VISUAL REVIEW | Vol. 18, No. 3, 2026 | ISSN 2695-9631
International Visual Culture Review / Revista Internacional de Cultura Visual
https://doi.org/10.62161/revvisual.v18.6238

DIGITAL TRANSFORMATION AND USER EXPERIENCE IN VIRTUAL MUSEUMS
An Exploratory Study with Generation Z at MAN Virtual

OLIVER CARRERO MÁRQUEZ [1]
ocarrero@ucm.es
JUAN ENRIQUE GONZÁLVEZ VALLÉS [1]
juanengo@ucm.es
LIDIA LÓPEZ MENA [2]
lidia.lopez@esic.university
[1] Universidad Complutense de Madrid, España
[2] ESIC Universidad, España

KEYWORDS

Digital transformation
Virtual museums
User experience
Accessibility,
Generation Z
Immersive environment
Cultural heritage

ABSTRACT

This study examines the digital transformation of museums by evaluating user experience (UX), accessibility, and usability within virtual environments, with a specific focus on Generation Z's interaction with MAN Virtual, the digital platform of Spain's National Archaeological Museum (Museo Arqueológico Nacional). Employing an exploratory quantitative design, the research investigates the influence of narrative coherence, interface design, and device type on engagement, sense of presence, and satisfaction. The findings reveal high ratings for usability and visual coherence; however, the perceived level of immersion varies according to the degree of interactivity and the emotional resonance of the virtual environment. These results underscore the critical importance of user-centred design and accessibility principles in the domain of digital heritage, highlighting the need to develop inclusive, emotionally meaningful, and educationally impactful virtual experiences tailored to emerging audiences.

Received: 23/ 01 / 2026
Accepted: 28/ 02 / 2026

1. Introduction

Nowadays, museums are configured as hybrid spaces where communication, learning, and participation converge, driven by accelerated digitisation processes and visitor-centred strategies (Rushton and Schnabel, 2020; Smykova, 2024). This shift responds to a redefinition of the relationship between audiences and heritage, in which digital interaction becomes a vehicle for expanding access, diversifying audiences, and generating new forms of symbolic appropriation (Stelmaszczyk et al., 2024). Furthermore, digitisation must be understood as a process of cultural innovation that restructures mediation practices and communication models (Wu and An, 2024). In this context, virtual environments and XR experiences are consolidated as key tools for promoting autonomous learning, inclusion, and multisensory visitor participation (Barreto-Paredes et al., 2022).

This constitutes a new museological ecosystem whose effectiveness depends on its ability to balance the technological dimension with the communicative one, ensuring that the user experience is clear, meaningful, and emotionally satisfying (Silva and Teixeira, 2022). In this reality, the evaluation of user experience (UX)—particularly among Generation Z—has become a critical tool for analysing how interface design, visual narrative, and accessibility influence content comprehension and visitor engagement (Bonel et al., 2023).

The present study aims to evaluate usability, accessibility, and user experience on the MAN Virtual platform of Spain's National Archaeological Museum, as the most recent benchmark environment in Spain for the integration of technology, narrative, and heritage communication (Samsung, 2017). From a methodological perspective, a quantitative, exploratory, and comparative approach was adopted, oriented towards identifying strengths and areas for improvement in digital interaction, following the methodological recommendations for empirical research in immersive environments (Paananen et al., 2022). A structured questionnaire was administered to 80 participants aged between 16 and 28 years. Users were able to choose their access device, opting exclusively for computer or tablet, with no records of mobile use.

The results reveal an overall positive experience, with high ratings in usability, accessibility, and visual coherence, suggesting that the environment is comprehensible and functional even for users with limited prior experience in virtual museums. However, more experiential dimensions—such as immersion or sense of presence—exhibit greater variability, indicating that emotional engagement requires additional conditions of design and interactivity. These conclusions align with findings from previous research on extended reality, which emphasise the importance of interactive narrative and aesthetic coherence in generating meaningful experiences (Alatrash et al., 2023; Gatto et al., 2025).

2. Theoretical Framework

2.1. The Impact of Digital Transformation on the Evolution from Object-Museum to Experience-Museum

The museum has become a space of communication and experience, thanks to an epistemological reconfiguration that places the visitor at the centre of the meaning-making process. In this view, the museum is conceived as a narrative and participatory ecosystem in which knowledge, emotion, and mediation converge (Giannini y Bowen, 2019). In this regard, the Contextual Model of Learning proposed by Falk y Dierking (2016) provides a theoretical foundation for understanding this transformation. According to this model, the museum experience is constructed through the interaction between personal, sociocultural, physical, and technological dimensions, where the latter factor enables the visit to extend beyond physical boundaries, generating experiences that persist over time through interactive platforms and transmedia content. This represents a qualitative leap for communication, which for Parry (2013) constitutes a turning point towards the museum as a network of connected meanings. Similarly, Giannini y Bowen (2019) agree that the digital museum distributes interpretive authority between professionals and audiences, fostering narrative co-authorship.

