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Co-design in virtual environments with 3D scanned childcare rooms in social virtual reality

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Abstract

This research proposes a virtual environment (VE) for co-designing in early childhood education and care settings using a social VR platform with 3D-scanned childcare rooms. Co-design workshops were analyzed focusing on perceived presence and experience and workshop outcomes. The results indicate a high level of presence in the VE, with unique advantages like facilitating 3D prototyping. However, challenges such as unbalanced prototyping tools distribution were also noted. The study highlights the potential of VEs with 3D scanned rooms in co-design.

Keywords: co-design, virtual reality (VR), digital twin, virtual prototyping, design methods

1. Introduction

Early Childhood Education and Care (ECEC) plays a significant role in forming an individual's identity. The quality of ECEC is defined as *"all the features of children's environments and experiences that are assumed to benefit their well-being"* (Oecd, 2015). Designing for improving the ECEC quality requires a deep understanding of the context of ECEC and the context of each childcare facility. Co-design is a promising approach that facilitates designers and co-designers, people not trained in formal design education, to work together in design activities (Sanders and Stappers, 2012). Co-design focuses on the actual practice and experience of co-designers (Steen, 2013) by using co-designers' contextual information collected by probes and co-designers' value elicited by generative tools (Sanders and Stappers, 2012). Co-design methods are generally based on face-to-face communication, and the designers and co-designers proceed with the design process by prototyping physical objects together. In addition, site visits and observation are powerful tools for understanding childcare settings. However, the presence of outsiders, namely designers, in childcare facilities interrupts daily childcare. Thus, on-site observation and discussion have been challenging, while they are crucial for increasing understanding of the childcare context.

The recent development of information and communication technology (ICT) triggered the current trend of using users' data as materials for user research (Bertoni, 2020). The latest technology also allows the creation of a precise digital twin, a dynamic virtual model that reflects the real-time state of physical products or systems (Grieves and Vickers, 2017; Kritzinger et al., 2018; Lyu et al., 2022). Digital twins of environments can be experienced by head mount displays (HMD). Since HMD and virtual reality (VR) can provide a sense of presence in digital twins, 360-degree pictures/movies are used in educational contexts (Hwang et al., 2022).

In the field of design research, professional designers are supported by VR tools in user research (Georgiev et al., 2023) and idea generation (Dorta et al., 2016), and VR for users is mainly limited to the contexts of user tests (Maurya et al., 2019). VR tools have also been developed to support collaborative design activities by professionals (Koutsabasis et al., 2012) and by both users and designers (Mei et al., 2021). The specialized software focuses on a particular phase of design, such as prototyping, and prototyping abilities are often limited to the selection of pre-defined options (Mei et al., 2021). Whereas immersive tools were developed for exploring and sketching without HMDs (Dorta et al., 2019), immersive prototyping with HMD by co-designers is still in the infant stage.

On the other hand, in broader societal contexts, users of VR are now no longer limited to experts since the rise of consumer HMDs has been popularizing social virtual reality (social VR), a 3D virtual environment with multiple users interacting through HMD (Freeman et al., 2020). Social VR offers a virtual environment (VE) where people interact with others through the bodies of virtual avatars (Roquet, 2023). Avatars afford conveying non-verbal communication, which is defined as the behavior of the face, body, or voice minus the linguistic content (Hall et al., 2019). Social VRs provide platforms to use nonverbal communication more effectively and flexibly in social VR than in traditional cooperative virtual environments (Maloney et al., 2020). Users' body movements in social VR, which is represented by avatars' movements, are similar to those in the real world (Freeman et al., 2022; Maloney et al., 2020). A gesture is a key communication tool as well as a voice in the current commercial social VR platforms (Freeman et al., 2020). In addition, some social VR platforms allow users to freely draw and create 3D objects, which is a crucial design step. Social VR users collaborate and create 3D objects within social VR platforms on a routine basis (Nem and Bredikhina, 2023)

In sum, social VR platforms could provide VE to host collaborative design activities, namely co-design, from problem identification to prototyping. We propose a virtual environment (VE) for co-designing ECEC quality improvement with a social VR function and digital twins of the users' context. Although digital twins are ideally dynamic representations of the real world, static 3D scanned data of a childcare room is considered digital twins for the first step of the research project. This research conducted co-design workshops with eight ECEC staff working at a childcare facility in Japan. The workshops were evaluated by qualitatively analyzing researchers' observations of the workshops, workshops' outcomes, questionnaires on perceived presence, and post-workshop interviews with ECEC staff. This study aims at reporting the potential and challenges of social VR and 3D scanned rooms for co-design in childcare.

