketching have equivalent affordance for creativity and its two components in face-to-face collaboration. In MUVE, participants are reluctant to develop spaces outside their avatars' perception ranges for immersive experiences, for example, large scaled site plan and space allocation. In addition, due to the participants' different immersive experiences in the same built environment, it takes time and effort to track each partner's different experiences for sharing necessary information and ideas.

In the case of sketching, two-dimensional and non-immersive representation of sketching can describe partial information about three-dimensional forms, thus participants struggle to share knowledge and information about the dimensions and details of forms. In addition, sketching's knowledge-based reasoning is not likely to inspire an unexpected solution beyond already installed problems, pre-knowledge, and participants' competence.

Chapter V The Affordance of Online Multiuser Virtual Environments (MUVE) for Creativity in Remote Collaboration

In Chapter V, I analyze the statistical data collected in the creativity assessments in remote collaboration. The creativity assessments are based on both participant's self-assessment and judges' consensual assessment. In addition, I present and evaluate the statistical analysis results based on interview questionnaires and video observations to find out the impacts of MUVE's on the creativity in remote collaboration.

5.1. Statistical Analysis: The Affordance of MUVE for Creativity in Remote Collaboration

In Section 5.1, I discuss the statistical analysis regarding the self-creativity and consensual creativity assessments in remote collaboration. In Section 5.2, I evaluate the statistical analysis of interviews and observations regarding the ways that MUVE influences the creativity in remote collaboration.

5.1.1. Creativity Analysis

The analysis for the self-creativity assessment in remote collaboration indicates that (1) MUVE's creativity score is not statistically different from that in Online Sketch (N=20, p-value>0.05) [Appendix Figure 17, Appendix Table 5]. In addition, (2) MUVE and online sketching are not statistically different in terms of their effect on the creativity scores for exterior form, interior exhibition space, material planning, and misc. requirements (N=20, p-value>0.05) [Appendix Figure 20, Appendix Table 5].

In another assessment, the judge's consensual assessments also indicate that (1) MUVE's creativity score is not statistically different from that in online sketching (N=70, p-value>0.05) [Appendix Figure 25, Appendix Table 7]. (2) MUVE's creativity scores for exterior form, interior exhibition space, and misc. requirements are also not statistically different from those of online sketching (N=70, p-value>0.05) [Appendix Figure 28, Appendix Table 7].

5.1.2. Novelty Analysis

In the statistical analysis for the self-novelty assessment in remote collaboration, (1) MUVE and online sketching's scores for novelty are not statistically different (N=20, p-value>0.05) [Appendix Figure 18, Appendix Table 5]. In addition, (2) MUVE's novelty scores for exterior form, interior exhibition space, material planning, and misc. requirements are not statistically different from those in online sketching (N=20, p-value>0.05) [Appendix Figure 21, Appendix Table 5]. However, in the 13 assessment factors[1] for street exhibition booth design, listed in Appendix Table 6, *the novelty score using MUVE for one element of exterior form (roof and wall design as a landmark) is statistically higher than that of using online sketching (N=20, p-value=0.01, <0.05)* [Appendix Figure 23, Appendix Table 6].

The analysis of the external judges' assessment in remote collaboration indicates the following results: (1) MUVE's novelty score is not statistically higher than that of online sketching (N=70, p-value>0.05) [Appendix Figure 26, Appendix Table 7]. (2) MUVE's novelty scores for exterior form, interior exhibition space, material planning, and misc. requirements are not significantly different from those in online sketching (N=70, p-value>0.05) [Appendix Figure 29, Appendix Table 7]. In addition, (3) in the 13 assessment factor analysis for street booth design, MUVE and online sketching do not have significant differences (N=70, p-value>0.05) [Appendix Figure 31, Appendix Table 8]. .

5.1.3. Appropriateness Analysis

In the analysis for the self-creativity assessment in remote collaboration, (1) MUVE's appropriateness score is not statistically different from that in online sketching (N=20, p-value>0.05) [Appendix Figure 19, Appendix Table 5]. In addition, (2) MUVE and online sketching are not statistically different in their effect on the appropriateness scores for exterior form, interior exhibition space, material planning, and misc. requirements (N=20, p-value>0.05) [Appendix Figure 22, Appendix Table 5]. However, in the 13 assessment factor analysis for exhibition booth design, MUVE's appropriateness score for one element of form (opening and entrance planning[2] to support users' activities) is statistically higher than that of online sketching (N=20, p-value=0.45, <0.05) [Appendix Figure 24, Appendix Table 6].

The judge's consensual assessments indicate that (1) MUVE's appropriateness score is not statistically different from that in online sketching (N=70, p-value>0.05) [Appendix Figure 27, Appendix Table 7]. (2) MUVE's appropriateness scores for exterior form, interior exhibition space, and misc. requirements are also not statistically different from those of online sketching (N=70, p-value>0.05) [Appendix Figure 30, Appendix Table 7]. Like other analysis, (3) about

[1] Exterior form category: 1) wall and roof design to support user's activities, 2) wall and roof design to support building performance (e.g. ventilation), 3) wall and roof design as a landmark, 4) opening and entrance planning to support user's activities, 5) opening and entrance planning to support building performance; Interior exhibition category: 1) interior space to support user's activities, 2) interior space to support building performance, 3) space for big-sized exhibits; Material planning categories: 1) materials to support user's activities, 2) materials to support building performances, 3) materials to support a landmark; Misc. requirement category: 1) a small café, 2) manager's seat

[2] This factor means partitioning and organizing exterior and interior spaces.

the scores for the 13 assessment factors of exhibition booth design, MUVE and online sketching do not have statistical differences (N=70, p-value>0.05) [Appendix Figure 32, Appendix Table 8].

In sum, in statistical analysis, MUVE and online sketching do not have significant differences for producing creative outputs, including the novelty and appropriateness of outputs. The exception is in self-assessment, when MUVE's novelty and appropriateness scores for exterior form elements (wall and roof design, and opening and entrance planning) are statistically higher than those in online sketching. One reason for the different assessment between the participants and external evaluators is probably that in self-assessment, the participants naturally considered not only the creativity of the final outputs, but also the experience in media, in order to propose the creative outputs. Meanwhile, the external evaluators merely evaluated the creativity of the final output. Another reason is probably the limited numbers of external evaluators. Although in expert evaluation, the arithmetical mean of MUVE's creativity score is higher than that in online sketching, due to the limited numbers of evaluators, p-value fails to achieve the statistical significance.

Based on the statistical analysis results, I propose the following modification of the hypothesis of this research: In remote collaboration, MUVE and online sketching have equivalent affordances for creativity and its two components, novelty and appropriateness, but in self-assessment, MUVE facilitates the production of novel and appropriate exterior form more than online sketching does in remote collaboration.

5.2. Evaluation of Statistical Results: The Impacts of MUVE on Creativity in Remote Collaboration

In this section, I analyze the impacts of MUVE on novelty and appropriateness in remote collaboration on the basis of interview and observation data. In general, MUVE and online sketching are not statistically different in both self- and creativity consensual assessments. Like face-to-face collaboration, I reason that each medium has its own capacity to influence creativity and its components, novelty and appropriateness, equivalently. However, in self-assessment, MUVE has the statistical significance to support the novelty and appropriateness for two exterior form factors (roof and wall design, and opening and entrance planning, which means partitioning and organizing exterior and interior spaces). In addition, arithmetical mean comparisons indicate that MUVE facilitates creativity, including its two components, novelty and appropriateness, more than online sketching does.

I reason that the results rest on the following characteristics of MUVE. The immersion in three-dimensional environment, a synchronously shared collaboration environment, and social presence and co-presence of partners, represented as avatars, are more effective in producing novel and appropriate exterior forms than online sketching's characteristics, two-dimensional, static and non-immersive representation, do.

In remote collaboration, the above characteristics in MUVE reduce miscommunication and misinterpretation, caused by reduction of the communication cues in face-to-face collaboration, like facial expressions and hand gestures. In MUVE's immersive environment, participants touch and examine the design outputs produced from manipulating three-dimensional geometries. Avatars' first or third person view and animated body actions promote the immersion, the feeling of being in the designed environment. The immersive experiences in the form iteration processes perhaps facilitate producing novel and appropriate exterior forms.

Since MUVE provides a synchronously shared environment based on three-dimensional and immersive representation, participants can experience partners' design outputs based on their own avatars' body and immersive view. The shared environment allows participants to understand what partners exactly think of, and it encourages them to participate in partners' decision making and complement each other's design competence to achieve creative solutions, regardless of the remote distance.

In remote collaboration, the roles of avatars, the representation of partners, are more significant than those in face-to-face collaboration. As in face-to-face collaboration, participants assess collaborative results using avatars' activities to enhance appropriateness of design. Activities of avatars in remote collaboration explicitly represent participants' design processes and work procedures. Furthermore, the representation of partners, avatars, in shared MUVE, influences the psychological and interpersonal relationships amongst participants. They feel like they are working together and this encourages them to try new things.

In contrast, online sketching's non-immersive representation, which means participants have a detached point of view from the representation, enables participants to share the same static sketches with partners. The static and non-immersive representation in online sketching allows participants to share problem analysis results and design strategies for proposing novel solutions. It also enables them to track and refer to partners' knowledge to achieve appropriate designs.

I reason that such advantages of online sketching's non-immersive representation equivalently influence creativity for interior spaces and site facilities as much as the immersion in MUVE does. The immersion in MUVE's three-dimensional representation allows participants to experience the organization of interior spaces using their avatars' first or third person view and body. However, the immersion is limited if the development of spaces is outside avatars' perception range. In contrast, the non-immersive representation in online sketching enables participants to see and develop the overall site and space plan. Its fast two-dimensional visualization also aids them to develop such site and interior space planning.

In spite of those advantages, online sketching's static and non-immersive representation requires time and effort to interpret partners' sketches because online sketching represents partial and fragmented information about a whole three-dimensional building (e.g. elevation and top views). Interpreting one's partners' sketches that represent forms require sufficient verbal and gesture communication. In the case of face-to-face collaboration, participants provide supplementary information via hand and body gestures. However, online sketching does not offer such supplementary communication cues. Therefore, participants struggle to interpret partners' representation about form development. In remote collaboration, online sketching's static and detached view and the lack of gestural communication cues invite misinterpretation and miscommunication amongst collaborators. Thus, they disturb participants' creative attempts for developing forms.

5.2.1. The Impacts of MUVE on Novelty in Remote Collaboration

The combination of form iteration and immersion in MUVE for novelty

In remote collaboration, both statistical analysis and arithmetical mean comparison indicates that MUVE facilitates novelty for exterior forms. The result probably rests on the fact that participants are immersed in three-dimensional form generation processes, based on their avatars' first or third person view and body range. Like face-to-face collaboration, in remote collaboration, the form generation provides participants with more opportunities for searching unexpected forms and spaces. At the same time, they can touch and use the quality of the newly generated forms and spaces through avatars' immersive experiences. The immersive experiences allow participants to explore potentials in the new forms. As explained in Chapter IV, the search for new forms in MUVE is close to puzzle making[3] rather than problem solving. Participants change geometries repeatedly to fit their immersive perception and experience. The immersion probably influences the participants' puzzle making, which assemble and develop form units in the search for novel forms.

For instance, in the collaboration case between J and M, J created a box and deformed it several times in search for novel forms. Through the iterations, he found the tunnel-like geometry which has a twisted crack, and used it for an entrance. When J worked on the scale and location of the entrance, he experienced the inside of the entrance using his avatar's immersive walk-through. Such immersive experience in the designed environment possibly facilitated the search for new forms and spaces. [Figure 5.1].

[3] John Archea and Yehuda Kalay define puzzle making as "the search for the most appropriate effects that can be attained in unique spatiotemporal contexts through the manipulation of a set of components, following a set of combinational rules" (Archea 1987, Kalay 2004).

Figure 5.1 Remote collaboration between J and M in MUVE: participant J develops the tunnel-like form by experiencing it through his avatar (sequences of participant J's design process, from left top to right bottom).

The immersion in MUVE's shared environment also facilitates reflection-in-action for the production of novel solutions, which is one mechanism of creative collaboration to explore the potential of proposals. Reflection-in-action possibly helps participants produce more feedback and new ideas. For instance, in the collaboration case between J and M, when participant M installed a bench to their exhibition booth, partner J sat on the bench and suggests to M to add a table near it. Based on J's suggestion, M created the "L" shaped table and integrated it with her original bench design [Figure 5.2]. J experienced partner M's bench using his avatar's immersive activities, and he proposed further ideas and feedback.

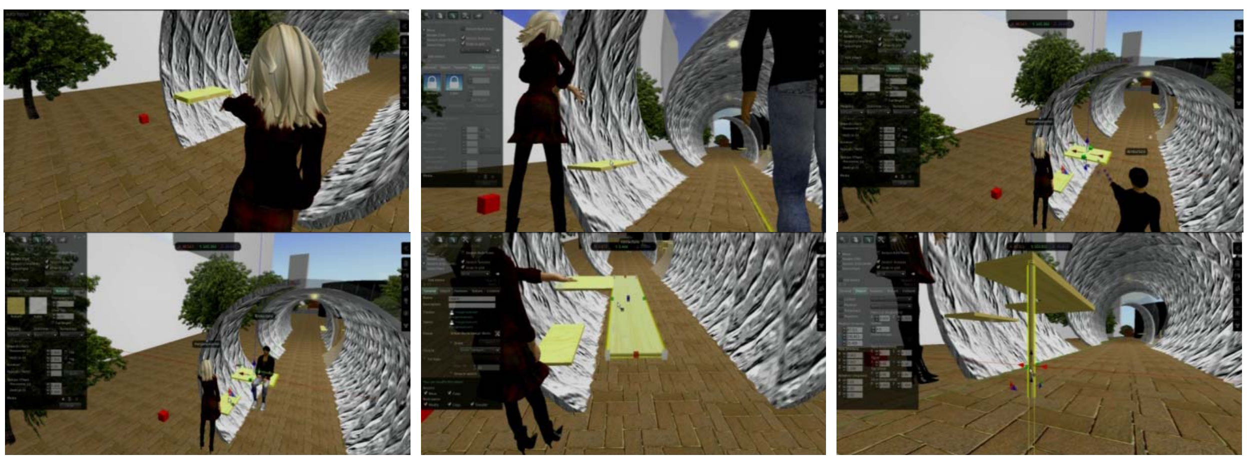


Figure 5.2 Remote collaboration between J and M in MUVE: when participant M developed her seat part, partner J examined the seat's potential and proposed ideas for further development via his avatar's immersive experiences (sequences of participant J's design process, from left top to right bottom).

The immersion in MUVE probably has both advantages and disadvantages for the production of novel interior space and site facilities. The advantage of the immersion in MUVE is that participants can experience the designed interior spaces and site elements with the feeling of being there. Avatars' first or third person view and sense of body prompt the feeling of immersion. Based on the immersive experiences, they can iterate the form generation and details of interior spaces and location of site facilities. However, the immersion, based on avatars' perception, is possibly limited to the perception of the spaces of the avatar's view and body. Therefore, participants occasionally struggle to develop overall site plans and interior space allocation, especially when those tasks are in the range of their avatars' view and body. In contrast, online sketching's non-immersive view, detached form of representation, enables participants to see and develop the overall site plan and space allocation.

Additionally, in MUVE, participants develop the ideas for architectural materials based on the changes of texture images and parameters for illumination, and their experiences of the results. Based on interviews, those material iterations and immersive experiences in the design processes help participants' search for new and unexpected material solutions. However, when participants are immersed in MUVE, they tend to be less critical in considering the feasibility of materials. Perhaps the photo-realistic material representation in MUVE's immersive experience persuades participants, so they skip critical evaluations for the material's use in the real world. Unlike MUVE, in online sketching, participants share each other's previous knowledge about materials already experienced in reality and reason the material's feasibility together. However, in online sketching, if participants do not have sufficient knowledge about the materials, the reasoning processes do not produce reliable and feasible results. The above advantages and limitations of MUVE and online sketching perhaps explain those two tools' equivalent affordances for the creativity regarding material planning.

The impact of synchronously shared environment in MUVE on novelty

MUVE's synchronously shared environment also influences the production of novel forms and spaces. In MUVE, participants can be aware of partners' design processes and experience their design outputs using avatars' immersive views and activities (e.g. sit, walk, and stand). In interviews, participants state that such shared design processes in MUVE inspire unexpected and new solutions. In MUVE, since participants can be aware of partner's design processes, they can refer to their design vocabularies and get inspirations from them. For example, in the collaboration case between C and M, participant C generated her curved exhibition walls and walked through them using her avatar. Partner M watched the activity of C's avatar, and he experienced partner C's curved walls using his avatar's immersive walking. This experience in partner C's design output inspired M to get a new idea: he proposed and developed the exhibition route like Moebius strip [Figure 5.3].

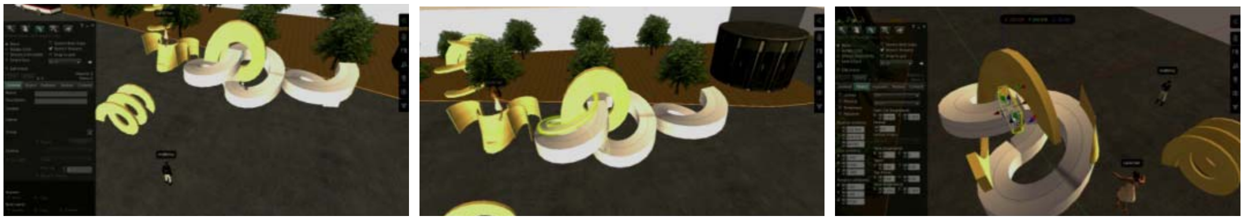


Figure 5.3 Remote collaboration between C and M in MUVE: participant M experienced partner C’s curved wall via his avatar’s immersive walk-through. The experience in partner C’s design inspired M to propose the Moebius strip-like exhibition route (sequences of participant M’s design process, from left top to right bottom).

The synchronously shared environment in MUVE also induces participants to join in a decision making process, which possibly allows them to share more new and unexpected ideas than one person can generate. In MUVE, since participants share objects with their partner, they can synchronously manipulate the objects together for sharing ideas. For instance, when participant D and S developed their exhibition booth model in sharing design strategies, they synchronously manipulated the model’s units together and perceived each other’s manipulation. The shared environment enabled D and S to understand each other’s ideas and helps their attempts for searching more new solutions [Figure 5.4].

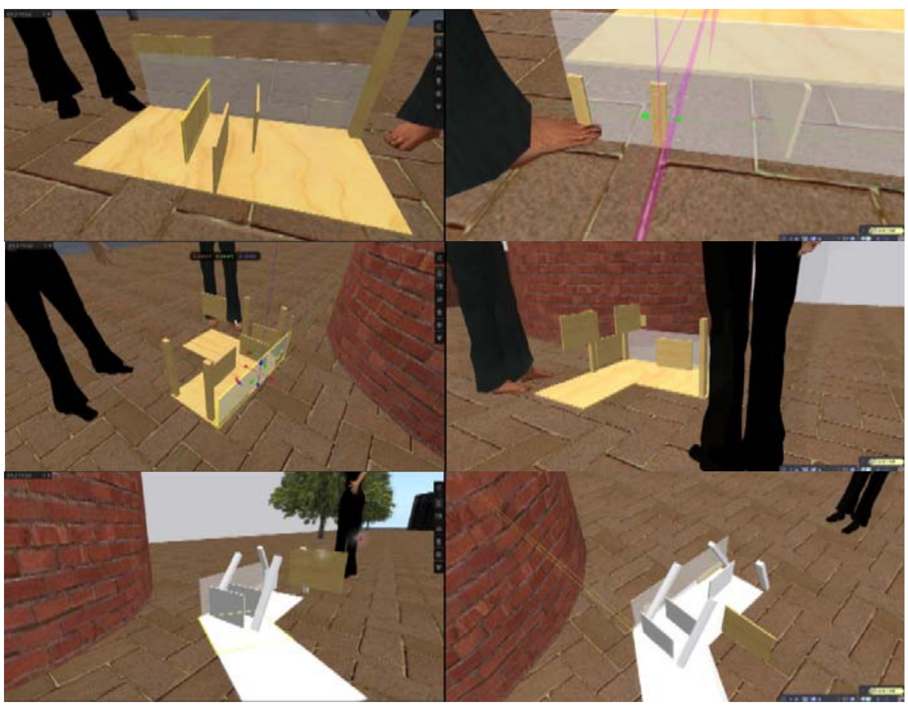


Figure 5.4 Remote collaboration between D and S in MUVE: participant D and S manipulate their model synchronously. The synchronously manipulation induces them to participate in the decision-making process actively for proposing more new solutions. D’ view (right side images), S’s view (left side images)

The social presence and co-presence of partner in MUVE for novelty

In remote collaboration, the existence of avatars is significant for not only for immersive experiences in the designed environment, but also for mutual communication, and psychological and interpersonal relationships amongst collaborators. To achieve novel solutions and unexpected inspirations, participants have to share their initial ideas and design processes sufficiently. However, in remote collaboration, the multiple communication cues, such as gesture languages, which exist in face-to-face collaboration are missing, thus sharing ideas amongst collaborators is strenuous. In face-to-face collaboration, participants use body gestures, like hand gestures, facial expressions, and arm movements for communication.

