



**HAL**  
open science

# Acceptability of Immersive Sketching and Prototyping Tool: VR-Sketcher Case Study

Alex Gabriel, Anaëlle Hily

► **To cite this version:**

Alex Gabriel, Anaëlle Hily. Acceptability of Immersive Sketching and Prototyping Tool: VR-Sketcher Case Study. ICE IEEE/ITMC Conference, Jun 2024, Funchal (Madeira), Portugal. hal-04624982

**HAL Id: hal-04624982**

**<https://hal.science/hal-04624982v1>**

Submitted on 25 Jun 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

# Acceptability of Immersive Sketching and Prototyping Tool: VR-Sketcher Case Study

Gabriel Alex  
Université de Lorraine  
ERPI

F-54000 Nancy, France

<https://orcid.org/0000-0002-3676-6417>

Hily Anaëlle  
Université de Lorraine  
ERPI

F-54000 Nancy, France

<https://orcid.org/0000-0002-7834-9769>

**Abstract**— Innovation projects benefit from inclusive stakeholder participation, but the complexity of traditional tools can hinder non-expert involvement, particularly in design projects. Virtual reality (VR) is emerging as a transformative solution, offering an immersive 3D environment for ideation. However, these tools are mainly used by "experts" with design or engineering experience, accompanied by training in the basic functionality of VR sketching tools. This study explores the acceptability of a simplified VR design tool for non-experts, focusing on interactions and menu use. With 11 participants, the experiment utilizes the System Usability Scale and reveals positive evaluations. It highlights the potential of VR in participatory design processes, which can be applied to user-centered design processes and living lab approaches. However, there are a few areas for improvement to make the tool even more accessible and acceptable.

**Keywords**—virtual reality (VR), virtual prototyping, user-centred design, user experience, sketching

## I. INTRODUCTION

The participation of all stakeholders in an innovation process is a key factor in the success of an innovation project. However, difficulties to contribute to the design of a system without mastering modeling and design tools limits the involvement of other stakeholders to idea sharing during the ideation phase. It is still possible to formalize ideas on paper, but this requires a capacity for abstraction to move from 3D to 2D. To bridge this gap, immersive technologies and notably virtual reality (VR) offer the possibility to immerse users of any expertise in a 3D scene to imagine or review a new concept. The advantage of VR lies in enabling the user to use more spontaneous gestures to represent volumes, interact with objects and visualize them. The resulting simplification of interactions tends to facilitate creative tasks [1].

Indeed, it has been demonstrated that the use of VR tools enables rapid creation of complex part geometries [2]. Additionally, VR generates a sense of tension compared with paper and pencil, allowing participants to concentrate more and enter a better state of fluidity [3]. In co-design and design approaches with users, an adapted representation system encourages active participation [4]. Furthermore, some studies have shown that VR can contribute to empathy when solving social problems, particularly through perspective-taking [5], which is a valuable feature for co-design and user-centred design.

Immersion and the transition to 3D seem conducive to creativity due to the more authentic and intuitive sensorimotor experience. However, users still rely on interfaces and functionalities made available to them in order to draw, create volumes, or generally design a product or service. Therefore, caution should be exercised when addressing human-machine interaction (HMI) issues in VR design projects, considering both creative performance and inclusiveness of diverse stakeholders. It is essential to address HCI issues in the context of participative design processes that may involve people without design or engineering knowledge and background, such as those encountered in living lab approaches or user-centered design methodologies.

The primary objective of this exploratory study is to assess the acceptability of a simplified VR visualization and sketching tool for non-experts named VR-sketcher. Observations focused particularly on interactions with the various tools and menus.

The next section provides a brief review of the state of the art in immersive technologies, with a specific focus on the use of VR applications for design and evaluation. The third section outlines the experimental protocol based on user testing observations, standard questionnaires, and interviews. The fourth section presents the results of the experiment conducted with 11 participants at a public event. The findings show an evaluation of acceptability as good according to the SUS scale. Finally, the last section discusses the results and concludes with perspectives on this study.

## II. RELATED WORKS

### A. Virtual reality for product and service design

Virtual reality can be used at different phases of the design, notably the early design stage for concept generation, the embodiment design phase or the design review phase [2], [6]. Feedback of professional in digital content creation raised the potential benefit of extended reality (XR) technology to improve creative expression [7]. Whatever the speciality, designer, engineer or even general user, the main benefit is the manipulation of full-scale model with close to natural interaction [2], [8]. However, according to the domain of expertise of the user, the feature of the tool might be very different.

From the engineering perspective, VR is currently mostly used to review candidate design solutions, but emerging usage is to model geometry directly within virtual environment [8]. In this case, expected functionalities are notably geometrical and dimensional constraints, volumic, surfacic and boolean operators, geometric entities and canonical shapes among others [8]. According to a systematic literature review of existing VR-CAD software, existing solutions have shown poor ergonomic

interfaces for modelling sketches, few 3D operators compared to traditional CAD and non-appropriate output files for engineering (i.e. mesh file instead of boundary representation) [8].