2. Method

2.1. The virtual environment having a 3D scan of a childcare room in a social VR

This study uses a commercially available social VR platform rather than developing an original social VR. Original social VR platforms generally have higher flexibility in creating a world and interaction in social VR. However, a commercial social VR platform was chosen because findings on workshops in commercial social VR would become applicable to broader groups of designers and researchers. Commercial social VR has several options, such as VRChat, cluster, and NeosVR, with different characteristics depending on the platform. We created a list of required functions for co-designing in social VR, which were the ability to put 3D scanned files in a VE, the ability to collaborate with several people, the ability to save VEs after workshops, and the ability to create prototypes in VEs. NeosVR was chosen because, in early 2023, NeosVR only fits the requirement.

The VE used for the experiment has three areas: ***lobby***, ***as-is room***, and ***empty room***, as shown in Figure 1-left. The ***lobby*** has a mirror allowing participants to see their avatars and a workshop timetable. A target childcare room was 3D scanned with a designated camera. The camera could provide high resolution scans but still lacks image consistency in details (Figure 1-right). The ***as-is room*** shows the 3D scan of the room without any change, and the ***empty room*** shows the 3D scan of the room with the removal of movable objects. The target childcare room is used for joint and age-specific childcare. Age-specific childcare is provided during regular childcare hours, from 9 a.m. to 5 p.m., and joint childcare is conducted outside the standard hours. The childcare room was selected to increase the number of childcare staff having daily childcare experiences in the room.

Note and prototyping tools and an object copy function were provided in the VE. As for taking notes, users cannot note memos on sticky notes in the social VR platform, although sticky notes are typical workshop materials in in-person workshops. Thus, voice recording functions were used for taking notes during workshops. The facilitator or researcher recorded audio notes by uttering a summary of the discussion. Symbolic objects, O and X objects, were also prepared to represent summaries of participants" opinions. O objects show positive opinions, while X objects show negative opinions. See the workshop timeline in Table 1 for more details. Prototyping was conducted by using the 3D pen tool to create three-dimensional prototypes and by scaling and rearranging the size of blocks of basic shapes prepared in advance. The object copy function could copy all data in the ***as-is room*** to the ***empty room***.

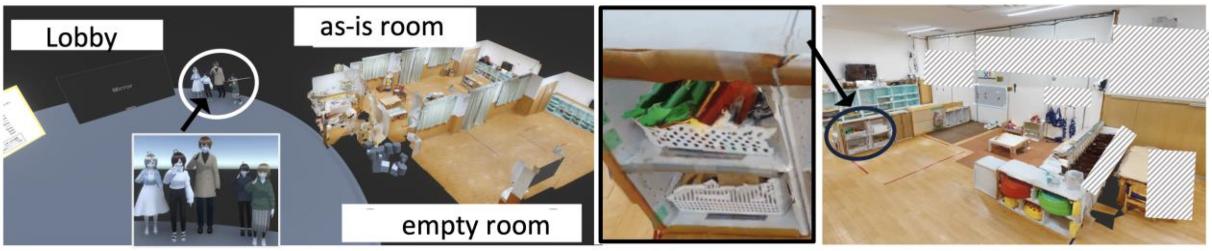

Figure 1. (left) The designed VE having 3D scan of a childcare room and avatars; (right) inside of as-is room and enlarged view of a shelf