Instead of the gesture communication cues in face-to-face collaboration, in MUVE, participants can communicate with the other partner using their avatar's activities and voice chat. In interviews, participants report that they can precisely understand partner's design processes through observing his or her avatar's interactions with objects in particular. The activities of avatar are synchronously shared amongst collaborators and help participants to communicate with each other. In addition, the human body represented by the avatars has a new value for communication. It allows participants to experience partner's representations depending on avatar's body. The body experience inside representations does not exist in any other media.

For example, in the collaboration case between S and Y, while participant Y stacked up boxes to create walls, partner S observed Y's work process and walked through the stacked boxes. Based on the experience in Y's proposal, partner S suggested a gentle slope of the boxes for achieving their form variations. In the same way, when S created the cone-shaped walls for street exhibition, partner Y also experienced the walls' quality and added more opinions on them [Figure 5.5]. In interviews, participant S and Y reported that the immersive experiences in partner's proposals allowed them to share each other's ideas actively and accurately, and it encouraged them to search more new solutions.

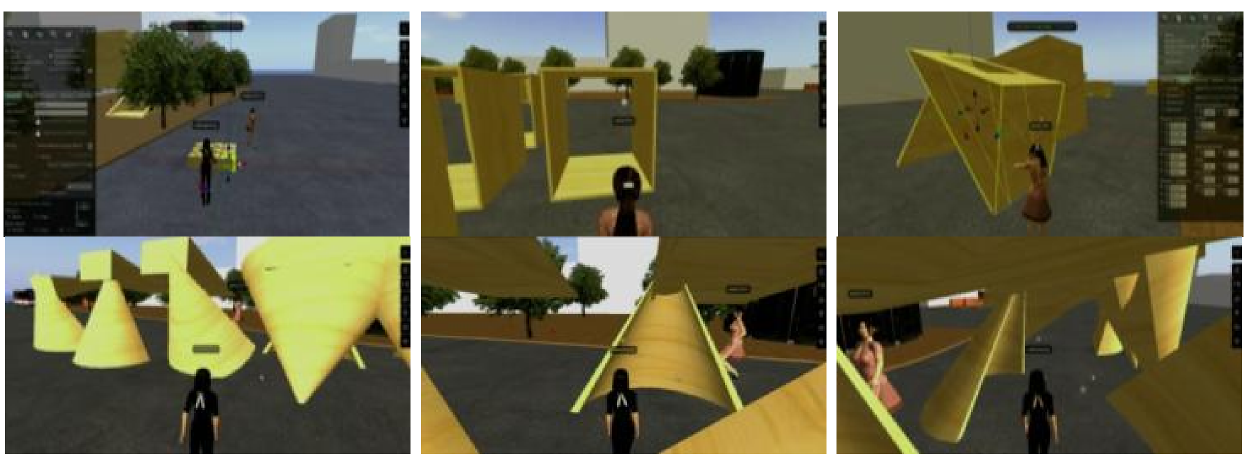


Figure 5.5 Remote collaboration between S and Y in MUVE: Participant S experienced partner R's proposal and directly modified it (4 images on top). In the same way, R also experienced S's proposal and added more opinions on it (4 images on bottom).

In addition, in interviews, participants state that in remote collaboration, the social presence and co-presence of partner, represented by avatar's presence and activity, make them feel like they are working together regardless of the remote distance. Avatars are ultimately the representation of the other partner who is physically separated. In MUVE, participants can be aware of partner's presence and design processes via his or her avatar's activities. Avatars also visualize the collaborative interactions amongst participants such as participation and evaluation. The awareness of partner's avatar and collaborative interactions with him or her probably promote intimacy amongst participants regarding reliability and comradeship. Those psychological and interpersonal relationships induce participants to have more tolerance for partner's new attempts.

For instance, while participant S manipulated the cube-shaped seats, she could perceive that partner D assessed the dimension of those seats using his avatars (left side images). As the same way, D was also aware of partner S's activities (right side images) [Figure 5.43]. In interview, participant S stated that the consistent awareness of partner D's avatar and interactions with him prompted the feeling of working together and led to more understanding and acceptance about partner D's new attempts.

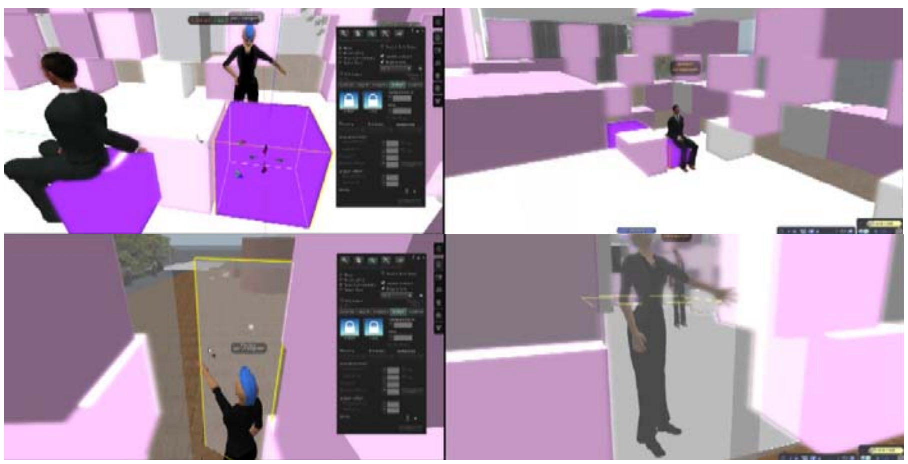


Figure 5.6 Remote collaboration between D and S in MUVE: Activities of avatar allowed participant D and S to perceive each other's work procedure consistently and unconsciously. This awareness of partner's avatar perhaps influenced the intimacy and comradeship amongst D and S. S's view (left side images), D's view (right side images)

The impact of static and non-immersive representation in online sketching on novelty

While MUVE provides participants with an immersive and synchronously shared collaboration environment, online sketching allows them to reason about proposals together for problem solving and sharing further ideas. Online sketching's static and non-immersive representation, which is a detached view form of representation, influences participants' collaborative problem solving. The advantage of online sketching's non-immersive representation rests on the fact that participants share the same and static view in sketches with partners, thus they can refer to each other's information in the sketches, such as problem analysis, design strategies, and necessary knowledge, without much effort and time for the cognitive process. The shared static representation in online sketching helps participants develop site planning and space zoning together in terms of interior space design, and it also aids them to share their previous knowledge for the material planning. Two-dimensional visualization also helps participants share problem analysis results and design schemes in the early design stage, called conceptual design. In online sketching, novelty emerges from the design concepts. The shared problem solving processes amongst collaborators, based on the static and non-immersive representation in online sketching, allows participants to accumulate more ideas for the development of original design concepts, and to synthesize the design strategies for problem solving, without a high cost for representing conceptual ideas.

For instance, in the collaboration case between G and S, when S analyzed users' potential interactions in the given site, partner G observed S's analysis diagrams and proposed the installation of a memo board to their exhibition booth walls. The memo board was a new strategy for enhancing the interactions amongst users, and this idea corresponded to partner S's site analysis. In addition, when participant G proposed an underground exhibition concept, the concept was also influenced by partner S's problem solving process, regarding the amount of traffic in traffic analysis diagrams [Figure 5.7].

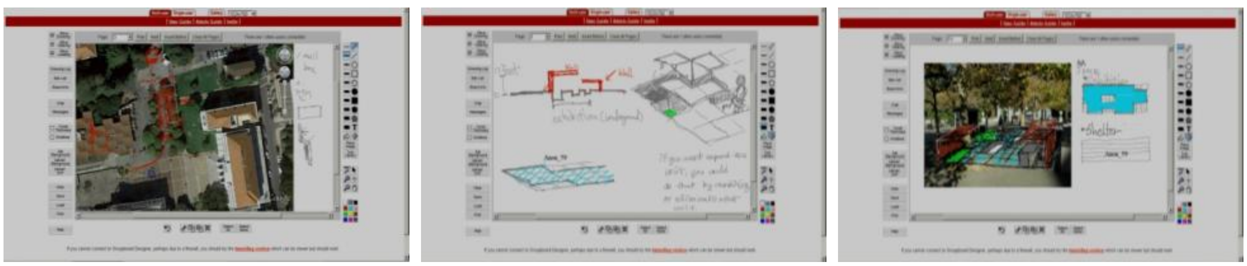


Figure 5.7 Remote collaboration between G and S in online sketching: participant G and S shared their problem solving processes and reasoned solutions together using online sketching's static and non-immersive representation and two-dimensional visualization. The shared problem solving processes helped G and S produce more new ideas.

Unlike online sketching, in MUVE, participants differently perceive the same environment depending on their own immersive experiences. Therefore, when a participant wants to share information about a building, she needs to explain the location and details of the building to her partner, and the partner also needs to spend time and effort to experience it.

Since online sketching does not allow participants to experience partners' proposals corporeally like MUVE, its static and non-immersive representation requires sufficient communication for interpreting partners' sketches in problem solving processes. However, online sketching' mediated environment does not provide the enriched communication cues, such as the gestural language in face-to-face Sketch. Participants cannot be aware of partners' physical actions and collaboration moods. In online sketching, they can share each other's design process only through the online sketching software's screen and voice chat[4]. Furthermore, online sketching's representation is abstract. The lacks of communication cues cannot supplement the abstract representation for communication. Therefore, misinterpretation and miscommunication happen amongst collaborators.

4 In remote collaboration, participants used Skype for voice chat, a tele-conferencing tool.

For example, in the collaboration between H and J, when participant H proposed the installation of metal plates to the trees in the given site for street exhibition, partner J struggled for interpreting H's sketches on the metal plate installation. Therefore, J repeated and redrew H's sketches to confirm whether she interpreted partner H's sketches correctly or not. In addition, when H draws trees in top view, J could not understand H's tree sketch and spent effort to interpret it [Figure 5.8]. The reason perhaps was that online sketching's static and non-immersive representation did not allow J to experience the scale and composition of the plates, thus she spent much effort interpreting partner H's representation. At the same time, online sketching's lacks of communication cues and abstraction representation made communication amongst participants strenuous. As a result, participants tended to accept partners' proposal passively, without sufficient attempts for searching for more new solutions.

Figure 5.8 Remote collaboration between H and J in online sketching: when participant H explained his metal plate idea for exhibition (the left top sketch in all images), partner J repeated and redrew H's sketches in order to confirm his idea (the right top sketch in all images). In addition, once H drew a top-view tree, J struggled for interpreting his sketch (the right bottom circles in the right side image). The difficulty of interpretation was perhaps based on online sketching's static and non-immersive representation, abstract visualization and lacks of communication cues.

Even if participants use an additional tele-video conferencing tool, it is uncertain that the video conferencing tool can reduce such misinterpretation and miscommunication in online sketching. The video conferencing tool can also capture only partial gestures depending on web-camcorders' camera angles, whereas the gesture languages to explain forms and spaces are more dynamic and improvisational.

In online sketching, participants struggle in sharing and interpreting partner's ideas for form development in particular. In Sketch medium, participants represent forms via particular view projections such as top, elevation, oblique, and perspective drawings. The drawings are based on static and non-immersive representation, and thus they represent fragmented and partial information of one completed building form. Therefore, participants require efforts to organize the information for understanding one completed building form in partners' mind. In face-to-face Sketch, hand gestures supplement participants' explanations about forms, but in online sketching, the gestural communication cues are missing, thus sharing the ideas for form development becomes strenuous.

For example, in the collaboration between S and R, while participant S developed her exhibition wall part, partner R was in charge of developing the roof part, which was correlated to S's walls. Since S described the partial information of her wall part depending on online sketching's static projective views – top and left side views, R spent efforts in organizing those two views and understanding the accurate form of S's walls [Figure 5.9]. In sum, in online sketching, supplementary communication cues in face-to-face Sketch did not exist. In addition, online sketching's representation was abstract. These bring misinterpretation and miscommunication. Therefore participants struggled in sharing design strategies and concepts and hesitated the search for new solutions.

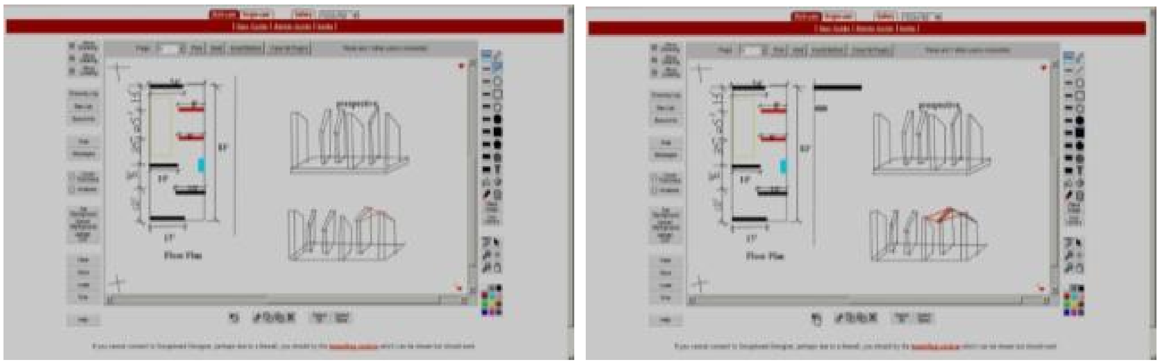


Figure 5.9 Remote collaboration between R and Y in online sketching: participant R struggled in interpreting the form of partner S's walls, thus she repeated erasing and redrawing her roof part (the red lines on the right bottom corner in all images). This strenuous interpretation was possibly caused by online sketching's static and non-immersive view, which describes partial and fragmented information about one completed three-dimensional form.

In addition, online sketching's misinterpretation and miscommunication make the search for new solutions, called a reflection-in-action as one of creative collaboration mechanisms, strenuous. Due to partial information about one view of the three-dimensional form (e.g. top view, elevation view and orthographic view), and lack of communication cues, gesture languages in particular, participants spend much time and effort in interpreting partners' representation and sharing proposed ideas, thus their communication cycles become slow and rigid. As a result, participants tend to avoid dynamic idea productions and feedbacks for searching novel solutions, and they tend to select one feasible idea without active reasoning with their partner.

For instance, in online sketching, when participant M proposed the tube-shaped exhibition wall, partner C passively accepted the idea without further feedbacks and ideations, thus M's initial tube form was not much developed in the final proposal [Figure 5.10]. In interviews, C and M reported that in online sketching, they were strenuous in sharing new ideas. Therefore M proposed a simple shape to avoid miscommunication with partner C, and participant C also passively accepted M's proposal. Therefore C and M did not fully explore the potential in their proposal.

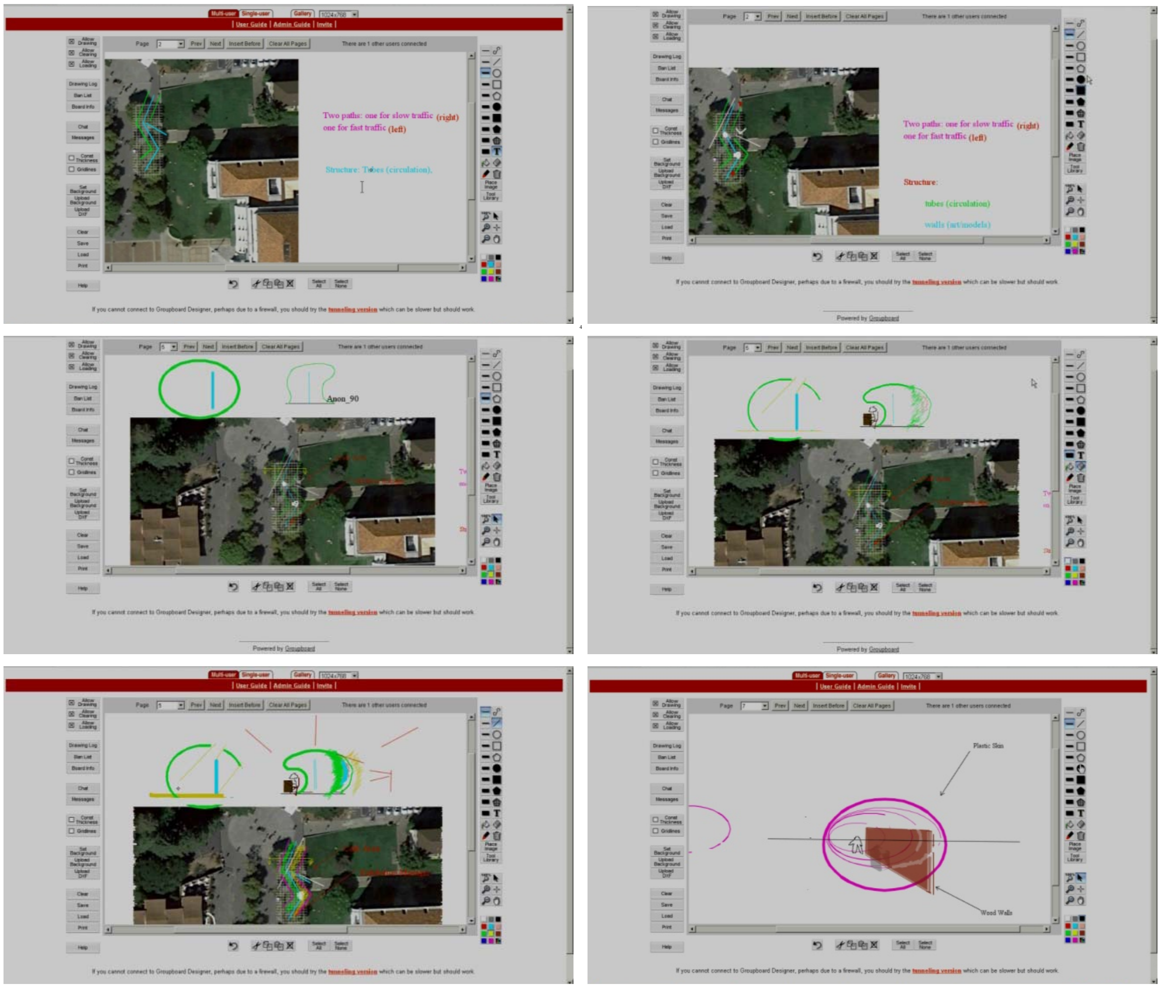


Figure 5.10 Remote collaboration between C and M in online sketching: when participant M proposed the tube-shaped wall, partner C passively accepted it without further feedback. C reported that the reason was the difficulty in sharing new ideas due to online sketching's partial representation about one three-dimensional form and lacks of communication cues (collaboration process between C and M, from left top to right bottom).

5.2.2. The Impacts of MUVE on Appropriateness in Remote Collaboration

The impact of immersive experience-based evaluation in MUVE on appropriateness

Statistical analysis indicates that MUVE affords appropriate opening and entrance planning, which means partitioning and organizing exterior and interior spaces. Arithmetical mean comparisons also inform that MUVE facilitates the design of exterior form and interior exhibition space. Based on interviews and observations, I reason that the results rest on "immersive experience-based evaluation in MUVE". In MUVE, participants can assess their building's dimension, location, and spatial organization via immersive experiences (e.g. touch, sit, and walk) inside the built environment. The avatars' activities and their first or third person view probably promote the feeling of immersion.