The participatory culture underpinning this evolution can be explained through the concept of spreadable media, developed by Jenkins et al. (2013). The authors argue that cultural content gains value when it can circulate, be shared, and reinterpreted by audiences. In the museum context, this idea drives the extension of physical exhibitions into digital environments, allowing the public to prolong their experience through social media, repositories, and virtual tours. Kidd (2014) also maintains that

the experience-museum functions as a distributed narrator capable of articulating multiple voices, promoting the inclusion of diverse perspectives and active visitor participation in heritage interpretation. Likewise, Hooper-Greenhill (2020) advocates for interpretive pedagogy, which conceives museum education as a relational process based on emotion, reflection, and the shared construction of knowledge.

Further support for this perspective comes from studies such as Zhou et al. (2022), who demonstrated through a meta-analysis that augmented reality (AR) and virtual reality (VR) technologies improve retention and conceptual understanding when used within coherent narratives aligned with defined educational objectives. Cecotti (2022) expands this view by introducing the concept of cognitive presence, which describes the connection between emotion and attention as the foundation of effective immersion. Complementarily, Trichopoulos et al. (2022) showed in the CHATS project that tangible interfaces and multisensory stimuli enhance autonomous exploration and emotional engagement among visitors.

More recently, Li et al. (2024) highlight that this transformation entails challenges related to sustainability and digital governance, as platform interoperability, technological obsolescence, and data preservation have become structural issues for museums. Similarly, Li et al. (2023) observed that recent museological research is increasingly oriented towards the evaluation of user experience (UX), accessibility, and personalisation, positioning extended reality as a central axis of museographic innovation. For example, the v-Corfu project, developed by Komianos et al. (2024), combines virtual exhibition, interactive materials, and educational resources within a coherent transmedia architecture. These authors conclude that the effectiveness of digital experiences depends not only on technical quality but also on narrative coherence and user engagement. On a broader level, Natale et al. (2024) emphasise the importance of implementing open governance models that balance innovation, ethics, and cultural sustainability in the development of digital museums.

Nevertheless, Marty (2009) warns of the risk that this transformation may entail if it loses focus and falls into the "spectacle effect," whereby technology displaces interpretive content in favour of visual spectacularity. This possibility, according to Giannini y Bowen (2019), may arise from fascination with technological novelty at the expense of cognitive depth in the experience, if not accompanied by critical reflection. From a technical perspective, Ponsard and Desmet (2022) stress the importance of adopting open standards and documentation practices to ensure the sustainability and preservation of digital projects. In terms of learning, Melendreras-Ruiz et al. (2024) compared in-person and virtual reality experiences, demonstrating that VR increases attention and enjoyment but does not necessarily improve knowledge retention without appropriate pedagogical scaffolding.

In another vein, accessibility has consolidated as another fundamental pillar of the experience-museum. Guedes et al. (2020) and Vaz et al. (2022) show that assistive technologies—such as haptic guides or multisensory tours—expand access to heritage and enrich the aesthetic experience. Along these lines, Al Sulaimani et al. (2023) developed an acoustic navigation system with 3D sound for visually impaired individuals, while Kasowski et al. (2023) proposed extended reality models that adjust contrast and field of view, thereby reducing visual fatigue and improving perceptual inclusion.

Finally, Yang et al. (2025) conceive the experience-museum as a polyphonic narrator that offers multiple interpretive trajectories, fostering autonomous exploration. This conception is complemented by Smets and Euser (2025), who add that hybrid ecosystems—combining the physical and the digital—extend the continuity of learning and strengthen emotional connection with heritage.

2.2. Immersive Experience and Museographic Communication in XR Environments (AR, VR, MR)

Extended reality (XR) technologies, encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR), shift the visitor from a contemplative role to an exploratory one, where heritage understanding occurs through action, emotion, and symbolic manipulation of digital objects (Silva and Teixeira, 2022). For example, Man and Gao (2022) demonstrate that archaeological reconstructions in VR facilitate a richer contextual understanding of tangible heritage by allowing users to explore three-dimensional environments in which objects are situated within their original historical framework. In a similar vein, Barreto-Paredes et al. (2022) found that XR environments, when integrating interactivity and immersive aesthetics, generate higher levels of sustained attention and a more favourable disposition towards learning than conventional online exhibitions.

Interest in the psychological dimension of immersion has led authors such as Ariya et al. (2025) to establish that the intensity of perceived presence—the sense of "being there"—depends on the coherence between visual stimuli, sound, and narrative, rather than solely on graphical realism. Likewise, Huang et al. (2025) introduce the concept of meaningful interactivity to explain how the virtual environment responds coherently to the visitor's actions in alignment with the museum's cultural and educational objectives. This impact has also been analysed by Hammady et al. (2021), who provide a framework for evaluating immersive design by developing a holographic guide model in MR capable of accompanying the visitor with context-sensitive information based on movement and distance. Their results show that perceptions of presence and satisfaction increase when the system adapts to the user's cognitive pace. Similarly, Hammady et al. (2018) emphasise that marker-based AR facilitates spatial appropriation of the environment and stimulates a more active relationship with heritage, provided the interface is intuitive and visual feedback is immediate.

