Innovative Process for Furniture Design: Contributions of 3D Scan and Virtual Reality

Sylvain Fleury [1], Benjamin Poussard[1], Philippe Blanchard[2], Laurent Dupont[3], Peter Meister Broekema[4] and Simon Richir[1]

[1] Arts et Métiers Institute of Technology, LAMPA, HESAM Université, F-53810 Change, France, sylvain.fleury@ensam.eu, Benjamin.poussard@ensam.eu, simon.richir@ensam.eu
[2] Ecole Supérieure du Bois, LIMBHA,F- 44306 Nantes, France, philippe.blanchard@esb-campus.fr
[3] Université de Lorraine, ERPI, 54000 Nancy, France, l.dupont@univ-lorraine.fr
[4] Hanze University of Applied Sciences, Zernikeplein 7, 9747 AS Groningen, Netherlands, p.meister-broekema@pl.hanze.nl

Corresponding author: Sylvain Fleury, sylvain.fleury@ensam.eu

Abstract. Technological development offers new opportunities that could change design processes. The present study explores the possibilities of technologies like virtual reality and 3D scan in the furniture design process. For this purpose, a co-creation process with help of new technologies was carried out from initial ideation to 3D modelling. Each tool has been characterized in terms of user experience measured by questionnaire. This research validates a design process of furniture based on immersive technology and provide some recommendations for the implementation and improvement of this process.

Keywords: Furniture design; virtual reality; Computer Aided-Design; Innovation process; User eXperience.
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1 INTRODUCTION

In the product design process, the early stages tend to require tools promoting the designers' creativity, while the later stages aim to model the product more accurately, considering as many constraints as possible. Digital tools are very common in the latter phases in the form of Computer-Aided Design (CAD) software, but are much less present in the early stages of projects where pen, paper and sticky-notes are very adequate to represent ideas [1] because of the central role of hand movement in facilitating thinking and supporting the emergence of ideas [24]. Technological development offers new opportunities that could change design processes. For example, [12] presented a digital workflow for orthotic design in which the designer starts by scanning the relevant part of the patient's body before working on the 3D model and 3D printing the part. Virtual Reality (VR) appears to be a category of media that can be successfully inserted into the early stages of design. Otherwise, [19] has shown that a Cave Automatic Virtual Environment can immerse a designer in a virtual environment that is conducive to its activity.

With the present study we want to propose an innovative approach to design based on the use of 3D scanning and virtual reality. We also want to evaluate this approach in terms of user experience. For this purpose, a co-creation process with help of new technologies was carried out from initial ideation to 3D modelling.

2 PREVIOUS WORK

2.1 Start with Ideation

In the context of product design, ideation is the generation of ideas of solutions to a defined problem or needs [27]. Brainstorming is a famous method of collective ideation that is generally used with a group of 8-10 people. The aim of brainstorming is to collectively generate many ideas which are then selected and organized. In a brainstorming session, participants are invited to produce ideas on a given subject, initially focusing on quantity rather than quality. Brainstorming is usually conducted in groups, because the ideas of other participants are supposed to generate other ideas by association and inspiration. This process could also be characterized as group creativity. Research shows that groups tend to be more creative than individuals and although in general more diversity leads to more creativity, there are boundaries in group size and the multitude of disciplines [21]. Therefore, this type of brainstorming in more homogeneous groups suffers from some drawbacks. Overall, participants tend to give less original and fewer ideas when they perform the divergence stage in a group than when they are alone [10]. In a more homogenous group, they may inhibit ideas which they think they will not be understood by everyone [26]. The idea selection stage is also biased by social influences related to the collective nature of brainstorming [6]. One mean to avoid the detrimental effects of the monodisciplinary group is to start the brainstorming by an individual idea generation phase.

2.2 Three-dimensional Scan in the Design Process

3D scanning technologies are evolving rapidly, making new use cases possible thanks to improved rendering, simpler implementation and better accessibility of devices. In the field of design, 3D scanning is the subject of various initiatives. For example, [15] describe the scanning of body parts for the design of products that need to be shaped to fit the body, such as clothing, glasses, headphones, watches, oxygen masks, prostheses or vehicle seats. [23] want to speed up and simplify the process for certain specific design cases by proposing an algorithm to automatically go from the scan of an object to its representation in CAD. The effects of different types of virtual environments on the designer's creative performance have been evaluated [8], but to our knowledge, 3D scanning as a means of facilitating creative work in VR has not been studied.

