The Influence of Context on Learning in a Social VR Historical Fashion Exhibition

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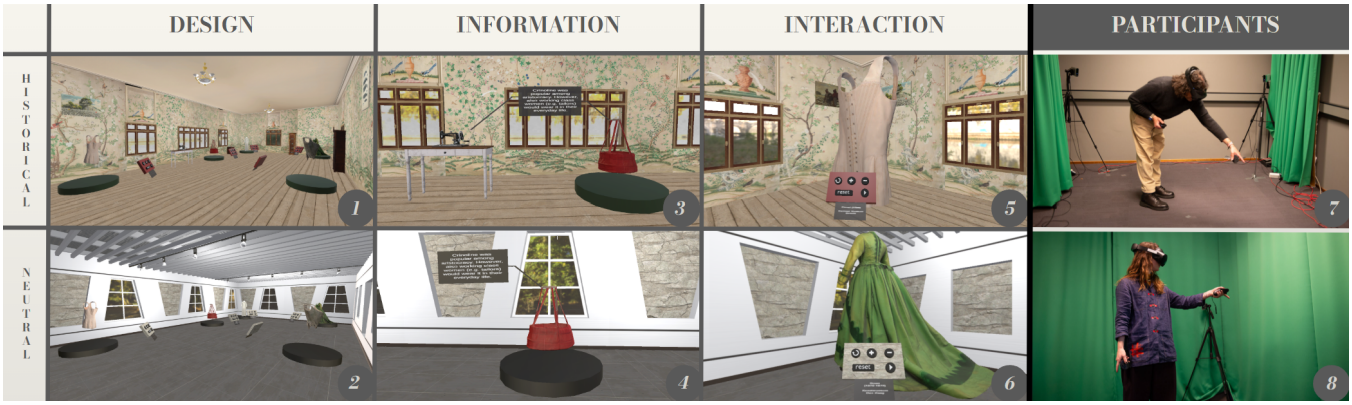

Figure 1: The designs of two rooms for a study exploring the influence of context on visitors in social VR exhibitions: Historical Room (1,3,5) and Neutral Room (2, 4, 6); the participants taking part in the study (7, 8).

Abstract

Social museums constantly search for new ways to satisfy and educate their visitors. One of the most important elements to success in those objectives is good exhibition design. It can be achieved by incorporating context, which is proven to improve understanding of exhibits and knowledge retention, and enhance the overall experience of the museum visit. While context is known to shape visitor experience in physical museums, its role in virtual reality museums remains underexplored, despite the flexibility in environment manipulation allowing for further adjustments. Moreover, social VR experiences allow for social interactions, which are crucial for the visitors' satisfaction and further improve their learning outcomes.

In this study, we design and implement a social VR fashion exhibition, which we evaluate in a real museum setting during a three-day event attended primarily by cultural heritage professionals. We also conduct a between-subject user study (N=56) with a varied group of end-users to explore the influence of context on users' learning, experience, and sociality in social VR exhibitions. To do that, we design two exhibition rooms with identical exhibits and information: one providing historical context through the surrounding environment (objects and style) without adding extra explicit knowledge, and one neutral without the contextually adjusted environment. During experiments, we collect quantitative data from questionnaire results, behavioral data, and qualitative insights through semi-structured interviews. The results show that when the context fits the exhibits, the participants' learning and experience improve. These results bring knowledge for future social VR exhibition designers on how to approach environment design in their projects.

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CCS Concepts

• **Human-centered computing** → **Virtual reality**; **Empirical studies in HCI**; **Collaborative interaction**; • **Applied computing** → *Fine arts*.

Keywords

Social Virtual Reality, VR Design, Exhibition Design, User-Centered Process, Social Museum, Mixed-Methods Evaluation

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1 Introduction

In the 20th century, the focus of museums has shifted from solely conserving and maintaining exhibits to responding to visitors' needs [39]. The emerged so-called social museums face the challenge of creating a good visit experience [28, 52], passing on knowledge [15, 28] and ensuring that the social needs of visitors are met [37]. The educational role of museums has been underscored by several scholars [18, 26, 45]. Learning in a museum is intrinsically linked to three interconnected aspects: personal, social, and physical [22]. In particular, the social aspect is highlighted in the literature as one of the main drivers of engagement and motivation [22, 51]. On a personal level, the visitor needs to get interested in the material, and keep this interest as they learn about the exhibits [53]. This can be achieved by introducing context [20]. Context also helps people to fully understand the artifacts [16, 17, 25].

Context can be introduced to the exhibition in various ways: by adjusting the architecture of the interior [8, 21, 59], putting additional objects around the exhibit [37], connecting multiple exhibits with each other [6], providing contextual information [28] or modifying the style of information transmission [28]. Some of these methods are challenging to introduce in physical exhibitions, but easier if developed as social Virtual Reality (VR) experiences, which can also incorporate sociality proven to improve learning [48] and experience [29, 44, 58]. Hence, the assumption of this article is that a social VR exhibition could have a positive influence on education and knowledge retention, at the same time providing a pleasurable experience and expanding the reach of museums' educational purposes beyond geographical limitations. However, while context is known to shape visitor experience, learning and sociality in physical museums, its role in virtual reality exhibitions remains underexplored.

In this work, we designed and implemented a social VR fashion exhibition engaging both curators and technical experts in the entire process. We brought the exhibition to the real world, where experts were highly satisfied with the experience and valued its potential, and we explored the impact of context in the lab, through a controlled study with non-experts. The lab study used a mixed-method approach, combining user responses and behavior analysis, enabling a holistic analysis of the results.

More concretely, while designing the exhibition, to ensure complete communication in VR (including both verbal and non-verbal cues, like posture or gestures), we decided to use point clouds [23], which provide a highly realistic user representation. The exhibition was validated in a real museum during a 3-day-long event, where a group of museum visitors, consisting mostly of cultural heritage professionals, came to experience it. Finally, we ran a between-subject user study (N = 56) to investigate the influence of context on users' learning, experience and sociality in social VR exhibitions. For the user study, we designed two exhibition rooms (presented in Figure 1) with identical exhibits and information. While introducing context, we focused on the environment surrounding the artifacts: one room provided historical context about the exhibits by introducing related objects and fitting architectural style (without including extra explicit knowledge), and the other room was neutral. The collected data, including users' positions and head rotations during the VR sessions, interview recordings, and filled-out questionnaires, were analyzed to examine different aspects of the experience. Results suggest that context fitted to the exhibits improves knowledge retention and user experience.

The contribution of this work can be summarized as follows:

- We design and implement a social VR fashion exhibition, and then validate it in an actual museum. The exhibition is well-received by cultural heritage professionals, who praise it for its potential for improving museum visitors' engagement with historical artifacts. They appreciate its educational role and value its immersive and collaborative character.
- We conduct a user study exploring the role of context (specifically the surrounding environment) on users' learning, experience, and sociality in a social VR fashion exhibition. We analyze the data using a mixed-method approach, combining data from questionnaires (e.g., Knowledge Test), interviews and navigation-behavioral analysis. The results of the study, comparing a neutral and a contextualized version of the experience (but both providing the same information), demonstrate that context improves users' learning outcomes and positively influences their experience.

Our results show that the social VR exhibitions play an important role in the cultural heritage sector and bring a satisfying experience to museum visitors. Moreover, they show that the context in the virtual exhibition plays a crucial role, and bring a reason to further explore how to use context in such experiences.

2 Related Work

2.1 The Role of Context in Social Museum Exhibitions

According to multiple studies, human perception of the object does not depend only on the object itself. Instead, the brain takes into account the contextual information provided by the scene surrounding the object and interprets it as a whole [16, 17]. Even though researchers do not agree on whether the recognition of the object is dependent on the context, the way we perceive and interpret the object is highly influenced [16, 17, 25].

