An investigation of design in virtual reality across the variation of training degree and visual realism

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***Abstract*— "Research showed that immersive technologies can significantly improve the design process. However, it is important to consider the ease of implementation of solutions (*e.g.* price, simplicity). Therefore, the objective of this study was to analyze the uses of two types of virtual environments that are relatively simple to implement: a basic model of a room and its 3D scan. Participants made sketches using a virtual reality application, provided by the instructors, in each of the two different VR environments. The sketches are proposals to a furniture co-creation task. Results indicate a better co-creation process during the second session than during the first, which reveals that training is an important criterion in this case. Furthermore, co-creation is felt to be better in the case of the modeled place compared to the 3D scan. This result could be due to the presence of useless virtual objects that can cause a distraction to the participants. These results are discussed from an applicative standpoint.**

Keywords— immersive technologies, creativity, visual representation, immersion intensity

I. Introduction

This investigation belongs to a series of study dedicated to understanding the impact of immersive technologies on individuals having to sketch ideas of furniture to fit a specific space according to a need[1]. These individuals are in fact students that are potential future users of the place or future product designers. This study was carried out during a two-day innovative design course module with 21 students specialized in various fields (management, design, engineering, etc.).

A large body of research has established that in a User-Centered Design (UCD) approach of a building or its layout, immersive visualization can improve performance on several levels, including engagement and spatial representation [e.g. 1, 2]. The effectiveness of visualization in this context through diverse 3D technologies like a Cave Automated Virtual Environment (CAVE), a Head Mounted Display (HMD), a large hemispheric display and a conventional display have already been compared [3]. The results indicate that on almost all levels, the CAVE performs best (perceived quality of visual presentation, level of realism, ease of navigation, overall perceived suitability for making decisions and performing tasks on models). The HMD and the hemispherical display performed less than the CAVE, but overall, more effective than a conventional screen display when they are combined with the 3D adapted model. It should be noted that these technologies are very sophisticated equipment, especially the CAVE, can be very expensive to buy and install. Therefore, this can be a major obstacle to the use of these immersive technologies in a user-centered design approach in the furnishing industry. This observation led to investigate much cheaper visual supports like different types of images [4]. This research was conducted based on the lowest possible degree of interaction, immersion, cost and technology, through the use of drawings or pictures/photos as visual representations; they could be displayed either on a low-cost screen or simply printed on paper. Furthermore, it also constitutes the simplest design support affordable to almost everyone, including potential future occupants. At this stage, participants were not asked to sketch their ideas but rather to vocally explain them in terms of both space allocation and corresponding furnishing while looking at each of the four different visual representations of the rooms: (a) top-view; (b) sectional-view; (c) perspective view; (d) inspirational photo. This study revealed that even with simple plans of the rooms, the layout influences the way ideas are

[1] This study was partly funded by the European Commission through the INEDIT E.U. innovation project (Grant agreement N 869952).

Draft's authors - reference: Fleury, S., Dupont L., Chaniaud N., Tamazart S., Poussard B., Gorisse G., Richir S. "An investigation of design in virtual reality across the variation of training degree and visual realism" in 2022 IEEE 28th International Conference on Engineering, Technology and Innovation (ICE/ITMC) & 31st International Association For Management of Technology (IAMOT) Joint Conference, 19-23 June, Nancy, France, pp. 1–7.

generated [4]. Additionally, the ability to generate a mental representation of furnishing a specific space from a printed drawing is not within everyone's reach. Hence, it is assumed that immersive technologies would bring a more realistic 3D view facilitating sensemaking and common understanding among stakeholders [5].