For example, in the collaboration between H and Y, once Y created a desk, he modified its scale to fit his avatar's body range. Y sat on the desk using his avatar and assessed its usability based on the immersive experience [Fig 5.11]. In another example, when participant J and M developed the tunnel-like exhibition booth, they assessed the dimension of the tunnel's entrance using their avatars' immersive walking [Fig 5.12]. Avatars' immersive experiences in MUVE assessed not only the physical usefulness of proposals, but also the qualitative aspects of design. One participant described the immersive experience-based evaluation in MUVE like *"the actions (of avatars) give an opportunity to think of space beyond modeling."*

Figure 5.11 Remote collaboration between H and Y in MUVE: participant Y assessed the size and scale of his desk design in use of his avatar's activities.

Figure 5.12 Remote collaboration between J and M in MUVE: participant J and M evaluated the dimension of their exhibition tunnel via immersive walking through it.

In addition, in MUVE, each participant experiences one design proposal differently depending on their own avatars' immersive experiences. The different experiences allow participants to assess one proposal independently, thus they can accumulate more evaluation data for enhancing appropriateness of design. Therefore, the different immersive experiences enable participants to complement each other's design competence to achieve reliable design outputs.

For example, in the collaboration case between C and M, while participant M developed his exhibition pathway part, partner C examined M's part using her avatar's walk-through. When C walked on the pathway, she found an unlinked joint between two pathway forms and fixed the error [Fig 5.13].

Figure 5.13 Remote collaboration between C and M in MUVE: participant C found the unlinked joint in partner M's pathway part, and she fixed it.

The different immersive experiences amongst participants have both advantages and disadvantages in producing the appropriateness of design. The advantages are the search for design errors and collection of evaluation data. The disadvantages rest on the fact that since each participant has independent and different immersive experience based on her or his own avatar's view and body, it takes time and effort to share design objectives and information gained by their independent experiences. Unlike MUVE, online sketching allows participants to share one static and non-immersive view, and thus participants can see the same information in partner's sketches, and they refer to the site problem analysis results, design strategies, and necessary knowledge from sketches. This shared view in online sketching probably influences participants' reasoning processes in search for a feasible solution. Those advantages and disadvantages of MUVE's immersive experiences of appropriateness perhaps explain why MUVE and online sketching do not have statistical differences for producing appropriate interior spaces.

Additionally, the immersion in MUVE allows participants to perceive site contexts in tangible ways. They can experience the scale of the given site and touch and move the site elements such as trees and curbs. Their avatars' scale and activities, including the avatars' first or third person view, facilitate the exploration in the given site contexts. Experiencing with site contexts supports zoning and spatial organization, and it is relevant to the appropriateness for opening and entrance planning which indicates partitioning and organizing interior and exterior spaces. Such immersive experiences in the given site contexts probably lead to a reliable site analysis for producing useful designs. For instance, when J and S developed the zones for exhibition and a coffee stand, they walked through those zones and assessed their scale compared to the elements in the given site, like adjacent buildings, street structures, and trees [Figure 5.14].

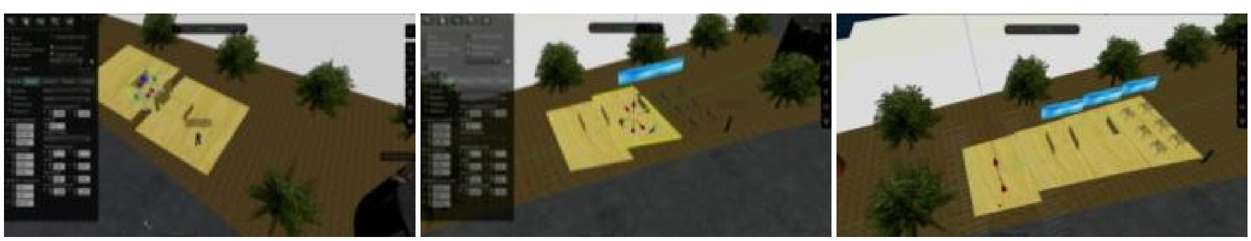


Figure 5.14 Remote collaboration between J and S in MUVE: participant J and S developed the zones for exhibition and a coffee stand compared to the scale of site elements such as trees and adjacent buildings.

The impact of synchronously shared environment in MUVE on appropriateness

In MUVE, participants can synchronously perceive activities of partner's avatar, designed objects, and design processes inside three-dimensional and immersive environment. The synchronously shared collaborative environment in MUVE induces participant to complement each other's design competence and facilitates participation in each other's decision making processes. These complementariness and joint-decision making mechanisms of creative collaboration, possibly help participant produce reliable and appropriate design solutions.

For example, when participant G and S located the coil-shaped exhibition booth on the given site, participant S changed the location of the booth from an immersive pedestrian's view, and partner G synchronously assessed it in a bird's eye view and added his opinion to S's design. Since G and S synchronously perceived each other's activities and share the same objects, their different immersive experiences in the built environment helped them collect more assessment data for locating the shape. In addition, the synchronously shared environment in MUVE enabled them to join in partner's decision making processes and complement each other's design competence [Figure 5.15].

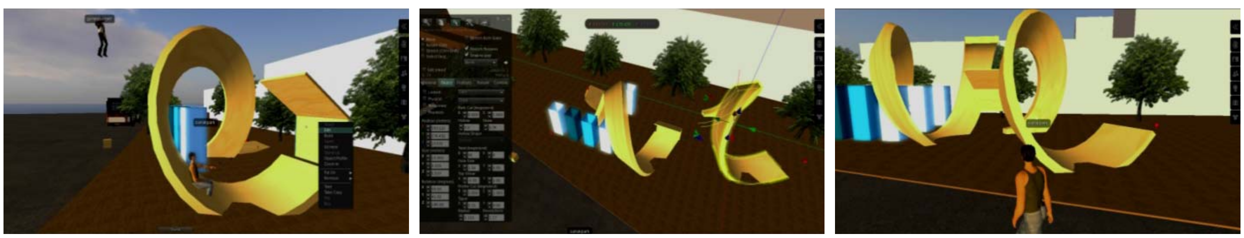
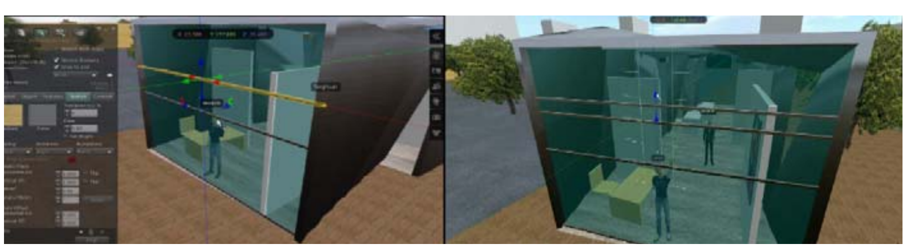


Figure 5.15 Remote collaboration between G and S: participant G and S evaluated the location of their exhibition booth synchronously. While S checked the location of the booth from a pedestrian's view, G evaluated them from a bird's eye view. The synchronous, and at the same time independent experiences between G and S helped them collect more assessment information and complement each other's design competence.

The impact of social presence and co-presence of others in MUVE on appropriateness

In MUVE, avatars' activities in three-dimensionally described environment explicitly inform participants' work procedures and contents to other partners. In addition, since participants share three-dimensional building objects with partner, they can manipulate the objects together and help partner's modeling works. The shared activities and objects in MUVE allow participants to distribute tasks mutually and help partner's complete their tasks, which possibly enhance the reliability and appropriateness of solution. For example, in the collaboration between H and Y, while participant Y installed the frame to their exhibition booth's entrance, partner H perceived Y's work contents based on the location and activities of Y's avatar, so H mutually distributed work and helped partner Y's frame installation and assessed the frame's scale and details. The mutual work distribution possibly increased the feasibility and completeness of the design proposal to satisfy appropriateness of design [Fig 5.16].



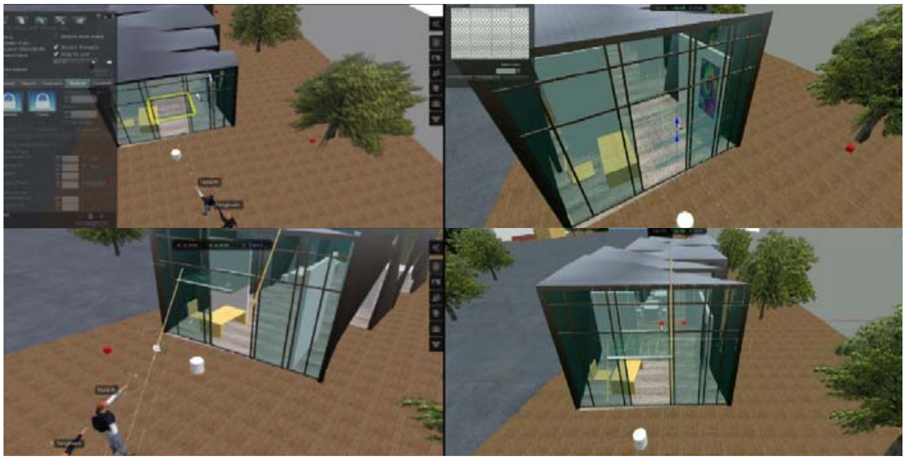


Figure 5.16 Remote collaboration between H and Y in MUVE: since participant H were aware of partner Y's location and work content, he could help Y's modeling tasks accurately. H's view: (left side images), Y's view (right side images)

The impact of knowledge-based reasoning in online sketching on appropriateness

While MUVE's affordance for appropriateness rests on the experience-based evaluation in the immersive and synchronously shared environment, online sketching's affordance for producing appropriate designs is based on knowledge-based reasoning. Online sketching's non-immersive representation allows participants to share the same and static sketches, and they refer to knowledge in the sketches for reasoning the feasibility and appropriateness of solutions. Unlike MUVE, online sketching's non-immersive and static representation does not provide participants with experiences inside the designed environment for evaluating appropriateness. Therefore, online sketching's evaluation relies on reasoning solutions based on knowledge. For example, when participants reason about the appropriateness of materials in their proposal, they refer to their own knowledge about the material.

The shared and static representation in online sketching, such as diagrams, aids participants to accumulate their knowledge for reasoning about the feasibility of proposed solutions, thus enhance appropriateness of design. For instance, when H and Y proposed the scheme which separates exhibition space and long-term seat area, they drew traffic analysis diagrams. Based on the diagrams, they reasoned about the validity of their scheme together and shared necessary knowledge for the reasoning [Figure 5.17].

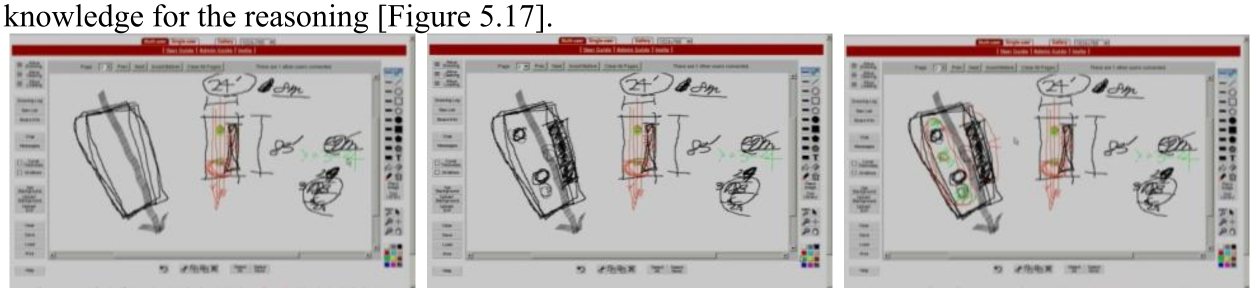


Figure 5.17 Remote collaboration between H and Y in online sketching: participant H and Y analyzed the traffic amounts in the given site and reasoned the location of exhibition space and long-term seat area.

Despite the above advantages of online sketching's representation, online sketching's static representation can describe only partial information of one completed, three-dimensional buildings (e.g. top view and elevation view). Therefore, participants need to integrate such information for the appropriateness of a building. When partners produce the information of forms in online sketching, participants need sufficient communication with their partners for interpreting the partners' sketches. However, online sketching's lack of gesture communication cues, such as hand and body gestures, obstruct the communication: participants cannot inform supplementary description about forms to partners. As a result, participants roughly assume the functionality of forms in partner's sketches. For example, when J and M developed a tensile fabric walls for their exhibition booth, M struggled in reasoning about the location and height of the walls because partner J's top view drawing did not include sufficient information of the walls. Therefore, reliable reasoning for the walls was strenuous [Figure 5.18].

Figure 5.18 Remote collaboration between J and M in online sketching: participant M struggles in reasoning the dimension of partner J's tensile fabric walls because partner J's top view sketch does not include sufficient information for the reasoning.

Furthermore, online sketching's representation is abstract, while its supplementary communication cues are missing. Therefore, accurate communication amongst collaborators is challenging. For instance, when participant H and Y developed their site plan, H misinterpreted the meaning of the circles drawn by partner Y. He understood that those circles were columns, whereas Y wanted to inform that they were chairs [Figure 5.19]. In online sketching, such misinterpretation is commonly observed.

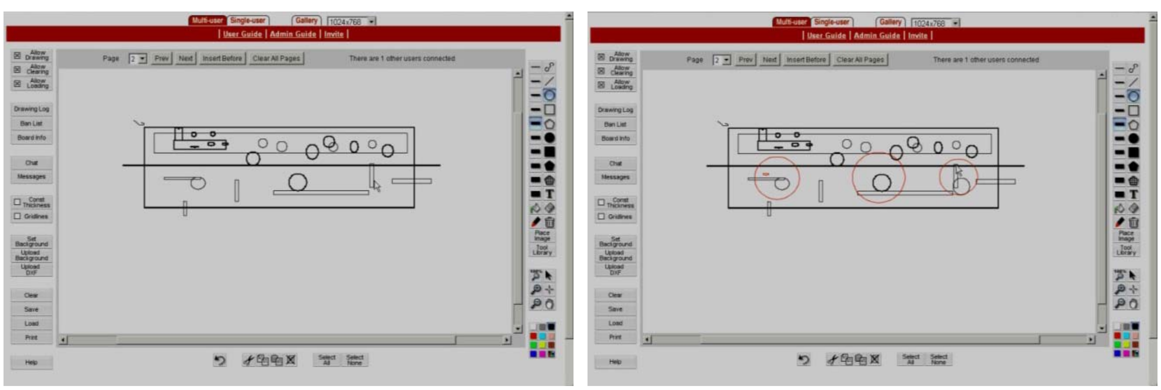


Figure 5.19 Remote collaboration between H and Y in online sketching: while participant Y drew the black colored circles to represent chairs, partner H misinterpreted the meaning of the circles as columns. In the pictures, the red circles are columns, and the black circles are seats and tables. Without a particular explanation, it is difficult to interpret the different meanings between those circles.

5.3. Summary

In remote collaboration, statistical analysis indicates that MUVE facilitates the production of novel and appropriate exterior forms (wall and roof design, and opening and entrance planning for partitioning and organizing exterior and interior spaces) more than online sketching does. In contrast to exterior forms, MUVE and online sketching have equivalent affordances for creativity and its two components, novelty and appropriateness, for interior spaces, material planning, and misc. requirements (site facilities).

Based on interviews and observations, I infer the ways in which MUVE facilitates the production of novel and appropriate exterior forms. In MUVE, participants are immersed in a three-dimensional form generation processes, based on avatars' first or third person view and body range. The generation of form initially facilitates the search for novel and unexpected forms and spaces, and the immersive experience in the newly generated forms enables participants to explore potentials with feedback and reflection-in-action. Participants also use and touch the forms using their avatar's activities and immersive views. This immersive, experience-based evaluation facilitates the production of useful and appropriate solutions. Another reason is the synchronously shared collaboration environment in MUVE. In the shared environment, participants are aware of their partners' design processes, represented by their avatars' activities and three-dimensional design outputs. The awareness of partners' design processes inspires unexpected ideas about form. In addition, participants assess the same design proposal using their different immersive experiences, thus they collect more evaluation data and complement each other's design competence for useful and appropriate forms. Additionally, social presence and co-presence of partner, represented by avatars in three-dimensional, immersive environment, prompt the feeling of working together. Participants report that the feeling, almost like comradeship, makes them feel generous regarding their partner's new attempts to search for creative solutions. In remote collaboration, social presence and co-presence of partner's avatar enable participants to create a collaborative mood and interdependence despite the remote distance.

In contrast, the two-dimensional and non-immersive representation in online sketching enables participants to share problem analysis results, design concepts, and knowledge with partners for problem solving and the feasibility of solutions. In online sketching, participants' views are detached from representation, and they can refer to necessary information and knowledge from partners' sketches without high cost for the cognitive process. The two-dimensional representation of online sketching also aids participants in sharing ideas about forms in the early design stage.

However, online sketching's two-dimensional and non-immersive representation allows participants to describe only partial and fragmented information about three-dimensional building forms. Thus, participants require time and effort to share the information and idea about forms. In addition, online sketching's lack of communication cues, such as gestural languages and collaborative moods, restricts the shared information and brings misinterpretation and miscommunication amongst participants. Therefore, participants are strained in their search for creative forms in online sketching.

In Chapter V, I also offer reasons why MUVE and online sketching have the equivalent affordances on the creativity for interior spaces, material planning, and other requirements, like site facilities. MUVE and online sketching have unique impacts on those kinds of creativity. In the case of MUVE, the immersion in MUVE's three-dimensional environment allows participants to feel as if they are in the designed environment and to experience the environment using their avatars' view and body range. The immersion in three-dimensional environment has both advantage and limitation for proposing creative interior spaces and site facilities. The advantage rests on the fact that immersion in MUVE helps participants assess and develop the scale and shape of interior spaces, details of site facilities (e.g. benches, and wheel chair lots), and objects (e.g. exhibit items). Its limitation is that participants feel difficulties in designing the spaces and objects that are not in the range of their avatars' view and reach.
The different immersive experiences amongst participants in MUVE, depending on their own avatars, also have both an advantage and a limitation. The advantage rests on the fact that participants can examine one proposal via their different experiences, and thus they can collect more evaluation data for proposing useful and appropriate solutions. The limitation of the different immersive experiences is that participants require time and effort to share their experiences with others, especially when they establish design goals, formulate the overall scheme, and allocate interior spaces and site elements.

In addition, MUVE enables participants to simulate materials (e.g. photo-realistic textures and illumination) in the immersive environment. The advantage of the simulated materials is that they helps participants' search for unexpected qualities of materials, while its limitation rest on the fact that participants tend to skip reasoning about the feasibility of materials, perhaps due to MUVE's photo-realistic representation, and immersive experiences about the materials.

In contrast, online sketching does not provide the immersive experiences in the designed environment as does MUVE. Therefore, participants rely on reasoning about proposals, based on knowledge, in the search for creative solutions. Online sketching's two-dimensional and non-immersive representation allows participant to share such knowledge and necessary information for the reasoning in a problem solving process. Since participants' views are detached from representation, they can directly see what partners draw, and amalgamate each other's knowledge and ideas to propose new solutions. Online sketching's two-dimensional representation also helps participants share and develop problem analysis results, design concept and strategies without the high cost for representation. In observation, participants use static and projective sketches to share ideas and information about traffic/movement analysis, overall site and space planning, space and site furniture allocation, and knowledge about materials for proposing creative interior spaces, site facilities, and material planning.

However, the limitation of online sketching's two-dimensional and non-immersive representation is that it requires much time and effort. In many cases, it is impossible to explore and develop three-dimensional qualities and details of interior spaces and site facilities. In addition, in online sketching, previous knowledge is necessary to evaluate the feasibility and reliability of proposed solutions.

Chapter VI Conclusion and Discussion

In Chapter IV and V, I investigate the affordance of MUVE for creativity in both face-to-face, and remote collaboration, compared to face-to-face sketching and online sketching. In this chapter, I summarize key discoveries in previous chapters, and discuss in what ways MUVE's characteristics, such as the immersion in the designed environment, synchronously shared environment, and presence of partners' avatars, have advantages and limitations for supporting creative collaboration, compared to sketching media.