However, as noted in the previous section, the immersive experience is not limited to technical spectacularity. Pagano et al. (2021) demonstrated this when evaluating usability perceptions in European MR exhibitions, concluding that narrative coherence and interaction fluency are the factors that most influence visitor satisfaction, above the level of technological sophistication. This principle is confirmed in the study by Pei et al. (2023), who analysed VR interfaces in digital museums and showed that navigation clarity and visual consistency directly correlate with perceptions of educational value.

From the perspective of museum learning, Jangra et al. (2025) found that VR experiences incorporating exploratory tasks and immediate feedback increase intrinsic motivation and conceptual retention, whereas passive simulations tend to produce less memorable experiences. In contrast, Enriquez et al. (2024) evidenced that web-VR integrations enable the expansion of educational reach for local museums, facilitating participation by geographically distant communities and consolidating models of autonomous learning.

Regarding narrative, the work of Paananen et al. (2022) highlights its role in perceptions of realism and the activation of emotional memory. Their analysis of an immersive educational environment inspired by Assassin's Creed Odyssey: Discovery Tour demonstrated that the combination of exploratory freedom and guided narrative structure promotes a more stable experience of "cognitive presence" than fully free navigation.

Another key aspect in the communicative effectiveness of XR experiences is interface design. Gilani et al. (2023) show that a coherent interface acts as a cognitive mediator, reducing mental load and favouring content comprehension, whereas visually overloaded interfaces or unpredictable navigation disrupt the sense of flow and weaken perceptions of immersion.

In addition to this, for Lyu (2024), the digitisation of cultural heritage implies a model of active conservation, in which each virtual experience constitutes a form of mediation that combines knowledge, emotion, and ethics. In this model, immersive museums do not replace the physical space but complement it through expansive narrative environments that extend interpretation and learning.

3. Methodology

In this immersive museological context, it is essential to evaluate usability and user experience (UX) on digital platforms such as MAN Virtual of the National Archaeological Museum (Museo Arqueológico Nacional – MAN), with particular attention to emerging audiences such as Generation Z. This group possesses advanced technological competencies but also holds high expectations in terms of interactivity, accessibility, and personalisation (Gilani et al., 2023; Yang et al., 2024).

The present study adopts a quantitative methodology with an exploratory and comparative design, aimed at identifying strengths and weaknesses in the virtual experience offered by MAN Virtual from the perspective of Generation Z users, who accessed the platform exclusively via computer, tablet, or mobile phone. The selection of these devices corresponds to the typical accessibility framework for this age group, excluding more specialised technologies such as head-mounted displays (HMDs), whose widespread availability remains limited (Jangra et al., 2025; Pei et al., 2023).

Within this framework, the following objectives are proposed:

OB1 Analyse users' perceptions of ease of use, accessibility, and navigation on the platform.

OB2 Evaluate levels of satisfaction, engagement, and sense of presence.

OB3 Identify potential barriers to use related to the interface or the museographic narrative.

OB4 Explore differences in the experience according to the type of device employed.

OB5 Formulate applicable recommendations for user-centred design (UCD) in virtual museological contexts.

To achieve these objectives, five research questions are posed, inspired by the work of Hammady et al. (2021), who argue that immersive design and the access platform directly influence the visitor experience:

R1: Do Generation Z users perceive the immersive experience of MAN Virtual as highly usable?

R2: Are engagement and sense of presence higher among users accessing via computer compared to tablet or mobile phone?

R3: Are there significant differences in UX ratings according to the type of device used?

R4: Does the narrative and visual structure of the environment positively influence perceptions of accessibility?

R5: Does at least one segment of the sample identify usability limitations when accessing via mobile phone?

3.1. Immersive Experience and Museographic Communication in XR Environments (AR, VR, MR)

This is a quantitative, exploratory, cross-sectional, and non-experimental study based on a comparative design across three access preferences: computer, tablet, and mobile phone. The sample consisted of 80 individuals selected through convenience sampling, with the following inclusion criteria: aged between 16 and 28 years, residing in Spain, familiar with the use of web platforms, and having no prior experience visiting MAN Virtual. The choice of a quantitative methodology is grounded in the need for an initial exploratory analysis of immersive environment evaluation, as recommended by recent studies (Ariya et al., 2025). Furthermore, the use of validated scales and instruments adapted to digital contexts ensures the reliability and validity of the questionnaire. Likewise, the comparative approach across devices responds to findings from Jangra et al. (2025) y Pei et al. (2023), who demonstrate that perceptions of usability vary significantly depending on the hardware employed.

Given the exploratory nature of the study and its focus on real-world usage experience, participants were allowed to freely choose the device from which they accessed the virtual environment. This decision was based on criteria of ecological validity, prioritising the reproduction of natural and habitual navigation conditions among young Generation Z users, who tend to spontaneously select the device they perceive as most comfortable or functional for digital interaction (Bonel et al., 2023). Forcing an equal distribution across devices would have introduced artificial distortion into access patterns and could have negatively affected the authenticity of the user experience. Therefore, the objective was not to compare numerically balanced groups but to observe qualitative differences and descriptive trends arising from users' real choices, in line with recommendations from research on usability and user-centred design (Gilani et al., 2023; Hammady et al., 2018). The absence of participants who opted for mobile devices is thus interpreted as a meaningful result in itself, revealing a spontaneous preference for larger screens in digital heritage exploration contexts, consistent with prior studies on ergonomics and visual perception in XR environments (Ariya et al., 2025; Pei et al., 2023).