In the present study, we wanted to continue this exploration of 3D spaces for layout and furniture design. The overall objective was to evaluate the relevancy of Virtual Reality (VR) sketching for participatory collaborative design of furniture, taking into account the type of virtual environment used (designed with 3D software or scanned) and the participants' training. The participants had to carry out sketching activities using HMD and while being immersed in a virtual environment that represents the place where they had to design the desired furniture. As [4], we wanted to analyze only conditions that are simple to implement in a real situation: participants were immersed in a 3D model of the place, and in a 3D scan realized with a smartphone (with Lidar). Due to the importance of the design tool's usability, when we want to involve non designers in a co-creation process, we also aim to explore the capability of novices to produce sketches in VR depending on their training. Design tools for non-designers have to be usable with a very short training. Thus, the feeling of the participants has been evaluated after one and two session in the present experiment to evaluate the training effect.

II. EXISTING THEORIES AND PREVIOUS WORK

A. User Centered Design and Participatory Design

Although it was first developed for software projects, UCD is nowadays popular within different sectors, such as: public services [6], health [7] or architecture [8]. Participatory design is a form of UCD that emphasizes the active role of users in the design process. While UCD ensures a good fit with expectations and needs, participatory design additionally promotes user engagement in projects and compliance to its outcomes [9]. Participatory design on the other hand raises questions about how to make design activities possible for users who do not have design skills. It is therefore necessary to imagine tools that are easy enough to use so that beginners can mobilize them without extensive training.

B. VR performance: creativity in the design process

It is generally accepted and widely demonstrated that sketching by hand, with or without digital media, is more conducive to the discovery of new concepts than working with a keyboard and mouse [e.g. 10]. [11] have conducted a study on both creativity and communicability of ideas (their capacity to be understood by partners) associated with different sketching tools. In their study, participants were asked to imagine improvements that can be added to an umbrella so that it would also be useful when it is not raining. They had to sketch as many ideas as they could within 15 minutes. They performed the task using each of the following tools: paper/pencil, Time2Sketch software (a virtual reality sketching tool prototype), Google Blocks and Solidworks. Results indicate that participants generated on average more ideas using paper/pencil or Time2Sketch than with Google Blocks or SolidWork. In fact, they generated more ideas with the freehand sketching tools allowing natural gestures. Moreover, Time2Sketch surpasses the other three conditions in terms of user experience. This is highly likely due to the stimulating nature of V R and the freehand use.

[12] explored differences in designers' cognition and creativity related to the use of a 2D or immersive VR design tools. Ten fashion designers participated, half of them used Photoshop CS6 with a digital pen, while the other half used an immersive 3D drawing tool (Google Tilt Brush). The objective of the participants was to draw a dress in 20 seconds and then in 30 seconds. In this experiment, participants performed better from a creativity standpoint using VR devices.

In the study of [13], participants were asked to sketch a wearable technological object with the properties of a smartphone, and which is not a smartwatch. In one condition, they had to do this in an immersive 3D sketching environment, while in the other condition, they had to make their sketches on paper. Results indicate that participants were more creative with VR than with paper. According to the authors, the VR tool tends to induce a state of flow which is beneficial to creativity.

In the study of [14], participants were asked to design a chair, either in VR or with Computer-Aided Design (CAD) software using a keyboard and a mouse. By observing the participants' productions, authors have noted that in CAD condition, the modelled chairs were simplistic. Many of them looked like the most minimalistic possible representation of a chair, *i.e.* four legs and a straight backrest. This suggests that participants, due to an unsuitable use of the tool, considered the task completed as soon as their 3D model resembled a chair. However, the models made by the group of participants using VR were more original in shape, and also more complex. It seems that with the immersive tool, participants were more involved in the task, and continued working to add extra elements even when their production resembled a chair.

To sum up, VR tools are identified for creative sketching as superior to paper [13], touchscreen tablets [15], graphic tablets [12] and CAD software with Keyboard and mouse [14]. Even within VR tools, freehand sketching software appears superior for creativity compared to a shape volume tool [11].

C. Visual Representation

The construction industry has embraced the use of Building Information Modeling (BIM) to communicate about projects between colleagues and partners, but also with users (future occupants).