On the other hand, from the designer perspective, expectations are rather on the initial design stage (mostly conceptual) with a lower interest in the exactness of the design induced by production. For the earlier stages in the product design methodology, pencil sketching on paper has been the go-to method for decades [9]. It is naturally that VR sketching also emerged, leading to an augmented concept design method [9]. Some of the questions already explored concerning these tools were about their impact on creative performance [10], processing times of sketches [11] and the temporal distribution of designers' actions [11]. It has been identified that sketching in VR is an effective and relevant way to boost creativity [10]. It was noted that it generated a higher level of fluency to generate ideas among test participants [10]. However, freehand drawing was pointed as a potential limitation on the level of elaboration of ideas represented in VR [10]. It can also be expected a potential time-saver for designing an object [11]. In overall, VR sketching led to a positive, stimulating, attractive, and engaging experience [10], [11]. It should be noted that participants in these experiments were mostly engineering students. In the work of [12], participants were design students, and the conclusion was more balanced. Although it provides a high degree of freedom, notably through the 3D view of a drawing, users' feedbacks highlighted lack of features (e.g. boolean operations), inefficiency, and increased mental load [12]. Surprisingly, this research concludes to a decrease of efficiency at the early stage of conceptualization [12]. Although some research estimates that participants quickly adapted to immersive 3D sketching without requiring further instruction after the initial training task [13], this critical article involved experienced students in VR sketching (from 1 to 14 months of experience).

A third category of VR design tool also exists which are voxel modelling and sculpting software. However, it is not much explored in scientific literature except in a literature review of emerging technologies [7]. The principle is akin to modeling virtual clay in an immersive environment.

Immersive modelling encourages behaviours common to paper sketching as well as gesture, physical modelling and 3D CAD [13]. However, in their systematic literature review, [6] put forward the lack of commonly accepted processes and platforms to allow more designers to implement VR for design purpose. Additionally, the user experience remains an area for improvement, with the involvement of novice designers and co-designers receiving insufficient attention in the literature.

These findings suggest that further exploration and development are necessary to optimize the application of immersive design along participatory design process, paving the way for more robust and intuitive VR experiences.

### *B. Evaluation and adoptability*

The diversity of technologies, functionalities, uses, and user profiles studied in the literature leads to a multitude of approaches to assessing the benefits of VR design tools.

A literature review on XR adopter profile shows the multiplicity of approaches and models to evaluate the adoption, such as Technology Acceptance Model, Theory of Reasoned Action, Unified Theory of Acceptance and Use of Technology, among others [14]. In a study that compared pen & paper sketching against immersive sketching, the authors measured the subjective workload using the NASA's Raw Task Load Index (TLX)[9]. The above-mentioned study that evaluated creativity impact used the Creativity Support Index complemented with the French version of the AttrakDiff [10]. An alternative to AttrakDiff instrument is the System Usability Scale (SUS) which was notably applied to evaluate a VR smartphone app for a cultural heritage site [15]. SUS is assumed to be a valid and reliable tool for measuring usability [16]. Both AttrakDiff and SUS have their French version respectively from [17] and [18].

In opposition to quantitative measures, other studies made the choice of qualitative data analysis using tools such as NVIVO to analyze retrospective interviews[19]. No trends were identified in terms of models to evaluate the adoptability, however methods based on subjective self-evaluation are extensively used.

Subjective self-reports are frequently used in VR user studies. We identified two distinct ways to administer the questionnaires: embedded questionnaire or physical questionnaire. The benefits of embedded questionnaire in a virtual environment are to be non-interruptive and particularly relevant for intermediate questions during the experiment [20]. As an example, the VR Questionnaire Toolkit allows the implementation of subjective measurement directly in VR. However, this toolkit is only available on Unity game engine [21].

## III. METHODOLOGY

This experimentation aims to evaluate the relevance and usability of VR-sketcher for inexperienced users to do a creative task. Thus, this protocol was applied during a public event to recruit non-experts' participants with various backgrounds, although all inexperienced in product design and development. This comes close to the real-life conditions of participatory design approaches that can be implemented as part of product or service design. It also means that participants could have some previous experience with the usage of VR.

As highlighted above, common experimental protocol with VR design tool includes user test observation and survey. It is sometimes completed with interview or focus group according to the experimental protocol. In this study, the protocol includes these three data collection phases. It has to be noted that participants were not trained, unlike other studies such as [11].

As illustrated in Figure 1, the protocol started with a global introduction to the study and the consent agreement signature. Then, the experimenter presented the conduct of the experiment and devices used (i.e. an HTC Vive pro connected to a workstation with large screen display to provide visual feedback to the experimenters). Once the participant equipped with the VR headset, they were instructed to design a storage furniture for a living room.