The emphasis on Generation Z aligns with research on emerging audiences in digital museums (Bonel et al., 2023; Gilani et al., 2023), recognising that this group constitutes the core of future museum audiences and exhibits specific characteristics in their relationship with digital platforms, such as a demand for immediacy, interactive narrative, high aesthetic sensitivity, and a preference for autonomous navigation (Aristeidou et al., 2023).

Participants were recruited through social media, educational centres, youth associations, and institutional channels linked to digital heritage. Once participation was accepted, they accessed the MAN Virtual environment and subsequently completed the questionnaire. They were previously informed of the study's purpose, with guarantees of anonymity and confidential data processing in accordance with the General Data Protection Regulation (European Parliament and Council of the European Union, 2016). Informed consent was obtained via the digital platform.

Access to the environment took place through a free exploration session lasting 15 to 20 minutes, after which participants completed an online structured questionnaire.

For data collection, a questionnaire was also designed, combining validated scales from similar studies (Hammady et al., 2020; Pei et al., 2023). The form was divided into the following sections:

- Sociodemographic and contextual data, including age, gender, education level, familiarity with digital museums, access device, and connection environment.

- Perceived usability, using an adapted version of the System Usability Scale (Brooke, 1996), along with items on navigation clarity, menu hierarchy, and ease of task completion (Pagano et al., 2021).
- User experience, incorporating indicators from the User Engagement Scale (O'Brien and Toms, 2010) to measure aesthetics, attention, satisfaction, and perceived novelty.
- Presence and flow, assessed through items from the Igroup Presence Questionnaire (Schubert et al., 2001) and the Flow Short Scale (Engeser and Rheinberg, 2008), focusing on perception of control, clarity of objectives, and concentration.
- Accessibility and inclusion, integrating questions inspired by WCAG 2.1 guidelines and models of cognitive and emotional accessibility proposed by Garcia Carrizosa et al. (2020).
- An open-ended question intended to gather free comments on improvable aspects, encountered difficulties, or highlighted elements of the experience.

The quantitative scales employed a 7-point Likert-type format, and the average response time was 8 to 10 minutes.

4. Results

4.1. Characterisation of the Sample and Access Conditions

The analysed sample is characterised by a young profile, predominantly university students, with access primarily from desktop devices. As shown in Table 1, the sample has an approximate mean age of 20.3 years, with moderate dispersion and a relatively narrow range, allowing it to be clearly characterised as a young cohort. A strong concentration is observed in the 19–20 age bracket, which accounts for 70% of the sample.

Table 1. Distribution of the sample by age group

Age group	n	%
16–18	6	7.5
19–20	56	70.0
21–22	2	2.5
23–24	15	18.8
25–26	0	0
27	1	1.2

Source: Own elaboration, 2025.

Regarding gender, the sample shows a higher presence of women, 58.8% (n=47), compared to 38.8% (n=31) men and 2.4% who preferred not to declare it (n=2). Although this distribution allows for descriptive contrasts between women and men, subsequent analyses did not reveal statistically robust differences in user experience ratings associated with this variable.

The level of education shows even greater homogeneity, with 97.5% (n=78) holding university studies. In terms of access conditions—where users were given the option to choose freely among the three devices—the use of the MAN Virtual environment took place predominantly from a computer, 81.2% (n=65), followed by tablet, 18.8% (n=15), with no instances of mobile access.

Finally, prior experience with virtual museums or immersive experiences, as presented in Table 2, indicates that 65% of participants had not previously used this type of environment. However, the comparative analyses conducted show that this variable is not associated with significant differences in user experience ratings, suggesting that the environment is comprehensible and usable even for novice users.

Table 2. Previous experience in virtual museums

Previous experience	n	%
No	52	65.0
Yes	28	35.0

Source: Own elaboration, 2025.

4.2. Descriptive Results of the User Experience

This section is addressed through the questionnaire items, organised into five analytical dimensions: usability, engagement, presence, perceived accessibility, and narrative/visual.

Table 3 shows an overall high rating of the experience, with means equal to or above 6 in four of the five dimensions. The narrative/visual dimension achieves the highest mean (M = 6.30; SD = 0.82), indicating that participants perceive the environment as visually coherent, attractive, and well structured. Perceived accessibility (M = 6.12; SD = 0.94) and usability (M = 6.04; SD = 0.91) also present high values, suggesting that the system is comprehensible, manageable, and clear even without external assistance. Engagement obtains a similar mean (M = 6.00; SD = 1.00), reflecting a pleasant and relevant experience for the majority of users. In contrast, presence is the dimension with the lowest mean (M = 5.54; SD = 1.15) and exhibits greater dispersion, pointing to a more heterogeneous perception of the immersive experience that is not equivalent to a physical, non-virtual one.

Table 3. Descriptive statistics by construct

Construct	Mean	SD	Median	Min	Max.
Narrative/visual	6.30	0.82	6.33	4.33	7.0
Perceived accessibility	6.12	0.94	6.25	3.50	7.00
Usability	6.04	0.91	6.17	3.42	7.00
Engagement	6.00	1.00	6.13	2.88	7.00
Presence	5.54	1.15	5.67	2.00	7.0

Source: Own elaboration. 2025.