2.3 Immersive Sketching

The activity of sketching is in some cases part of ideation as sketching can be the means of representing the ideas generated by the designers. On the other hand, sketching can be considered as a way of prototyping, which is therefore assumed to occur later in the design process. Sketching activity leads to generating more ideas than quick and dirty prototyping with tangible materials and leads to exploring more design spaces [2]. In recent years, many studies have focused on VR as a tool for creativity and it is generally considered to be beneficial for creative activities (e.g. [3], [29]). VR Sketching software would be more effective than tablet for creative sketching, as VR would support more flow and task motivation of the users [18]. VR is also superior to pen and paper for creative sketching because it leads to a satisfying level of efficiency, effectiveness, ease of use and enjoyment [28] and because it generates more extension of solution space, enhancement of idea transformation and inducement to a more holistic design approach for idea generation [30]. More details have been provided on the determinants of creative performance in VR by [9]: It appears that the stimulating nature of the tool (linked to the novelty) is important, and that cybersickness, which is specific to VR, can hinder creative performance.

2.4 Three-dimensional Modelling

CAD is a stage that should ideally take place at a moment in the design process when the main ideas have already been generated in detailed, as CAD software are not effective for creativity [11]. With a CAD software, participants tend to focus on the accuracy of the representation, to the detriment of thinking about the concepts [17]. [1] provide a list of reasons why CAD software are not adequate to support the early conceptual design stages. They indicate that CAD leads to poor designs in the early stages, that it is impossible to explore many concepts quickly and that designers are distracted by technical issues and software usage issues rather than by the concepts. The functional capabilities of CAD tools limit the possible solutions. These functions are numerous, but not always sufficient to represent everything that designers can imagine. Actually, designers may even limit their imagination, not only to what is feasible with the software, but to what is easy to represent [22]. The more detailed the CAD model becomes during the project, the more there is a disincentive to make significant changes [22]. There is therefore both an early fixation of ideas and an inertia of concepts that become frozen as they become more detailed. However, in the advanced phases of the project, CAD allows for improved visualization and communication of ideas within the teams [22].

2.5 Visualization in Virtual Reality

It was mentioned that CAD software is not relevant for creative tasks. Therefore, a creative iteration aiming at imagining improvements and corrections on the 3D model should rather be done in VR than with the CAD software. VR is a media that promotes spatial inspection behaviours [30], which consist of changing one's point of view by rotating around the object in order to observe it in a general or specific way. This frequent change of viewpoint is considered a key element of design as it would lead to an increase in idea transformation, the designer identifies more elements to improve, and it also leads to a more holistic approach to design [4].

2.6 Objectives of the Study

[20] discussed some specificities of a "living lab" approach to the furniture design. In particular, they mentioned the favourable role that the use of immersive technologies could have in facilitating co-creation process of furniture design.

The objective of the present study was to propose an innovative process for furniture design based on the integration of 3D scanning and VR sketching technologies. To provide a critical view of this process, we also aimed to test it in a controlled way, with evaluation of the tools in terms of user experience in order to identify possible "pain points", as well as specific feedback to lead to recommendations for improvement.

3 METHOD

3.1 Participants

The participants in this study were 17 engineering school students (14 males et 3 females) specialized in wood engineering. The youngest was 20 years old and the oldest 22 years old with an average age of 21.1 (Standard Deviation = .412). None of them were used to use VR tools to make sketches.

3.2 Measures

The user experience associated with the use of the tools during the 3D scanning, VR sketching, 3D modelling and visualization and correction phases was again evaluated by means of a widely used questionnaire named *AttrakDiff* [14]. This questionnaire consists of 28 items for which participants respond on a 7-points Likert scale. These items measure the following dimensions:

- *Pragmatic qualities* that are usefulness and usability, what will support the achievement of the objectives (the clarity of the device, its predictability, *etc*);
- *Hedonic qualities* refer to the capacity of the product to give pleasure to the user;
- *Identification*, ability to provide him popularity, to connect him to others;
- *Stimulation*, the ability of the system to stimulate the user, to give him a sense of control;
- *Attractiveness* is the combination of pragmatic and hedonic qualities to arrive at an overall appreciation derived from perceived quality.