2.2. Overview of workshop program

Four workshops were conducted to explore to what extent participants could discuss for improving the quality of childcare in the social VR space with digital twins of the childcare room. Each experiment invited two childcare workers who had daily childcare experience in the room, and eight staff (seven females and 1 male, in their 20s to 30s) participated in total. The eight participants had worked in the rooms mainly during joint care hours because they were in charge of different childcare rooms. The joint care is conducted from 6 to 9 a.m. and 5 p.m. to 8 p.m. In addition to the childcare staff, a facilitator team participated in each experiment. The facilitator team comprises two designers, one researcher, and one support staff to help with VR operations. The designers have fluent experience in co-design workshops, and one of the designers facilitated all workshops. The VR support staff was a graduate student with extensive experience using *NeosVR* and supported the operation of all participants, including researchers and designers. The childcare staff was also supported to use social VR by other researchers than the facilitator team, who stayed in a collocated location with the participants. The childcare staff joined VE from their childcare facilities after childcare work while the facilitator team did it from their home. The two designers did not visit the childcare facility or meet the childcare staff before the workshops.

Table 1. Workshop timeline

Task: at *used area*	Time [min.]	Task detail
Introduction: at *lobby*	5	Sharing the purpose of the workshop and self-introduction
Exploring: at *as-is room*	30	**Reflection**: The ECEC staff walked around the room and introduced their daily activities, putting O (I like) and X (There is something...) objects.
	10	**Deepen the issue**: Each ECEC staff chose a critical issue and then dug deeper to find out why ECEC staff thinks so. When having dug more profound, the facilitator tried to look at the regulations, systems, and perceptions influencing the ECEC staff's desires.
Prototyping: at *empty room*	20	**Prototyping**: Based on the findings of the explore phase, generate prototypes that are needed to make the room an ideal environment.
	5	**Experience a generated idea**: Experience the room with the generated prototype

In the VE, everyone wore avatars. The researcher chose the childcare workers' avatars, while the facilitator team could choose their avatars. The childcare staff avatars had a 3D pen in their dominant

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hand and could freely draw 3D objects in VE. The childcare staff was allowed to conduct all operations of the avatar. Their controller controlled body movement and facial orientation with controllers' joysticks, while changes in viewpoint height (sitting and standing) reflected the actual posture within the real space. The facilitator prompted changes in viewpoint during prototyping.
Table 1 shows the timetable of the experiment. The workshop consisted of two phases: exploring opportunities in the childcare room and generating ideas for the opportunities. Multiple small breaks were taken to avoid fatigue and cyber-sickness. In the first phase, The ***as-is room*** was used to explore issues, and the ***empty room*** was used for prototyping ideas. The ***empty room*** aimed to provide enough space for 3D prototyping and to unleash the fixation due to the existing room.

2.3. Assessment and analysis

The workshops were assessed by four criteria: questionnaire on presence, post-experiment interview, design outcomes, and observation during the workshops. The igroup presence questionnaire (IPQ) measured presence on four subscales of presence with 14 questions on a seven-point Likert scale (Regenbrecht and Schubert, 2002). IPQ was used because it provides examples of Japanese translations. The questions consist of one question on *presence*, five on *spatial presence*, four on *involvement*, and four on *experience realness*. For example, the question on presence is, *"In the computer-generated world, I had a sense of being there,"* and the question on spatial presence is, *"Somehow, I felt that the virtual world surrounded me."*. The mean value and standard deviation were calculated on childcare staff (n=8) and facilitators(n = 5) because statistical tests could not be done due to the limited number of participants.
The post-experiment interviews were conducted in a semi-structured format, asking about perceptions of the realness and presence of the VE and their overall experiences of designing in the VE. The interviews with each participant lasted 15 minutes. All recordings were transcribed, and short summaries were appended to each chunk of meaning. Summary statements were classified based on content similarity. Workshop outcomes were assessed by counting the number of created prototype objects, objects of O, X, and voice notes generated during the workshops. The recordings of the workshops were transcribed, and raised issues and ideas in the childcare room were counted by evaluating the workshop transcripts. The video recordings were analyzed to observe the participants' behavior during the workshops. These qualitative analyses were performed by one author and confirmed by another.