Regarding the items with the highest means, these are concentrated in those addressing instrumental aspects of the design, such as information organisation, visual coherence, text clarity, and the sense of control during navigation. These results reinforce the notion that the MAN Virtual environment functions robustly as an interface, facilitating orientation and reducing the user's cognitive load.

In the item "The information you found was well organised and structured" (M = 6.49; SD = 0.77), the mode is at the maximum scale value (7), indicating that the value most frequently selected by participants corresponds to the highest level of agreement. The combination of a near-ceiling mean, low standard deviation, and mode at 7 suggests a strongly negatively skewed distribution, with responses clustered in the upper values (6–7) and very limited presence of low scores. This statistical pattern allows us to assert that the perception of good information organisation is highly consensual within the sample and does not depend on extreme cases.

A very similar pattern is observed in the item "The platform seemed visually coherent to me" (M = 6.46; SD = 0.80), where the mode again corresponds to 7. The low dispersion and the alignment between high mean and maximum mode indicate that the majority of participants converge on a very positive evaluation of the environment's visual coherence. From the perspective of user experience, this result is statistically relevant because visual coherence acts as a structural variable that reduces cognitive load and promotes fluid navigation, as reflected in the homogeneity of responses.

The item "The colours and texts were easy to distinguish" (M = 6.45; SD = 0.81) likewise shows a mode of 7, together with moderate standard deviation. This pattern indicates that basic visual accessibility not only achieves high average values but does so consistently across participants. The slightly greater dispersion compared to the previous items suggests the presence of a few isolated cases with lower ratings, although insufficient to alter the central tendency. Statistically, this translates into a distribution concentrated at the upper extreme, consistent with an effective visual design for the majority of users.

In the global item "Overall, using this environment was a good experience" (M = 6.44; SD = 0.82), the mode is again at 7, confirming that the positive evaluation of the experience is not merely an effect of the mean but the result of a dominant frequency of maximum scores. This item exhibits slightly greater dispersion than the purely instrumental ones, which is expected given that it represents a synthetic evaluation integrating multiple dimensions of the experience.

Finally, the item "The system responded appropriately to my actions" (M = 6.41; SD = 0.85) shows a mode at 6, unlike the previous items. This statistical detail is noteworthy because, although the rating remains high, the most frequent value is not the absolute maximum. The higher standard deviation and the shift of the mode to 6 suggest greater heterogeneity in the perception of system responsiveness, possibly associated with occasional experiences of latency, variable fluidity, or differences in the access device. From the user experience perspective, this item constitutes an initial quantitative indication of

mild friction, consistent with the comments collected in the open-ended question, which will be examined later.

In contrast, the items with the lowest means in the questionnaire are all linked to complex experiential dimensions, such as immersion, spatial orientation, and the motivational impact of the environment (Table 4).

Table 4. Items with the lowest mean ratings

Item (summary)	Mean	DT
I lost track of time	5.03	1.47
My interest in archaeology improved	5.19	1.33
I found it easy to find my way around the tour	5.62	1.24
Sense of physical presence	5.64	1.32

Source: Own elaboration, 2025.

The item "I lost track of time while exploring" (M = 5.03; SD = 1.47) presents the lowest mean in the entire questionnaire and, at the same time, the highest standard deviation, indicating considerable heterogeneity in responses. The mode falls at intermediate values (5), rather than at the upper extremes of the scale, suggesting a lack of clear consensus among participants. In terms of user experience, this result indicates that the environment does not consistently generate states of flow or deep absorption; rather, such a sensation appears only in a portion of the sample.

In the item "This environment has increased my interest in archaeology" (M = 5.19; SD = 1.33), the mode is at 6, indicating that the most frequent response level is positive, though not maximal. The relatively high standard deviation suggests the coexistence of two subgroups of users: one that perceives a clear impact on their thematic interest, and another for whom this impact is limited or neutral. Statistically, this item exhibits less pronounced negative asymmetry towards the upper extreme compared to the functional items, reinforcing the idea that motivational impact depends to a greater extent on individual and contextual factors.

The item "I found it easy to orient myself within the tour" (M = 5.62; SD = 1.24) shows a moderately high mean but notably greater dispersion than that observed in basic usability items. The mode is at 6, indicating that the predominant perception is positive, though not unanimous. The breadth of the standard deviation suggests that while some users encounter no orientation difficulties, others experience moments of disorientation or a lack of clear references. From a statistical perspective, this item occupies an intermediate position between the well-established functional aspects and the more fragile experiential dimensions.

Similarly, the item "I felt a sense of presence, as if I were physically there" (M = 5.64; SD = 1.32) follows a comparable pattern, with a mode at 6 and relatively high dispersion. The difference between the mean and the mode suggests that, although the most frequent rating is positive, a relevant number of responses fall at intermediate levels of the scale. This statistical configuration indicates that the sense of presence depends on specific conditions of use, prior expectations, or the degree of personal involvement.