3.3 Procedure and Material

After signing a consent form, participants began a two-week furniture design process and worked 4 hour a day. The participants were asked to design and model furniture that would replace the existing one in a meal and coffee area of their campus. Three groups were formed, consisting of 6, 6 and 5 students. Each group had to work on the design of furniture for a specific area of the kitchen. The five stages of the process are schematized on figure 1.

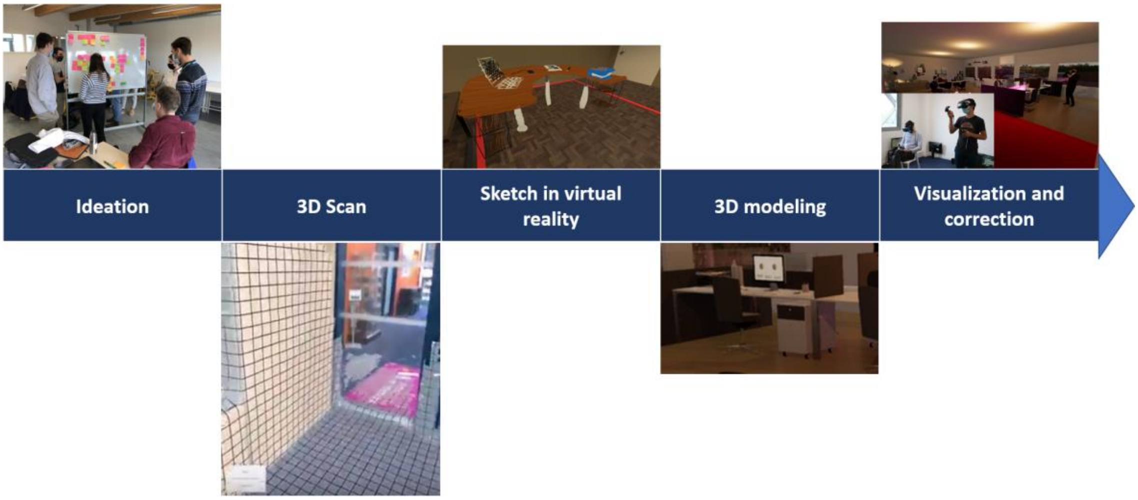

Figure 1: Schematic representation of the design phases carried out by the participants.

3.3.1. Ideation

After visiting the kitchen and taking pictures of it (see Figure 2), each group of participants carried out a brainstorming about the features that the future furniture in their area should have. It began with 15 minutes of warm-up activity, then 15 minutes of individual generation of ideas on sticky notes, to avoid negative effects of groups [26], and finally 30 minutes for sharing their ideas within groups, to generate new ones, organize and select them.

Figure 2. Photographs of the three areas of the kitchen to be renovated: the space where users sit (left), the sink area (center) and the "storage" area (right).

3.3.2. 3D scan

After the brainstorming stage, the participants made a 3D scan of their kitchen area. To do this, they used an iPhone 12 smartphone and a prototype of scan application based on Lidar technology. The interface of the scanning application was composed by one button to start the scan and one to stop it. During the scan, a grid appeared dynamically on the screen to specify to the users which volumes are scanned. The participants had to move the smartphone around in the room to scan it. Each participant made a scan, and each group then selected the best scan among those made by its members. All participants had to answer the French version of the user experience questionnaire named attrakdiff [14], about the scanning tool they had just used.

3.3.3. Sketch in VR

The participants had 30 minutes to take the VR sketching software called Time2Sketch [17] in hand. The facilitator was nearby to answer questions. Time2Sketch allows participants to immerse themselves in a 3D scan made with the application mentioned in the previous section, and allows them to sketch ideas in 3 dimensions in this virtual environment. Users can choose the size and colour of the brush to draw in space around them, teleport, move their sketches, resize them, use an axis of symmetry, and erase their work or pieces of the scan they want to remove.

Then, for a two-hour sequence, they immersed themselves in their scanned environment and had to make sketches of furniture. At the end of the two hours, each group had to produce a sketch of a main furniture idea. Participants had one VR headset per group (Oculus Quest 2), with visual feedback on a screen to facilitate verbal collaboration between the person with the headset and the other members of their group. All members of each group were asked to spend time in the headset working on the sketches. At the end of the two hours, each group took some screenshots of their sketch and each participant filled in the attakdiff for the VR sketches.