Because of its properties, context plays an important role in social museum exhibitions. Contextualization helps people dive into the world of the exhibit and engage in its story [20]. Context can also be used to evoke the phenomenon of contextual priming [42, 56],

which is based on familiarity, and which is proven to improve the sense of presence [11]. In social museum exhibitions, curators can use connections between exhibits to build the context of events, people, and times, fostering deeper visitor engagement by framing exhibits as parts of a larger narrative, enhancing both experience and learning [6]. Likewise, nearby "additional" objects can add meaning to otherwise neutral exhibitions by providing contextual significance [37]. Context helps convey information by situating exhibits within their political or social background, shaping visitors' perspectives [28]. Equally important is how the information is presented - the narration should align with the museum's theme to create a coherent experience that enhances visitors' understanding without disrupting the exhibition [28]. Finally, the museum space's appearance and layout greatly affect audience enjoyment and sociality [37]. Even small details like background colors and frame shapes impact visitors' emotions and memory retention [8, 21, 59]. In case of context usage in VR exhibitions, Chung et al. [14] found that reality-based (high fidelity) VR environments help users focus on exhibits, virtuality-based (low fidelity, surreal) environments encourage exploration and curiosity, and there is an expectation among participants that the space's design fits the exhibition topic.

Previous work [67] outlines key requirements for social VR fashion exhibitions, based on focus groups, co-design sessions, and validation with curators and Extended Reality (XR) experts, stressing the importance of a fitting context, shown in physical exhibitions to enhance experience and learning [43]. A gradual transition is proposed from a real-world-like starting environment to more imaginative spaces, with most exhibits displayed in a contextually themed middle room. It is also pointed out that context should be integrated into the information given during the exhibition. Beyond context, the exhibition must support meaningful interaction with exhibits and the environment, present information in an interesting way (e.g., through videos or audio guides), and introduce the story gradually as users learn to navigate through the environment. Exhibits should be scans of real garments contributing to a coherent, narrative-driven whole [67].

In our work, we decided to follow such guidelines for implementing the context in the social VR fashion exhibition. We created three spaces: first, an introductory area similar to a physical museum where the exhibition later took place; second, an environment having context fitted to the artifacts serving as the main exhibit space; and third, an out-of-this-world experience that challenges visitors with a knowledge quiz, encouraging cooperation and helping them retain what they learned in the previous space. Additionally, we ensured that all other requirements identified during their collaboration with curators are met. Then, we also explored how the context influences visitors' learning, experience and sociality in social VR exhibitions by comparing two exhibition rooms: one with context fitted to the exhibition topic following the guidelines described above, and one neutral, without fitting context.

2.2 Creating and Evaluating Social VR Fashion Exhibition

Existing commercial social VR platforms include Roblox[1], Bigscreen[2], VRChat[3], Rec Room[4] or Horizon Worlds[5]. Among those, only VRChat allows for full environment customization with the possibility to upload high-quality, custom models of objects. It was also used to create virtual exhibitions in the past [10]. Roblox also allows for world creation with imported custom models; however, it is style-wisely adjusted to the platform, which limits the creative possibilities. In the case of our exhibition, there is a need for highly realistic, live user representation of the visitors, which is necessary to provide high-quality social interactions - the possibility to use non-verbal communication influences how people convey emotions, feelings and complex information [38]. Such representation also provides a better sense of presence and immersion compared to avatars [41, 47]. None of the platforms listed above provides a system for creating a realistic user representation. VR2Gather[6] provides all of the listed above requirements, coming with a system to create and manage point cloud representation. Moreover, VR2Gather is already tested as a tool to create social VR exhibitions [54]. These characteristics made us choose VR2Gather to create our social VR fashion exhibition.

The evaluation of the user experience in a VR exhibition can be performed on different axes, depending on the factors that are of interest to the practitioner. A common distinction is made between explicit and implicit methods. The former can be done with either quantitative (questionnaires) or qualitative (interviews) methods, which aim at directly gaining insights from the user about their experience. In contrast, implicit methods rely, for example, on behavioral data, such as spatial dynamics of social interaction, which provide indirect indicators of engagement and interpersonal relationships within social VR experience.

In terms of explicit evaluation of VR exhibitions, previous literature has focused on factors such as presence [5, 60], user experience [61, 68], knowledge retention [46, 65], engagement [5], absorption and immersion [31]. In the case of fashion VR exhibitions, evaluations have been reported focusing on user experience [2], and factors related to presence, immersion, and dimensions of experience [66]. No standard set of questions or interviews is recommended in the literature to approach a quantitative or qualitative evaluation of fashion VR exhibitions. In our evaluation, we focus on assessing how context influences knowledge retention, and how it affects the personal aspect of the VR experience, considering factors such as usability [9], cybersickness [30], presence, immersion, engagement, and connection to the material [33], as well as the social aspect of the VR experience [36]. We complement our quantitative data with qualitative insights gathered from semi-structured interviews.

In terms of implicit evaluation in social VR, movement trajectories and head rotation have been used to characterize patterns of exploration, attention allocation and engagement [55, 63]. Beyond

[1] https://www.roblox.com/
[2] https://www.bigscreenvr.com/
[3] https://hello.vrchat.com/
[4] https://recroom.com/
[5] https://horizon.meta.com/
[6] https://www.dis.cwi.nl/vr2gather/

individual motion, proxemics, which is defined as the interpersonal distance between individuals, has emerged as a metric of social measure to investigate spatial distance, social distance and interpersonal evaluation in VR [40, 49]. In the case of museum VR exhibitions, similarly evaluations have been focused on navigation patterns as proxies for engagement [57], or on object-focused interaction via large-scale analyses of visitor behavior [1]. Adaptive frameworks have also been proposed to personalize virtual museum experiences based on behavioral profiles, leading to higher engagement and knowledge levels [13]. However, research on social VR fashion exhibitions remains limited and focused on consumer psychology, usability, or design aspects, with limited attention to behavioral analysis [12].

Our work addresses this gap by incorporating implicit behavioral metrics, such as spatial trajectories, interpersonal distance, and joint attention, into the evaluation of a social VR fashion exhibition.

3 Part 1: Museum Exhibition

3.1 The Design of the Exhibition

Although existing literature highlights the benefits of social VR in fashion exhibitions and provides design guidelines, these guidelines have yet to be validated in a museum setting. Therefore, this project adopted the guidelines from previous work [67] to design a social VR fashion exhibition and conducted its validation in a museum setting.

Over the course of nine months, a team of 2 museum curators, 3 XR specialists, and an experience designer collaborated to develop the exhibition design. The first room, shown in Figure 2a, was designed to be a reflection of the museum building where the exhibition was later physically located. In this room visitors get an introduction to the exhibition and learn how to interact with the environment. Figure 2b presents the second space, which is styled for a 19th-century room, where the visitors can view and learn about four garments coming from the 19th and the end of the 18th century. They can also interact with those exhibits: rotate them, and make them bigger and smaller. Apart from the exhibits, there are multiple decorative elements in the room, like chandeliers or old cabinets. The last space, presented in Figure 2c, was designed to be out-of-real-world. Here, the participants have to cooperate to solve quizzes testing the knowledge they gained in the previous room to unblock the final garment - the 20th-century gown.

Throughout the whole experience, information about the exhibits was delivered through videos triggered by standing on platforms, with participants guided by assigned colors and supported by an audio guide for navigation.

3.2 Development

3.2.1 The Exhibits Scans. To ensure accurate representation of the artifacts (presented in Figure 3), they have been scanned using photogrammetry. The process involved taking between 400 and 1000 pictures of each garment and then processing the pictures into 3D models using Agisoft Metashape[7]. To find the most optimal approach, objects were photographed in slightly different conditions: three of the exhibits were photographed on their museum displays, with different lighting setups; another two were captured in the photography studio, with one considering the goal of finding the minimal lighting conditions. The models obtained through this method have around 1-10 million polygons. They were optimized using Cinema 4D[8] to a polygon count of around 10-50 thousand. The models' final file format is .fbx.

3.2.2 Development of the Application. The three rooms were created as separate scenes using Unity 2022.3.21f. The assets used to decorate the rooms are open-source resources available online[9][10] or were created purposefully for this project. To support realistic point-cloud representations of participants, we employed *VR2Gather* [27, 62] - an open-source package for Unity, that enables the creation of networked Social VR applications. VR2Gather comes packaged with *cwipc*[11], a point-cloud compression library with support for various commercial depth cameras such as Intel Realsense and Microsoft Azure Kinect. The library handles acquisition, registration and compression of point cloud streams from multiple depth-sensing cameras, which are then made available and rendered in Unity.

3.3 Social VR Fashion Exhibition Validation

The exhibition was displayed in a museum between June 25-28, 2024. The first three days were open for the general public to attend and try out the experience. The last day was an invitation-only event, focusing on experts from the cultural heritage sector. The visitors waiting for their turn to take part in the experience could observe live the steps of others, currently visiting the exhibition. This event allowed us to validate the exhibition in an actual museum, with real museum visitors experiencing "Fashion beneath the Skin" - our social VR fashion exhibition. The photograph from the event is presented in Figure 2d.