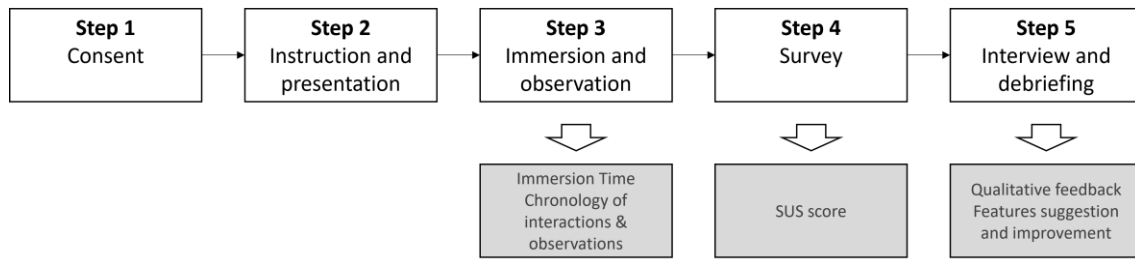


Fig. 1. 5-step experimental protocol

In the third stage, the participant designs their/her concept. Meanwhile, a first experimenter ensures that the participant does not leave the experimentation space to avoid collisions with the real environment. Additionally, he/she answers any questions formulated by the participant and can intervene to help when he/she encounters difficulties, in order to avoid frustration build-up. A second experimenter takes note of the various issues faced by the participant, as well as their questions, comments, and reactions. These observations collected information such as the time since the beginning of the experiment, the type of action done by the participant, the interface used or the functionality used, and were coditized in real time by the observer into 3 categories: help, observation, and question. These three categories were defined as follows:

- **Help:** noting that the participant is unable to do the intended action, the experimenter spontaneously intervenes to explain how to proceed.
- **Observation:** reaction or behavior from the participant that is notable from the observer point of view. It can enthusiasm reaction or difficulty encountered with the tool. It is event that does not require the intervention of the experimenters, participant manages without requiring exterior help.
- **Question:** the participant explicitly asks for assistance.

Once the participant was satisfied by their creation or reached the time limit of approximately 10 minutes, they removed the headset and started the step 4 which consists in completing alone a survey containing demographic questions such as gender, job, age, previous experience with VR, and the 10 SUS questions[16], [22].

Finally, at the end of the survey, the step 5 consisted in an exchange between experimenter and participant to collect qualitative data about the experiment. The exchange took the form of a semi-structured interview concerning design intentions, needs and constraints for formalizing the idea (What concept did you want to create? What needs/constraints did you have in mind to structure your idea?), as well as the satisfaction of the functionalities available for designing, as well as shortcomings and desirable modifications (Were the functionalities satisfactory for the design? What's missing? What would you change?).

#### A. Software Features

The VR design tool used was VR-Sketcher, an open-source tool developed in-house using the Godot game engine. Given the evidence in the literature that VR can significantly enhance creativity, we felt it was important for the tool to be open-source. This tool was designed to address three primary use cases: project review, immersive 3D modeling, and immersive ergonomic simulation.

The first use case involved visualizing 3D models for 3D printing within a scene featuring modular scenery (360° images). The goal was to evaluate the object's shape and scale in context before proceeding with 3D printing. Since 3D print files do not include textures, a feature was added to allow texture assignment directly within the tool. Recognizing that this visualization might reveal inadequacies in the model or necessitate a new concept, the second use case for immersive 3D creation included functions such as free drawing and the creation of volumes from geometric primitives (e.g., spheres, cubes).

Finally, the third use case involved simulating the use of 3D objects within an environment. To facilitate a swift transition from prototyping to evaluation, measurement functions were integrated, currently limited to distance measurements between two points and angle measurements, with plans to include a simplified mannequin. All these features are accessible through a menu, as illustrated in Figure 2.