6.1. Conclusion

This research addresses, as discussed before, two main questions. (1) *What is the affordance of MUVE for creative collaboration in architectural design? (2) In what ways does MUVE influence creative collaboration in architectural design?* In response to those research questions, I investigate MUVE's affordance for creativity in face-to-face and remote collaboration using both quantitative (statistical Independent T-test and arithmetical mean comparison), and qualitative methods (interviews and observations). To collect the quantitative and qualitative data, I use comparative experiments in MUVE and in conventional media: sketching in face-to-face mode and online sketching in remote mode. The purpose of those comparative experiments is not merely for confirming statistical superiority of any one tool, but for systematically analyzing the affordance of MUVE through correspondences amongst statistical results, interviews, and observations. Based on the above research questions and methods, I propose conclusions and argumentations as follows.

Regarding the affordance of MUVE for creative collaboration, in face-to-face collaboration, statistically, both tools have equivalent affordances for creativity and its two components, novelty and appropriateness in face-to-face collaboration. Yet, in remote collaboration, MUVE facilitates the production of novel and appropriate forms (novelty for wall and roof design, appropriateness of opening and entrance planning, which means partitioning and organizing exterior and interior spaces) more than online sketching does. Except for exterior form, MUVE's creativity scores for interior spaces, material planning, and site facilities (miscellaneous requirements) are arithmetically higher than those in online sketchinges, but do not have statistical significances.

Based on interviews and observations, I reason that the statistical results are as follows. In face-to-face collaboration, MUVE's characteristics, immersion in the designed three-dimensional environment, synchronously shared collaboration environment, and presence of self and others, have almost symmetrical and equivalent impacts on creativity compared with the characteristics of sketching, namely, with two-dimensional, non-immersive representation. MUVE's immersion in the designed environment enables participants to experience and examine the newly generated forms and spaces based on avatars' views and body actions. This facilitates the search for novel and useful exterior forms in particular, which are not provided by sketching's non-immersive and static representation. In contrast, the non-immersive representation of sketching allows participants to perceive overall information in sketches and track knowledge in former sketches for reasoning about problem solving processes. It helps participants organize and develop overall planning and design schemes, such as the allocation of interior spaces and site facilities that avatars' immersive perception in MUVE struggles to manage. The line visualization in sketching also helps participants generate the schematic planning of interior space and site facilities.

In addition, MUVE's synchronously shared collaboration environment also allows participants to be aware of partner's presence and her design processes. The shared environment in MUVE allows participants to observe and touch partners' proposals using their avatars' immersive views and activities, which the static and non-immersive representation of sketching cannot do. Thus, it inspires unexpected solutions and enables participants to evaluate a solution together. In contrast, the two-dimensional and non-immersive representation of sketching helps participants perceive and refer to partners' sketches with ease, whereas in MUVE, participants spend time and effort to track partners' different immersive experiences. The non-immersive representation of sketching allows participants to share and organize each other's knowledge for improving novelty of solutions, and reasoning feasibility about solutions. In face-to-face collaboration, while the social presence and co-presence of partner's avatar in MUVE influence psychological and interpersonal aspects of collaboration.

While in face-to-face collaboration MUVE and sketching have equivalent impacts on creativity, in remote collaboration the aforementioned characteristics of MUVE have advantages in support of the production of creative solutions compared with online sketching. In MUVE participants can experience the interior of their partners' proposals, represented in three-dimensional forms, regardless of remote distance. Avatars' immersive views and activities enable participants to explore and evaluate those partners' proposals. In addition, in MUVE participants manipulate and develop the forms together, thus they share ideas about form without misinterpretation and miscommunication. The immersive experiences in MUVE's synchronously shared environment also allow participants to evaluate the usability of forms and the dimensions of the relevant spaces with partners. In contrast, the static and non-immersive representation in online sketching is limited to shared ideas about three-dimensional forms. Furthermore, in online sketching, participants cannot see participants' body gestures and the collaboration mood, both useful for sharing information about forms in face-to-face collaboration. The above advantages of MUVE and limitations of online sketching are probably among the ways in which MUVE facilitates the production of creative exterior forms more than online sketching does in remote collaboration. Additionally, in remote collaboration, the presence of partner's avatar facilitates communication and interdependency amongst participants.

In sum, I conclude that the affordance of MUVE for creative collaboration initially rests on immersion in the designed environment, represented by three-dimensional objects. The views and activities of avatars as the representation of self are a means of the immersive experiences in MUVE. In addition, MUVE's synchronously shared collaborative environment with partner, and social presence and co-presence of partner's avatars also facilitate the production of novel and appropriate solutions. Those characteristics have more advantages than the non-immersive presentation of online sketching, in remote collaboration. They prevent misinterpretation and miscommunication amongst collaborators, caused by the absence of partners' physical presence, and thus they facilitate collaborative reflection-in-action, participation in a collaborative process, complementariness of design competence, and interdependence amongst participants. These characteristics encourage participants' creative attempts despite the remote distance.

6.2. Further Discussion and Critical Evaluation

6.2.1. The impacts of the immersion in MUVE on creative collaboration

In MUVE, participants are immersed in the designed environment described by three-dimensional representation. The immersion in MUVE, the feeling of being there, is initiated by the first or third person view and activities of avatars, the representation of self and others. Participants can perceive and experience the built environment in MUVE through those avatars' views and body actions.

In MUVE, immersive experiences are combined with form generation processes. The form generations, based on three-dimensional geometries, provide opportunities for discovering unexpected new exterior forms and relevant interior spaces. At the same time, avatars' immersive views and body activities allows participants to experience the dimensions, details, and usability of the new forms and iterate the rules for form generation and combination. This approach is close to puzzle making[1], the search for the most suitable effect based on the iterations rule for the manipulation and combination of a set of components. In MUVE, the rules of puzzle making follow avatars' immersive experiences that examine the appropriateness of new forms in light of avatars' body actions and eye views. Therefore, the avatars' immersive experiences in the form generation processes possibly aid participants in producing both novel and appropriate forms.

In addition, each participant in MUVE has different and independent immersive experiences in a single, common designed environment, depending on his or her own avatar's view and body range. The different immersive experiences amongst participants possibly enable them to collect more evaluation data and fix design errors. The different immersive experiences prompt participants' reflection-in-action, such as feedback and exploration of the potential of proposals for the production of novel and useful solutions.

However, from interviews, I learned that the MUVE's immersion limits the perception of spaces and objects outside avatars' view and body ranges. It is a phenomenon that also occurs in the physical world. If an object is not in range of our eyesight and body, we cannot perceive its presence. Although MUVE provides zoom-in and -out views to observe the objects from a distance, most of participants' experiences are based on avatars' immersive views and activities.

[1] Independently, John Archea (1987) and Yehuda E. Kalay (2004) define the puzzle making paradigm in "Computability of Design", and "Architecture's New Media".

In addition, in MUVE, the immersive experiences amongst participants are different depending on their avatars' independent views and activities. As discussed before, the different immersive experiences amongst participants bring advantages for collaborative ideations and evaluation. However, when participants share and integrate each other's ideas, it takes time and effort to track what the other partner sees and experiences. Therefore, due to the difficulty in perceiving objects outside avatars' view and body range, and due to the different immersive experiences with the other partner, participants occasionally struggle when developing large scale site plans, allocating interior space and site facilities, and designing overall procedures for problem solving.

In contrast, in sketching, since participants' views are detached from representation, they can see overall and whole information in sketches without the high effort for cognition. Thus, it enables participants to organize problem analysis results and necessary information to propose novel and useful design schemes. Sketching's quick visualization also supports such problem analysis and solution synthesis. In addition, when participants reason about the feasibility of their solutions, they directly refer to their former sketches and their partners', and track flows of problem solving and reasoning processes. The sketching's non-immersive and static representation is probably appropriate for the processes of problem solving[2] in the early design development stage.

As discussed before, the non-immersive and two-dimensional representation in sketching influences problem solving and reasoning processes to improve novelty and feasibility of solutions. However, the non-immersive representation in sketching is mainly used for collecting and organizing pre-knowledge which participants already have, rather than supporting the search for unexpected potential in solutions like MUVE. Therefore, sketching has limitations regarding the discovery of unexpected new solutions beyond participants' knowledge and design competence.

Furthermore, due to the two-dimensional and non-immersive representation in sketching, participants describe fragmented and partial information for one building. They have to integrate and interpret such information to imagine the completed building form. In many collaboration cases, the fragmented information caused by the two-dimensional and non-immersive representation in sketching obstructs the development and evaluation of formal spatial details. In remote collaboration, the search for novel and useful forms becomes more difficult because participants cannot see partner's gestures and feel collaboration, both of which supplement the description of forms.

6.2.2. The impacts of the synchronously shared environment in MUVE on creative collaboration

[2] Peter G. Rowe and Geoffrey Broadbent state that design processes rest on cycles of problem analysis, solution synthesis, and evaluation. Those cycles are typical problem solving processes to propose a solution in response to the given design constraints (Rowe, 1987; Broadbent, 1973)

MUVE allows participants to be synchronously aware of three-dimensional objects and the presence of their partners. They can manipulate the objects with partners and observe their processes, represented by activities of partners' avatars in the three-dimensional environment. The MVUE's synchronously shared environment leads to collaborative reflection-in-action and participation in a collaborative process. As results, participants complement each other's design competences to propose novel and appropriate solutions. In interviews, participants report that, while working in the three-dimensional representation, it is not economical to share the initial design schemes such as location of spaces and overall forms. On the other hand, it is useful to share dimensional and details of forms and spaces. In remote collaboration, the above characteristics of MUVE's synchronously shared environment support participants' communication and collaboration mechanisms for producing creative solutions regardless of the remote distance.

In contrast, in sketching, since participants share the same static sketches with their partner, they can directly add and modify partner's sketches in order to share knowledge and solutions. In face-to-face sketching, the awareness of partner's body gestures and facial expression also helps participants interpret the information in partner's sketches. However, in remote sketching, such additional communication cues are missing due to the computer mediated environment, thus sharing of information frustrates participants.

6.2.3. The impacts of MUVE on the psychological and interpersonal aspects of creative collaboration

Ijsselsteijn and Riva discuss the three types of presence[3] as follows: physical presence of self, the feeling of being there, social presence of partner, the feeling of being together, and co-presence with them, the feeling of being together in a shared space. These types have two aspects for facilitating creative collaboration: one is a representational aspect, and the other is a psychological and interpersonal aspect.

In the representational aspect, the scales and activities of anthropomorphic avatars are useful for evaluating the dimension and detail of forms, spaces, and furniture. For example, when a participant develops a bench, her avatar sits on the bench and assesses its scale and detailed shape in light of her avatar's body scale and activities. The presence of partner's avatar also assesses the dimensional scale of forms and spaces when they are acting. Initially, the presence of avatars is a means of evaluation to facilitate appropriate and useful solutions.

In the psychological and interpersonal aspect, social presence and co-presence of others influence interdependency and collaboration moods amongst participants. In interviews, participants report that in remote collaboration, the presence of partner's avatar promotes

[3] In "Being There: The experience of presence in mediated environments", Wijnand Ijsselsteijn and Giuseppe Riva defines those three types of presence for theoretical frame of multi-user collaborative virtual environment (CVEs): physical presence, social presence, and co-presence.

psychological and interpersonal emotions amongst participants more than does the presence of avatars in face-to-face collaboration. In remote collaboration, since participants cannot see physical presence of partners, they rely on the presence of their partner's avatar for communication. In remote collaboration, the activities of avatars in the three-dimensional environment represent their partner's intentions and help participants feel collaboration flows and moods despite the absence of partner's physical presence. The consistent awareness of partner's design processes and interaction of partner's avatar in a collaborative process also promote the feeling of working together and comradeship, which encourages new and unexpected attempts.

6.2.4. Neuroscience and the creative processes in MUVE and sketching

Although this research does not focus on the creative process within the framework of neuroscience, I briefly discuss the relationship between immersion in MUVE and brain activities for future research. In *The Silent Language*, anthropologist Edward T. Hall (1973) analyzes culture and communication of human beings in view of the three brain layers: reptilian, mammalian or limbic layer, and neo-cortex. According to Hall, the reptilian part of the brain is the source of "formal" knowledge that is deeply ingrained by experiencing the forms of how "things are done" at a very early age. The mammalian part of the brain holds "informal" and socio-emotional knowledge that people learn verbally from primary care givers at home before going to school. The neo-cortex holds the rational and technical knowledge that peoples are taught explicitly, usually in schools." (Cranz & Chiesi, 2012)

Hall's analysis provides a new viewpoint to interpret immersion in MUVE, based on anthropomorphic avatars. The implied physicality and immersion in MUVE are probably related to the lower brain layers: the brain parts of reptilian and mammalian rather than the reasoning in sketching that takes place in the neo-cortex.

For instance, in MUVE, when participants develop a seat, they operate their avatars to sit on a geometrical object and refer to the immersive experience of their avatars' activity in the search for a novel and appropriate solution. In contrast, in sketching, participants imagine the usability of the seat through calculating its dimension and composing necessary knowledge. The reasoning in sketching is probably related to neo-cortex that holds rational and technical knowledge. In contrast, in MUVE, the evaluation on the designed seat is prompt and not as reasoned as sketching. The immersive experience through avatars' simulated body probably stimulates participants' prompt response to the physical properties of the designed seat, for example, the seat's slope for safety, which the reptilian part of the brain detects. Mirror neurons[4] are also possibly related to the emotional response on the designed seat, such as the feeling of "coziness" and "comfort", which the mammalian part of the brain holds. The immersion in MUVE, for

[4] Giacomo Rizzolatti (2004) discovers the existence of mirror neurons and explains that a mirror neuron is a neuron that fires both when an animal acts and when the animal observes the same action performed by another. Thus, the neuron "mirrors" the behavior of the other, as though the observer were itself acting.

example when a participant feels she is sitting when her avatar is sitting on the designed objects, is probably the outcome of the mirror neurons.

The aforementioned theoretical discussion about the relationship between MUVE and neuroscience has a potential to investigate the mechanism involved in creativity. In *Inquiry by Design*, John Zeisel (2006) explains creative design development from a neuroscience perspective. He proposes the three steps of a creative process: imagining, representing, and testing[5] . Zeisel mentions that the brain's frontal lobe comparator is related to evaluating (testing) solutions. The brain's frontal lobe takes charge of rational reasoning through recalling pre-knowledge and memories. Zeisel's analyses of the brain's activities targets the creative process in conventional sketching, while the immersive experience-based evaluation in MUVE does not rely on knowledge-based reasoning as sketching does. Thus I assume that MUVE stimulates different parts of the brain rather than the frontal lobe. However, the relationship between immersive media like MUVE and brain's activities in a creative process is not investigated yet. Future research could focus on the relationship between MUVE and the mechanism of creativity from a neuroscience perspective.

6.2.5. Future research

In this research, I compare MUVE and sketching media to investigate in what ways MUVE's immersion using avatars' views and activities, and social presence and co-presence of others influence creative collaboration in contrast to the two-dimensional and non-immersive representation of sketching. To further investigate the impacts of those MUVE's characteristics on creative collaboration, future research aims to compare MUVE and other non-immersive and three-dimensional modeling tools in synchronous collaboration. In addition, in this study, I find that social presence and co-presence of others in MUVE inspire unexpected solutions and help in the evaluation and production of useful solutions. However, such presence of partners' avatars rests on the participation of human collaborators in the real world. Involving more partners costs time and money. Probably, anthropomorphic artificial agents called Virtual Users (V-User) have the potential of simulating the presence of others. Therefore, in future research, I plan to investigate the potential of artificial V-Users for the support of creative collaboration. In addition, as I discussed in Section 6.2.4, I will have more research on how neuroscience explains the creative processes in MUVE and sketching, which are observed in this research. Future research could develop current design theories and methods for creative collaboration.

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[5] John Zeisel (2006) defines that imagining means a person's internalized pictures and mental images, presenting is externalizing the mental images, and testing includes all types of tests such as evaluations, comparisons, reviews, and confrontation .

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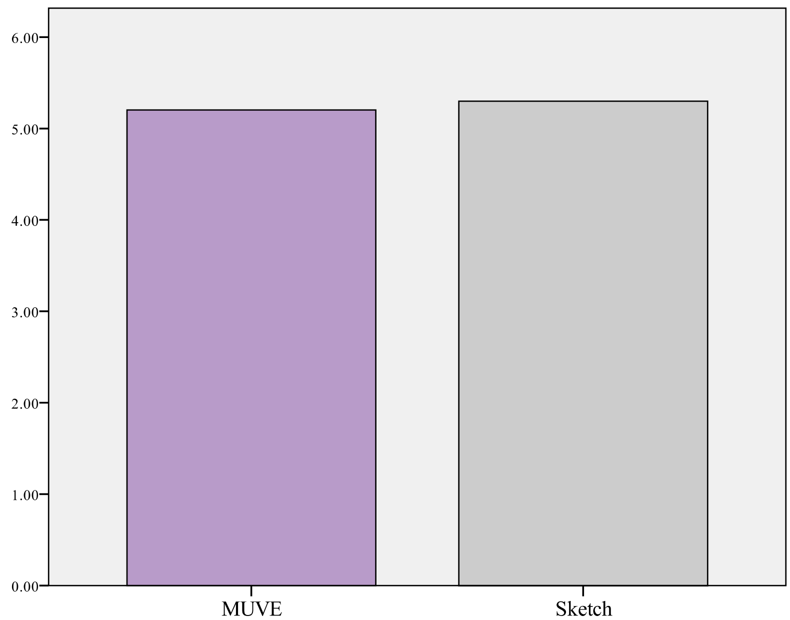
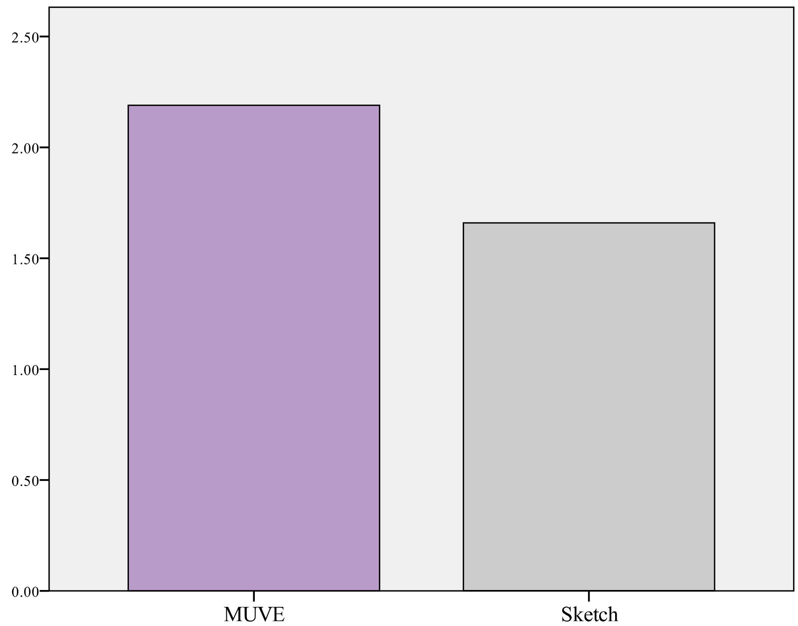
Appendix: Graphs