From the perspective of user experience, these results show that the dimensions related to immersion, spatial orientation, and motivational impact constitute the main sources of variability in the experience. These are not structural deficits, as the means are not low. Rather, they represent areas where the experience does not consolidate uniformly across all users. Conceptually, this pattern suggests that usability, accessibility, and visual coherence function as necessary but not sufficient conditions for generating states of presence and flow.

4.3. Relationships between Dimensions of User Experience

In order to explore the internal structure of the perceived user experience in greater depth, a correlational analysis was conducted among the five evaluated dimensions: usability, engagement, presence, perceived accessibility, and narrative/visual. Given the ordinal nature of the scales and the potential presence of non-normal distributions, Spearman's rho coefficient was employed, which allows the identification of monotonic associations without assuming normality. To avoid spurious interpretations arising from multiple comparisons, significance levels were adjusted using the false discovery rate (FDR) correction.

Table 5 presents the correlation matrix between the constructs. Overall, the results reveal a pattern of positive and statistically significant correlations across most dimensions, suggesting that the user

experience in the MAN Virtual environment is configured as an interconnected system rather than a set of independent components.

Table 5: Correlations between dimensions of user experience (Spearman)

Related constructs	ρ (Spearman)	p
Usability – Accessibility	0.71	<.001
Usability – Narrative/visual	0.68	<.001
Accessibility – Narrative/visual	0.66	<.001
Engagement – Presence	0.64	<.001
Usability – Engagement	0.59	<.001
Narrative/visual – Engagement	0.57	<.001
Accessibility – Engagement	0.54	<.001
Presence – Usability	0.42	<.01
Presence – Accessibility	0.39	<.01

Source: Own elaboration, 2025

From a statistical perspective, all observed correlations are positive and significant, with ρ values ranging from 0.39 to 0.71, indicating associations of moderate to high magnitude according to conventional interpretation criteria (Cohen, 1988). This pattern confirms that the various dimensions of the user experience do not operate independently but form part of a coherent relational structure.

The strongest correlations are concentrated between usability, perceived accessibility, and narrative/visual. In particular, the relationship between usability and accessibility (ρ = 0.71) constitutes the strongest association in the matrix, indicating that users who perceive the environment as accessible (legible, comprehensible, and cognitively manageable) also tend to rate it as highly usable. The high magnitude of the coefficient suggests that both dimensions share a common perceptual foundation and that, from the user's perspective, ease of use emerges as a direct consequence of design accessibility.

Similarly, the correlation between usability and narrative/visual (ρ = 0.68) and between accessibility and narrative/visual (ρ = 0.66) highlights the structural role of visual design and information organisation in constructing the functional experience. Statistically, these coefficients indicate that improvements in the visual and narrative coherence of the environment are systematically associated with enhanced perceptions of clarity and control during interaction.

Engagement shows moderate correlations with all functional dimensions, particularly with usability (ρ = 0.59), narrative/visual (ρ = 0.57), and accessibility (ρ = 0.54). This pattern suggests that user involvement does not depend solely on intrinsic interest in the content but is reinforced when the interaction is fluid and the environment presents clear visual logic. From a statistical viewpoint, engagement acts as a bridging variable, linking instrumental dimensions with the subjective experience of enjoyment and motivation.

Presence exhibits its highest correlation with engagement (ρ = 0.64), indicating a strong association between emotional involvement and the sense of "being inside" the environment. By contrast, its correlations with usability (ρ = 0.42) and accessibility (ρ = 0.39), although significant, are noticeably lower. This statistical gradient suggests that presence does not arise automatically from a usable or accessible environment but requires additional elements

4.4. User Experience and Access Device

In order to explore whether the type of device used to access the National Archaeological Museum's virtual environment influences the perceived user experience, descriptive and comparative analyses were conducted between the two groups present in the sample: users who accessed via computer and users who accessed via tablet. Given that no accesses from mobile phones were recorded, this device is excluded from the analysis and not incorporated as an analytical category.

As indicated in section 4.1, the distribution of the sample by device is clearly asymmetrical, with a predominance of access from computer (n = 65) compared to tablet (n = 15). This difference in group size requires cautious interpretation of the results, prioritising the reading of descriptive trends and effect sizes over strict statistical significance.

Table 6 presents the means and standard deviations of the five user experience constructs according to the access device. In general terms, users who accessed via computer show slightly higher means across all analysed dimensions, particularly in usability, narrative/visual, and engagement. Nevertheless, the observed differences are moderate and do not reach statistical significance after the

application of robust contrast tests, indicating that the device alone does not account for substantial differences in the perceived experience.

Table 6: User experience based on the device used

Construct	Computer (Mean ± SD)	Tablet (Mean ± SD)
Usability	6.08 ± 0.88	5.87 ± 0.96
Perceived accessibility	6.16 ± 0.92	5.96 ± 1.01
Narrative/visual	6.34 ± 0.79	6.12 ± 0.90
Engagement	6.05 ± 0.96	5.78 ± 1.08
Presence	5.60 ± 1.12	5.29 ± 1.24

Source: Own elaboration, 2025.