3. Result

3.1. Workshops' outcome

Four experiments successfully delivered workshop outcomes, as shown in Table 2. The participants' years of experience in childcare are also shown in Table 2, and from P1 to P8 will be used as an identifier for citing interview quotes in the following sections. The facilitator team placed voice memos and O and X objects and drew most prototypes with the 3D pen. The participants in workshop three did not have childcare experience in the room having the furniture layout when the space was 3D-scanned, which apparently limited their participation in the workshop. Workshop three was repeatedly interrupted by the poor internet, while the other three workshops did not suffer from the network problem.

Table 2. The participants profiles and workshops' outcome

	Criteria	Workshop 1	Workshop 2	Workshop 3	Workshop 4
Demographic Information	Participants' experience in childcare	P1: 1 year P2: 3 years	P3: 4 years P4: 13 years	P5: 2 months P6: 2 months	P7: 7 years P8: 8 years
Exploring Step	Object O: Like	2	3	3	4
	Object X: not like	5	2	2	5
	Voice Note	11	11	7	6
	Raised issues	4	5	2	4
Prototyping Step	Ideas	1	2	2	4

In the explore phase, O and X objects were placed in the ***as-is room*** to discuss opportunities and issues in the childcare room, as shown in Figure 2-left. The number of voice notes roughly represents to what

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extent the discussion explored issues in Table 2. Workshop four had more O and X objects than other workshops. The issues raised in each workshop were later counted by an author based on the transcript of each session, and 11 issues were raised in total. An example of the raised issue was *"A child concentrating on playing with a picture book or blocks is interrupted here."* All issues had links to a particular area in the 3D-scanned room. 3D objects were generated in the prototyping phase, as shown in Figure 2-right. A partition was set up between the eating and playing areas. The lower part of the partition was a shelf storing toys, and the upper part was a curtain blocking a view. The number of ideas was counted by an author based on the transcript and the VR world of each session.

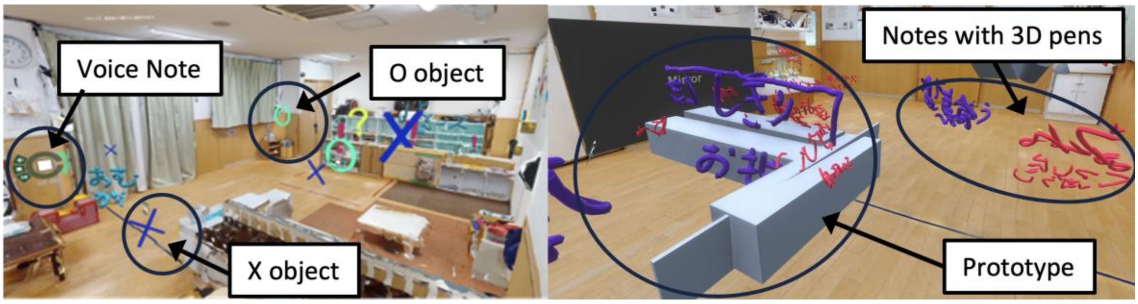

Figure 2. (left)The result of problem identification; (right) The result of prototyping

3.2. The participants' perception of presence

Table 3 shows the presence questionnaire results of both ECEC staff and facilitators. The results show means and standard deviations; values in parentheses are standard deviations. Presuming that the presence score of a workshop held in person at the childcare room is 7, the maximum value of the Likert scale, the childcare staff's presence score in the social VR is considered high. The post-experiment interview results support the questionnaire results. All participants made positive comments on their perceived presence, such as.

> *I think it's very accurately reproduced. [...]I felt like it was a view I always saw. [...] It's my usual room. I was able to recognize that place even more. [P2]*

The scores of the other three aspects are lower than the presence score and have larger standard deviation. The elements may have been influenced by the quality of the Internet and the quality of 3D scan data.
The interview asked what additional things would be good to be reproduced in the virtual world. The participants listed several aspects, such as children's behavior/movement, typical children's height, and sunlight in the room. Children's behavior/movement includes movement typical of their age and actual behavior in daily childcare.