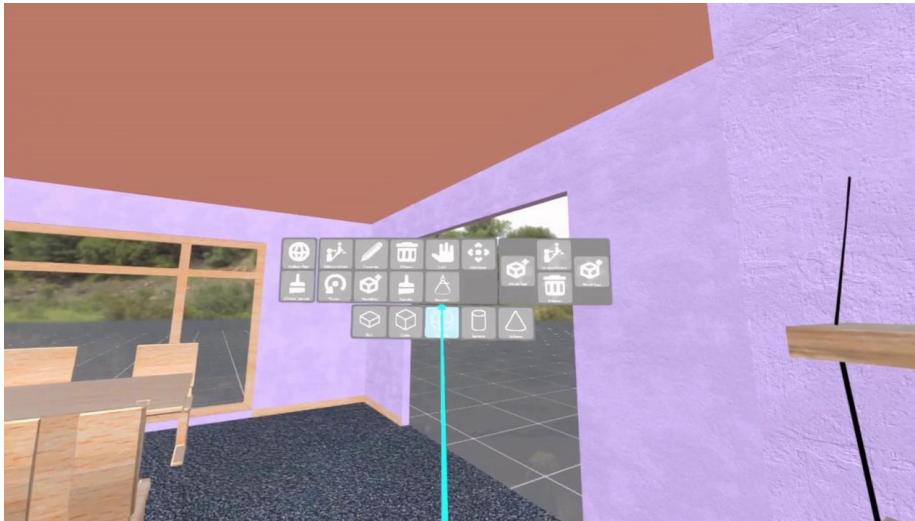


Fig. 2. Screenshot of VR-sketcher menu to access to functionalities

## IV. RESULTS

### A. Sample Description

A total of 11 participants were recruited for the study through a public event. All participants signed an informed consent form before beginning the experiment and were informed that they could stop at any time. One participant discontinued the experiment due to symptoms of cybersickness, resulting in a final sample of 10 participants (3 females; 8males; mean age=38.6, min 19-max 69).

Six out of the ten participants had prior experience with VR technologies (4 seldom, 2 occasionally), but none had used VR for sketching, drawing, or designing activities. A sample of the furniture designed by participants is presented in Figure 3. Various types of storage solutions were created, including closed cabinets and open shelves for storing items such as bottles, books, vinyl records, musical instruments, and for displaying decorative items like aquariums, flowers, and figurines.

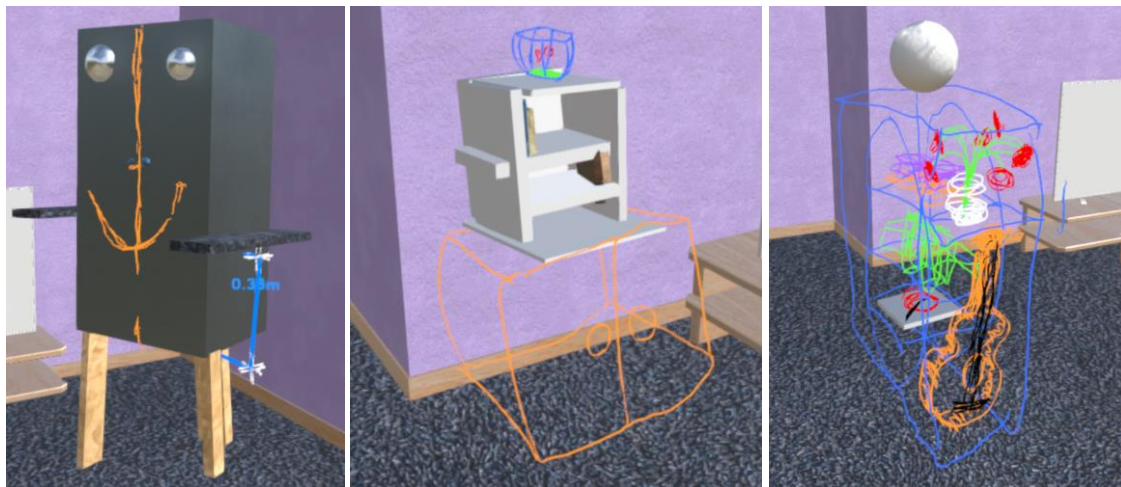


Fig. 3. Examples of furniture designed during the experiment

### B. Usage situation monitoring

As outlined in the protocol, step 3 involved observing participants as they designed a piece of furniture for the living room. Participants' actions, interactions, and behaviors were categorized into three types of usability-related events. These events pertained to the general use of VR technologies (e.g., aiming the controllers), the locomotion interface (i.e., teleportation), or the functionalities and tools available in the application used by participants to design their concept (e.g., display menu, drawing, erase, model, move object, texture).

Figure 4 shows the timeline of the different events for each participant. Assistance was provided 22 times; participants directly asked 9 questions, and experimenters noted 12 usability issues. A high density of events was observed in the first three minutes of the experiment.

Participant 9 was the only one who interrupted the design task early due to overall frustration with the software, despite minimal solicitation of experimenters and no major observed usability issues.