During the exhibition, the visitors filled out the survey (N = 32), attached in Appendix A, which was later aggregated in order for us to understand the visitors' thoughts and opinions about the experience. Most of the visitors were regular museum goers aged 17 to 49, primarily working in cultural heritage, education, or research. Over 40% had no familiarity with XR technology, while 27% were somewhat familiar and 31% familiar or very familiar with it. The satisfaction rating was high at 81%, calculated from responses indicating 'satisfied' or 'completely satisfied' on a 5-point agreement scale. 82% of visitors would recommend the experience to someone else, and 100% would share something about their experience. The coding of responses to open-ended questions revealed that the visitors were excited about the potential of the technology for future engagement with and learning about heritage, including heritage that might be fragile or located in other places. They anticipated improvements and advancements in technology, which are exciting in terms of enhancing the museum visit in the future. The visitors believe that digital heritage experiences, like this one, can help to improve information retention and that the immersiveness of the experience and gamification help to extend the engagement with objects.

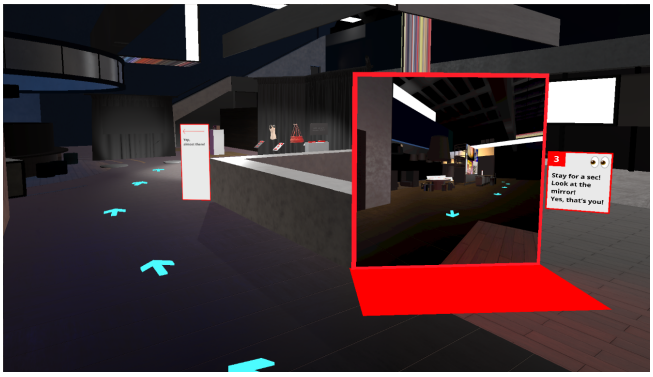
[7] https://www.agisoft.com/

[8] https://www.maxon.net/en/cinema-4d

[9] https://free3d.com/

[10] https://www.cgtrader.com/

[11] https://github.com/cwi-dis/cwipc



(a) The first space design of social VR fashion exhibition - the Museum Room.

(b) The second space design of social VR fashion exhibition - the Historical Room.

(c) The third space design of social VR fashion exhibition - the Unreal Space.

(d) Museum visitors attending the exhibition.

Figure 2: The design (a-c) and display (d) of social VR museum exhibition titled "Fashion Beneath the Skin".

The visitors appreciated the type and clarity of the presented information ("Video, voice over, the 3D models of the garments"). They highlighted that the combination of the object with context and information brings valuable learning possibilities. They emphasized the collaborative character of the experience. They noted that this exhibition could be extended to multiple remote locations and still feel like a shared museum visit, especially due to the realistic representation of other visitors. They also valued the possibility to interact and view the exhibits in a different way, like zooming-in or rotating, and the aesthetic of the experience.

On top of that, the visitors can imagine even more ways to use this technology to develop and enhance digital heritage experiences and see the potential of using more 'old footage' in VR using existing collections. They acknowledge this as a new way of engaging with (fragile) archival materials and "preserving culture for future generations", and that engaging through VR means that one can spend more time with the objects. The visitors suggest that the usage of VR can make more people engage with heritage.

4 Part 2: User Experiment

Literature shows that context in physical museums influences learning, experience, and social behavior, with curators often emphasizing its importance in cited studies. Yet, little is known about context in VR exhibitions, where it can be easily manipulated. Therefore, we investigated its influence on learning, experience, and sociality by comparing two new designs: a Historical Room (HR) - a historically contextualized room strongly fitted to the exhibition topic, and a Neutral Room (NR) without contextual fit.

4.1 The Experience Design for User Experiment

The HR, presented in Figure 1 (1, 3, 5), is designed to look like a 19th-century space. The exhibits are arranged keeping equal distances between them, and decorative objects are added. To build the context around the exhibits, one element is directly associated with each of them. These elements are objects or pictures connected with the information about the exhibit, but they do not provide any new knowledge. The example of such an object is shown in Figure 1.3. The information is given in the form of text pointers, which the users can go through using arrow buttons. The participants can interact with exhibits by rotating and resizing them.

(a) Reform Dress, 1912

(b) Corset, 18th century

(c) Crinoline, 1825-1875

(d) Green Gown, 1870-1873

(e) Corset, 1830

Figure 3: The garments scanned using photogrammetry.

The NR, shown in Figure 1 (2, 4, 6), features a generic exhibition room design with decoration unrelated to the exhibition topic: stone wall elements, modern windows, suspended ceiling and a nature skybox. The exhibits have exactly the same layout and interactions as in the HR. The information and the way of transferring it are also identical in both rooms. However, in the NR there are no extra objects: neither those connecting to the exhibits, nor the ones having purely decorative purposes.

4.2 Experiment Setup and Procedure

4.2.1 Participants and Setup. The study was conducted at CWI between October 25 and November 15, 2024. A total of 28 pairs

(N=56) took part in the experiment. The participants were recruited using the Convenience Sampling method - most of the participants were the employees of CWI or students from a nearby university. The participants were between 15 and 75 years old; 41 of them were male and 15 were female. Notably, the participants were not cultural heritage professionals, but mostly university students of various study programmes, or computer science or mathematics researchers. Each session lasted approximately 1 hour, and a 10-euro voucher was given as compensation.

4.2.2 Technical Setup. In each session, two participants joined the experience from separate rooms, using Meta Quest Pro headsets and controllers. Each participant was captured in real time by four Microsoft Azure Kinect cameras. Using VR2Gather, these captures were processed to represent the participants as point clouds in the VR. Users' movement data was collected using VR2Gather's built-in tool.

4.2.3 Procedure. At the beginning, the researcher gave participants an introduction, asked them to read and sign the informed consent form and collected their email addresses needed to complete the experiment. Then, the participants were asked to fill out the first Simulator Sickness Questionnaire (SSQ). The experiment had a between-subjects design, where half of the pairs (N=28) experienced the HR, and the other half (N=28) - the NR. The condition was alternated across sessions, such that the first pair experienced HR, the second NR, the third HR, and so on. The study consisted of 3 steps:

Step 1: Participants explore the environment in pairs (15 min). Participants started their VR journey in a training room, where they learned how to move around and interact with the environment using controllers. After they acquired all the necessary skills, they moved on to the next space - either the HR or the NR. Here, they were given 10 minutes to explore the space, interact with the exhibits, read the information, and play.

Step 2: Semi-Structured Interview and the Questionnaires (15-20 min). After the participants had finished exploring the virtual exhibition, they were asked to fill out the second SSQ. Then, the researcher gave the set of questionnaires to one of them and invited the other for the interview. After the interview was finished, and the other participant had answered all of the questions, the tasks were switched - now the participant who had already done the questionnaires was taken for the interview, while the other proceeded with the questionnaires.

A) The interview. The semi-structured interview was conducted in a separate room, in order not to disturb or bias the other participant, in a non-VR setting. The interviews were recorded for the analysis.

B) The questionnaires. Each of the participants was asked to fill out a set of questionnaires, including: System Usability Scale (SUS), Social Virtual Reality Sociality Experience Questionnaire, VR Exhibition Experience Questionnaire and Knowledge Test.

Step 3: Delayed Knowledge Test (5 min). In our study, the participants were asked to fill out one more questionnaire that they received one week after the experiment in their mailboxes. This questionnaire was the Knowledge Test - exactly the same one that they had filled out just after the experience. However, the participants were not informed in advance what this questionnaire would be - it was uncovered when they opened the email. The delayed Knowledge Test is considered useful to test the long-term knowledge retention [35]. The participants took the delayed Knowledge Test one to two weeks after the experience.

4.3 Data Collection and Analysis

During the experiment, three types of data were collected and analysed as described below.

Quantitative Data Five questionnaires were used to collect data during and after the experiment. SSQ [30] was given to the participants just before and just after they experienced the social VR exhibition, in order to assess the virtual experience's influence on their physical state [7]. To measure the experience and sociality, two questionnaires were adjusted to the exhibition use case and given to the participants just after the experience: VR Experience Questionnaire and Social VR Sociality Experience Questionnaire. These questionnaires were chosen based on their previous successful use in the cultural heritage sector and their validated effectiveness for evaluating XR experiences and social VR [33, 36]. On top of that, the participants filled out SUS [9]. Finally, they were asked to solve the Knowledge Test (attached in Appendix B) designed specifically for this experiment. 17 multiple-choice questions with a single correct option tested how much they remembered the information given during the experience. The information was based on the videos provided by the curators for the exhibition described in Section 3 and, like the test itself, was identical in both conditions. The participants were asked to take the test twice: just after the experience and after one to two weeks.