There are already examples of virtual environment applications in the construction sector:

- Immersive virtual environment engaging future occupants in the building design process by delivering a sense of presence while integrating pre-construction mock-ups and BIM models. This app allows evaluating alternative design options in the building model in a timely and cost-efficient approach [16];
- Immersive virtual environment for evaluating future occupants' lighting preferences through virtual scenes allowing to control of the blinds and artificial lights in the virtual environment [17].

The idea behind this work is that for certain design activities, immersing designers in a realistic environment, *i.e.* one that resembles reality as closely as possible, would be a facilitating element to all stakeholders involved in the process.

D. Virtual environment and presence

When exploring the field of VR, we often encounter some key concepts that describe the experience inside a virtual environment. One main concept that we often come across is "the sense of presence" [18-20]. [21] consider three forms of presence:

- Self-presence, related to the perception of one's own body and identity,
- Social presence, the illusion of being with others,
- Physical presence, the sense of being there, in cyberspace.

In the context of the present study, we are particularly interested in physical presence, also named "place illusion" [19] as our questioning is related to the types of visual representations to support the furnishing design. It is traditionally assumed that visually realistic environment provides a more believable virtual experience [22]. Previous studies explored this assumption by investigating the impact of textures realism on the sense of presence and immersion [23]. They demonstrated that consistency between realism and virtual environments elements contributes to the sense of spatial presence.

According to [24], spatial immersion reflects the degree to which a participant perceives the virtual environment as a real one and contributes to the sense of presence [25]. The higher the immersion, the more likely users will feel a sense of presence and will perceive the mediated environment as a plausible space [26].

E. Hypotheses

Both CAD and 3D scan could be used as a simple, yet efficient, way to create an immersive virtual environment based on a real place. The rendering of these two methods is different, CAD leads to simplify the environment by focusing more on volumes, but without details (objects that are lying around, lamps, electrical ducts, etc.), while 3D scan includes these various objects, but will also have visual artifacts, induced by technical limitations. We hypothesized that these two methods influence differently the sense of presence (H1) and that this difference could translate into a change in the way co-creation takes place (H2). Finally, we hypothesized that training participants to use VR tools (Time2Sketch) leads to a better collaboration in co-creation situations (H3).

III. METHODOLOGY

A. Context and Purpose

Although many studies unveiled the effectiveness of immersive technologies in improving project visualization and participant engagement [1, 2], CAVEs are not so common within industrial companies, especially SMEs, due to their cost. To enable most designers, particularly in the construction and furnishing sectors, to adopt a more user-centered and participatory approach, it is necessary to provide them with solutions that are usable and affordable. A previous study focused on the use of low-tech means like printed or displayed drawings and photos [4].

The present investigation was conducted as part of a project intended to develop and experiment innovative design tools usable by both designers and by non-designers. It aims to evaluate the relevancy of VR as a design tool in a product design project, using simple CAD model of environment or 3D scan.

B. Sample

A total of 21 students from different fields of study (business, design, marketing, engineering) participated to the experiment. There were 9 men and 13 women, the oldest was 27 years old while the youngest was 21 years old for an average age of 23.39 years (*SD*=2.43). Among them, 17 respondents declared that they were novices in the use of VR; 11 had previous experience with CAD and 12 were familiar with design activities. The experiment took place on October 4 and 5, 2021 at Lorraine Fab Living Lab® platform and in the nearby third place dedicated to the cultural industry, Nancy, France.

C. Protocol

The protocol was based on the three first steps of the innovative design process described by [27]: brainstorming, 3D scanning of the room and VR sketching.

Three groups of seven participants were created and each group had to co-create a furniture layout for a specific room. They had to sign a consent form to take part in the experiment. In a first step, each group was asked to carry out fifteen minutes of brainstorming to generate ideas of furniture and constraints.