Face-to-Face Collaboration

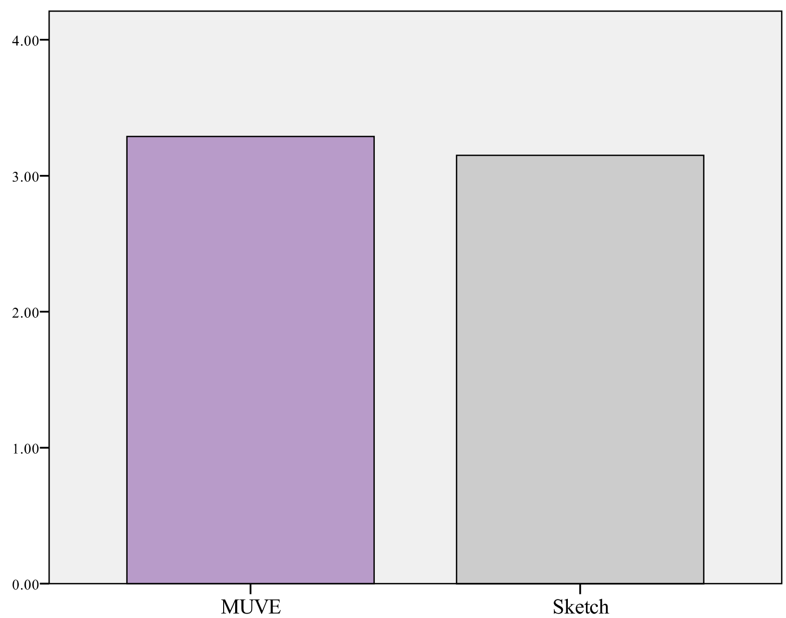
Self-Assessment



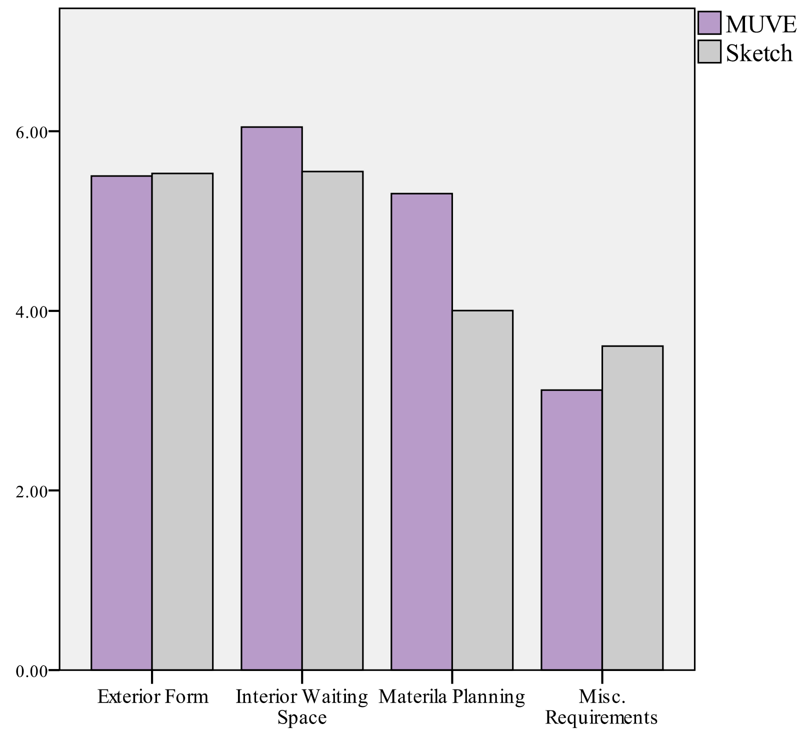
Appendix Figure 1 Creativity in MUVE and sketching, self-assessment in face-to-face collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



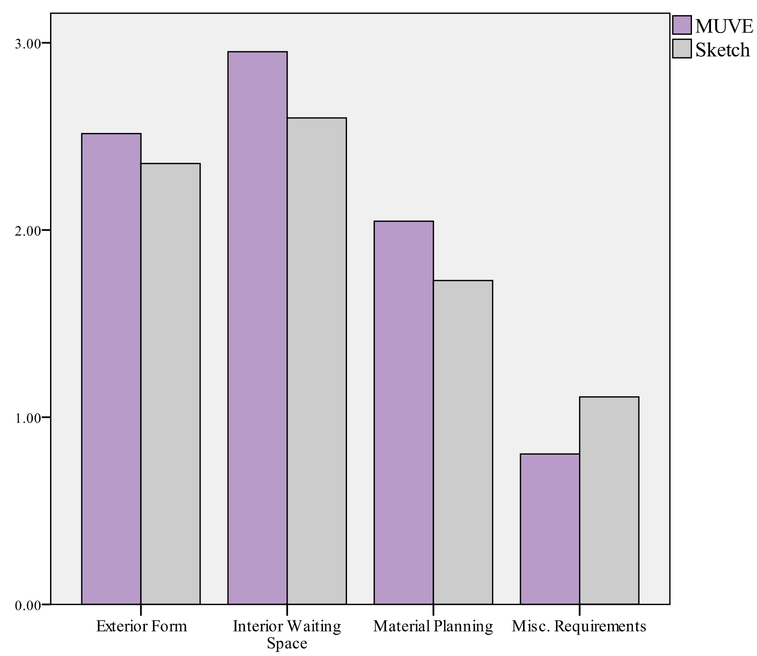
Appendix Figure 2 Novelty in MUVE and sketching, self-assessment in face-to-face collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



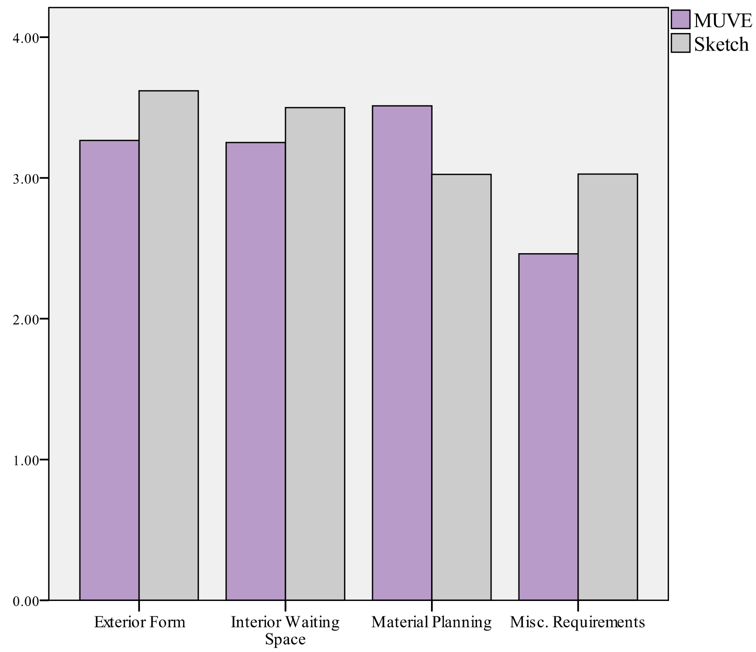
Appendix Figure 3 Appropriateness in MUVE and sketching, self-assessment in face-to-face collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



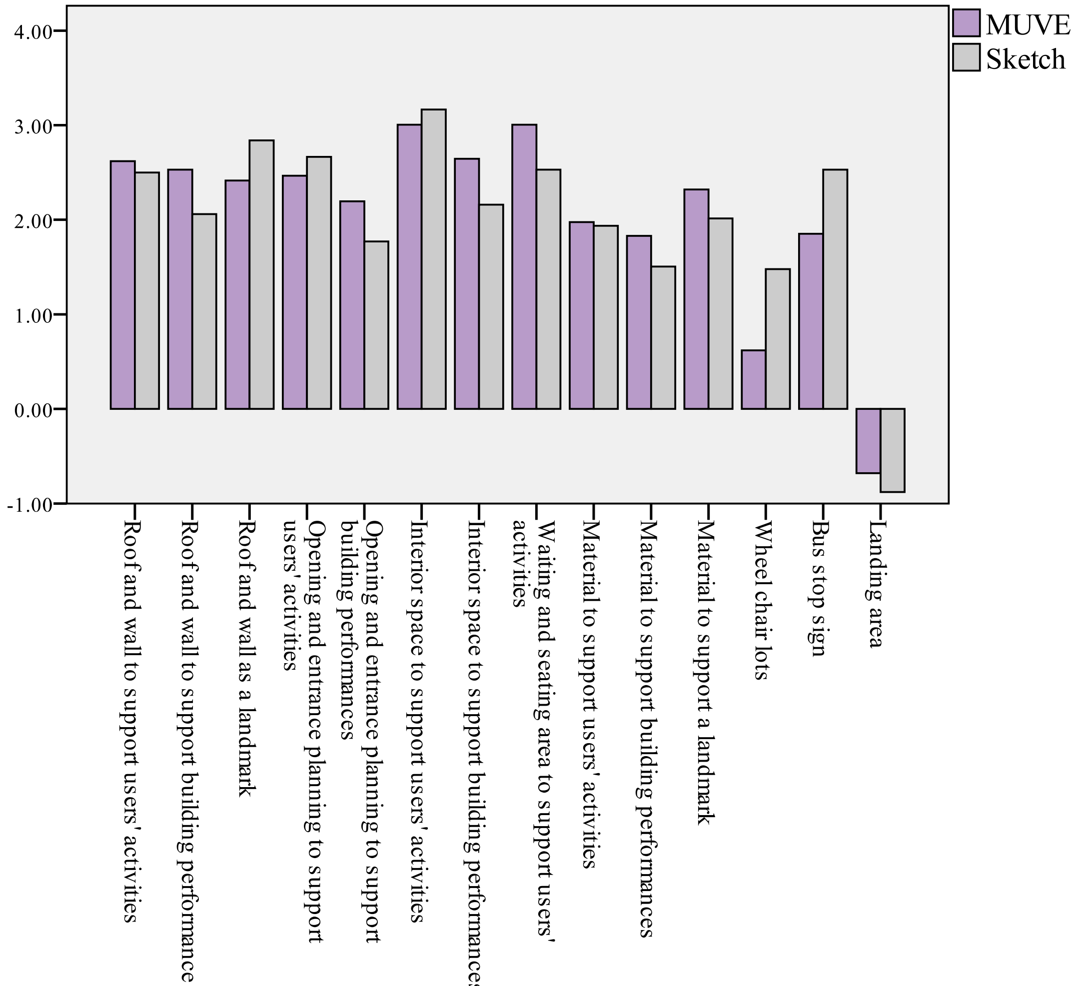
Appendix Figure 4 Creativity for exterior form, interior waiting space, material planning, and misc. requirements in MUVE and sketching, self-assessment in face to face collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)



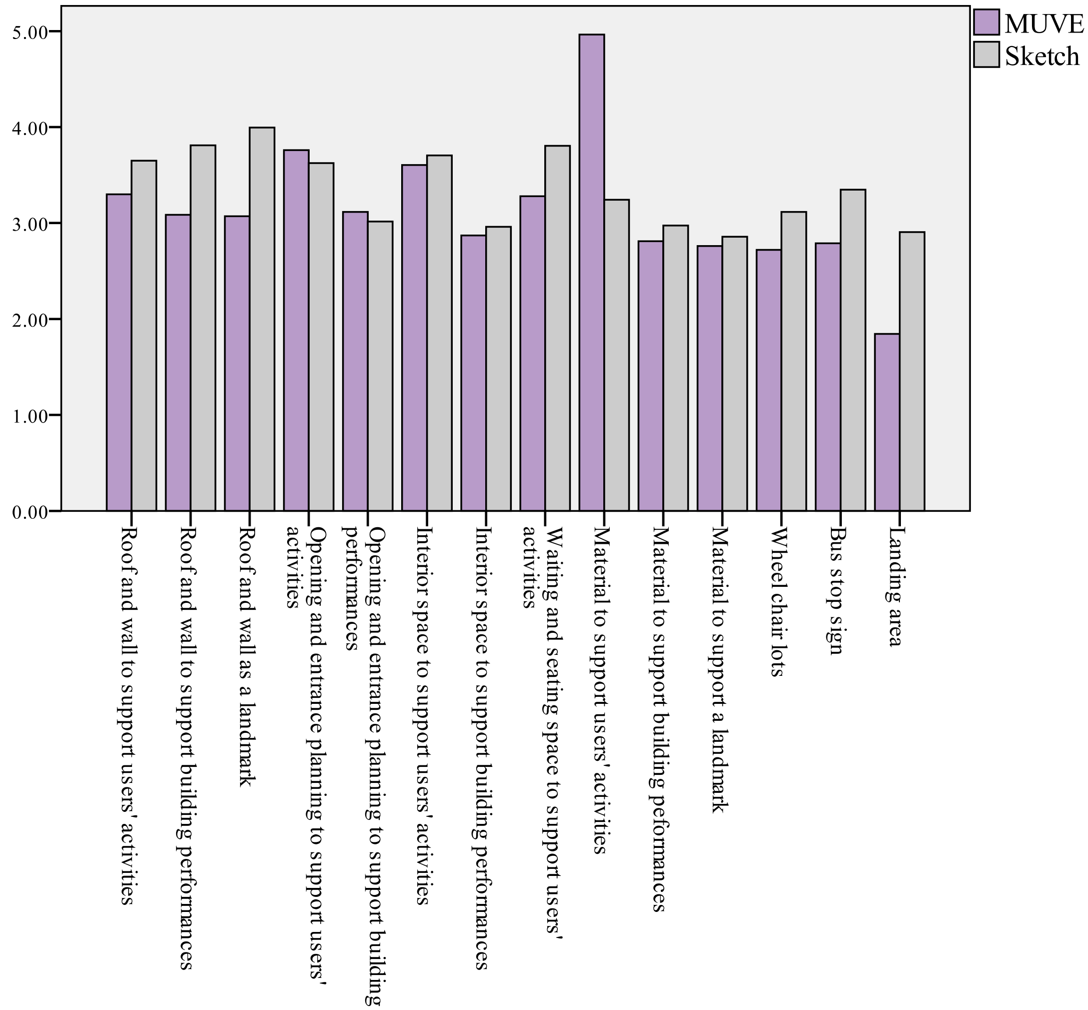
Appendix Figure 5 Novelty for exterior form, interior waiting space, material planning, and misc. requirements in MUVE and sketching, self-assessment in face to face collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)



Appendix Figure 6 Appropriateness for exterior form, interior waiting space, material planning, and misc. requirements in MUVE and sketching, self-assessment in face to face collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)

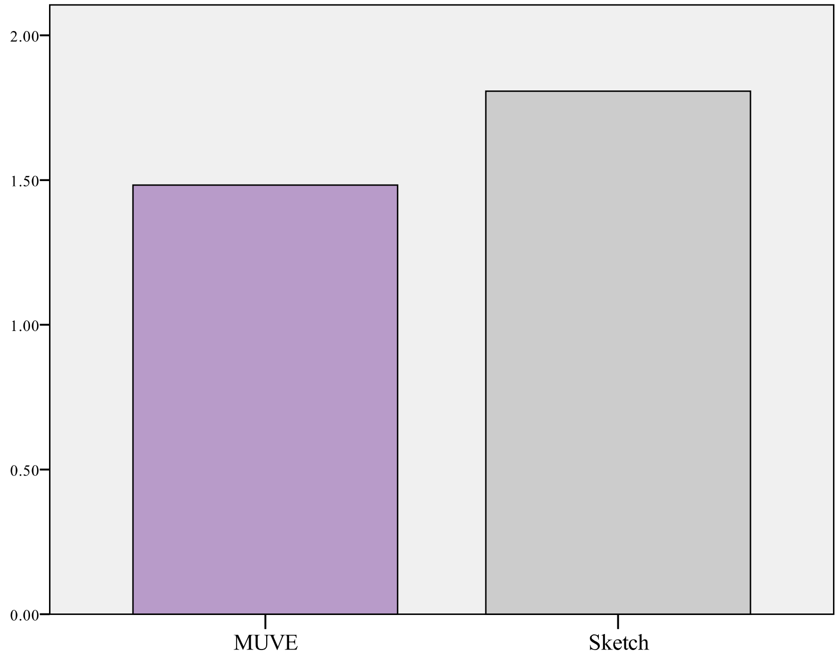


Appendix Figure 7 Novelty for fourteen evaluation factors, self-assessment in face-to-face collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)

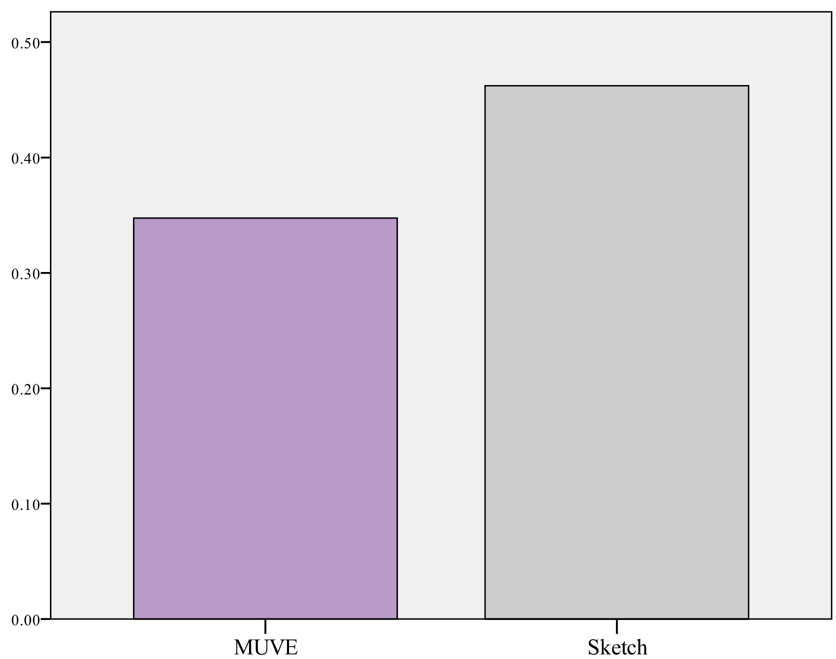


Appendix Figure 8 Appropriateness for fourteen evaluation factors, self-assessment in face-to-face collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)

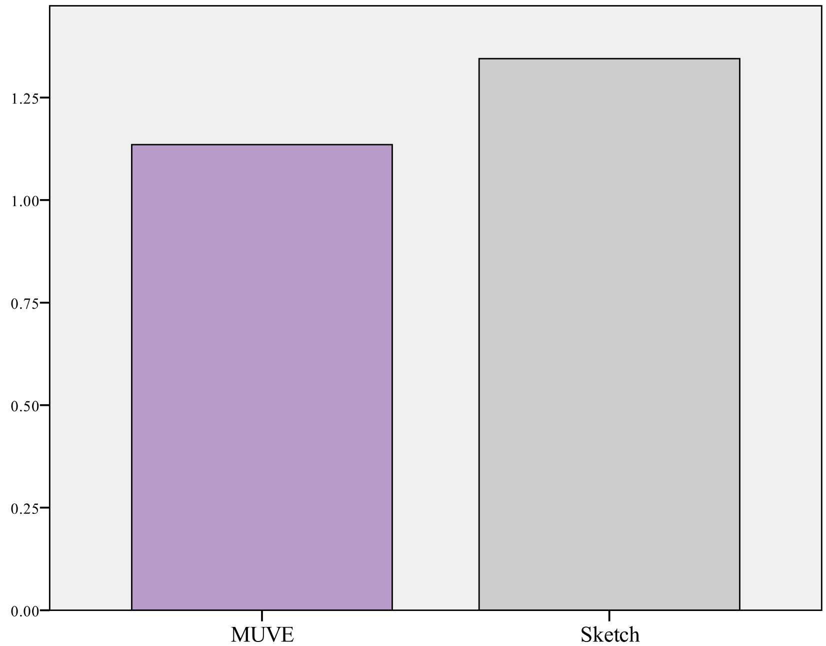
External Judge’s Consensual Assessment



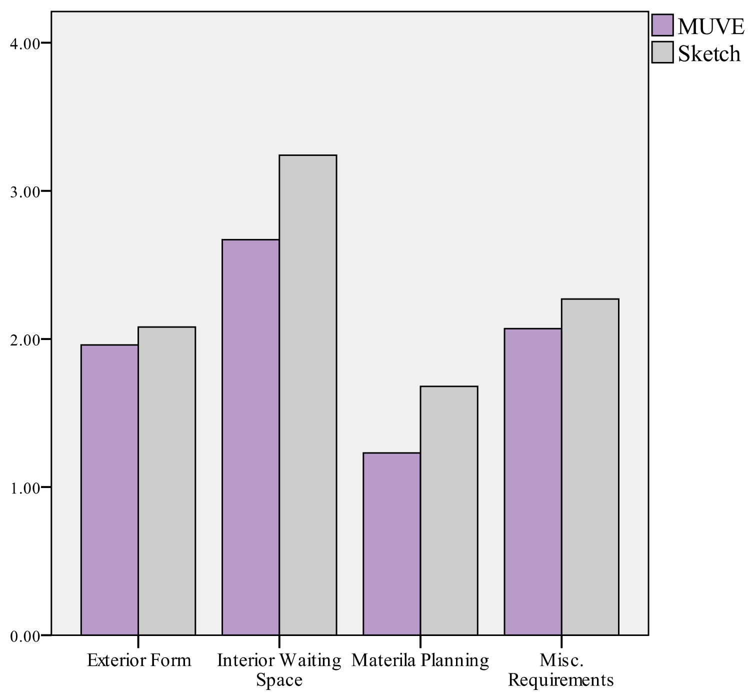
Appendix Figure 9 Creativity in MUVE and sketching, consensual assessment in face-to-face collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