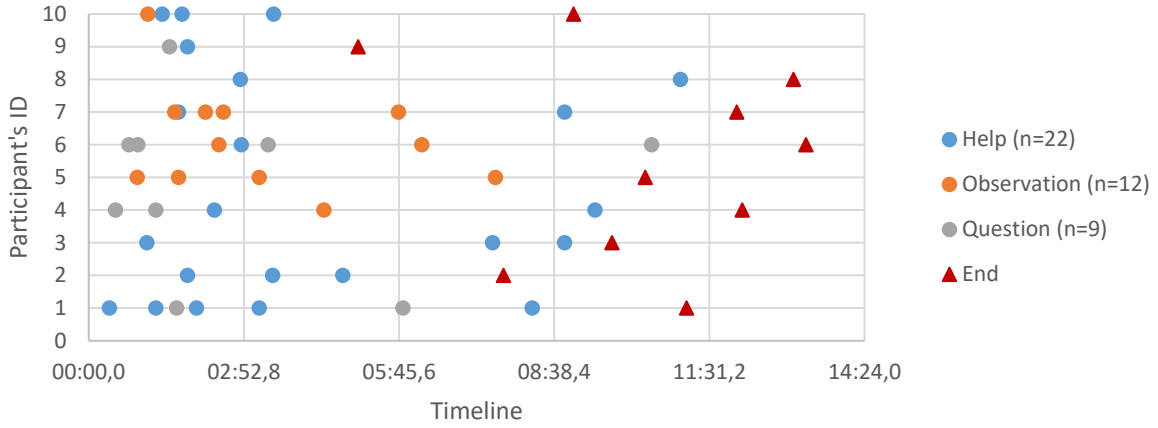


Fig. 4. Timeline of usability related events

Regarding the subject of these 43 interventions and observations, Figure 5 left shows that most (n=28) focused on the use of the tools. In contrast, the general use of the VR setup (n=7 events) and the teleportation interface (n=8) did not cause much trouble for users. Detailing the different events related to tool utilization, Figure 5 right reveals that drawing and modeling were the features requiring the most intervention from experimenters (5 and 6 occurrences, respectively), followed by the 'move object' function. The overall distribution of observations and questions was quite balanced across the different features.

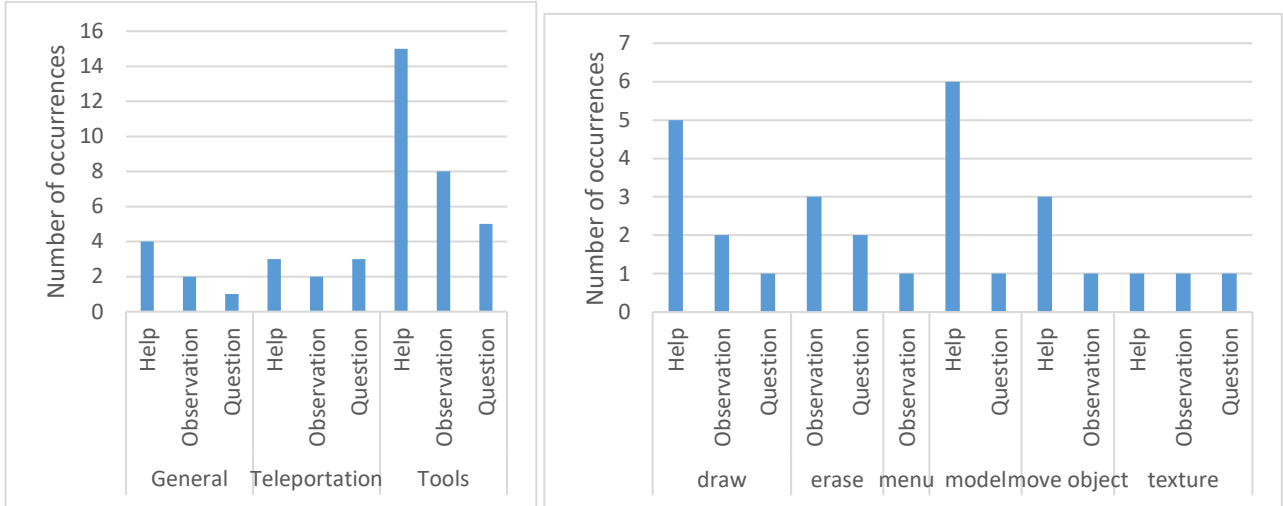


Fig. 5. Total of event's type for each interface (left) et for each tool (right)

### C. Questionnaire

Step 4 of the protocol utilized the SUS scale, a single-score, technology-agnostic scale [16], [22], [23]. The evaluation of the 10 items on the scale produces a score ranging from 0 to 100. In this experiment, the mean score of the 10 participants who completed the protocol was 71.5 (SD = 12.97, min 57.5, max 92). As the score alone is not sufficient for interpreting the evaluation, various scales were explored, such as the letter grade scale, adjective rating scale, and acceptability ranges [23]. According to these scales, VR-Sketcher can be considered acceptable with a grade of C or even classified as good.

### D. Debrief

Concerning step 5, an open interview followed the furniture design phase. During this interview, participants suggested functionalities to address the issues they encountered. Table 1 lists the proposed functions and their frequency. Additionally, participants expressed frustration regarding depth visualization, which made it difficult to place objects correctly in the virtual environment. One participant expected more interaction with the environment. Overall, half of the participants provided explicitly positive feedback during the interview sessions. These results and potential improvement scenarios are discussed in the following section.