Table 3. The results of questionnaires on presence

	Presence	Spatial presence	Involvement	Realness
Childcare Staffs	6.50(0.76)	5.33(1.77)	4.88(1.52)	4.09(1.78)
Facilitators	6.00(0.71)	4.46(1.86)	4.20(2.07)	3.55(1.32)

3.3. Perception of the participants on workshops in the VE

The post-experiment interview transcripts were categorized into the perception of having attended the workshops shown in Table 4 and the advantage of discussion in the social VR shown in Table 5. The count columns in Table 4 and Table 5 represent the number of participants who made the comment categorized into each code, with pros indicating the number of participants who commented positively while cons indicating the number of participants who made negative comments. The texts within square brackets represent the participants who made each comment. For example, P1 in Table 2 mentioned the quote having [P1] in Table 4 and 5. Four of the six impressions might be common to social VR, while two may be unique to the workshop in the world having a digital twin of the real room.
The difficulties in controlling avatars were the major issue for the participants manifested as the code *operation*. The participants could not move as fluently as they could in the real world and had limited,

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often no, ability to prototype with 3D pens. *Non-verbal communication* was also taken place without prior instruction by facilitator teams. Positive feedback mainly addresses gestures and nodding, which the participants recognized to some extent. Negative feedback mainly points out the inability to recognize expression and determine whether others are listening. *Cyber sickness* due to HMD was another major problem during the workshops, which half of the participants experienced. It limited the

Table 4. Impressions of participating in the workshop conducted at the VE

Code		**Definition** - *"Quote"*	Count
Common to workshops in VEs	Operation	**Impressions of moving around in VR space and manipulating prototypes** - *"It is a little difficult because I am not yet used to doing (prototyping) while talking."* [P7]	7 Pros:0, Cons: 7
	Non-verbal communica-tion	**Impression of non-verbal communication such as nodding and gestures by others** - *"In the metaverse, it is not possible to read facial expressions."* [P4]	6 Pros:4, Cons:6
	Cyber sickness	**Wearing a head-mounted display made for cyber chicness** -- *"I felt that I got sick by moving fast (inVE) even though my body is not moving."* [P1]	4 Pros:0, Cons: 4
	Avatar use	**Impressions of discussing with avatars without being able to see their faces** - *" If (avatar's) face were like the person, it would lead to have a more realistic conversation. I felt like it would be easier to talk to than a real person."* [P8].	4 Pros:1, Cons: 3
Unique to workshops in the VE having 3D scanned room	Size and distance	**Impressions about the size and distance of objects in the VR space** - *" When I want to see an object or get closer and reach out to, I feel an error where, somehow, I can't quite reach it."* [P2]	3 Pros:0, Cons: 3
	Movement and point of view	**Effects of experiencing a different viewing height (child, bird's eye view) from the normal adult's view** -- *"I moved the viewpoint with my manipulation, but it did not work the way I wanted it to. For example, the speed of movement."* [P7]	2 Pros:2, Cons: 0

Table 5. Advantages of the workshop in the VE

Code	**Definition** -- ***Example***	**Count**
The advantages of ***empty room***	**Advantage of discussing ideas in a "space from" that eliminates movable furniture** -- "*I was able to think broadly because there was nothing in the room. When (things) are placed in a room, I have the impression that ideas become narrower, as if you have to shift them around a little."* [P8]	5
Effect of prototyping	**Prototyping of 3D objects helps common understanding during discussions** -- *"Sometimes we don't know how others imagine things, but I thought it was easier to have a common understanding that this is how everyone feels when it is actually in front of us.*" [P2]	3
No need to physically move existing furniture	**A virtual space is convenient because there is no need to rearrange furniture during discussions** -- *It was easier to talk about than in reality, in that you can freely move (objects) around and listen to and discuss the opinions of various people."* [P8]	2
Imaginable childcare scene	**Discussions could be held while imagining oneself taking care of children in the recreated space** -- *"I could imagine more concretely than usual what it would be like to see children like this, or what the caregivers' behavior would be like."* [P2]	2
Effect of changing the viewing height	**Thinking from a perspective other than that of an adult helped me to think differently than I normally do** -- *"I had never tried to look at it from above. I haven't really thought about the child's perspective or the crawling gaze."* [P8]	2

participants' movement in social VR and sometimes made them remove their HMDs. Three participants mentioned that an avatar would be nice to have the face of an actual person rather than illustrations. One