Tabla 6 allows for an analysis of whether the user experience in the National Archaeological Museum's virtual environment varies according to the access device. The results show, first, that the experience is positive on both devices—computer and tablet alike. The means for all constructs are clearly situated at high values, indicating that the environment functions adequately regardless of the device used.

However, upon closer examination of the results, access via computer tends to yield slightly higher ratings across all dimensions of the experience. In terms of usability, computer users describe a more stable and uniform experience. This suggests that the environment adapts particularly effectively to a large-screen context with keyboard and mouse control, where spatial orientation, text reading, and interaction are more predictable. In contrast, on tablet, while some users rate it very positively, others encounter greater difficulties.

This greater variability is also observed in more experiential dimensions, such as engagement and presence. On computer, ratings tend to cluster at high levels, pointing to a more consistent experience in terms of involvement and sense of control. On tablet, however, responses are more heterogeneous. This suggests that emotional involvement and the sense of "being inside" the environment are not activated in the same way for all users when the experience occurs on a touch-based device.

A particularly relevant aspect is that accessibility and visual narrative maintain high values on both devices. This indicates that the basic elements of the design (visual clarity, legibility, graphic coherence, and content comprehension) function robustly and are not compromised by the device.

4.5. Analysis of the Open-Ended Question and Triangulation with Quantitative Results

In general terms, the open-ended responses confirm the overall positive evaluation of the National Archaeological Museum's virtual environment, consistent with the high quantitative scores observed in usability (M = 6.04), perceived accessibility (M = 6.12), and narrative/visual (M = 6.30). Notably, 14 participants (17.5% of the sample) explicitly stated that they would change nothing or that the experience had been entirely adequate, reinforcing the existence of a core group of users for whom the experience is fully satisfactory.

Table 7: Open-ended question results, triangulated with quantitative results

Identified thematic axis (open-ended question)	Frequency (n / %)	Associated quantitative evidence	Observed difference (means)
Orientation and navigation	22 / 27.5%	The item "I found it easy to find my way around the site" has a lower mean and greater dispersion than other usability items	Usability: 5.70 (mention orientation) vs 6.16 (do not mention)
Interactivity/controls	9 / 11.3	The Presence dimension is the lowest and most dispersed in the study	Overall presence: M = 5.54 (SD = 1.15); item "I lost track of time": M = 5.03 (SD = 1.47)
Content and mediation (more information, context)	10 / 12.5	Item "This environment has increased my interest in archaeology" with moderate mean and high dispersion	Interest in archaeology: M = 5.19 (SD = 1.33)
Technical aspects / performance	4 / 5.0	Direct association with the Presence dimension	Presence: 4.08 (technical mention) vs 5.61 (rest)
Explicit satisfaction ("would not change anything")	14 / 17.5%	Consistent with high averages in usability, accessibility and narrative/visual	Usability: M = 6.04; Accessibility: M = 6.12; Narrative/visual: M = 6.30

Source: Own elaboration, 2025.

Nevertheless, when analysing the critical or constructive comments, the need to improve orientation and navigation within the environment emerges as the most recurrent theme, mentioned by 22 participants (27.5%). This qualitative recurrence is particularly relevant when contrasted with the quantitative data. The item “I found it easy to orient myself within the tour” shows a lower mean (M = 5.62) and a higher standard deviation (SD = 1.24) compared to other usability items, indicating a less homogeneous experience. Moreover, participants who explicitly mention orientation problems consistently report lower mean scores on the usability construct (5.70) than those who do not refer to this aspect (6.16). This convergence supports the conclusion that spatial orientation acts as a key explanatory factor for the observed variability in perceptions of ease of use.

A second relevant thematic axis is the demand for greater interactivity, identified in 9 responses (11.3%). This qualitative finding aligns with the quantitative results concerning presence, the dimension with the lowest mean in the study (M = 5.54) and the highest dispersion (SD = 1.15). Items related to immersion, such as “I lost track of time while exploring” (M = 5.03; SD = 1.47), exhibit considerable heterogeneity, indicating that the immersive experience is not consistently activated across the entire sample. The triangulation of both sets of results suggests that, although the experience is clear and usable, the lack of meaningful interaction limits the sense of presence for a portion of users.

The need for deeper content constitutes a third thematic axis, mentioned by 10 participants (12.5%), who request more contextual information, expanded explanations, or additional layers of content. This qualitative discourse helps interpret a quantitative result that might otherwise appear ambiguous: the item “This environment has increased my interest in archaeology” shows a positive but clearly lower mean (M = 5.19) compared to other engagement indicators. The associated dispersion (SD = 1.33) indicates that the motivational impact is selective, and the open-ended responses suggest that this variability relates to the perception of insufficient cultural mediation for certain user profiles.

Finally, although less frequent, references to technical or performance aspects appear in 5% of responses (4). However, their analytical relevance is high. Participants who mention such issues report a significantly lower mean score on the presence dimension (M = 4.08) compared to the rest of the sample (M = 5.61). This pattern allows us to establish that occasional technical frictions can disrupt the continuity of the experience and weaken the sense of immersion, without necessarily affecting the overall system evaluation.