TABLE I. FREQUENCY OF IMPROVEMENT SUGGESTIONS FORMULATED BY THE PARTICIPANTS

Suggested new features	Frequency
More pre-designed shapes or objects available (e.g. chairs, table, cones, pyramids, etc.)	4
Anchoring points to allow more precise positioning	2

Suggested new features	Frequency
Draw straight lines	2
Clearer icons to depict each tool, particularly the "draw" feature	2
More precise cursor to interact with small objects	2
Exchange controller's binding between teleportation and menu display (i.e. facilitate access to the menu button)	2
Sculpture of the 3D models imported	2
Choosing dimensions more precisely when creating an object	1
Personalized organization of the different functions, as can be found in gaming	1
Quick switch between two functions (e.g. draw and erase)	1
Palette to select colours and textures	1
Changing dimensions of a drawing	1
Position the display of the menu interface on the controller	1

## V. DISCUSSION

This exploratory study focused on testing the acceptability of simplified VR software designed for non-experts, providing 3D visualization and sketching tools. The aim of the following section is to discuss the results obtained, as well as the methodology and indicators chosen to evaluate the application. We then share the improvement scenarios and perspectives envisioned for further development of the application.

Considering the data collected during the usage situation, the listing of the interfaces and features concerned by each type of event provided us with valuable insights into the usability issues of our software. Regarding our categorization of "help," "question," and "observation" instances, the high number of help interventions compared to the number of questions asked suggests that participants might be reluctant to directly ask the experimenter for assistance. This could be because the person wearing the VR headset is visually isolated from the experimenter and thus tries to manage the issues encountered alone. Additionally, the pressure of the experiment could lead people to try using the software without asking questions. Further studies on a larger population should enable us to determine more precisely the relevance of this categorization, potentially identifying user profiles that are more inclined to ask questions or providing insights into prioritizing the usability issues encountered by users.

The distribution of different events on the timeline of the ideation session showed that occurrences seemed concentrated in the first minutes of the immersion, which is consistent with participants discovering how to use the various functions available. We expect that documenting a longer immersion period could enable a more precise identification of different learning levels, highlighting moments of confrontation with the system accompanied by requests for additional information and moments approaching a state of flow with no discernible usage issues.

The number of usability issues linked to the tools' interface is far higher than the issues related to teleportation and general use of VR, which aligns with the session's aim. However, one must consider that if a difficulty is encountered when using a tool, the negative impact it may have is limited to the time spent using it, and possibly the quality of the final result of the ideation. On the other hand, a problem linked to the general use of VR technologies or movement in the environment is likely to have an impact on the whole task. Numerous feedbacks and suggestions concern the positioning of elements and visualization in space and the participants involved in this study have little experience of using this type of technology. Thus, these comments could very well be linked to the fact that they were not sufficiently proficient in teleportation to appropriate space in three dimensions, evolve freely around their concept and be more accurate in their design. To minimize this effect, future experimentation could involve a familiarization time prior to design session to ensure that people are comfortable with moving around the virtual environment and using the controllers.

The distribution of issues documented among the different features highlighted that the drawing and modeling features are crucial for the software. This was expected, as they are the primary means of giving shape to ideas. Consequently, these two features were prioritized in the evolution scenario of our application.

Comments on potential improvements mainly relate to facilitating design with more ready-made elements and improving the precision of the tools provided. This aligns with the concepts of "threshold" and "ceiling" that are recurrent in software creation [24]. The threshold refers to ease of use, which is essential for novice users, while the ceiling defines the limit of what is possible with the tool. It is essential to conduct user studies with novices to ensure low thresholds, as recommended for XR authoring tools [25]. However, the need for a high ceiling quickly becomes apparent as novice users familiarize themselves with the tool, leading to requests for advanced features, such as the precise creation of objects.

With these observations in mind and considering the feasibility of the various suggestions collected during this experimentation, a list of improvements to be implemented was drawn up and is presented in Table 2.



TABLE II. LIST OF IMPROVEMENTS FOR A SECOND VERSION OF VR-SKETCHER

Feature	Improvements envisioned
Draw	Predrawn simple figures (e.g. circles, squares) Straight lines More colours available
Model	More primitive shapes available Modification of the shape's dimension once imported Simple boolean extrusion of imported shapes
General	Palette-style menu interface for easy selection of the sub-type of a tool (e.g. colour for drawing, type of primitive shape, etc.) New controller binding to provide easier access to functionalities, and notably teleportation Quick change between certain tools (e.g. drawing and erasing) Change of icons to better display the functionality Possibility to anchor objects to prevent collision between models and approximative positioning

## VI. CONCLUSION AND PERSPECTIVE

The objective of this article is to evaluate the acceptability of a VR sketching tool used by non-experts in a design task that involves modeling storage furniture in a virtual living room. This is part of a broader effort to contribute to participative design and user-centered approaches with tools that enable design neophytes to participate in the process. The initial hypothesis is that virtual reality, which approximates natural interaction modalities, such as three-dimensional interaction, enables people to express their ideas more naturally and easily. To this end, we are exploring human-machine interactions by designing the VR-Sketcher tool for novice users and evaluating their acceptability and feedback.