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participant commented that it was less stressful to participate with an avatar than an in-person setup. The code *size and distance* address the difficulties of **feeling** size and distance in the VE. As the participants cared for children in the room, the mismatch between real and virtual made them feel uncomfortable in VE. Similarly, the participants felt wired when moving in VE because their avatar's movement speed did not fit their experience in the real world. The weirdness was also triggered by the difference in the eye level between real and virtual.
As shown in Table 5, five participants said the empty room successfully unleashed their fixation on the current room design. Two participants also commented that they felt they ideated too freely, which resulted in generating unfeasible ideas. 3D Prototyping in the VE was considered positive because it could provide boundary objects during discussion. However, it should also be noted one participant pointed out that the 3D objects were too vague to understand what they were because similar objects represented different ideas. For example, box shapes represented a shelf and a partition in a discussion. Prototyping in VE let the participants discuss without moving furniture in the actual room, which they usually did in the real room. Thanks to the 3D scanned models, the participants could imagine themselves doing children in the room. The easiness of changing eye level was also perceived positively in experiencing children's eye levels.

3.4. Noteworthy behavior during workshops

Figure 3 shows an excerpt of a transcribed discussion to visualize how prototyping and dialogue took place during workshops. We noted the intention of the utterance to clarify the meaning of the translated utterance, and the prototyping column shows that the facilitator team prototyped during the "yes" cells. Bold and underlined demonstrative pronouns in the utterances column visualized that the participants used demonstrative pronouns to designate locations in the VE. Although Figure 3 shows an example of the successful use of directive pronouns, some utterances could not specify the location as the speaker intended. Figure 3 also shows how dialog and prototyping moved the co-design process. After the childcare worker proposed an idea (row 1), the designer began to draw 3D objects. Figure 3 indicates that the conversation and the prototyping were taking place simultaneously. When the designer finished drawing, he mumbled, "Something like this? (row 3), the childcare worker responded by expressing her thoughts and ideas about the entry/exit (row 4). The facilitator's questioning (row 6) included the facilitator's interpretation of the childcare worker's opinion that preventing free access meant a door. The questioning further fleshed out the childcare worker's idea (row 7). The excerpt shows an example of 3D prototyping facilitated co-deign dialog by allowing discussion on the prototype. Ideas were gradually fleshed out, and the facilitator's interpretation of the childcare workers' words accelerated the fleshing out of the ideas.

<table>
<tr><th>Speaker</th><th>Intention of utterance</th><th>Utterance</th><th>Prototyping</th></tr>
<tr><td>P1</td><td>Proposition of idea</td><td>"If there is some kind of partition that is half the height of children and high enough that children can't jump over it."</td><td></td></tr>
<tr><td colspan="3">[omitted]</td><td>yes</td></tr>
<tr><td>F1</td><td>Question</td><td>"Something like <u>this</u>?"</td><td>yes</td></tr>
<tr><td rowspan="5">P1</td><td rowspan="5">Response and Shape idea</td><td rowspan="5">"In addition to that, it should allow children to look around when sitting but not let them jump over. And, leave one part of <u>that</u> (the partition) open so that children can go in and out. It should let children be able to look around even when they are sitting down (on the floor) to play."
"<u>That</u> is similar to what I imagined."
"It would be good to make it more three-dimensional than that line so that it can separate the space. If it is not thick enough, it will be free to go in and out."</td><td></td></tr>
<tr><td>yes</td></tr>
<tr><td></td></tr>
<tr><td>yes</td></tr>
<tr><td></td></tr>
<tr><td>F1</td><td>Response</td><td>"I see…"</td><td></td></tr>
<tr><td>F2</td><td>Question and Interpretation</td><td>"Do you imagine the place for going in and out like a door?"</td><td></td></tr>
<tr><td rowspan="4">P1</td><td rowspan="4">Shape idea</td><td rowspan="4">"If it were a door, children might slam them (e.g., their fingers) in it.
So…
<u>Here</u>. Well… You could (partially cut the partition and) open an entrance.
Partition continues to <u>this point</u>."</td><td>yes</td></tr>
<tr><td></td></tr>
<tr><td>yes</td></tr>
<tr><td></td></tr>
</table>