3.3.4. 3D modelling

Based on the picture of their sketch, each group had to model a 3D representation of their idea of furniture using the CAD software named "Fusion 360". They first were trained on the main functions, and during two days, they worked on their models with the possibility to ask for help from the trainer if needed. All of the groups used the collaborative mode of Fusion 360 to facilitate the sharing of 3D models generates by each participant. At the end of this sequence, all the participants completed the attrakdiff concerning Fusion 360.

3.3.5. Visualization and correction

The 3D models made with Fusion 360 were imported into a model of the kitchen. The participants were then asked to return in VR to visualize their model in the context of the remodeled kitchen with a headset and to see if there was anything that needed to be corrected or improved. All of the above-mentioned functions of Time2Sketch were available to them. For one and a half hours, the participants could sketch freehand corrections in VR to specify future corrections to be made to the models. Finally, they answered the attrakdiff questions about Time2Sketch for this visualization and correction activities.

4 RESULTS

Figure 3 shows the results of each stage for the 3 groups. We see that the intermediate design objects evolve over the course of the project from a set of ideas written on sticky-notes (180 in total) to four freehand, but more elaborate sketches, then as a whole set of 3D models, and finally these 3D models were annotated and corrected by hand. Although there were only 3 groups, the process resulted in 4 projects because one of the groups decided, during the sketching stage, to explore two tracks in parallel.

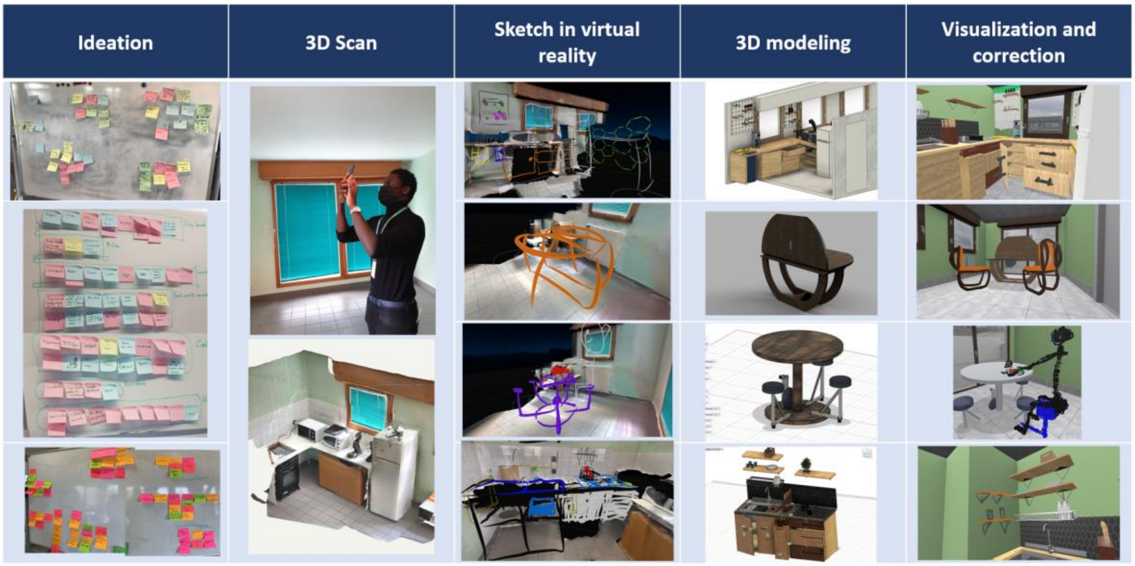

Figure 3. Images of the productions of the three groups for each of the five stages.

All groups identified design issues when visualizing in virtual reality. Figure 4 shows two examples of the achievements in the final correction stage. First picture shows the drawing of a participant who tried to physically place himself in front of the table by sitting on a tangible chair and drew his own silhouette to find that the stool he had modelled was not well positioned for use. In the second picture, we can see that one participant had become aware in VR that the shelves he had modelled above the sink were far too high and inaccessible.

In this second image, we also see the drainer: the principle was that the water would flow into the sink. The participants identified through immersive visualization that the water would flow over the wooden rim rather than into the sink and that the shape of the furniture would have to be modified. Finally, one group identified difficulties related to the presence of their furniture in addition to those of the other groups: the connection between these pieces of furniture in the corner of the room was poor and made an area inaccessible.