This article presents findings from a 11-person evaluation using the SUS scale, showing that VR sketching tools are well-received by individuals new to design as part of a participative design process. Based on observations of behavior during the design phase, VR technology itself is not questioned; rather, the implementation of design functions such as drawing or creating primitives is more critical. However, ease of use does not imply inaccuracy, as there is a clear demand for precision according to the feedback. Post-experience exchanges reveal both a need for assistance with more shapes and anchor points between shapes, as well as the creation of shapes with precise dimensions and finer control. This highlights the challenging balance between a low threshold and a high ceiling [24].

In summary, this experimentation provides an initial assessment before exploring more advanced interaction modalities, based on participants' suggestions and the opportunities offered by artificial intelligence. Despite the small number of participants, this initial measure sets the stage for further exploration of advanced interaction modes. With the generalization of generative artificial intelligence (AI), new interaction modalities could be explored to evaluate the benefits for non-experts. AI and XR have been shown to benefit people in the fields of creativity and design [26]. New interaction modalities, such as gesture-based and speech-based interactions coupled with generative AI, could potentially save time in exploring solution spaces. Beyond the sketching function, which remains central to the design process, VR technology can also be implemented in product development to determine essential functions of new products and assess weak points of the first 3D prototypes [27] during an immersive evaluation phase.

The experimentation focused on the experience of contributors using VR during a participative design process. However, this kind of process is facilitated and prepared by someone responsible for managing the user-centered design process. This person must not only facilitate the workshop but also prepare the environment that will be used. This involves designing an easy-to-use interface for scene creation to be used by workshop participants. The current version is a desktop interface that allows the importation of 3D models and the modification of some parameters. A future perspective would be to explore the topic of VR design workshop preparation through a multi-platform approach, notably using web technologies to make it more accessible and versatile.

## ACKNOWLEDGMENT

The authors would like to express their gratitude to Julien Michaux for his contribution to software development. The authors also extend their appreciation to the Lorraine Fab Living Lab for hosting the experimentation.

## REFERENCES

- [1] S. Fleury et S. Richir, *Immersive Technologies to Accelerate Innovation: How Virtual and Augmented Reality Enables the Co-Creation of Concepts*, vol. 38. in *Smart Innovation SET*, vol. 38. Wiley-ISTE, 2021. Consulté le: 6 novembre 2023. [En ligne]. Disponible sur: <https://www.iste.co.uk/book.php?id=1809>
- [2] D. Vlah, V. Çok, et U. Urbas, « VR as a 3D Modelling Tool in Engineering Design Applications », *Applied Sciences*, vol. 11, n° 16, Art. n° 16, janv. 2021, doi: 10.3390/app11167570.
- [3] X. Yang, L. Lipsmeyer, P.-Y. Cheng, X. Yang, Y. Ren, et Y.-M. Huang, « Examining creativity through a virtual reality support system », *Educational Technology Research and Development*, vol. 66, juin 2018, doi: 10.1007/s11423-018-9604-z.
- [4] T. Dorta, S. Safin, S. Boudhraâ, et E. B. Marchand, « Co-Designing in Social VR. Process awareness and suitable representations to empower user participation ». arXiv, 26 juin 2019. doi: 10.48550/arXiv.1906.11004.
- [5] É. Estrada Villalba, A. L. San Martín Azócar, et F. A. Jacques-García, « State of the art on immersive virtual reality and its use in developing meaningful empathy », *Computers & Electrical Engineering*, vol. 93, p. 107272, juill. 2021, doi: 10.1016/j.compeleceng.2021.107272.