Second, they were immersed using HMD in a virtual version of the room to be furnished. Some groups were immersed in a simple CAD and others were immersed in a smartphone-made 3D scan (see Figure 1). The CAD environment was a simple square room with two windows and basic textures on the walls and floor (NB: It was possible to see the neighborhood also reproduced in the CAD environment). The scan version was less clean, but showed some additional details like a heater, electrical outlets, the emergency exit block above the door or the moldings of a former fireplace. None of the participants were able to go to the real room before the experiment.

They had two hours and a half to sketch their ideas in the virtual environment using a sketching VR software. At the end of this phase, the participants had to perform the same activities (brainstorming and sketching in VR), but the groups in the CAD condition switched to the 3D scan condition and conversely. The order of exposure was balanced between groups. We compared the results of phase 1 (occurred during day 1) and phase 2 (occurred during day 2) to analyze the training effect. We named this variable "*phase*" in the analysis and in the results' section.

The VR sketching task was conducted with six HMD (HTC Vive and Oculus Quest) with an external screen to display the content of the virtual environment allowing other members of the group to visualize the 3D sketching process (see Figure 2). Each group had two HMD during the experiment, the two types of HMD were balanced in the two experimental conditions. All the participants were involved in the activity by commenting and sharing ideas when not in VR, and all the participants had to spend time in VR. Time2Sketch was a laboratory prototype previously mobilized in published research [e.g. 11]. This software

allows participants to be immersed in a 3D scanned virtual environment and to use 3D sketching tools. Users can choose the size and color of the brush to draw around them, teleport, move and resize their sketches and erase their work or parts of the scan they want to remove.

Fig. 1. The two different environments: CAD (left) and 3D scan (right)

Fig. 2. During the experiment, each group had to sketch their ideas in VR

Two questionnaires were completed by the participants during the experiment:

- Igroup Presence Questionnaire (IPQ), measuring *spatial presence* (the feeling of being present in the virtual environment), *involvement* (psychological state experienced because of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events), experienced *realism* (how real the virtual environment seemed) and *general presence* (aggregation of *spatial presence, involvement* and *realism*) [28].
- Co-creation questionnaire measuring 3 dimensions of collaboration: *cognitive* (cognitive substance of the work, the problem that is studied and the meanings individuals attach to it), *interactional* (the ways in which members' relationship with other weave the symbolic fabric that keeps the group together and gives rise to the emerging customary rules, rituals, expectations, standards, habits and artefact) and *emotional* (how members emotionally engage with the shared project and with its ideas, as well as with other members) [29]

D. Analysis Methods

In this experiment, we collected numerical Likert based data from questionnaires and qualitative software design results. Concerning numerical data (co-creation and IPQ questionnaires), analyses of variances, non-parametric tests and correlations were conducted to identify the links between variables and the differences depending on *environment* (CAD or 3D scan) and *phase* (1 and 2).

The design produced by the participants were twofold: those generated with a whiteboard and papers before and during the VR exposure and those composed with the VR tool. The transformation of the ideas between these two media has been classified into categories.

IV. Findings

A. Quantitative statistical analysis

Levene's tests have been carried out to check the homogeneity of variances for all the dimensions measured. It revealed acceptable homoscedasticity for *spatial presence* ($F(1)=.357$, $p=.554$), *involvement* ($F(1)=1.226$, $p=.275$), *realism* ($F(1)=1.291$, $p=.263$), *general* ($F(1)<.001$, $p=.981$), *emotional* ($F(1)=.715$, $p=.403$) and *interactional* ($F(1)=.962$, $p=.332$). However, homoscedasticity is not sufficient for *cognitive* ($F(1)=6.429$, $p=.015$). Thus, this variable is analyzed using non-parametric tests.

The inferential comparison of means between the two types of environments (CAD and 3D scan) and between the two phases were carried out using analyses of variances with repeated measures.