Figure 3. Excerpt of workshop 4 during the prototyping phase

4. Discussion

4.1. The potentials of in the VE with 3D scanned childcare room

The co-design workshops were conducted in the VE, where the results of the 3D scans of the existing childcare rooms were placed. Although the results of each workshop varied, the participants could identify multiple issues and generate new ideas for the childcare room in each workshop. Workshop three revealed two prerequisites for successfully co-design workshops in VE, namely a stable Internet and the participation of childcare staff having experience in the room at the time of 3D scanning. The results suggest that VE having a 3D scanned room has profound potential to foster co-design processes.

High perceived presence in the 3D scanned room at VE: The questionnaire and interview results show that the ***as-is room*** and ***empty room*** provided a high enough perceived presence although the 3D scan data was messy in magnified appearance, such as toys. Consequently, the ***as-is room*** afforded the discussion related to different areas in the 3D scanned room in the exploration phase. The participants used demonstrative pronouns to indicate specific areas under discussion. The dialog may have been similar to face-to-face workshops. In addition to sharing issues in the childcare room, the participants could discuss the background and causes of the problems and current operational practice. The interview also showed that experiencing different eye levels, i.e., children's eye level worked well in the workshops. It implies that the 3D-scanned room affords perspective-taking, as it has been reported in research using VR for empathy (Georgiev et al., 2023).

Using two spaces that do not coexist in reality: The workshop program using the ***as-is room*** and ***empty room*** is unique in VE. The ***as-is room*** allowed in-situ problem identification and the ***empty room*** unrestricted solution generation. Both rooms could not coexist in reality because they were the same room in different statuses. The use of two rooms was hardly achieved in in-person workshops. The participants commented on the benefit of the ***empty room*** in the interview without any specific questions about the effect of the ***empty room***. It speaks volumes about the impact of the ***empty room*** on co-designers. The ***empty room*** may play a significant role in co-design at social VR platforms because knowing co-designers' concrete practice may also lead to co-design participants' fixation on the current state. This study created the ***empty room*** by physically removing objects in the childcare room. Future research would be useful to test the effectiveness of a virtually created ***empty room*** from ***as-is room***.

3D prototyping in VE provided boundary objects: 3D prototypes were generated to roughly visualize ideas with 3D pens and pre-made 3D objects. The prototype enabled codesign in VE by providing a common understanding corresponding to what the real 3D objects do in in-person co-design. Whereas the facilitator team mostly conducted prototyping, prototyping on behalf of childcare staff even fostered discussion as shown in Figure 3. The proxy prototyping required having asked questions confirming the co-designers' intentions. Conversation and prototyping in parallel concretized ideas. The 3D prototyping can quickly generate prototypes perceived as real-size in VE. The proxy prototyping may have been a form of "joint inquiry and imagination," which is a key process in co-design (Steen, 2013).

Taking advantage of social VR's communication means: The facilitator team and childcare staff met for the first time at the workshops. The interview results and the excerpt show that participants could use non-verbal communication means in social VR. The facilitator teams also perceived that the participants communicated better than traditional online video conference systems. The interview results also show that the participants did not have weird feelings about collaborating with strangers. In addition, avatars may also be designed to foster creativity by changing their appearance, which reportedly increased the participants' performance in desktop virtual environments (Guegan et al., 2016). The influence of avatar appearances may be another interesting research topic.