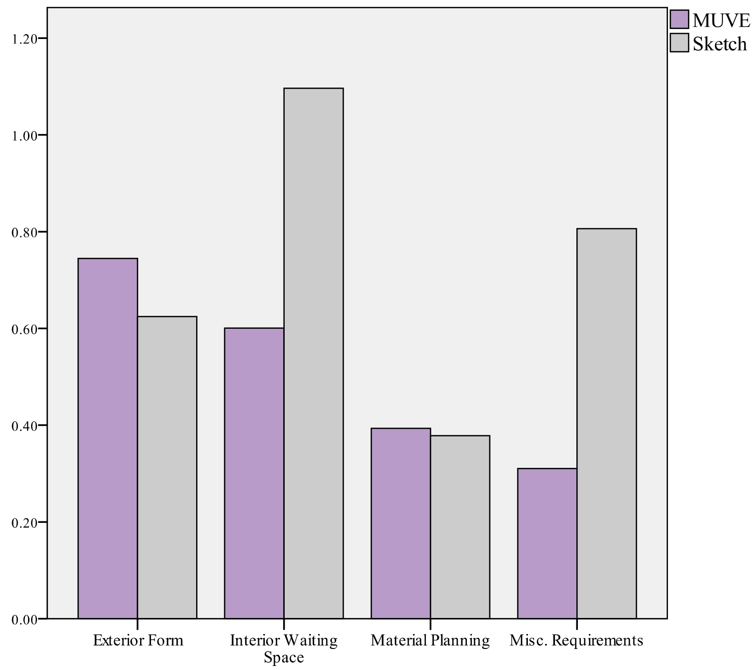
Appendix Figure 10 Novelty in MUVE and sketching, consensual assessment in face-to-face collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



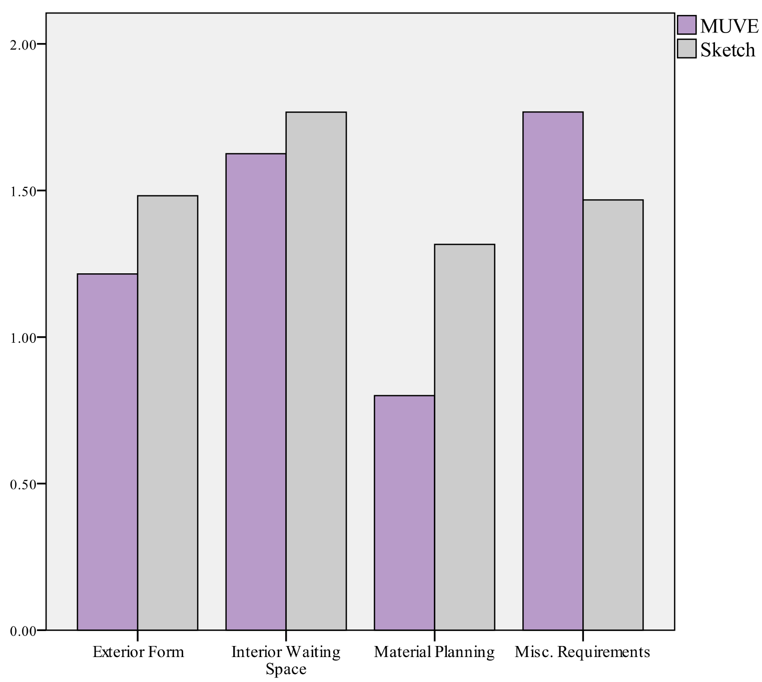
Appendix Figure 11 Appropriateness in MUVE and sketching, consensual assessment in face-to-face collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



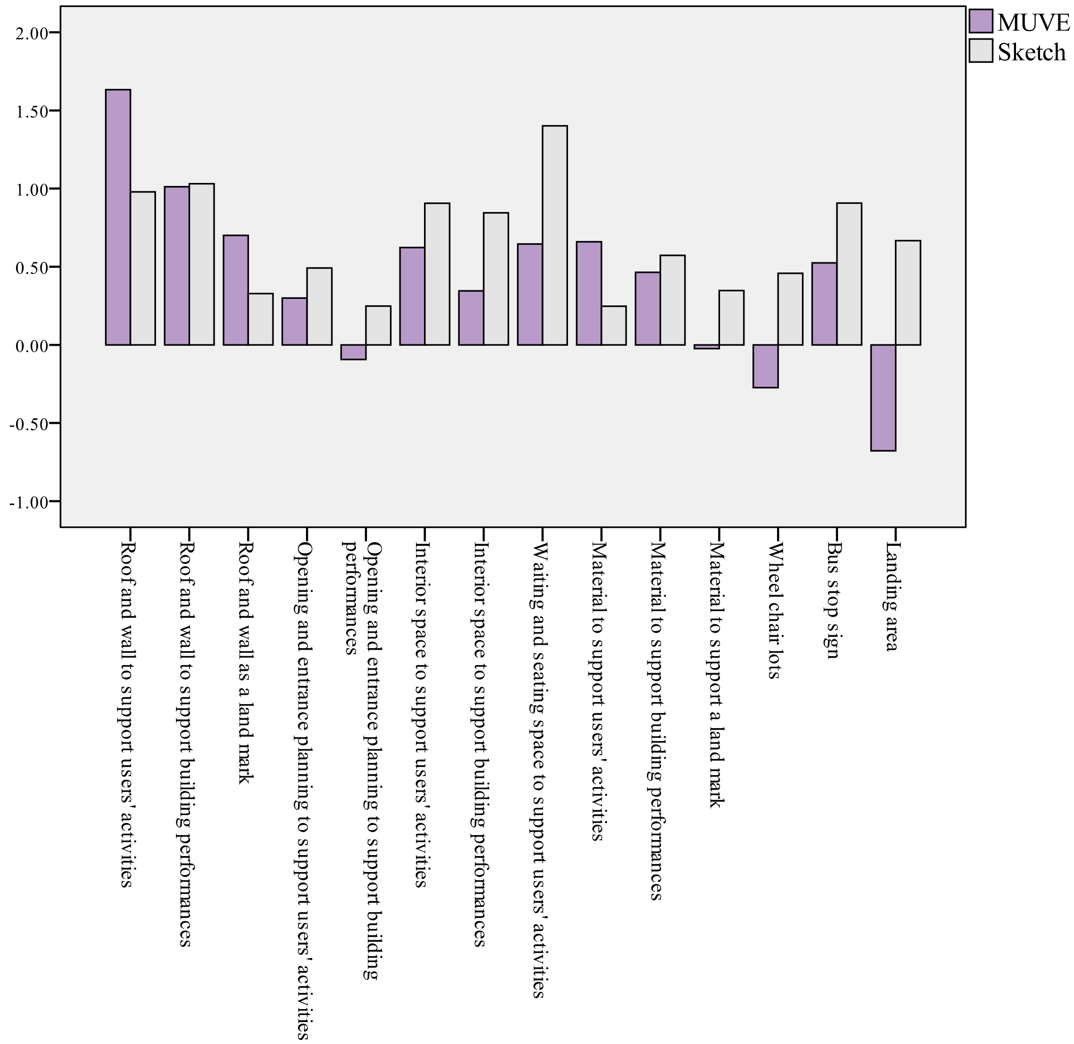
Appendix Figure 12 Creativity for exterior form, interior waiting space, material planning, and misc. requirement in MUVE and sketching, consensual assessment in face-to-face collaboration (p-value>0.05, the mean difference s between MUVE and sketching are not statistically significant.)



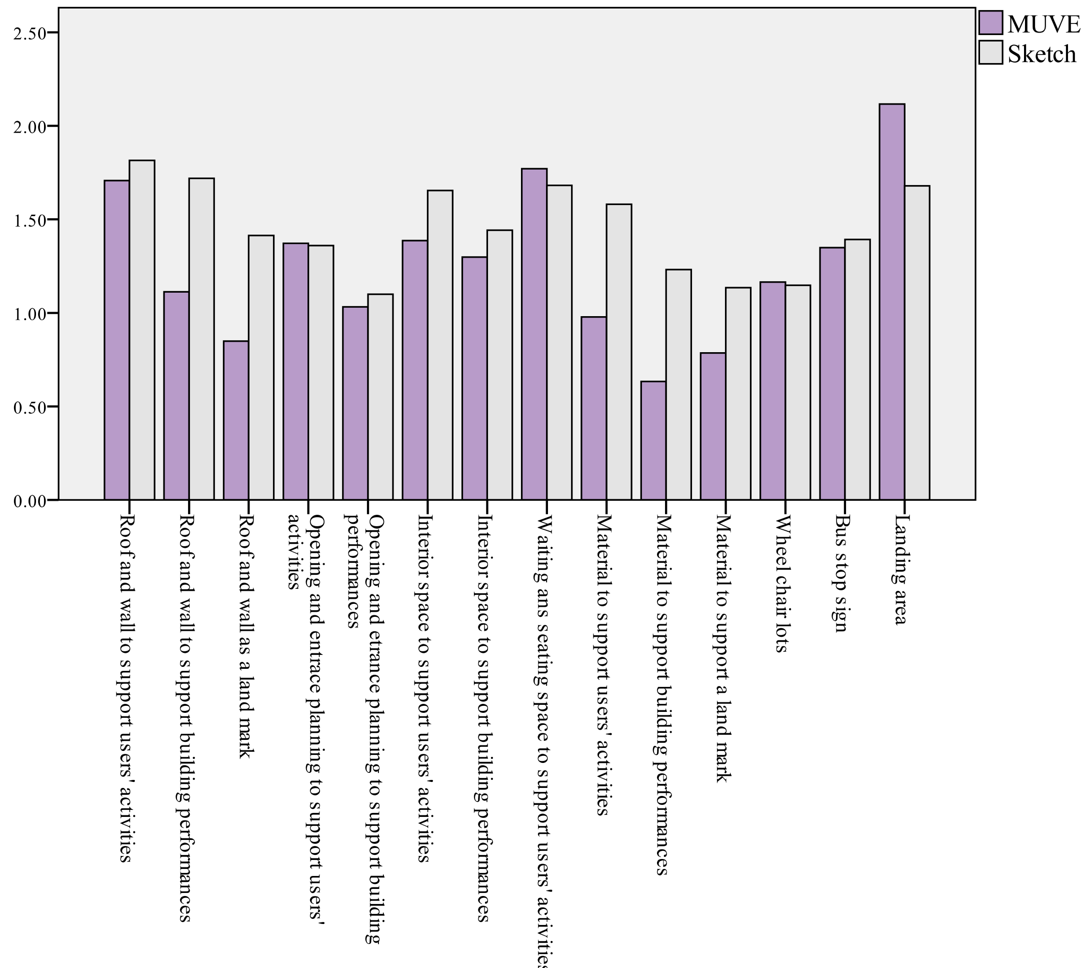
Appendix Figure 13 Novelty for exterior form, interior waiting space, material planning, and misc. requirement in MUVE and sketching, consensual assessment in face-to-face collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)



Appendix Figure 14 Appropriateness for exterior form, interior waiting space, material planning, and misc. requirement in MUVE and sketching, consensual assessment in face-to-face collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)



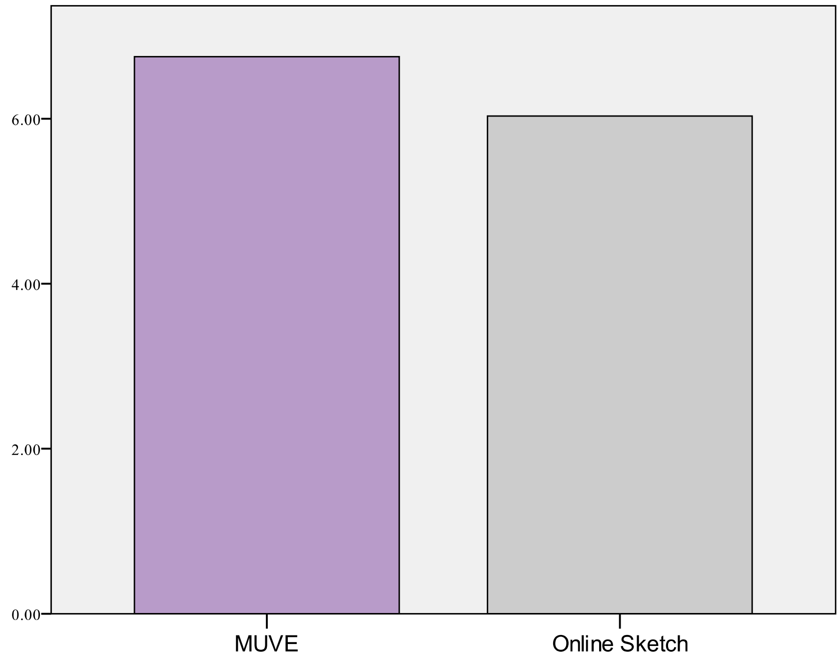
Appendix Figure 15 Novelty for fourteen evaluation factors, consensual assessment in face-to-face collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.) Note: in this research, the score range for novelty and appropriateness is -6 (very banal/inappropriate) to 6 (very novel/appropriate), thus the downside graphs are allowable.



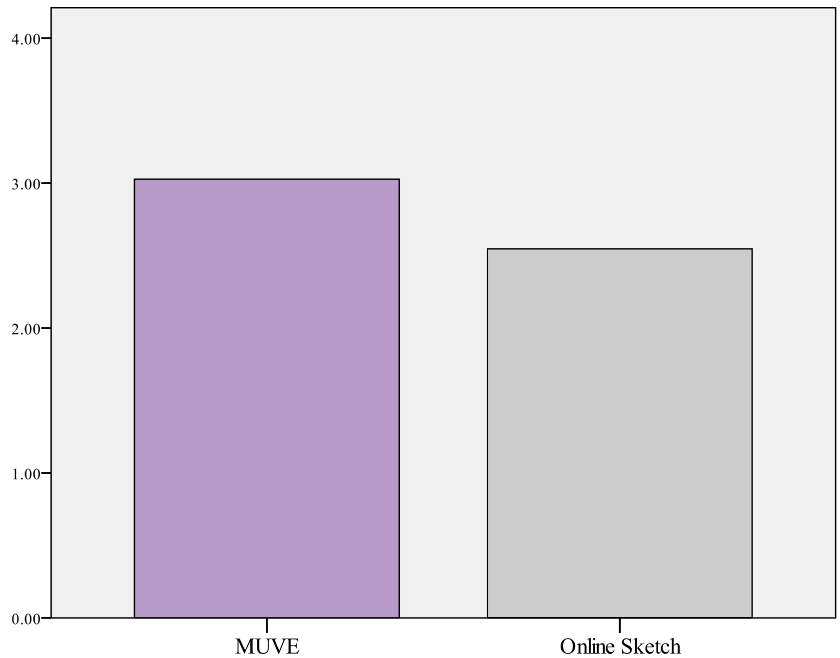
Appendix Figure 16 Appropriateness for fourteen evaluation factors, consensual assessment in face-to-face collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)

Remote Collaboration

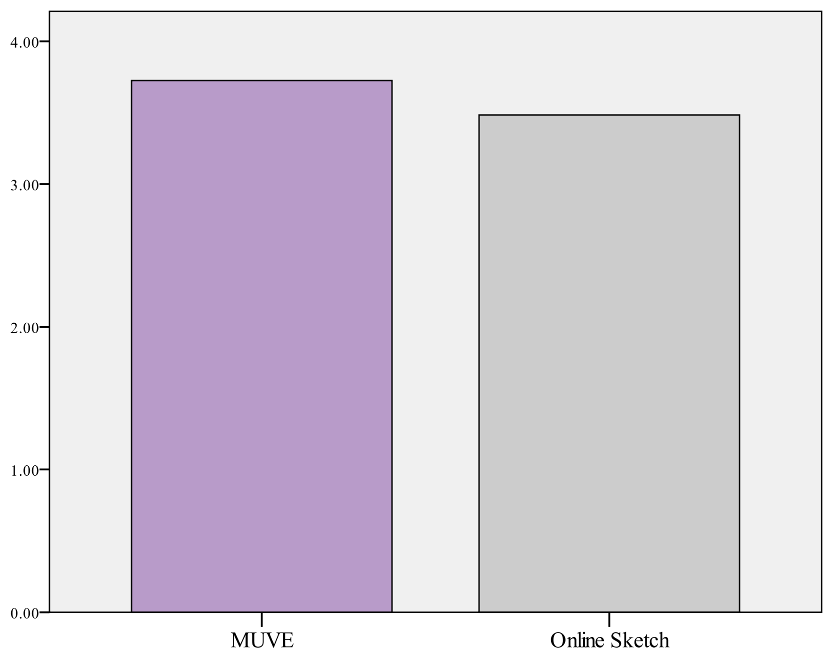
Self-Assessment



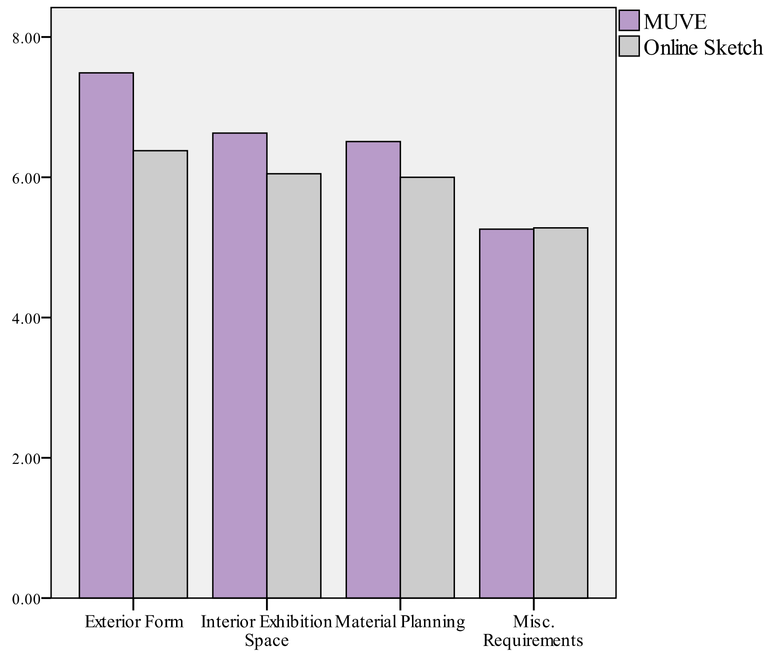
Appendix Figure 17 Creativity in MUVE and online sketching, self-assessment in remote collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



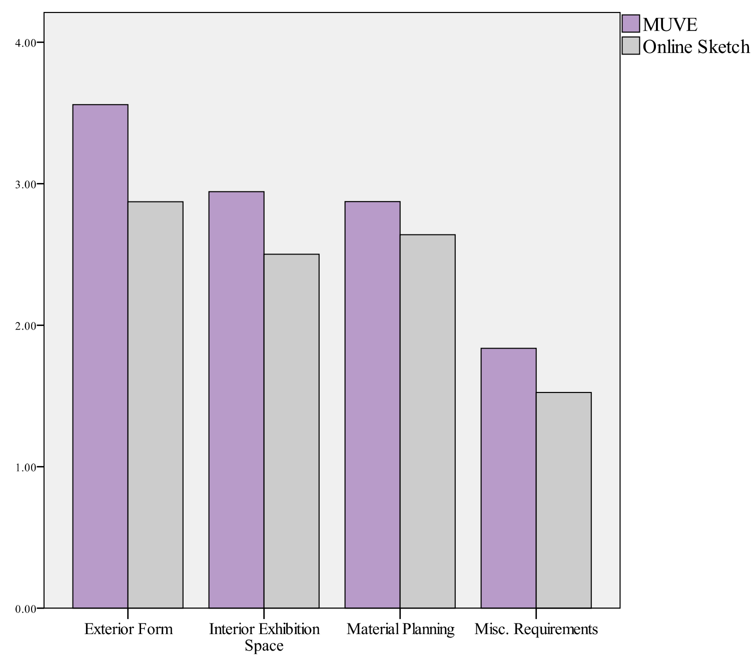
Appendix Figure 18 Novelty in MUVE and online sketching, self-assessment in remote collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