Concerning the attrakdiff questionnaires, figure 5 shows the four tools positioned according to their average perceived hedonic and pragmatic qualities. First of all, as expected, the scanning tool appears to be superior on pragmatic qualities, which is understandable given the extreme simplicity of the « one button » interface. Concerning the VR sketch tool, it should be noted that it is the best positioned in terms of hedonic qualities. Overall, the evaluations of the different tools are very positive in terms of hedonic qualities, but more moderate in terms of pragmatic qualities. It therefore seems that an effort to improve the usability of the tools should be prioritized, particularly with regard to VR sketches and 3D modelling.

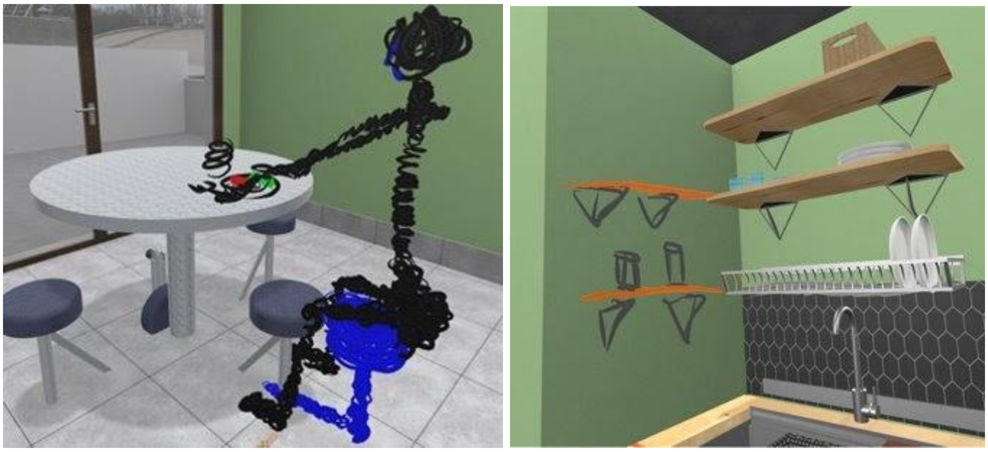

Figure 4. Screenshots of some corrections made during the last stage.

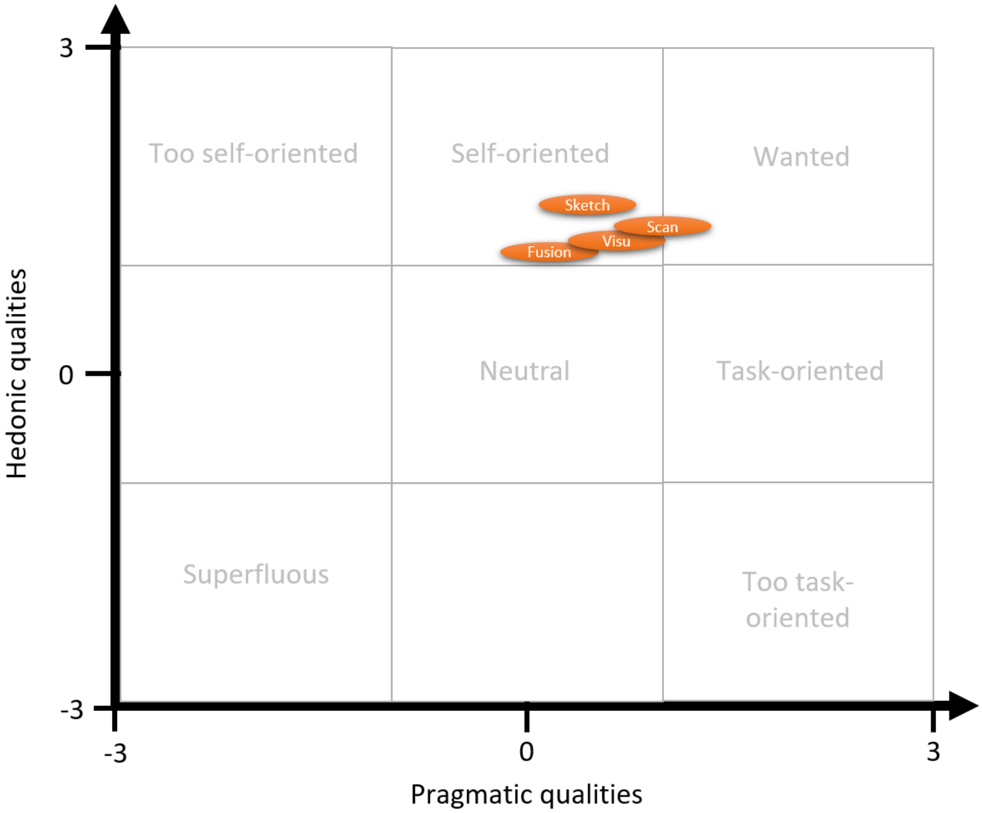

Figure 5. Graph showing the positioning of the four tools in terms of pragmatic and hedonic qualities.