The data collected from the questionnaires were grouped into the corresponding factors, as detailed in each of the reference papers for the questionnaires [9, 30, 33, 36]. To compare the results obtained in the two conditions, we run a statistical analysis on the data. Specifically, we first checked for normality of the data using the Shapiro-Wilk test. If the normality assumption was not rejected at $\alpha = 0.05$ significance level, we applied the unpaired Welch's t-test on the data; otherwise, we used Mann-Whitney to compare the distributions.

Behavioral Data The data collected consists of the positions and head rotations of users at each given time stamp - every 200 ms. All data were resampled at 10Hz to ensure consistent resolution. We conducted a comprehensive analysis focusing on both individual and paired navigation patterns.

At the individual level, we first generated a visual overview of the most visited locations in the virtual spaces. Then, we characterized how differently participants were interacting by analysing motion patterns in terms of spatial displacement and rotational movements. Following the behavioral analysis presented in [55], we considered a participant to be interactive if their relative position changed more than 20 cm between time steps, or if their angular velocity exceeded 0.65 rad/s. These thresholds correspond to the 75th percentile of observed movements across all participants and ensure that small jitters and micro-movements are excluded while capturing deliberate translations and head rotations.

At the paired level, we exterminated interpersonal space through pairwise Euclidean distance and coordination through joint attention. Specifically, joint attention was defined as the temporal overlap of participants' attention to the same object. To identify the object

of attention, we combined spatial distance and head rotation: a participant was considered to look at an object if (1) they were within 5 meters, and (2) their head orientation was within 30 degrees from the connecting line to the object. When multiple objects met these criteria simultaneously, the object with the smallest angular deviation was selected. Finally, joint attention was calculated as the percentage of time in which both paired participants were simultaneously looking at the same object.

Qualitative Data The semi-structured interview was designed to explore four main topics: general enjoyment and engagement in the experience, sociality, exhibits and their influence on the experience, and environment and its influence on the experience. The interview consisted of 13 questions, attached in Appendix C. The interviews were recorded, transcribed using Condens[12], and reviewed to ensure accuracy and completeness. The data were then transferred to Excel for analysis. The Qualitative Content Analysis method [19] was chosen to identify the most frequent themes, concepts, opinions and ideas expressed by participants. Firstly, the responses to each interview question were carefully reviewed, and distinct answers were identified and labeled as codes. Next, these codes were organized into broader categories based on their similarities to represent related ideas. Finally, the frequency of each code and category was analysed to determine the most frequently occurring ideas.

5 Results

5.1 Quantitative Results

5.1.1 Knowledge Retention. Internal reliability of the 17-item knowledge test was verified with the Kuder–Richardson Formula 20 for binary data, showing acceptable reliability ($r = 0.71$, $N = 56$). Test–retest reliability was assessed using a two-way mixed-effects Intraclass Correlation Coefficient (ICC) with absolute agreement for single measures (ICC(3,1) = 0.67, 95% CI [0.45, 0.82]). No significant learning or fatigue effect was observed between administrations (mean difference $= -0.71, p = 0.11, d = -0.25$). Figure 4a shows the violin plot depicting the results of administering the Knowledge Test at two points in time: just after the experiment and after 1-2 weeks. For each plot the left side displays the results for the NR condition, and the right side - for the HR condition. The results from the test taken directly after the experience show that the HR group achieved overall better results than the NR group ($M_H = 9.82, M_N = 7.36$).

The Shapiro-Wilk test for normality failed to reject the null hypothesis for both conditions in the immediate Knowledge Test ($p_N = 0.08, p_H = 0.46$) and in the delayed Knowledge Test ($p_N = 0.43, p_H = 0.26$). We applied two-sample t-tests on the normally distributed data, and achieved a significant difference between the experimental groups for the immediate Knowledge Test (p = 0.007, $t(53.99) = 2.79$). The Cohen's d was calculated and showed a medium effect size ($d = 0.74$). For the delayed test, the two-sample t-test showed no significant difference between the conditions (p = 0.43, $t(39.88) = 0.8$).

5.1.2 VR experience. Figure 4b shows the violin plot depicting the results of administering the VR experience questionnaire [33]. For each plot, the left side displays the distribution for participants experiencing the NR condition, whereas the right side displays the HR condition. It can be seen that high levels of *Engagement* were experienced by both groups ($M_N = 6.44$, $M_H = 5.89$), as well as moderately high levels of *Immersion and Presence* ($M_N = 4.90$, $M_H = 5.00$) and *Realism* ($M_N = 5.17$, $M_H = 5.00$). It can also be observed that the factor *Connection to Performance* had a higher dispersion of values and lower median values with respect to the other factors ($M_N = 3.50$, $M_H = 3.38$). The results are in line with what was indicated in the original paper [33], perhaps suggesting that the factor was not applicable to the experience at hand.

Shapiro-Wilk test for normality rejected the null hypothesis for at least one of the two conditions for factors *Engagement* ($p_N < 0.001, p_H = 0.011$), *Connection to performance* ($p_N = 0.258, p_H = 0.0330$), and *Realism* ($p_N = 0.002, p_H = 0.107$), whereas it failed to reject it for factor *Immersion and Presence* ($p_N = 0.220, p_H = 0.497$). We applied Mann-Whitney tests on the non-normally distributed data, and no significant difference was seen between the two groups for any of the factors (Engagement: $z = 1.05, p = 0.29, r = 0.14$; Connection to Performance: $z = 0.43, p = 0.67, r = 0.06$; Realism: $z = 0.93, p = 0.35, r = 0.12$). Welch's unpaired t-test for the factor *Immersion and Presence* also revealed no statistical differences between the two conditions ($t(50.45) = -0.99, p = 0.33, d = 0.27$).

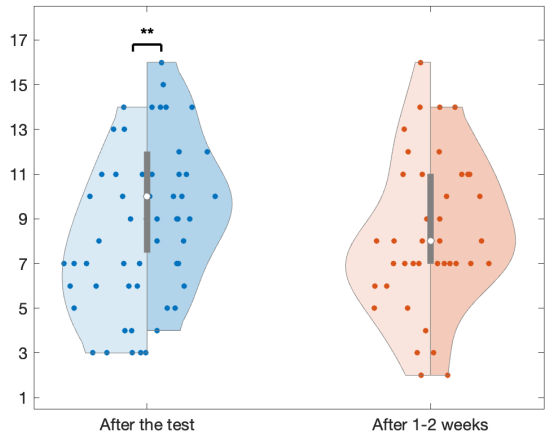
5.1.3 Social Presence. Figure 4c displays the results of administering the social presence questionnaire [36] to the groups experiencing the NR (left) and the HR (right). Results have been normalized to $[1, 5]$ for ease of comparison. It can be observed that the factor Quality of Interaction had the most dispersion among the three factors, with a moderately high median value ($M_N = 3.67, M_H = 3.83$). Conversely, the factors Social Meaning and Presence/Immersion showed a tighter distribution, with slightly lower medians for Social Meaning ($M_N = 3.56, M_H = 3.33$) than for Presence/Immersion ($M_N = 3.67, M_H = 3.67$).