- [6] T. Liao et J. She, « How Does Virtual Reality (VR) Facilitate Design? A Review of VR Usage in Early-Stage Engineering Design », *Proceedings of the Design Society*, vol. 3, p. 2115-2124, juill. 2023, doi: 10.1017/pds.2023.212.
- [7] H. El-Jam et G. Southern, « Can co-creation in extended reality technologies facilitate the design process? », *JWAM*, vol. 12, n° 2, p. 191-205, juill. 2020, doi: 10.1108/JWAM-04-2020-0022.
- [8] T. Tran, G. Foucault, et R. Pinquie, « Benchmarking of 3D Modelling in Virtual Reality », *CADandA*, vol. 19, n° 6, p. 1184-1190, mars 2022, doi: 10.14733/cadaps.2022.1184-1190.
- [9] S. Van Goethem *et al.*, « The Use of Immersive Technologies for Concept Design », in *Advances in Usability, User Experience, Wearable and Assistive Technology*, vol. 1217, T. Ahram et C. Falcão, Éd., in *Advances in Intelligent Systems and Computing*, vol. 1217, Cham: Springer International Publishing, 2020, p. 698-704. doi: 10.1007/978-3-030-51828-8\_92.
- [10] S. Houzangbe *et al.*, « Is virtual reality the solution? A comparison between 3D and 2D creative sketching tools in the early design process », *Frontiers in Virtual Reality*, vol. 3, 2022, Consulté le: 9 novembre 2023. [En ligne]. Disponible sur: <https://www.frontiersin.org/articles/10.3389/frvir.2022.958223>
- [11] C. Seybold et F. Mantwill, « 3D Sketches in Virtual Reality and their Effect on Development Times », *Proceedings of the Design Society*, vol. 1, p. 1-10, août 2021, doi: 10.1017/pds.2021.1.
- [12] M. H. Lin, M. A. Sarwar, Y. A. Daraghmi, et T. U. Ik, « On-Shelf Load Cell Calibration for Positioning and Weighing Assisted by Activity Detection: Smart Store Scenario », *IEEE Sensors Journal*, vol. 22, n° 4, p. 3455-3463, 2022, doi: 10.1109/JSEN.2022.3140356.
- [13] A. Oti et N. Crilly, « Immersive 3D sketching tools: Implications for visual thinking and communication », *Computers & Graphics*, vol. 94, p. 111-123, févr. 2021, doi: 10.1016/j.cag.2020.10.007.
- [14] S. H.-W. Chuah, « Why and Who Will Adopt Extended Reality Technology? Literature Review, Synthesis, and Future Research Agenda ». Rochester, NY, 13 décembre 2018. doi: 10.2139/ssrn.3300469.
- [15] M. K. Othman, A. Nogoibaeva, L. S. Leong, et M. H. Barawi, « Usability evaluation of a virtual reality smartphone app for a living museum », *Univ Access Inf Soc*, vol. 21, n° 4, p. 995-1012, nov. 2022, doi: 10.1007/s10209-021-00820-4.
- [16] J. Brooke, « SUS: A Retrospective », *JUX - The Journal of User Experience*, févr. 2013, Consulté le: 7 novembre 2023. [En ligne]. Disponible sur: <https://uxpajournal.org/sus-a-retrospective/>
- [17] C. Lallemand, V. Koenig, G. Gronier, et R. Martin, « Création et validation d'une version française du questionnaire AttrakDiff pour l'évaluation de l'expérience utilisateur des systèmes interactifs », *European Review of Applied Psychology*, vol. 65, n° 5, p. 239-252, sept. 2015, doi: 10.1016/j.erap.2015.08.002.
- [18] G. Gronier et A. Baudet, « Psychometric Evaluation of the F-SUS: Creation and Validation of the French Version of the System Usability Scale », *International Journal of Human-Computer Interaction*, vol. 37, n° 16, p. 1571-1582, oct. 2021, doi: 10.1080/10447318.2021.1898828.
- [19] M.-H. Lin, I.-C. Chiang, L. Lee, et H.-X. Lu, « Examining performance of VR sketch modeling tool in personal sketches », présenté à DRS2022: Bilbao, Bilbao, Spain, 2022. doi: 10.21606/drs.2022.200.
- [20] D. Alexandrovsky *et al.*, « Examining Design Choices of Questionnaires in VR User Studies », in *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, Honolulu HI USA: ACM, avr. 2020, p. 1-21. doi: 10.1145/3313831.3376260.
- [21] M. Feick, N. Kleer, A. Tang, et A. Krüger, « The Virtual Reality Questionnaire Toolkit », in *Adjunct Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*, in UIST '20 Adjunct. New York, NY, USA: Association for Computing Machinery, oct. 2020, p. 68-69. doi: 10.1145/3379350.3416188.
- [22] J. Brooke, « SUS: A quick and dirty usability scale », *Usability Eval. Ind.*, vol. 189, nov. 1995.
- [23] A. Bangor, P. Kortum, et J. Miller, « Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale », *The Journal of User Experience*, vol. 4, n° 3, p. 114-123, mai 2009.
- [24] B. Myers, S. E. Hudson, et R. Pausch, « Past, present, and future of user interface software tools », *ACM Transactions on Computer-Human Interaction*, vol. 7, n° 1, 2000.
- [25] A. Dengel, M. Z. Iqbal, S. Grafe, et E. Mangina, « A Review on Augmented Reality Authoring Toolkits for Education », *Front. Virtual Real.*, vol. 3, p. 798032, avr. 2022, doi: 10.3389/frvir.2022.798032.
- [26] B. Atiker, « The Creative Use of Artificial Intelligence in XR applications », *TOJDAC*, vol. 12, n° 3, p. 587-605, juill. 2022, doi: 10.7456/11203100/003.
- [27] H.-P. Balzerkiewitz et C. Stechert, « Product Development Methods in Virtual Reality », *Proceedings of the Design Society*, vol. 1, p. 2449-2458, août 2021, doi: 10.1017/pds.2021.506.