4.2. The challenges of co-design in the VE with 3D scanned childcare room

Behaving in the VE is not the same as in the real world: The interview result and observation show that cybersickness due to HMD severely restricted participation and controlling avatar was also problematic for childcare workers. People who have been in social VR for a long time seem to overcome the problem, but childcare workers, i.e., co-designers, are not expected to be native to social VR. Thus, those problems should be addressed in future studies to maximize the value of co-design in VE. The

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interview also suggests that non-verbal communication means should be supported further. While participants used nodding unconsciously, gestures and facial expressions were not fully used in the current social VR platform. Although social VR generally affords a higher degree of non-verbal communication than video meetings, co-design may benefit from further development of non-verbal communication in social VR. This study's participants had never experienced HMDs and social VR before the experiment. Getting used to VR may solve some problems. It is the future research direction to explore how designers might support co-designers to behave in social VR for better co-designers' engagement to co-design in social VRs.

More accuracy of VE and avatars needed for higher perceived presence: The interview shows that participants felt a gap in the perceived body between real and VE. The interview implies the need for accurate reproduction of the physical environment and physical participants' bodies. The participants pointed out that slight differences in eye level and movement speed resulted in weirdness in VE. The careful setup of avatar height and moving speed may solve the issue. The result suggests that facilitators must pay attention to the configurations of participants' avatars. It also limited the participant's gesture, which conveyed the size of the participant's idea because the participant could not imagine the object's size indicated by her gesture. The problem may be unique to co-designing in VE having digital twins. Either technology development or workshop strategies should address the gap.

Co-design tools in social VRs: In this experiment, audio notes were used to keep records of dialog during discussion, aiming to fill the role of sticky notes and whiteboards in in-person workshops. However, the memos were not reviewed because it was necessary to pause the discussion conversation to check the contents of the voice memo. In a workshop within a real space, sticky notes and whiteboards are essential tools to facilitate discussion. Tools are needed to present the discussion processes so they can be easily checked during the workshops in social VRs.

Unbalanced tools distribution during Co-design: The facilitator team prototyped with 3D pens and objects on behalf of co-designers in this experiment. Although proxy prototyping fostered discussion as shown in Figure 3, it also faced challenges. One was the degree of fidelity of prototypes. The facilitator team had to discuss with other members and materialize prototypes simultaneously. Consequently, each object had low fidelity because the facilitator team could not spend much time drawing each object. However, the interview result shows that the low fidelity was linked to difficulties imagining the ideas. The low fidelity might have limited the prototypes' role as a common language. In addition, the equally shared use of tools is linked to a higher quality of collaboration at in-person design activities (Détienne et al., 2016). The unbalanced use of prototyping tools could also have mitigated the childcare staff's creativity.

What in reality to reproduce in VE for co-design: What, how, and to what extent to reproduce the physical room in the **as-is room** influenced co-design. The discussed issues in this study were linked to the area of the 3D scanned room because the ***as-is room*** only visualized the static environment of the childcare room. Future research should consider the effectiveness of visualizing human environments, such as the children's and childcare workers' movements. It is also interesting to develop a co-design method that enables discussion of issues that are not location-dependent, such as workplace rules.

5. Conclusion

This study proposed a co-design workshop at a VE having the 3D scan data of a childcare room in a commercial social VR platform, NeosVR. The experiments were conducted with eight childcare workers. The results show the VE could provide a high enough perceived presence to discuss challenges in and ideas for the childcare room. The interview with the participants also showed that workshops in the VE had advantages such as the use of the empty room for unleashing fixation to the current childcare room and 3D prototyping for providing boundary objects to co-design dialogs. The workshops in VE also faced challenges unique to social VR platforms such as control and cybersickness. Investigating ideal combination of real and VR activities in a series of co-design is an interesting direction of research. It should be noted that this study reports the result of a limited number of participants in a particular context, childcare, and that the VE's benefit could be greater when co-designing with participants without cybersickness. This study demonstrated the potential of VE for co-design and suggested research with a larger number of participants in diversified contexts is needed to generalize the findings.

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