Shapiro-Wilk test for normality rejected the null hypothesis for at least one of the two conditions for factors *Quality of Interaction* ($p_N = 0.014, p_H = 0.035$) and *Presence/Immersion* ($p_N = 0.032, p_H = 0.93$), whereas it failed to reject it for *Social Meaning* ($p_N = 0.167, p_H = 0.223$). By applying the Mann-Whitney test on the non-normal data, no significant differences were observed between the two groups (Quality of Interaction: $z = -0.88, p = 0.38, r = 0.12$; Presence/Immersion: $z = -0.49, p = 0.62, r = 0.07$). Similarly, the Welch's t-test applied on the normally-distributed data revealed no difference between the two groups ($t(52.88) = 0.61, p = 0.54, d = 0.16$)

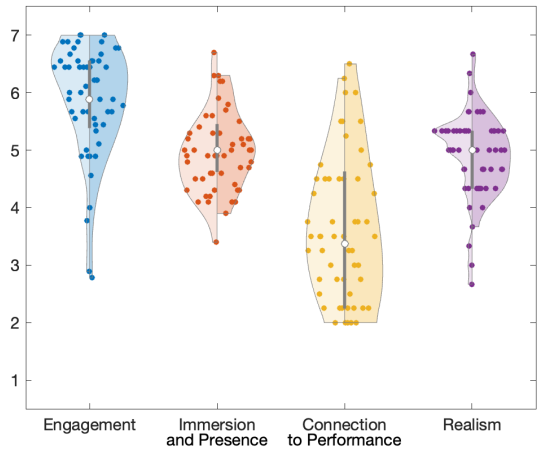
We also examined the correlation between shared presence and immersion, and individual presence and immersion. To do so, we computed Spearman's rank correlation coefficient ρ between the factor *Immersion and Presence* from the VR experience questionnaire, and the factor *Presence/Immersion* of the social presence questionnaire. Results showed a significant correlation between the two factors ($\rho = 0.62, p < 0.001$), indicating a strong relationship between individual and shared presence.

5.1.4 SSQ and SUS. The SSQ show that in HR condition, the score for Nausea is minimal both before ($N = 7.16$) and after ($N = 9.88$) the experience. For Ocumulator and Disorientation it turns from significant ($O = 11.1$, $D = 10.44$) to concerning ($O = 17.33$, $D =$

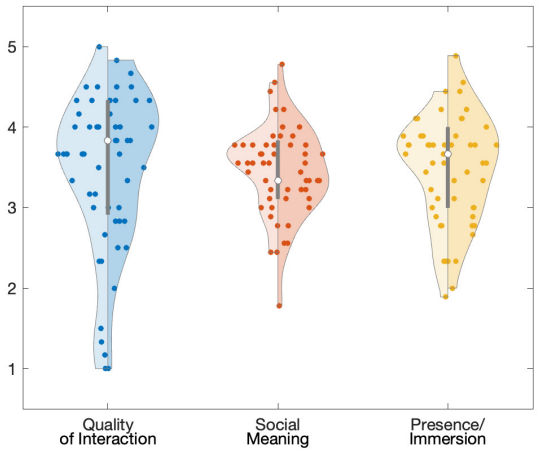
[12]https://app.condens.io/



(a) Results of the knowledge retention questionnaire, administered right after the experience (left), and after a delay of 1-2 weeks(right) with statistically significant difference with medium size effect shown between conditions in the immediate knowledge test.



(b) Results of the VR experience questionnaire showing high levels of engagements for both groups, and moderately hight levels of immersion and presence, and realism. Connection to Performance has a higher dispersion of values and lower median values with respect to the other factors.



(c) Results of the social presence questionnaire normalized to 1,5, showing that the factor Quality of Interaction has the most dispersion among the three factors, with a moderately high median value, and the factors Social Meaning and Presence/Immersion show tighter distribution, with slightly lower median for Social Meaning.

Figure 4: Results of Questionnaires distributed to the participants during the context study. For each violin plot, the NR condition is displayed on the left, and the HR condition on the right. Dots represent individual participants, horizontal bars are medians, and the shape reflects the distribution

19.39). The total score before the test is equal 107.32 and increases to 74.26 after the test. In case of NR condition, the score for Nausea is significant both before (N = 12.27) and after (N = 10.56) the experiment. Ocumulator is concerning before (O = 16.51) and after (O = 15.70). Disorientation changes from being concerning before the experiment (D = 15.91) to being bad after (D = 22.37). The total score before the test is equal 167.13 and increases to 181.89 after the test.

SUS score for the HR condition is 80.71, making it rank as "Excellent". For the NR condition, the score equals 77.5, ranking as "Good".

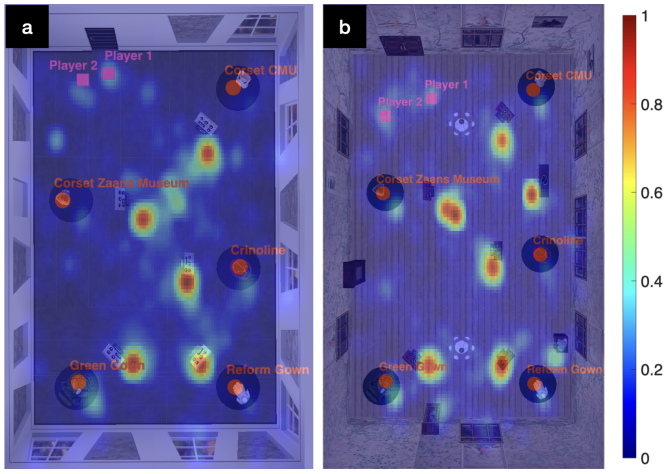


Figure 5: A floor map of the two VR rooms with the user heatmap of the main location visited over time by participants as (a) NR and (b) HR experience.

5.2 Navigation Behavioral Results

Figure 5 provides a general overview of participants' navigation behaviour showing a heatmap of the most frequently visited locations in both virtual environments. These maps aggregate the head position collected from all pairs in the NR (Figure 5 (a)) and HR (Figure 5 (b)). In both conditions, the high-density areas, indicated by red regions, correspond to the interaction points close to the five exhibits, confirming that participants primarily engaged with the exhibition elements. To be noted, participants in the HR explored a broader range of locations, as indicated by yellow/green spots near decorative wall elements. This visible spatial distribution is reflected by a higher standard deviation in the HR heatmap (SD = 0.1038) compared to the NR condition (SD = 0.0980). Additionally, participants in the HR covered a larger area of the walkable area (M = 4.39%, SD = 1.85%) and decided to stay for longer session (M = 15.41 min, SD = 4.15 min) compared to those in the NR space (M = 3.62%, SD = 1.81%; M = 13.53 min, SD = 3.56 min, respectively). These differences in spatial distribution and duration provide a first indication that the HR space encouraged broader exploration.

To further characterize navigation behaviour, we analysed participants' overall motion patterns by combining both spatial position and rotational movements as described in Section 4.3. Figure 6 (a) displays violin plots of the percentage of time in which participants engaged in motion. The three graphs report only spatial movements (blue), rotational movements (middle graph in orange), and their combination (yellow). For each violin plot, the NR condition is shown on the left (lighter shade) and the HR condition on the right (darker shade). Dots also represent individual participants, horizontal bars are medians, and the shape reflects the distribution. Across all three measures, users in the HR showed consistently higher interactivity motion both in terms of spatial and rotational movements, compared to the ones in the NR environment. Specifically, in the NR condition, interaction was relatively low and highly variable (M = 0.24, SD = 0.26) while higher and more stable in the HR (M = 0.52, SD = 0.10). These observations consolidate the previous findings, indicating that the enriched historical environment results in more frequent movements and engagement with the space.

Finally, we examined the interaction between paired participants by evaluating their joint attention and pairwise Euclidean distance. Using spatial proximity and head orientation data, we calculated the percentage of time in which participants simultaneously focused on the same exhibits as described in Section 4.3. The left plot in Figure 6 (b) shows joint attention of pairs in the HR condition (M = 7.57%, SD = 7.67) and NR condition (M = 3.61%, SD = 1.85). No significant difference was found between the two groups.

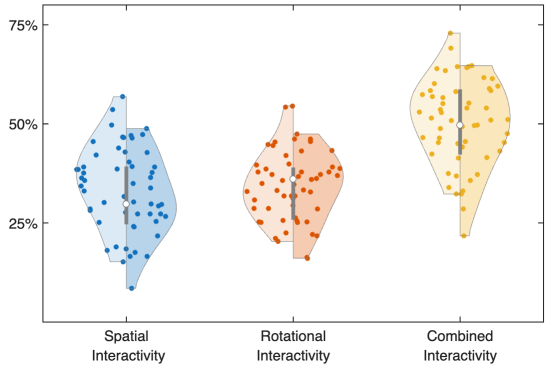
The right plot in Figure 6 (b) displays the distribution of the distance between paired users for both conditions. The two distributions were highly similar between conditions (NR: M = 5.43 m, SD = 3.81 m; HR: M = 5.51 m, SD = 3.87 m), indicating that proxemic behaviour was broadly consistent and that the room design did not influence interpersonal spacing preferences.