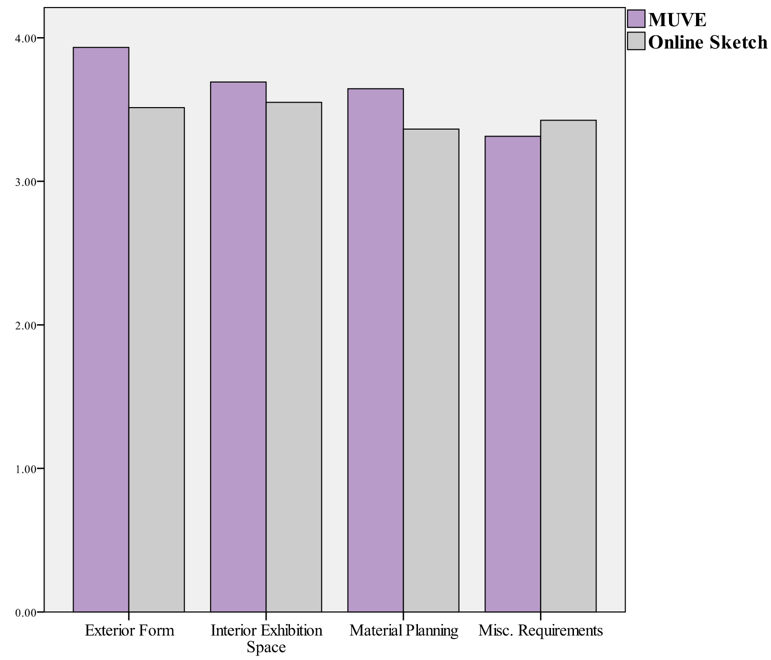
Appendix Figure 19 Appropriateness in MUVE and online sketching, self-assessment in remote collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



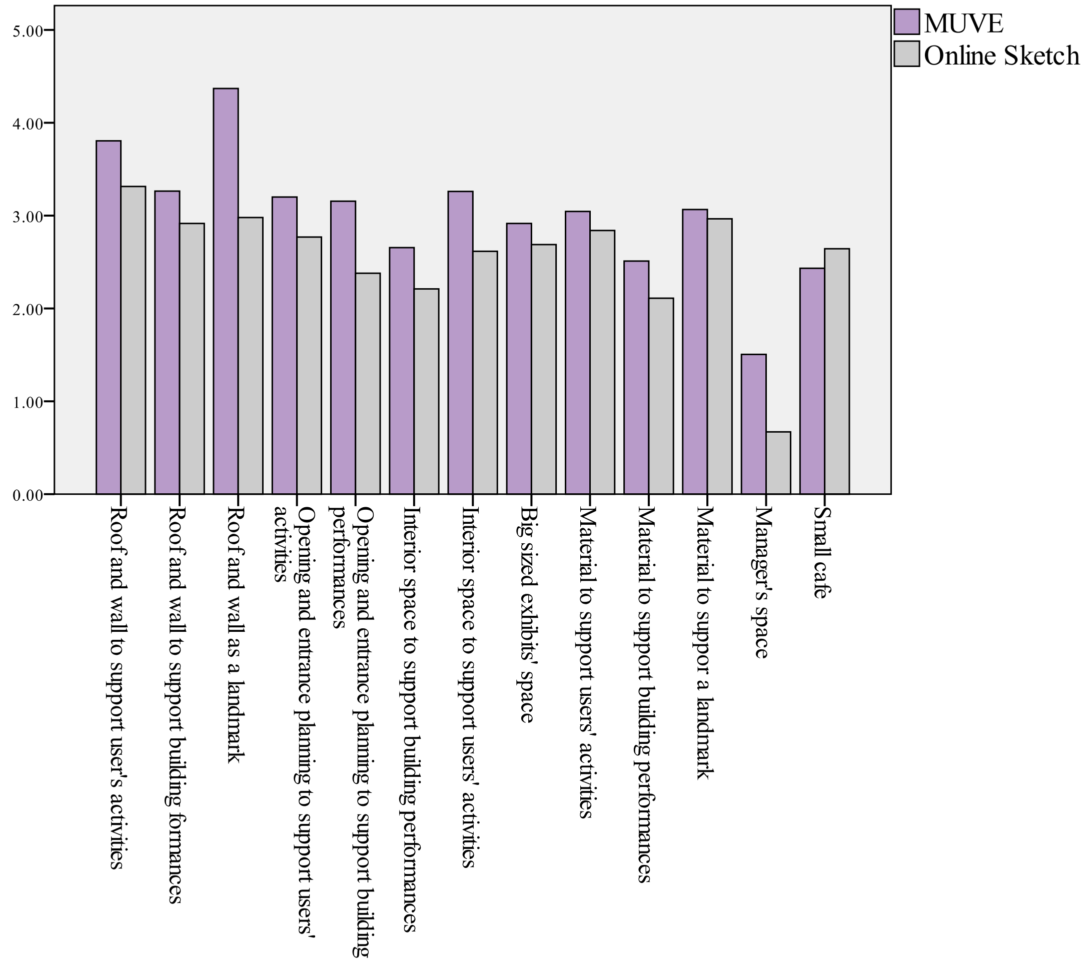
Appendix Figure 20 Creativity for exterior form, interior exhibition space, material planning, misc. requirements in MUVE and online sketching, self-assessment in remote collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)



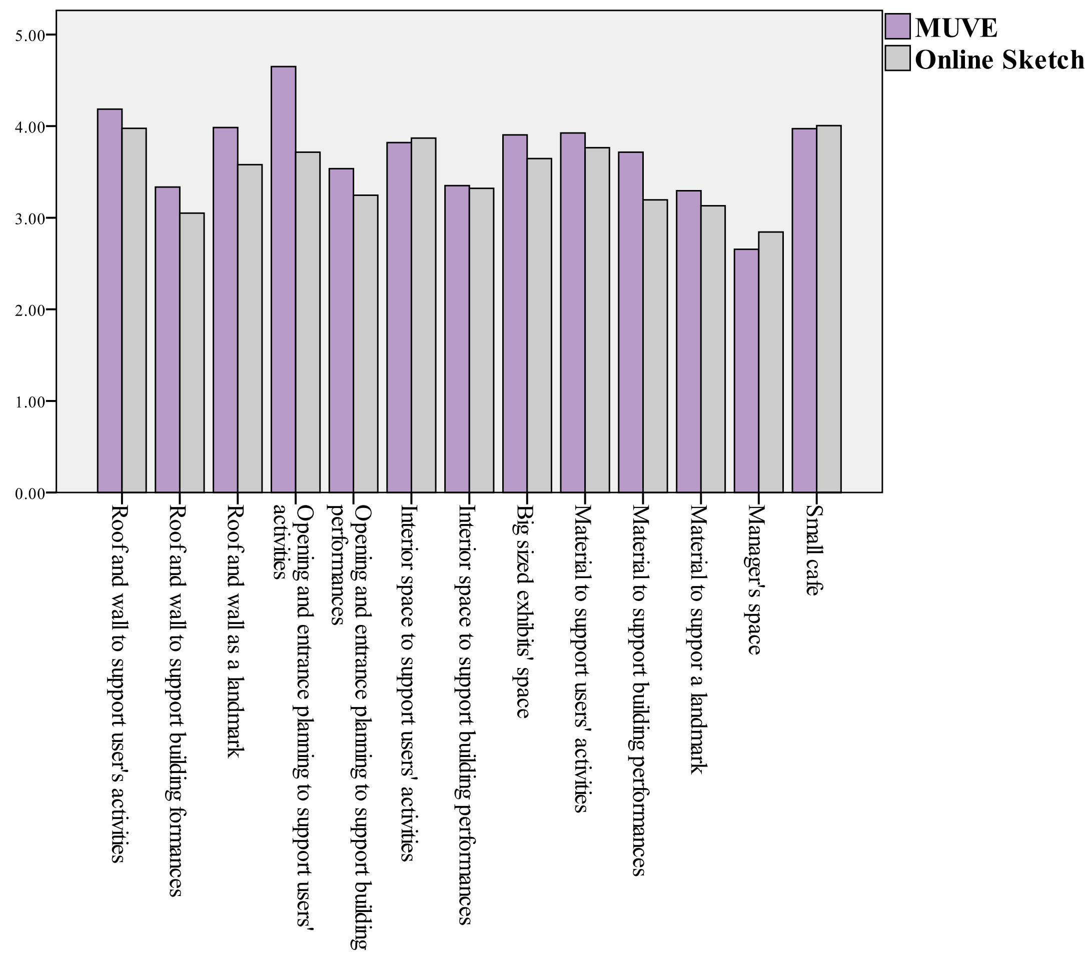
Appendix Figure 21 Novelty for exterior form, interior exhibition space, material planning, misc. requirements in MUVE and online sketching, self-assessment in remote collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)



Appendix Figure 22 Appropriateness for exterior form, interior exhibition space, material planning, misc. requirements in MUVE and online sketching, self-assessment in remote collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)

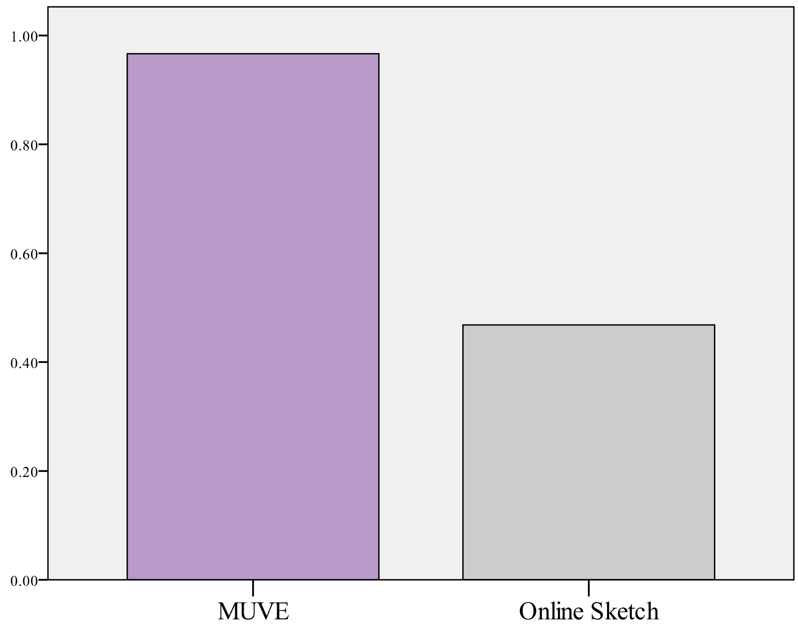


Appendix Figure 23 Novelty for thirteen evaluation factors, self-assessment in remote collaboration (the p-value for roof and wall design as landmark<0.05, thus it has statistical significance. Except it, other factors' p-value>0.05 the mean differences between MUVE and sketching are not statistically significant.)

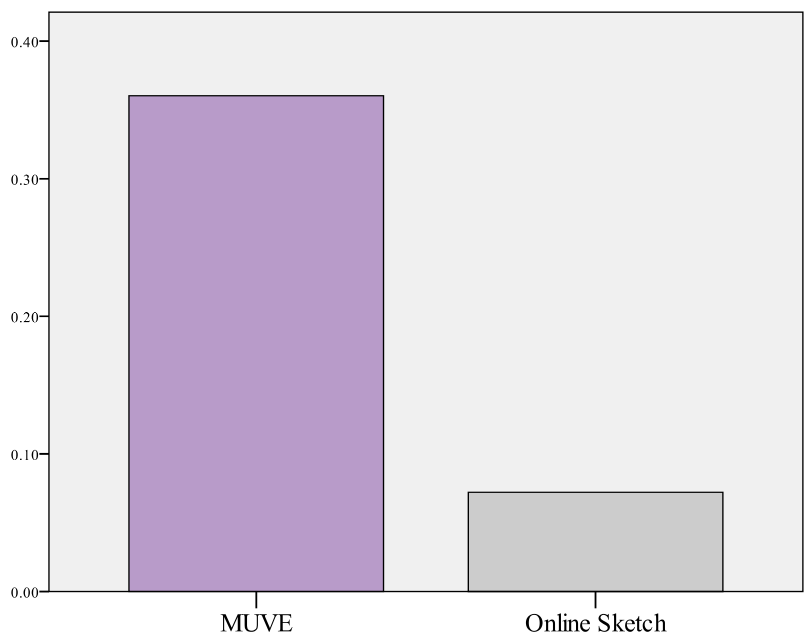


Appendix Figure 24 Appropriateness for thirteen evaluation factors, self-assessment in remote collaboration (the p-value for opening and entrance planning to support users' activities<0.05, thus it has statistical significance. The factor means partitioning and organizing interior and exterior space. Except it, other factors' p-value>0.05 the mean differences between MUVE and sketching are not statistically significant.)

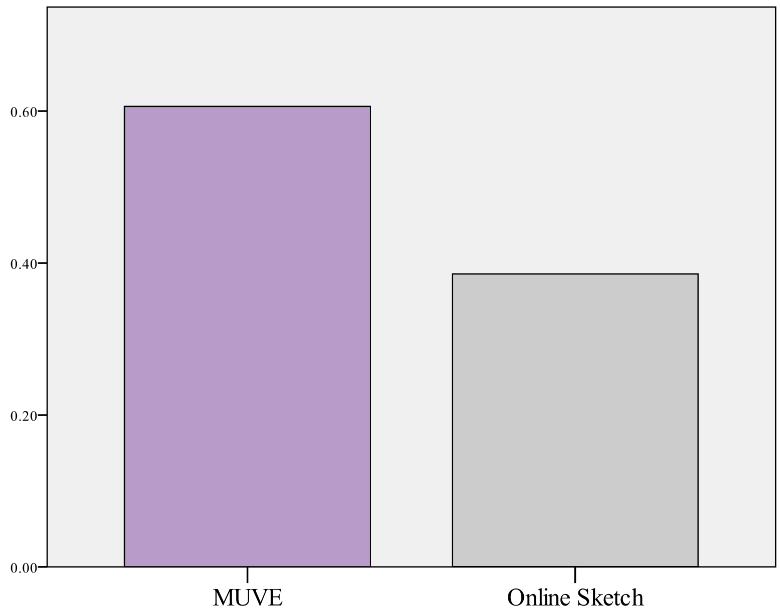
External Judges' Consensual Assessment



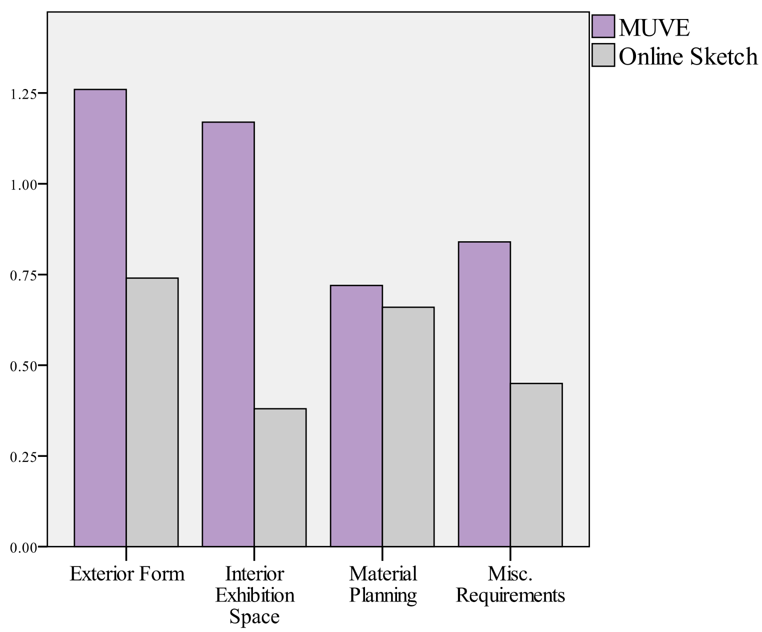
Appendix Figure 25 Creativity in MUVE and online sketching, consensual assessment in remote collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



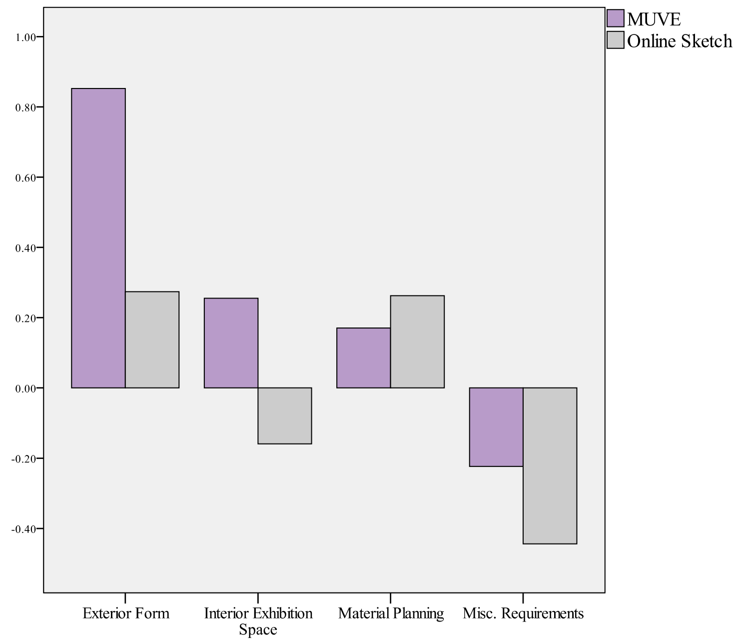
Appendix Figure 26 Novelty in MUVE and online sketching, consensual assessment in remote collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



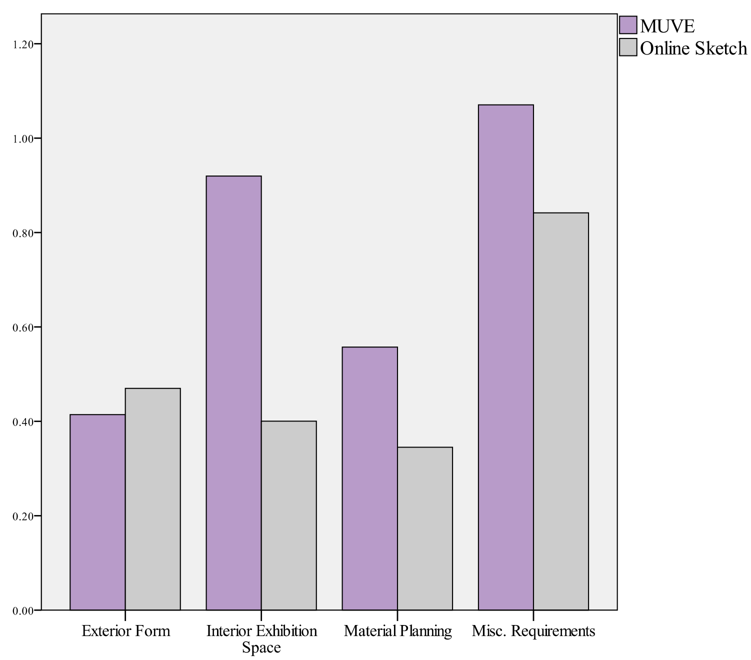
Appendix Figure 27 Appropriateness in MUVE and online sketching, consensual assessment in remote collaboration (p-value>0.05, the mean difference between MUVE and sketching is not statistically significant.)