The Table 1 shows means and standard deviations of the four dimensions of user experience for all the tools tested. Scores of attrakdiff are considered as acceptable between 0 and 1, and really good when higher than 1. Concerning our results, all the dimensions are higher than 0 and some of them are higher than one. There is no major pain point identified in the assessed process.

	Scan	VR Sketch	3D modeling	Visualization & correction
Pragmatic Quality	1(.360)	0.441(.876)	0.229(.486)	0.729(.769)
Hedonic Quality - Stimulation	1.685(.660)	1.840(.726)	1.017(.680)	1.455(.618)
Hedonic Quality - Identity	0.991(.708)	1.159(.962)	1.205(.775)	0.892(1.016)
Attractiveness	1.718(.809)	1.676(1.126)	1.458(.952)	1.739(1.038)

Table 1. Means and standard deviations (between brackets) for the four dimensions of user experience concerning the four stages of tools uses.

5 DISCUSSION AND CONCLUSIONS

The objective of this study was to propose a process based on the use of 3D scan and VR sketches for furniture design. The evaluation of the tools of this process in terms of user experience also aimed at identifying possible pain points in order to specify recommendations for improvement. Generally speaking, the user experience evaluations associated with each tool reveal that there are no real pain points in this process. Fusion 360 appears to be the best evaluated on the "identification" dimension. This is understandable since the identification items refer to notions of "high-end" and "professional aspect" of the device, and Fusion 360 is a commercial product whereas the Scan tool and Time2Sketch are prototypes from lab. The fact that VR appears to be stimulating and attractive is not a surprise and coincides with the findings of [17]. Finally, the perceived ease of use of the scanning tool was expected as the interface is extremely simple.

The results also revealed that the visualization in VR of the modelling in context was effective in allowing participants to identify problems that were not visible in Fusion 360 on screen. This result is related to the ability of VR to facilitate spatial explorations of a 3D object [30, 4]. All the groups improved their proposal through this stage because they saw problems in VR that had previously gone unnoticed.

Regarding the improvements to be made to the proposed process, we have identified several points. First of all, we saw that the usability of the CAD software could be improved, as well as its hedonic qualities. We can imagine, for example, working on gamification techniques to guide the user and make the use more playful [13], or even performing the modelling directly in VR [5]. Furthermore, the usability of Time2Sketch can be improved. Based on the users' feedback, simplifying the interaction by better choosing the buttons corresponding to the different functions would probably be enough to make it more intuitive. In addition, the collaboration feature of Fusion 360 was particularly appreciated by the participants as it facilitated working with several people on the same models. Based on this feedback, a possible improvement to Time2Sketch would be to allow users to immerse themselves in the scanned environment with several people at the same time to facilitate collaboration during the sketching stages. Finally, the ideation stage was carried out with sticky-notes, but electronic brainstorming could be used, since we know under what conditions it is effective [16], [25], or even immersive storming [7], since VR brainstorming tools exist and it is known that VR can have a high potential for ideation (e.g. [7], [17].

The present study has two main limitations. The first one concerns the level of generalization of the results in terms of application cases. It was about furniture design, but the proposed process is not necessarily relevant for other design domains such as architecture or mechanical parts design, as each domain is subject to specific constraints. The second limitation concerns the participants. The test population consisted of students, therefore with little experience in terms of design, and relatively new to VR. We can expect better results with a trained population, used to these tools and this process. Future studies should explore further improvements to this process, including more VR, but also evaluate the process with more trained participants. Co-creation processes will have to be analyzed too, as well as how can VR technology help to promote it.

Sylvain Fleury, https://orcid.org/0000-0002-9229-6632
Philippe Blanchard, https://orcid.org/0000-0003-0777-3252
Laurent Dupont, https://orcid.org/0000-0002-8279-9690
Peter Meister Broekema, https://orcid.org/0000-0002-7926-4118
Simon Richir, https://orcid.org/0000-0003-2075-6609

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