To conclude, our behavioral analysis showed different patterns between the two virtual environments. While interpersonal space was consistent across conditions, the HR space engaged more extensive individual exploration as indicated by increased spatial coverage (21% larger), longer exploration time (14% increase), and higher interactivity levels.

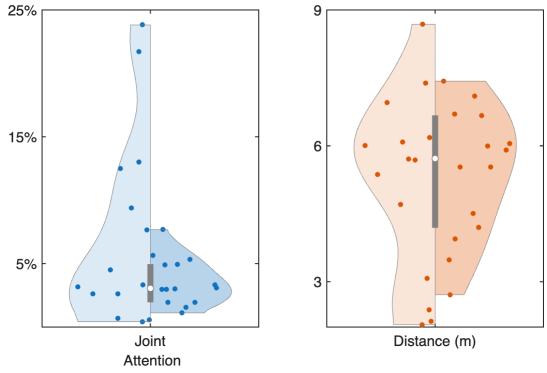
5.3 Qualitative Results

The semi-structured interviews gave us insights into what the participants thought about the experiences. There are many differences between experimental groups; however, some of the results are universal throughout both of them.

5.3.1 Enjoyment. Firstly, the interactions with exhibits were among the most enjoyed elements in both groups. During the interviews, 14 participants from the HR group and 13 from the NR group mentioned interactions while talking about what they enjoyed in the experience (*PN3: "I like the clothings or the exhibits could be rotated around and zoom in, zoom out. Like making it bigger or smaller so that I could check the details of the exhibits."*). In the NR group, 11 participants mentioned windows and outside environment as one of the most enjoyed elements of the environment (*PN15: "The beautiful view out of the window. Because I noticed that out of the window there are many trees and the blue sky and it's so beautiful and looks real. So I also love this part."*). In the HR group, it was only 2 participants. However, we have to take into account that in the HR the windows and skybox were just one out of many additional objects placed in the environment. If we count how many people listed the extra objects as the most enjoyed element of the experience, the number rises to 13. From these results we can see that, in both cases, the participants appreciated the extra contextual or decorative objects in the environment. It is also important to notice that the participants from the NR group, when asked about what they would change in the environment, often responded with a proposition of adding more objects to the space (7 participants, *PN22: "Maybe also put some other images for context or where it was used in context, historical images and such."*). In addition, in the HR group participants listed sociality (8 participants), exhibits (7 participants) and aesthetics (4 participants) as the most enjoyable



(a) Violin plot of users' motion based on both spatial movement (blue) and rotation movements (orange) and their combination (yellow), showing higher interactivity motion for participants in HR condition.



(b) Distribution of joint attention time and pairwise distance per paired participants across conditions.

Figure 6: Navigation analysis based on (a) single and (b) paired participants. For each violin plot, the NR condition is displayed on the left, and the HR condition on the right. Dots represent individual participants, horizontal bars are medians, and the shape reflects the distribution.

elements of the experience, while in the NR group they appreciated that it was possible to see the inside of garments (3 participants).

5.3.2 Engagement. When talking about engagement, the participants from both groups were in strong agreement. Firstly, they were particularly engaged while interacting with exhibits (5 participants from the HR group and 9 from the NR group; *PN14: "I think I was pretty engaged during the time when I was interacting with the dresses and I would make them bigger and I could look at them from all sides. That was pretty amazing."*). Secondly, their engagement was high when interacting with the other person (8 participants from the HR group and 3 from the NR group; *PH2: "When we both experience zooming in or zooming out or talking or watching the text, I felt yes we are both engaged in the same thing."*).

Even though the additional objects in the environment are strongly desired by the participants, they need to behave in a realistic way. The lack of the possibility to interact with objects that are in the environment was one of the causes of reported disengagements (5 participants in the HR group and 2 participants in the NR group).

5.3.3 Environment. During the interviews we asked the participants directly how the environment influenced their experience and understanding of the presented exhibits.

Firstly, in both groups the participants pointed out that the design of the space made their experience pleasant. In the NR group, participants attributed it to the presence of big windows and the space outside (7 participants), but also to other, even though limited, decorative elements: door or stone materials on the walls (*PN9: "Positively, I think, because it had these stone niches on the walls and it had the door. So it at least gave the impression that you could exit the room and it had the windows and you could look outside and there was grass. And that was, in general, very nice"*). Similar reasons were given by the HR group; however, there were more decorative elements to talk about. The participants listed: flower wallpaper, windows and outside scenery, paintings and other additional objects, both related to the main exhibits, but also the ones playing purely decorative purposes (8 participants; *PH2: "I like how the wall is designed with flowers. And then I also like, after looking at the stuff that you assigned to us, I have the curiosity and I went to see the piano. And I was also close to the stones to watch them. I feel it succeeded in catching my attention."*).

Similarly, both groups stated that the design made them feel as if they were in the real room. Once again, they attributed it to the possibility of seeing an environment outside of the windows, and in the HR group - also to the additional objects.

Moreover, 7 participants from the NR group stated that the design did not influence their experience (in the HR group there was only one person with this opinion) and 3 participants called the design "boring". On the contrary, the participants from the HR group stated that the design was "engaging" (4 participants), "fitted well with the exhibition, creating one whole" (3 participants) and was overall a good design (7 participants), because of the "extra objects and how they connected with the main exhibits".

5.3.4 Sociality. 20 participants from the HR group and 22 from the NR group felt positive about the other person being in the experience with them (*PH7: "That was really nice, really fun to also hear. A feeling of doing something together, looking at an object together and see whether this dress suits me from his point of view, if I'm standing in"*). 8 participants from the HR group and 6 from the NR group felt indifferent about it. The participants mentioned the presence of other people made the experience "socially connecting", "fun" and "helping explore new possibilities". Also, most of the participants claimed the conversation with their partner went well, with just a few grading it to be medium or bad. No influence of the context, nor the fact of knowing each other, is visible based on the interviews.

The difference between groups is clear in participants' answers about the virtual space's influence on their understanding of the exhibits. In the NR group, 16 participants felt the virtual space did not enhance their understanding of the exhibits. Those who did cite positive effects mentioned the room's museum-like atmosphere, which promoted focus and learning (4 participants), and the minimal distractions in the space (3 participants; *PN2: "Because it's very tidy. So you will only see exactly what you need to see. Super minimal apart from the clothes."*).

In the HR group, 11 participants pointed to related objects as elements that improved their understanding of the exhibits (*PN16: "The other elements, how they connected to the story. For instance, two elements that I found very compelling were the arsenic stones, and also the picture with the whale bones, because the whale bones were used in the corset. It was a nice connection."*). They also listed the design of the environment fitting the exhibits' times (2 participants) as a factor improving their learning (*PH23: "Yes, because they put it into a time, into a place like a museum space. It felt like it was a real place that actually existed."*). Overall, in the HR group, 20 of the participants claimed the design enhanced their understanding of the exhibits, and the remaining 8 did not agree with that statement.

6 Discussion

6.1 Limitations

During the event at the museum, our exhibition was well-received by the visitors. Participants recognized the exhibition's potential to engage visitors with cultural heritage, praised its topic-appropriate design, and found the overall experience satisfying and well-suited to the museum setting. Even though these findings validate the design approach for this specific exhibition focused on historical fashion, we cannot be sure it will be generalizable for other types of exhibitions. However, the cultural heritage experts believe this type of exhibitions have a place in the museums' future, so more studies about social VR exhibitions' design should be conducted to conclude a more universal set of requirements.

Many participants in the user study mentioned that fashion does not lie in their area of interest, which could influence the attention they paid to the objects and information about them, the level of interaction between partners, and their overall experience. It would be hence beneficial to conduct a similar study in a fashion museum, engaging people who are interested in that kind of exhibition.

During user studies, we also collected many comments from the participants on what could be improved. Three main areas were identified for improvement: adding more interactions, especially with the additional objects, adding more objects and pictures related to the exhibits or the times they come from, especially demonstrating how the garments were worn, and providing more information.

6.2 Benefits of Mixed-Methods Evaluation

Following a holistic approach, this work validates the social VR fashion exhibition (Section 3. Part 1: Museum Exhibition) and explores the role of context in social VR experiences for fashion, combining qualitative user feedback, questionnaires on experience, sociality and knowledge retention, and quantitative analysis of behavioral interaction (Section 4. Part 2: User Experiment).