5. Discussion

5.1. Theoretical Implications

The theoretical implications of this article reinforce and expand the conceptual frameworks that interpret the digital museum as a user-centred communicative ecosystem, rather than as a mere technological transposition of the physical space. In line with the Contextual Model of Learning (Falk and Dierking, 2016) and the notion of the experience-museum (Giannini and Bowen, 2019), the results confirm that usability, accessibility, and narrative coherence function as structural conditions for meaning-making, particularly among young audiences. The research demonstrates that the immersive experience does not arise solely from technological realism but from the balanced integration of interface design, visual narrative, and cognitive mediation, thereby strengthening the arguments advanced by Gilani et al. (2023) y Parry (2013).

Furthermore, the study contributes to the theory of user experience in digital heritage by showing that presence and engagement depend more on meaningful interactivity than on technical sophistication, which engages with the contributions of Hammady et al. (2021) and Huang et al. (2025). From a critical perspective, the findings support Marty's (2009) warnings regarding the "spectacle effect", emphasising the need for theoretical models that integrate ethics, accessibility, and cultural sustainability (Lyu, 2024; Natale et al., 2024). Taken together, the article provides empirical evidence that consolidates user experience (UX) as a key theoretical category in contemporary digital museology.

5.2. Practical Implications

First, the results demonstrate that usability and accessibility must be conceived as strategic requirements, rather than as add-on layers introduced at the end of development. A clear, coherent, and visually stable interface facilitates orientation and reduces cognitive load, as noted by Gilani et al. (2023) and Gao and Foulen (2024), which in turn translates into higher levels of satisfaction and engagement.

Second, the study shows that presence and immersion are not guaranteed solely through advanced technological resources but through an interactive narrative that gives meaning to exploration, reinforcing the practical recommendations of Hammady et al. (2021) and Paananen et al. (2022). This implies that museum teams must incorporate communication, education, and UX design profiles from the initial phases of the project.

Furthermore, the spontaneous preference for large-screen devices suggests the need to optimise the cross-platform experience, prioritising visual ergonomics and spatial navigation, as indicated by Pei et al. (2023). Finally, the results support the systematic incorporation of UX evaluations based on real users, aligned with user-centred design models and inclusive accessibility approaches (Gatto et al., 2025; Smets y Euser, 2025), as standard practice in the management of digital heritage.

5.3. Research Limitations

First, the study adopts a quantitative, exploratory, and cross-sectional design, which prevents the establishment of causal relationships between the analysed variables. Second, the sample was obtained through convenience sampling and consists predominantly of university students from Generation Z, limiting the generalisability of the findings to other age groups or sociocultural profiles. Likewise, the absence of users accessing from mobile devices restricts the comparative analysis across platforms. Finally, the evaluation relies on self-reported perceptions, without incorporating behavioural or observational measures to complement the real-world usage experience.

5.4. Future Lines of Research

It would be relevant to expand the sample to include other age groups and sociocultural profiles in order to compare patterns of use and perception across generations and diverse audiences. It is also proposed to incorporate mixed-methods designs that integrate qualitative methods (interviews, observation, analysis of user journeys) and behavioural metrics to complement self-reported perceptions. Furthermore, it would be pertinent to analyse the experience on mobile devices and in XR environments using head-mounted displays, evaluating how hardware influences presence and engagement. Another

promising line of inquiry involves studying the impact of adaptive and personalised narratives, based on artificial intelligence, on learning and emotional involvement. Finally, future research could address the sustainability, governance, and ethics of digital museums, exploring models that balance technological innovation, accessibility, and long-term heritage identity.

6. Conclusions

In relation to R1 (analyse perceptions of ease of use, accessibility, and navigation), the results show high ratings in usability and perceived accessibility, confirming that the platform is easily understood and used by Generation Z. This evidence provides an affirmative response to R1, as users perceive the MAN Virtual experience as highly usable. Likewise, the high levels of visual coherence and information organisation allow a positive response to R4, confirming that the narrative and visual structure directly and favourably influences perceptions of accessibility. Nevertheless, the greater variability observed in orientation-related items indicates that spatial navigation constitutes an area susceptible to improvement.

R2 (evaluate satisfaction, engagement, and presence) is fulfilled by confirming an overall satisfactory experience and high engagement, while presence presents more heterogeneous values. These results provide a partial response to R2, as although engagement and presence tend to be higher among users accessing via computer, the differences do not reach statistical significance, indicating a descriptive trend rather than a conclusive one.

Regarding R3 (identify potential barriers to use), the conclusions identify frictions related to orientation, limited interactivity, and certain occasional technical aspects, thereby responding to R5. Although no accesses from mobile devices were recorded, the absence of this device and the qualitative comments allow the inference of perceived usability limitations in small-screen contexts.

With respect to R4 (explore differences according to device), the study evidences a clear preference for computer over tablet or mobile, and a more stable experience on large screens, which responds to both R2 and R3 from an exploratory perspective. While no statistically significant differences were identified, consistent patterns of use are observed.

Finally, R5 (formulate UCD recommendations) is supported by the set of findings, proposing the integration of usability, accessibility, and interactive narrative as central axes of digital museological design. In this way, the conclusions not only address the research questions but also provide applicable guidelines for user-centred design in virtual museums, reinforcing the validity and practical utility of the study

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