TABLE 1. Means (and standard deviation) of co-creation and IPQ dimensions depending on phase and environment

Variables	CAD Environment		3D scan Environment
	Phase 1	*Phase 2*	*Phase 1*
Cognitive	5.450(.438)	6.000(.508)	5.308(1.005)
Emotional	5.725(.501)	6.057(.824)	5.308(1.280)
Interactional	5.189(.994)	5.892(.656)	5.026(1.278)
Spatial Presence	4.300(.576)	4.457(.327)	4.569(.509)
Involvement	4.000(.720)	4.696(.722)	4.654(.582)
Realism	2.844(.981)	3.768(.762)	3.385(.496)
General Presence	4.375(.916)	5.143(1.512)	5.769(1.235)

Concerning the IPQ questionnaire, *environment* had no significant effect on *general presence* ($F(1)=1.995$, $MS=1.929$, $p=.174$), *spatial presence* ($F(1)=.005$, $MS<.001$, $p=.947$), *involvement* ($F(1)=.073$, $MS=.013$, $p=.790$) and *realism* ($F(1)=.376$, $MS=.121$, $p=.547$). Therefore, our first hypothesis (H1) about the effect of environment (CAD vs. 3D scan) on IPQ dimensions is not validated.

Phase had no significant effect on *general presence* ($F(1)=.213$, $MS=.206$, $p=.650$), *spatial presence* ($F(1)=1.454$, $MS=.300$, $p=.243$), and *involvement* ($F(1)=.810$, $MS=.149$, $p=.380$). Nevertheless, phase have a significant effect on *perceived realism* ($F(1)=4.682$, $MS=1.502$, $p=.043$) which tend to be higher on phase 2 compared to phase 1 (see Table 1).

Concerning the co-creation questionnaire, we observed a trend *environment* on *emotional* ($F(1)=3.093$, $MS=.915$, $p=.095$) and a significant effect on *interactional* ($F(1)=4.364$, $MS=1.720$, $p=.050$). Wilcoxon non-parametric test revealed non-significant effect of *environment* on *cognitive* ($W=276.5$, $p=.272$). Means tend to be higher in the CAD condition compared to the 3D scan condition for *emotional* and *interactional* (see Table 1), which is in line with our second hypothesis (H2). The *phase* variable had a significant effect on *emotional* ($F(1)=10.556$, $MS=3.123$, $p=.004$) and *interactional* ($F(1)=11.015$, $MS=4.342$, $p=.004$). Wilcoxon non-parametric test revealed significant effect of *phase* on *cognitive* ($W=142$, $p=.031$). Phase 2 tend to be higher than phase 1 for *emotional, interactional* and *cognitive* dimensions (see Table 1), which is totally in line with H3.

Table 2 shows the results of Pearson's correlations between co-creation dimensions and IPQ dimensions. No correlation is significant except three tendencies: between *cognitive* and *realism* (p=.076), between *cognitive* and *general* (p=.063) and between *interactional* and *realism* (p=.069).

TABLE 2. PEARSON'S CORRELATIONS BETWEEN THE CO-CREATION DIMENSIONS AND IPQ DIMENSIONS

	Cognitive	**Emotional**	**Interactional**
Spatial Presence	r=-.111 p=.479	r=-.208 p=.181	r=-.218 p=.161
Involvement	r=.178 p=.253	r=.107 p=.495	r=.171 p=.272
Realism	r=.274 p=.076	r=.154 p=.326	r=.280 p=.069
General Presence	r=.286 p=.063	r=.068 p=.665	r=.144 p=.356

B. Qualitative design production and feedback analysis

On Figure 3, we can see 3 productions in which the first step was a sketch in perspective on the whiteboard, and the second step was the equivalent 3D representation in VR. It should be noted that a group of participants who sketched a circular shelves had the idea, when immersed in the 3D scan, to incorporate this piece of furniture in the former location of the fireplace. We also see that the participants perceived better the spaces and adapted the position of the furniture.