The potential for VR technology for cultural heritage emerges clearly from the feedback of museum visitors during our VR fashion exhibition. Findings highlight how VR can offer new ways to access fragile materials, enhance engagement, and foster inclusive participation. For example, visitors noted that VR can make cultural heritage accessible to children, remote audiences, and those unable to visit museums in person. They also valued the educational dimension of VR experiences for a better understanding of broader socio-economic history, and expressed enthusiasm for expanding and enriching the collection with additional content.

Based on these initial results, we further investigated the influence of context on learning, experience and sociality in a user study. The findings show that the context has a clear positive effect on knowledge retention: participants in the room enriched with context related to the exhibition topic achieved significantly higher scores in the Knowledge Test compared to those in the neutral spaces. Interviews also confirmed this outcome, with users noting that additional objects in the space enhanced their understanding of the exhibits.

While questionnaire scores on experience did not differ significantly, behavioral navigation data and qualitative feedback point to clear contrasts between the two conditions. For example, interviews revealed that additional contextual and decorative items greatly contributed to participants' enjoyment. In the NR, participants more frequently expressed boredom and shifted their attention to what was happening "outside the window". In contrast, the HR, thanks to its richer design and numerous points of interest, successfully maintained their engagement. This is also confirmed by the behavioral navigation analysis: participants in the HR space explored more extensively, covering a larger area, spending more time in exploration, and interacting more actively. Together, these results highlight the importance of spatial design and contextual richness in sustaining attention and fostering a more engaging experience, suggesting that contexts (or contextually rich spaces) can act as anchors/attractors that encourage visitors to explore and move around.

In terms of sociality, the interviews confirm that the social dimension was essential to the overall experience in both environments. Given these preliminary results, further research is needed to clarify whether and how environmental context shapes sociality in VR exhibitions.

6.3 The Context

In our work, we used four strategies of introducing context: we created a room styled for a 19th-century house, we decorated it with objects from the epoch and items related to the exhibits, we connected the exhibits with a story about how fashion has changed over time, and we introduced contextual information about the exhibits. These contextual strategies turned out to be effective: the participants achieved better learning results, and had a more positive experience compared to the group where the context usage was reduced (no architectural style adjustment, nor extra objects in the space). In our experience, we did not adjust the style of information transmission to the topic of the experience. This decision, made together with curators, was based on the concern that using 19th-century language might make the information too difficult for

visitors to understand, especially considering that many may already find using a VR headset and controllers mentally demanding. However, this method of introducing context can still be effective and should be explored in future research across various types of exhibitions, not limited to 19th-century fashion.

Another important factor is the amount of context that should be introduced to the VR exhibition. In our study the amount of context we introduced turned out beneficial; however, increasing the number of objects in the space could potentially result in too much attention being taken away from the exhibits. Ultimately, one of the most common benefits of the NR mentioned by the participants during interviews was that the room was not distracting them from the exhibits. Too many elements in the virtual environment might also lead to high cognitive load of the users, which in turn can make their experience unpleasant [24]. Hence, it is important to always consult curators while designing the virtual exhibitions. The knowledge they have from creating physical exhibitions can be of great help; however, more research should be done on the optimal usage of context in social VR exhibitions specifically.

6.4 Curators' View on Exhibitions in (Virtual) Reality

While working on the exhibition, we gained many interesting insights from the curators. During the co-design sessions, various ideas of what types of models to use were discussed. There was a proposition to hire an artist to create 3D models that would allow the participants to try out the garments. However, this idea was rejected by the cultural heritage professionals because of two main reasons: firstly, the body movement and posture of people in the 19th century were different from today [69], so showing the participants a cloth from these times displayed around their bodies and saying that is how they would look like in the 19th century would be historically inaccurate. Secondly, it was very important for curators to show the audience actual artifacts, not artistic representations of them. That is why we decided to use the scans created utilizing photogrammetry. However, for some cultural heritage professionals, it was still not enough. During the exhibition in the museum, some of them noted that, for them, the scans were a symbol of an object, and not the object itself. When choosing the exhibits for the virtual exhibition, together with curators, we decided to use the garments that cannot be displayed physically anymore due to their fragility. In hindsight, it proved to be the right choice, considering the comments we gathered from cultural heritage professionals during the exhibition: most professionals would rather see the actual object rather than a scan, but if the object is not available anymore (due to fragility, and in the future even complete disappearance), the scan could be the most accurate representation of this object, which was also noted during the exhibition.

During the design process, curators often mentioned that the VR exhibition should offer something that cannot be provided in the physical world. They claimed that the virtual world cannot compete with the real world, because the real world would always win. That is why it was important for them, as already mentioned, to use scans of the exhibits that are too fragile to be put on physical exhibition, and that could not be seen anymore if not for the virtual exhibition. Similarly, the environment should always offer something that the physical exhibition cannot give to the audience, whether through environmental design (like introducing context or providing an out-of-real-world experience), or through the possibility to interact with the exhibits.

6.5 Design Recommendations for Social VR Exhibitions

During the whole process of the virtual exhibition design with the curators, the user studies and the analysis of the results, we collected a list of design recommendations that future social VR exhibition designers can follow while creating their exhibitions. The list contains the following recommendations:

Added value. Firstly, the virtual exhibition should always bring something new to the visitors that they cannot experience in real life [67]. This could be showing exhibits that cannot be shown in the physical world (because they are too fragile or located in a remote place [48]) or allowing them to interact with the exhibits [28, 50]. The curators repeatedly emphasized that we should not try to replicate the real world, because it is impossible to successfully do that - the real world will always be more attractive. Instead, the virtual experience should complement the real world - offer things that otherwise are impossible.

Content. The experience should always be a mixture of exhibits, interactions, and information, which should be connected in harmonious synergy [67]. According to the curators, the main exhibit, as the central element of the exhibition, should be surrounded by other related objects; however, it is important to maintain balance in the number of exhibits to not take all of the attention away from the main exhibit. Moreover, the main exhibit should be accompanied by an interaction to bring the visitors closer to the artifact [28, 50]. The amount of interactivity in the experience should be well thought through - too many interactive elements can overwhelm the visitors [3]. Additionally, the exhibit and the interactive element have to be complemented by well-curated information. On its own, they do not give the visitor an understanding of what is the purpose of the interaction and why they are watching the presented artifact. This information has to give the complete story and be understandable - otherwise, it may lead to visitors' frustration [4]. All those elements: exhibits, information and interactions, need to be connected together in a perfect balance, creating one, well-functioning experience.

Context. As shown by this work, context has an important role in the social VR exhibitions, as it positively influences the learning and experience of the visitors. Context can be introduced to the experience in multiple ways: by adjusting the architecture of the interior [8, 21, 59], putting additional objects around the exhibit [37], connecting multiple exhibits with each other [6], providing contextual information [28] or modifying the style of information transmission [28]. The selection of methods for introducing context in a specific exhibition should be made by the curators responsible for that exhibition, as different methods may prove effective for different topics. However, the context should always be well-suited to the artifacts and complement the story to be transmitted. Additionally, users often mentioned the importance of the environment outside of the exhibition room (such as scenery visible through

virtual windows). This form of contextualization - placing visitors in a world that does not end at the walls of the virtual museum - was shown to make them feel like they are in a real, unrestricted place.

Sociality. Sociality can be introduced in the experience in various ways. In our experience, while working closely with the curators, we developed three types of interactions between the visitors that can be reused in other experiences. Firstly, Guided Interactions are the actions that participants have to take together in order to progress with the experience (like clicking teleportation buttons - one per visitor - to move to the next space). Secondly, Natural Interactions are all interactions that the participants have because they can see and hear each other. In our experience, it is strongly reinforced by the point cloud representations of users ensured by VR2Gather. Finally, Environment-triggered Interactions describe all of the actions the users take together that are directly influenced by the elements of the virtual world. An example of such interaction is throwing a virtual training ball at each other or trying to adjust the size of the dress by one of the participants while the other one plays the role of a model. This type of interaction is the least dependent on the designers and is mostly discovered while testing the experience with users. Nevertheless, it constitutes an integral element of the experience and is worth highlighting [67].

Transition between spaces. Finally, using context can help gradually move the visitors into the virtual world. The approach assumes starting the experience in a setting resembling a physical space where the users are located (in our case, the museum where our exhibition was displayed) to avoid the shock associated with a sudden appearance in a completely unfamiliar, possibly unusual surrounding. Then, the visitors should move to the space contextually suited to the topic of the exhibition, where they explore the exhibits and interact with them. Finally, the last environment the visitors see should offer a surreal experience, where they can fully engage with interactions, surroundings and events that would not be possible in real life. This approach allows the participants to slowly enter the virtual museum and learn how to interact with it, then fully understand and appreciate the content of the exhibition, and finally, experience new ways of engaging with exhibits that are impossible in the real world [67].