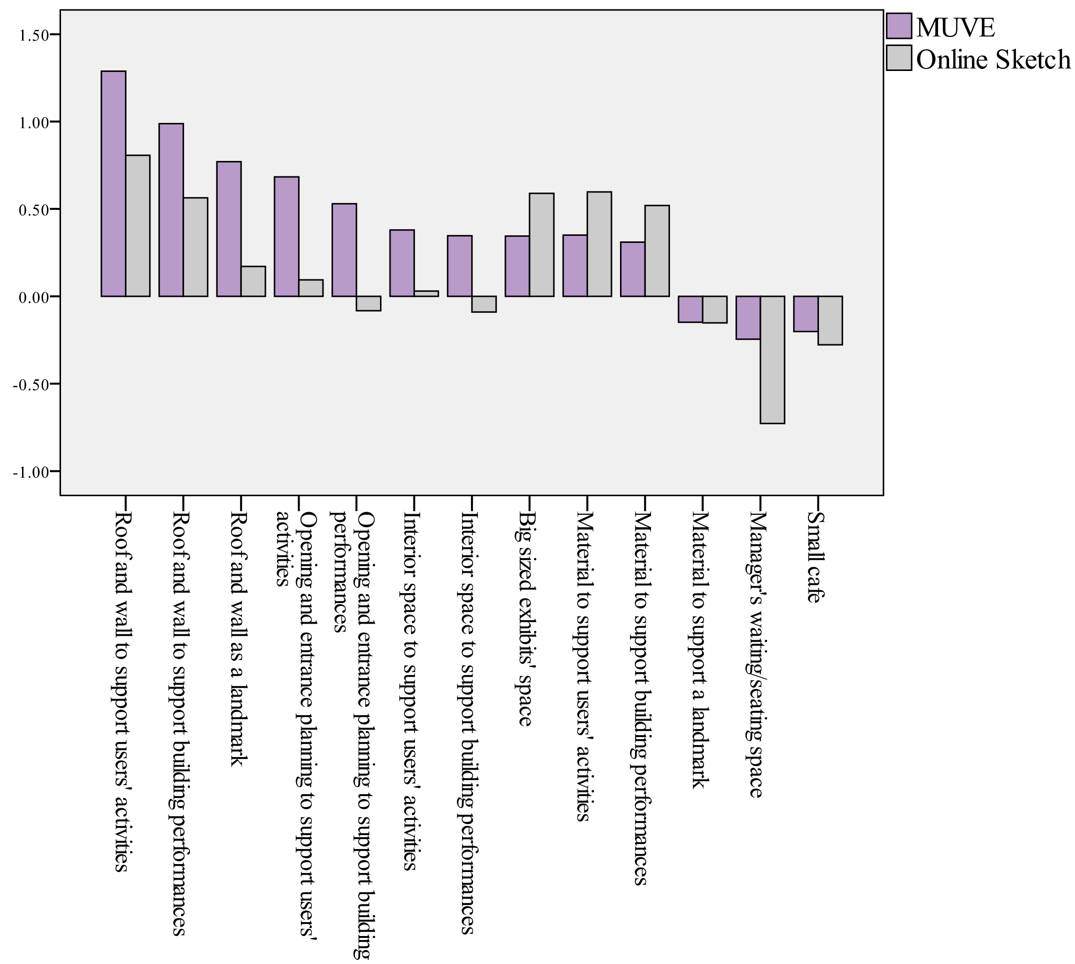
Appendix Figure 28 Creativity for exterior form, interior exhibition space, material planning, misc. requirements in MUVE and online sketching, consensual assessment in remote collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)



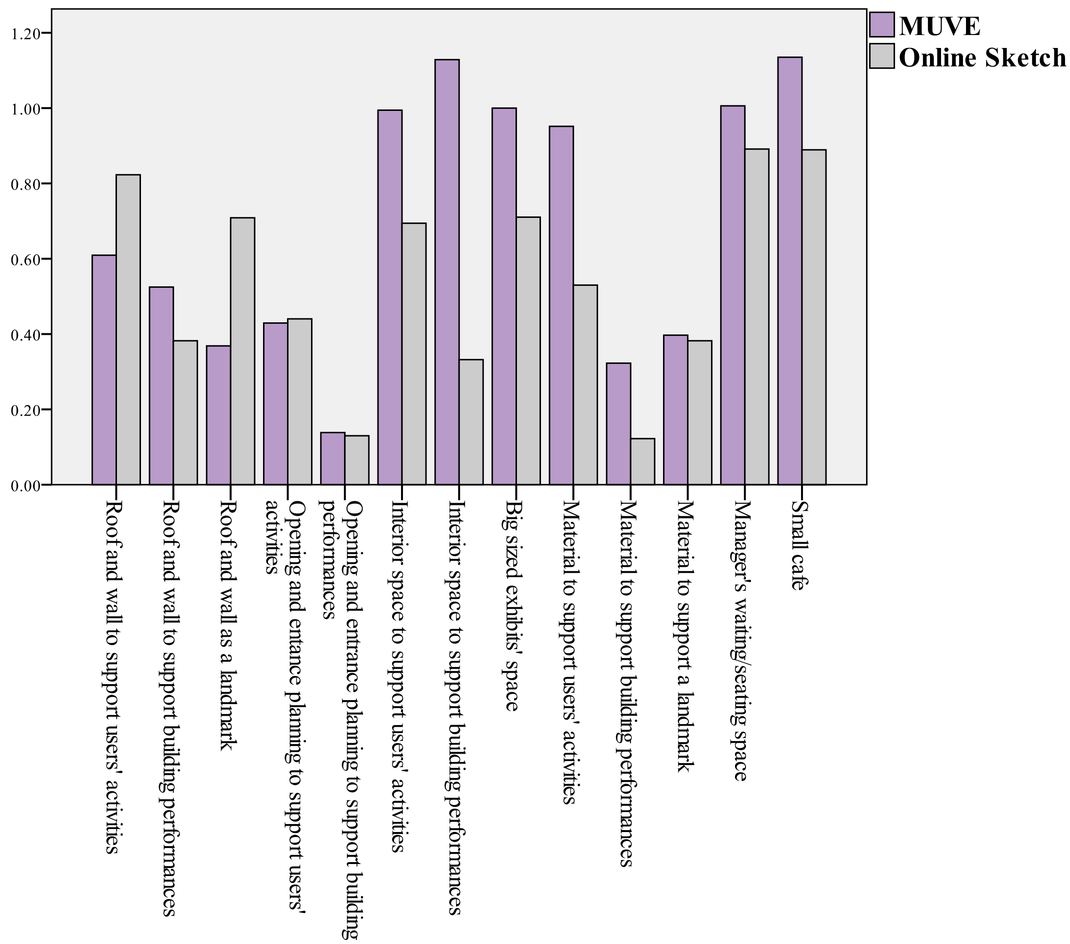
Appendix Figure 29 Novelty for exterior form, interior exhibition space, material planning, misc. requirements in MUVE and online sketching, consensual assessment in remote collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant) Note: in this research, the score range for novelty and appropriateness is -6 (very banal/inappropriate) to 6 (very novel/appropriate), thus the downside graphs are allowable.



Appendix Figure 30 Appropriateness for exterior form, interior exhibition space, material planning, misc. requirements in MUVE and online sketching, consensual assessment in remote collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)



Appendix Figure 31 Novelty scores for thirteen evaluation factors, consensual assessment in remote collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.) Note: in this research, the score range for novelty and appropriateness is -6 (very banal/inappropriate) to 6 (very novel/appropriate), thus the downside graphs are allowable.



Appendix Figure 32 Appropriateness scores for thirteen evaluation factors, consensual assessment in remote collaboration (p-value>0.05, the mean differences between MUVE and sketching are not statistically significant.)

Appendix: Tables

Face-to-Face Collaboration

Self-Assessment

Categories \ Scores	Creativity Mean (Standard Deviation)		Novelty Mean (Standard Deviation)		Appropriateness Mean (Standard Deviation)	
	MUVE	Sketching	MUVE	Sketching	MUVE	Sketching
Total	5.20(2.91)	5.29(2.39)	2.1(1.56)	1.9(1.94)	1.9(3.14)	3.3(0.98)
Exterior Form	5.50(2.47)	5.55(2.6)	2.515 (2.12)	2.355(1.90)	3.266(1.76)	3.619(1.26)
Interior Waiting Space	6.04(2.44)	5.55(2.48)	2.951 (1.52)	2.598(1.86)	3.251(1.92)	3.490(1.17)
Material Planning	5.30(3.807)	4.00(2.97)	2.046(2.01)	1.729(2.04)	3.511(3.33)	3.0246(1.25)
Misc. Requirements	3.11(2.88)	3.60(2.44)	0.803(1.55)	1.108(1.82)	2.461(1.95)	3.027(1.22)

Appendix Table 1 Creativity, novelty, and appropriateness scores in MUVE and sketching, self-assessment in face-to-face collaboration (p-value>0.05, the creativity score is the sum of novelty and appropriateness scores.)

Categories	Factors	Novelty Score Mean(Standard Deviation)		Appropriateness Score Mean(Standard Deviation)	
		MUVE	Sketching	MUVE	Sketching
Exterior Form	Wall and roof to support users' activities	2.61(2.19)	2.51(2.37)	3.3(2.02)	3.65(1.78)
	Wall and roof to support building performances	2.57(2.58)	1.96(2.04)	3.085(2.01)	3.81(1.25)
	Wall and roof as a landmark	2.50(2.77)	3.03(2.52)	3.07(2.20)	3.995(1.66)
	Opening and entrance planning to support users' activities	2.59(2.29)	2.57(2.39)	3.76(2.07)	3.625(1.32)
	Opening and entrance planning to support building performances	2.3(2.54)	1.7(2.21)	3.115(1.97)	3.01(1.75)
Interior Waiting Space	Interior space to support users' activities	3.095(1.80)	3.18(2.26)	3.605(1.90)	3.70(1.15)
	Interior space to support building performances	2.72(2.02)	1.995(2.12)	2.87(2.21)	2.96(1.93)

	Waiting and seating area to support users' activities	3.04(1.67)	2.62(2.17)	3.28(2.39)	3.80(1.39)
Material Planning	Material to support users' activities	2.075(2.13)	1.7368(2.21)	4.96(8.84)	3.24(1.49)
	Material to support building performances	1.72(2.08)	1.36(2.37)	2.81(2.04)	2.97(1.54)
	Material to support a landmark	2.34(2.47)	1.93(2.40)	2.76(2.09)	2.85(1.85)
Misc. requirements	Wheel chair lots	0.81(2.53)	1.5789 (2.89)	2.72(2.45)	3.11(1.87)
	Bus stop sign	1.9526(2.53)	1.07(2.78)	2.76(2.50)	2.85(1.77)
	Landing area	-0.58(1.75)	-0.7(2.97)	1.84(2.17)	2.90(1.84)

Appendix Table 2 Novelty and appropriateness scores for fourteen evaluation factors, self-assessment in face-to-face collaboration (p-value>0.05)

External Judges' Consensual Assessment

Categories \ Scores	Creativity Mean (Standard Deviation)		Novelty Mean(Standard Deviation)		Appropriateness Mean(Standard Deviation)	
	MUVE	Sketching	MUVE	Sketching	MUVE	Sketching
Total	1.48(4.11)	1.807(4.39)	0.34(2.33)	0.46(2.58)	1.13(2.13)	1.34(2.09)
Exterior Form	1.95(4.39)	2.08(4.55)	0.74(2.60)	0.62(2.62)	1.22(2.35)	1.48(2.18)
Interior Waiting Space	2.67(3.82)	3.24(4.09)	0.89(2.27)	1.30(2.21)	1.78(2.17)	1.93(2.23)
Material Planning	1.23(4.77)	1.68(4.61)	0.39(2.60)	0.37(2.69)	0.8(2.59)	1.31(2.25)
Misc. Requirements	2.07(3.88)	2.27(4.19)	0.31(2.45)	0.80(2.45)	1.77(1.91)	1.47(2.00)

Appendix Table 3 Creativity, novelty, and appropriateness scores in MUVE and sketching, consensual assessment in face- to-face collaboration (p-value>0.05, the creativity score is the sum of novelty and appropriateness scores.)

Categories	Factors	Novelty Score Mean(Standard Deviation)		Appropriateness Score Mean (Standard Deviation)	
		MUVE	Sketching	MUVE	Sketching
Exterior Form	Wall and roof to support users' activities	1.63(3.00)	0.97(3.14)	1.70(2.55)	1.81(2.54)
	Wall and roof to support building performances	1.01(3.06)	1.03(2.80)	1.11(2.87)	1.71(2.49)

	Wall and roof as a landmark	0.70(3.20)	0.32(3.17)	0.84(2.53)	1.41(2.53)
	Opening and entrance planning to support users' activities	0.299(2.74)	0.49(2.56)	1.37(2.62)	1.36(2.56)
	Opening and entrance planning to support building performances	-0.93(2.5)	0.248(2.56)	1.03(2.76)	1.1(2.52)
Interior Waiting Space	Interior space to support users' activities	0.62(2.49)	0.90(2.61)	1.38(2.57)	1.65(2.61)
	Interior space to support building performances	0.34(2.65)	0.84(2.44)	1.29(2.60)	1.44(2.51)
	Waiting and seating area to support users' activities	0.64(2.73)	1.40(2.57)	1.77(2.63)	1.68(2.69)
Material Planning	Material to support users' activities	0.6594(2.56)	0.2478(2.86)	0.97(2.81)	1.58(2.30)
	Material to support building performances	0.4647(2.62)	0.5725(2.71)	0.63(2.81)	1.23(2.33)
	Material to support a landmark	-0.024(3.05)	0.3471(3.12)	0.78(2.64)	1.13(2.60)
Misc. requirements	Wheel chair lots	-0.27(2.83)	0.45(2.51)	1.16(2.48)	1.14(2.47)
	Bus stop sign	0.52(2.63)	0.90(2.51)	1.34(2.68)	1.39(2.41)
	Landing area	-0.067(2.94)	0.66(2.63)	2.11(1.95)	1.67(2.11)

Appendix Table 4 Novelty and appropriateness scores for fourteen evaluation factors, consensual assessment in face-to -face collaboration (p-value>0.05)

Remote Collaboration

Self-Assessment

Categories \ Scores	Creativity Mean (Standard Deviation)		Novelty Mean (Standard Deviation)		Appropriateness Mean (Standard Deviation)	
	MUVE	Online Sketching	MUVE	Online Sketching	MUVE	Online Sketching
Total	6.75(2.11)	6.03(2.50)	3.02(1.27)	2.55(1.45)	3.73(1.02)	3.48(1.28)
Exterior Form	7.49(2.46)	6.38(2.63)	3.56(1.43)	2.87(1.51)	3.93(1.26)	3.51(1.40)
Interior Exhibition Space	6.63(2.41)	6.05(2.55)	2.94(1.58)	2.50(1.75)	3.69(1.04)	3.56(1.31)
Material Planning	6.51(2.15)	6.00(2.83)	2.87(1.46)	2.64(1.68)	3.64(0.93)	3.36(1.47)
Misc. Requirements	5.26(5.26)	5.28(5.28)	1.84(1.72)	1.52(2.75)	3.31(1.62)	3.42(1.81)

Appendix Table 5 Creativity, novelty, and appropriateness scores in MUVE and online sketching, self-assessment in remote collaboration (p-value>0.05, the creativity score is the sum of novelty and appropriateness scores.)

Categories	Factors	Novelty Score Mean (Standard Deviation)		Appropriateness Score Mean (Standard Deviation)	
		MUVE	Online Sketching	MUVE	Online Sketching
Exterior Form	Wall and roof to support users' activities	3.81(1.62)	3.32(1.68)	4.19(1.89)	3.98(1.28)
	Wall and roof to support building performances	3.27(2.14)	2.91(1.74)	3.34(2.27)	3.05(1.85)
	Wall and roof as a landmark	**4.37*(1.39)**	2.98(1.85)	3.99(1.79)	3.58(1.82)
	Opening and entrance planning to support users' activities	3.2(2.56)	2.77(2.33)	**4.65*(0.89)**	3.72(1.78)
	Opening and entrance planning to support building performances	3.16(2.20)	2.38(2.38)	3.54(1.71)	3.25(1.85)
Interior Exhibition Space	Interior space to support users' activities	3.26(1.89)	2.62(1.79)	3.82(1.35)	3.88(1.14)
	Interior space to support building performances	2.66(2.06)	2.21(1.95)	3.35(1.63)	3.32(1.78)
	Big sized exhibits' spaces	2.92(1.89)	2.68(2.15)	3.90(1.28)	3.65(1.59)
Material Planning	Material to support users' activities	3.05(1.98)	2.84(1.94)	3.93(1.24)	3.77(1.84)
	Material to support building performances	2.51(1.73)	2.12(1.96)	3.71(1.13)	3.19(1.54)

	Material to support a landmark	3.07(1.99)	2.97(1.82)	3.30(1.81)	3.13(2.02)
Misc. requirements	Manager's space	1.51(2.46)	0.67(2.61)	2.66(2.38)	2.84(2.14)
	Small café area	2.43(1.90)	2.64(2.55)	3.97(1.54)	4.01(1.82)

Appendix Table 6 Novelty and appropriateness scores for thirteen evaluation factors, self-assessment in remote collaboration (*: statistical significant. The p-values of 1) novelty for wall and roof design as a landmark, 2) appropriateness for opening and entrance planning to support users' activities<0.05. Except those two factors, other factors' p-values is higher than 0.05, thus they do not have statistical significant.)

External Judges' Consensual Assessment

Categories \ Scores	Creativity Mean (Standard Deviation)		Novelty Mean (Standard Deviation)		Appropriateness Mean (Standard Deviation)	
	MUVE	Online Sketching	MUVE	Online Sketching	MUVE	Online Sketching
Total	0.96(4.32)	0.46(4.88)	0.36(2.16)	0.07(2.49)	0.61(2.50)	0.39(2.58)
Exterior Form	1.26(4.55)	0.74(5.19)	0.85(2.37)	0.27(2.69)	0.41(2.64)	0.47(2.78)
Interior Exhibition Space	1.17(5.02)	0.38(5.07)	0.26(2.32)	-0.02(2.60)	0.92(3.24)	0.40(2.71)
Material Planning	0.72(4.26)	0.66(5.20)	0.17(2.42)	0.26(2.84)	0.56(2.31)	0.34(2.70)
Misc. Requirements	0.84(4.44)	0.45(4.01)	-0.22(2.41)	-0.44(2.20)	1.07(2.56)	0.84(2.20

Appendix Table 7 Creativity, novelty, and appropriateness scores in MUVE and online sketching, consensual assessment in remote collaboration (p-value>0.05)

Categories	Factors	Novelty Score Mean (Standard Deviation)		Appropriateness Score Mean (Standard Deviation)	
		MUVE	Online Sketching	MUVE	Online Sketching
Exterior Form	Wall and roof design to support users' activities	1.29(2.67)	0.81(2.92)	0.61(2.97)	0.82(3.04)
	Wall and roof design to support building performances	0.99(2.60))	0.56(2.95)	0.53(2.98)	0.38(3.04)
	Wall and roof design as a landmark	0.77(2.82)	0.02(3.12)	0.37(2.65)	0.71(3.13)
	Opening and entrance planning to support users' activities	0.68(2.50)	0.09(2.85)	0.43(2.91)	0.44(2.87)
	Opening and entrance planning to support building performances	0.53(2.59)	-0.08(2.81)	0.14(2.74)	0.13(3.16)
Interior Exhibition	Interior space to support users' activities	0.38(2.56)	0.03(2.77)	0.99(2.68)	0.69(2.79)

Space	Interior space to support building performances	0.35(2.47)	-0.09(2.72)	1.12(5.99)	0.33(2.93)
	Big sized exhibits' space	0.35(2.38)	0.59(2.45)	1(2.95)	0.71(2.65)
Material Planning	Material to support users' activities	0.35(2.45)	0.6(2.87)	0.95(2.53)	0.53(2.86)
	Material to support building performances	0.31(2.51)	0.52(2.90)	0.32(2.47)	0.12(2.86)
	Material to support a landmark	-0.15(2.71)	-0.15(3.14)	0.4(2.54)	0.38(2.93)
Misc. requirements	Manager's space	-0.25(2.53)	-0.72(2.46)	1(2.95)	0.89(2.32)
	Small café area	-0.20(2.85)	-0.28(2.33)	1.1(2.80)	0.89(2.44)

Appendix Table 8 Novelty and appropriateness scores for thirteen evaluation factors, consensual assessment in remote collaboration (p-value>0.05)