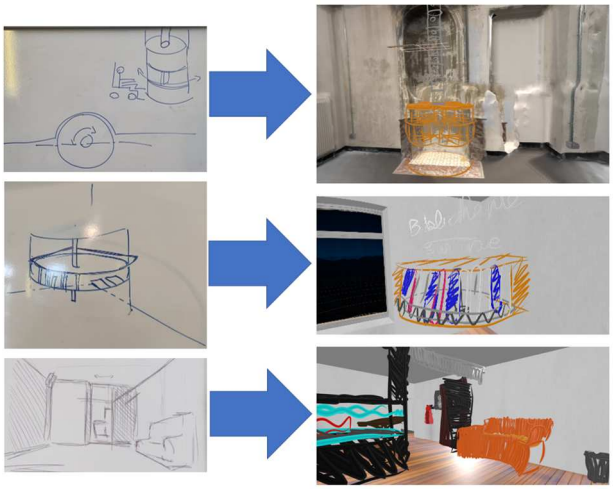

Fig. 3. Direct copy of the initial idea

On Figure 4, we can see two productions in which the first step consisted in simple representations of space layouts without furniture, and the second step was 3D representations of all the furniture in the right place.

On Figure 5, a group of participants designed three ideas on the whiteboard: a desk fixed in a corner of the room, with table legs, adjustable in height, with incorporated elements (flexible lamp for example). In VR, this group merged these three desks in one 3D sketch with all these properties.

Figure 6 shows two groups who improved their idea in VR. We can see that the VR sofa have a lamp with a vegetal form and a trashcan, and the chair shape was improved, and a plant was added.

On Figure 7, we can see the productions of a group who used three media in parallel: paper, whiteboard and VR. The consequence is that the ideas in VR and physical mediums were different and not the result of any transformation.

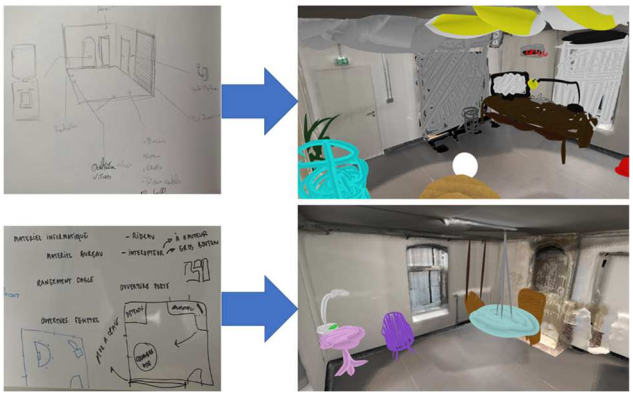

Fig. 4. 3D representations of simple plans

The results did not allow to show an effect of virtual environment (CAD or 3D scan) or training (phase 1 or 2) in inducing any specific type of transformation.