6.6 A reusable framework for Social VR

Through the course of our research over the last few years, we have developed a reusable framework for creating social VR cultural experiences, covering the entire process from requirements definition, through system development, to user evaluation. This framework has been applied across multiple projects in different cultural domains, including not only fashion heritage as in this work but also opera[13] [33], pop music [54], broadcasting[14], and, most recently, bibliology[15] and history[13].

The requirements definition phase relies on a co-design process that iteratively engages domain experts such as museum curators, musicians, or actors, at each stage of development, from initial focus groups through co-design sessions to final validation [67]. Requirements for integrating machine learning capabilities into XR use cases have also been explored following this approach [32]. We are currently extending this co-design approach to support remote co-design with distributed stakeholders [34], which will further consolidate the process for long-distance partnerships.

The system infrastructure is based on VR2Gather [27, 62], an open-source Unity package. Using VR2Gather, immersive cultural user experiences can easily integrate highly realistic 3D humans as participants that can naturally communicate with each other. It has been deployed across cultural heritage, performing arts, and journalism contexts[14].

Finally, we have developed an evaluation and validation framework based on mixed-methods, combining quantitative measures, including standardized questionnaires on presence, immersion, usability, and experience, with behavioral navigation analysis and semi-structured interviews. Instruments are selected per project depending on the specific research questions, while the overall structure remains consistent across studies [33, 54, 64]. In particular, behavioral analysis, including spatial trajectories, head rotation, proxemics, and joint attention, has shown to capture engagement patterns that self-report measures alone would miss, as demonstrated in this study and in prior work [64].

Taken together, the framework we have created and adapted over the years (co-design, infrastructure, evaluation) for social VR cultural experiences has been validated across several domains beyond fashion heritage. This has enabled a general and reusable process, beyond current ad-hoc approaches, for the creation of immersive cultural applications.

7 Conclusion

This paper presents the design, implementation and real-world validation of a social VR fashion exhibition. It also describes a user study exploring the influence of context on users' experience, learning and sociality in social VR exhibitions. The results show that the context has a strong influence on learning (based on statistically significant difference between experimental groups in the results of the Knowledge Test and the participants' answers in the interviews) and experience (based on interview answers). Moreover, in both conditions, participants found sociality to be very important. Overall, the study proves that social VR fashion exhibitions are well-received by museum visitors, who see potential in using social VR in the cultural heritage field. Moreover, it shows the importance of adapting the context to the themes in social VR exhibitions and presents its influence on how people learn and experience the environment.

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A Survey Questions Used for Social VR Fashion Exhibition Validation

(1) To what extent are you satisfied with your experience today? [5 point agreement scale]
(2) What did you enjoy most about your experience today? [open text]
(3) To what extent do you agree that you will share something about your experience today with someone else? [5 point agreement scale]
(4) Did this experience make you think differently about digital cultural heritage? If yes, please tell us how. [open text]
(5) What could be improved? [open text]
(6) To what extent do you agree that you would recommend this experience to others? [5 point agreement scale]
(7) How familiar are you with XR? [5 point familiarity scale]
(8) What is your age? [16 or younger; 17 - 34; 35 - 49; 50 - 69; 70+]
(9) During the last 12 months, have you visited any museums, galleries, libraries or archives, or did you attend any concerts or other cultural events (not for work)? [yes, more than 10 times; yes, between four and ten times; yes, between one and three times; yes, once; no, I only came to this exhibition]
(10) During the last 12 months, have you visited an online museum collection or exhibition? [yes, more than 10 times; yes, between four and ten times; yes, between one and three times; yes, once; no]
(11) Which of the following applies to you? I am currently or in the past was: [Employed in cultural heritage; Employed in education and/or research; Employed in another sector; Out of work; A homemaker; A student; Retired; Unable to work; Other (open text)]

B Knowledge Test

Social XR Fashion Museum - knowledge test

1. Your participant ID (as stated in the email):

_____

The following questions concern Corset from Centraal Museum Utrecht.

2. What materials is this corset made of?

Mark only one oval.

- ◯ Silk, bone
- ◯ Cotton, metal
- ◯ Silk, metal
- ◯ Cotton, bone

3. What was a goal of using this corset?

Mark only one oval.

- Enhancing the waistline by drastically reducing its size.
- Increasing mobility and flexibility during physical activities.
- Bringing physical comfort and confidence to the wearer.
- Creating an exaggerated hourglass silhouette for fashion trends.

4. Which century is the corset from?

Mark only one oval.

- 17th
- 18th
- 19th
- 20th

The following questions concern Corset from Zaans Museum.

5. Who would have worn this corset?

Mark only one oval.

- Only upper class
- Both upper class and working class
- Exclusively royalty and nobility
- Only upper-middle-class women

6. What material is this corset made of?

Mark only one oval.

- Green damask, flannel and whalebones
- Green silk, linen, and ivory
- Green damask, linen and steel
- Green silk, linen and steel

7. Which century is the corset from?

Mark only one oval.

- 17th
- 18th
- 19th
- 20th

The following questions concern the Crinoline.

8. Who would have worn the crinoline?

Mark only one oval.

- Only members of the aristocracy
- Both aristocracy and working class
- Exclusively royalty and nobility
- Only upper-middle-class women

9. What were the risks of wearing crinoline?

Mark only one oval.

- The crinoline hoops could become entangled by the machinery or carriage wheels, gusts of wind could catch the wide skirts and highly flammable fabrics posed fire risks.
- The crinoline skirts could become entangled by machinery, and heavy fabrics could lead to trips and falls.
- The crinoline skirts could become entangled by gusts of wind, and heavy fabrics could cause overheating.
- The crinoline hoops could get caught in carriage wheels, tight-fitting bodices could restrict breathing and thick fabrics could cause overheating.

10. Which century is the crinoline from?

Mark only one oval.

- 17th
- 18th
- 19th
- 20th

11. What material was it made from?

Mark only one oval.

- Silk
- Cotton
- Velvet
- Linnen

The following questions concern the green gown.

12. What was the pigment taken from to give the dress its colour?

Mark only one oval.

- Arsenic and zinc
- Copper and titanium
- Cobalt and titanium
- Arsenic and copper

13. Which century is the gown from?

Mark only one oval.

- 17th
- 18th
- 19th
- 20th

14. What is the gown’s colour?

Mark only one oval.

- Fern’s green
- Moss green
- Scheele's green
- Beryl green

The following questions concern the Reform Gown.

15. Who was this dress created by?

Mark only one oval.

- Association for the Improvement of Women's Clothing
- Institute for the Advancement of Women's and Children's Fashion Design
- The National Dress Reform Association
- Vocational Academy for Fashion and Textiles

16. What materials was it made from?

Mark only one oval.

- Soft, flowing fabrics: rip silk, rhinestones, wood
- Lightweight, luxurious fabrics: satin, sequins, metal
- Durable, high-quality fabrics: polyester, beads, rubber
- Flexible, breathable fabrics: rip silk, beads, wood

17. Who did this dress belong to?

Mark only one oval.

- Mrs. A.M. van Dijk
- Mrs. J.L. Redeke-Hoek
- Mrs. E. Meijer-Brouwer
- Mrs. K. Janssens

18. Which century is the reformation dress from?

Mark only one oval.

- 17th
- 18th
- 19th
- 20th

C Semi-Structured Interview Questions

(1) What did you like the most in the experience?
  (a) (if not already answered) Did you get particularly interested in any physical element of the space?
(2) Were there any moments when you felt particularly engaged or disengaged? What caused these feelings?
(3) How did you feel about the other person being in the experience with you?
(4) How did the conversation with your partner go?
(5) Do you know the person that you were sharing this experience with? For how long?
(6) How would you assess the quality of audio and your partner's visual representation?
(7) Did you feel more connected to any of the garments in comparison to the other ones? Why?
(8) Were the garments scans of good quality?
(9) Did you have knowledge about concepts introduced in the experience? (The information about exhibits)
(10) How did the design of the VR space influence your experience?
(11) Do you feel like the environment influenced communication between you and your partner? How?
(12) Did the virtual space enhance your understanding of the presented garments? If so, how?
(13) What would you change in the environment?