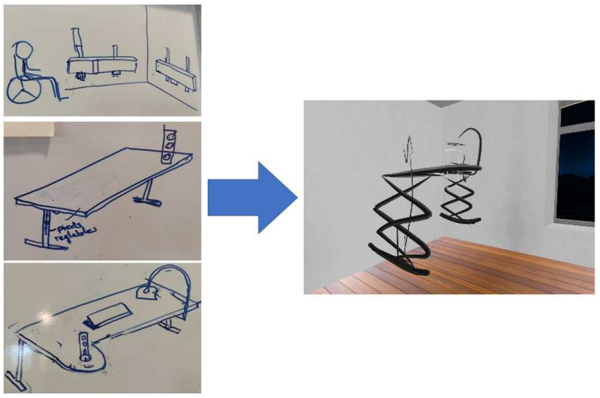

Fig. 5. Fusion of ideas

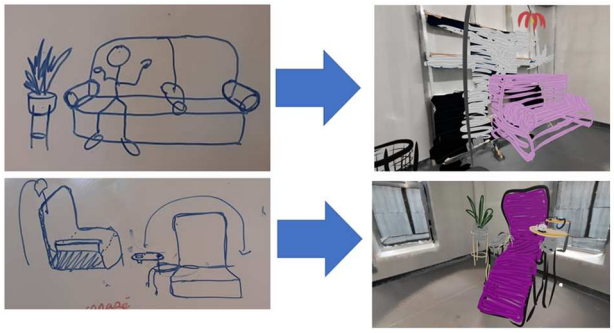

Fig. 6. Improvement of the initial idea

V. DISCUSSION AND CONCLUSION

The objective of the present study was to explore the potential contribution of VR sketching tools for non-designers working on layout and furniture design. We decided to conduct this study based on conditions that are easily usable in a real project, thanks to CAD models or 3D scanned environments. We also wanted to consider the impact of training on participants' productions.

The first hypothesis of the study was that CAD and scanned environment would impact the sense of presence as measured by the IPQ. This hypothesis was not validated by our results as we did not find any significant effect of the type

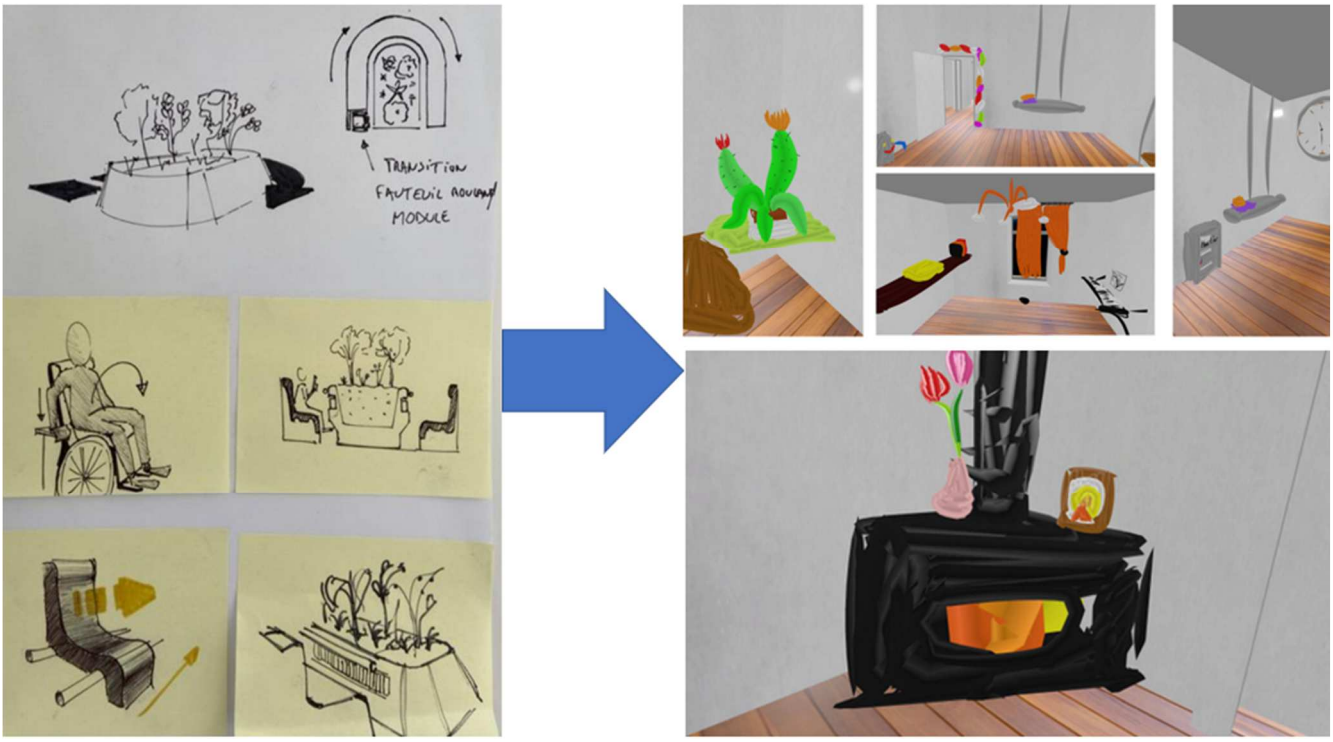

Fig. 7. Work on the two media in parallel

of environment on presence. The difference between the two environments was quite low in terms of realism. Furthermore, an important factor of spatial presence is the realism consistency between the elements of the environment [23]. Both conditions of our experiment presented consistent, yet not realistic, environments.

The second hypothesis was that the differences between the virtual environments would result in difference in the co-creation process measured by the co-creation questionnaire. The results are consistent with this hypothesis as *emotional* and *interactional* dimensions tend to be higher in CAD condition compared to 3D scan condition. It may seem surprising that H2 is validated while H1 is not, as both were supposed to be closely linked. Based on the ideas drawn by the participant, in the 3D scan condition, they were considering the various additional elements such as the moldings of the fireplace or the presence of a heater, which may have distracted them in their activity. Some participants spontaneously expressed that they preferred the CAD condition because they were in a clean environment “without unnecessary detail”.

The third hypothesis of the study was that trained participants in the use of VR tools would have performed better in terms of co-creation than non-trained participants. The results are totally in line with this hypothesis since the participants performed significantly better during the second phase of experiment regarding the three dimensions of co-creation: *cognitive*, *interactional* and *emotional*. As expected, participants who faced difficulties using the VR tool impacted the performance of the group. Even if the VR sketching tool was quite easily learnable, users were more comfortable after a little practice. They also tended to be better organized as a group for the brainstorming and the task sharing.

We also have seen a great diversity in the evolution of ideas from whiteboard to VR. The transition from one medium to another is not a simple transposition. Ideas continue to evolve throughout the process, and the virtual environment allows to better consider the context.

This study has the following limitations: (i) in the context of the covid19, the interactions between participants were somewhat constrained (distance, masks, etc.) and the implementation of the experiments required a sanitary protocol which can slow down a certain spontaneity associated with the act of creation and creativity; (ii) it was based on a specific project that has the advantage of being a real case, but with local specific characteristics hindering the generalization of the findings; (iii) the relatively small number of participants hinders any deeper the statistical analysis; (iv) no professional from the interior design/furniture sector was able to be involved in evaluating the students' work and the level of creativity; (v) the choice of a design tool cannot rely on the subjective feelin of users only, the speed and quality of creation are also important and have to be evaluated in future research.

From an applicative standpoint, depending on technologies available, the 3D scan can be the easiest and fastest way to immerse users in an environment resembling a specific real place [27]. However, capturing over-detailed rooms is not necessarily an advantage, and could even be a drawback in some cases. However, the instruction during the experiment did not emphasize the use of constraints (radiators, etc.) It is possible that with a different instruction concerning the constraints, the results would have been different.

Fig. 8. Illustration of different situation of visualization of VR content in real time

Future research should explore other types of devices that could be beneficial to asymmetric collaborations. For instance, immersive curved screen can stream VR content in real time to make it accessible to participants not equipped with VR headsets in a more immersive way (see figure 8). It would also be interesting to investigate the influence of the level of details on the results of following steps of design, such as CAD.

ACKNOWLEDGMENT

This study was partly funded by the European Commission through the INEDIT E.U. innovation project (Grant agreement N 869952). The authors thank Université de Lorraine and its resources: the Lorraine Fab Living Lab® platform, the teaching staff of ENSGSI and its Master 2 IDEAS, the scholarship provide by scientific Pole EMPP, the pictures. OK3 association, Octroi Nancy open community, and Agence Culturelle Régionale Grand Est, France.

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