

Creating Phygital Cultural Heritage Experiences: Key Design Principles

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Abstract

This study develops design principles for creating phygital (physical and digital) cultural heritage experiences, integrating advanced technologies such as VR/AR, digital twins, and interactive storytelling. Through thematic analysis of existing literature and validation via a professional survey, five key principles were identified: Human-Centered Design, Technological Integration, Narrative Fidelity, Cultural Sensitivity, and Sustainability. These principles offer a framework for preserving cultural authenticity while enhancing user engagement and accessibility. This study explores key challenges in integrating sustainability and cultural authenticity into phygital cultural heritage projects and provides cultural heritage professionals with flexible design strategies that leverage digital technologies to create immersive, educational, and culturally respectful experiences. These adaptable strategies ensure that projects remain viable, relevant, and capable of balancing innovation with preserving heritage integrity.

Keywords: Cultural Heritage, Phygital Experiences, Design Principles, Technological Integration, Authenticity.

1. INTRODUCTION

1.1. Research Background

The integration of advanced digital technologies, such as extended reality (XR), which includes augmented reality (AR), virtual reality (VR), mixed reality (MR), digital twins, and interactive storytelling, into cultural heritage practices represents a significant evolution in how we preserve and engage with cultural heritage. For instance, the implementation of AR technology in the 'Rome Reborn' project allowed users to virtually explore ancient Roman sites in real time, enhancing public engagement with historical artifacts while maintaining the authenticity of the physical locations [1]. Similarly, the use of digital twins in the preservation of Notre Dame Cathedral after the fire in 2019 demonstrated the role of digital technologies in both restoration and public education [2]. The whole process is well-documented [3]. This approach, often referred to as "phygital experiences," seeks to merge physical and digital elements to enhance the education, access, and preservation of cultural heritage [4]. By offering immersive and multi-sensory interactions, phygital experiences have the

Manuscript Received: September. 24, 2024 / Revised: October. 30, 2024 / Accepted: November. 5

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potential to deepen public engagement with cultural artifacts and narratives.

While advanced technologies offer innovative ways to engage with cultural heritage, they also pose challenges. Ensuring these technologies enhance rather than compromise cultural authenticity is critical [5]. Existing design principles, while useful in various domains, often do not fully address the unique challenges of integrating advanced technologies with the preservation of cultural heritage. Therefore, there is a growing need to develop specific design principles that ensure technological innovation enhances, rather than compromises, the integrity and sustainability of cultural heritage experiences.

Additionally, professionals must address ethical concerns, such as cultural sensitivity and sustainability, to ensure that these digital interventions do not detract from the cultural heritage they are meant to enhance [6]. While the potential benefits are clear, the exact principles that should guide the creation of these phygital experiences to achieve these goals remain to be thoroughly explored and defined.

1.2. Research Purpose

This study aims to develop a comprehensive set of design principles for phygital cultural heritage experiences, focusing on user engagement, cultural authenticity, and technological integration. The primary goal is to balance technological innovation with the preservation of cultural narratives while fostering interactivity and respecting cultural sensitivity. Specifically, the research will explore how digital technologies can seamlessly integrate into cultural heritage projects without compromising narrative authenticity. By analyzing engagement metrics and collecting stakeholder feedback, the study will provide actionable insights and practical guidance for ensuring cultural relevance and sustainability in phygital heritage experiences.

1.3. Research Question & Hypothesis

This study investigates the delicate balance between technological innovation and the preservation of cultural authenticity in phygital cultural heritage projects. The research question is designed to examine the essential design principles that are necessary for creating engaging, authentic, and sustainable phygital heritage experiences.

Research Question: What fundamental design principles are required to create immersive, culturally authentic, and sustainable phygital cultural heritage experiences? This study seeks to identify how advanced digital technologies can be seamlessly integrated into cultural heritage projects while preserving the integrity and authenticity of cultural narratives.

Hypothesis: The hypothesis posits that the effective integration of technological innovations, in conjunction with narrative fidelity and cultural sensitivity, is crucial for creating phygital cultural heritage experiences that preserve authenticity and ensure long-term sustainability.

This hypothesis suggests that the successful balancing of these elements enables phygital cultural heritage projects to utilize technological advancements without compromising the cultural significance and authenticity of the heritage being represented. The study aims to provide measurable insights into the applicability of these design principles and their impact on user engagement and the preservation of cultural integrity.

2. LITERATURE REVIEW

2.1. Overview of Design Principles Theory

Design principles provide a structured framework that guides innovation and ensures effective outcomes in

technology and digital services. Grounded in theory, these principles organize key concepts into actionable guidelines that enhance both research and practical applications [7]. By codifying design knowledge into frameworks like the double diamond model, they make it accessible for solving new challenges and driving innovation across various fields [8]. The principle of iterative improvement, particularly in educational contexts, ensures that these guidelines remain relevant and effective over time, allowing for adaptation to new discoveries or shifts in user needs [9]. However, while existing design principles are valuable, they often fall short in addressing the unique needs of cultural heritage projects, such as the ethical implications of representing diverse cultures. The integration of advanced technologies with cultural heritage requires a careful balance between innovation and the preservation of cultural authenticity. For example, while VR can enhance engagement, it may risk oversimplifying cultural narratives if not properly handled. Current principles do not fully capture the complexity of maintaining cultural sensitivity and ethical integrity, especially in contexts where cultural misrepresentation or commodification can be problematic. Therefore, developing specific design principles tailored to phygital cultural heritage experiences, incorporating both technological flexibility and ethical guidelines, is essential.

2.2. Integration of Digital Technologies in Cultural Heritage and Their Impact

Advanced digital technologies like XR and digital twins have revolutionized cultural heritage by merging physical and digital elements, creating immersive "phygital" environments. Projects such as Rome Reborn and the Notre Dame Cathedral restoration demonstrate how these technologies enhance public interaction while preserving authenticity. However, challenges arise in ensuring these tools enrich rather than diminish cultural authenticity. While AR and VR can enhance user immersion by contextualizing historical elements, improper use risks oversimplifying or distorting cultural narratives. A balanced approach is essential [10].

Digital twins offer global audiences virtual access to cultural heritage sites, supporting conservation and education. For example, the Mogao Caves' digital twin allows millions to explore the site without compromising its physical integrity [11]. However, these digital representations must reflect cultural sensitivities and narrative accuracy.

Other emerging technologies, such as AI, blockchain, and IoT, offer additional opportunities to enrich heritage experiences. AI personalizes user interactions, such as generating museum tours based on preferences, while blockchain secures the provenance of cultural assets [12]. IoT enhances real-time engagement with artifacts, linking them to environmental data and supporting preservation efforts [13].

Nevertheless, ethical concerns persist. The risk of commodifying or misrepresenting cultural narratives grows as these technologies evolve [14]. To avoid this, community and stakeholder engagement is crucial to ensure the respectful integration of technology, and maintain cultural integrity [15]. The COVID-19 pandemic further accelerated the use of digital tools in cultural heritage, with virtual tours and digital archives becoming essential for continued public access. These tools democratized access, underscoring the importance of inclusivity and sustainability [16]. Virtual tours of sites like the British Museum and the Louvre emphasized the need for adaptable, sustainable heritage strategies.

2.3. Enhancing Cultural Heritage Engagement through Innovative Approaches

Phygital projects aim to engage the public through innovative methods such as Human-Centered Design (HCD), interactive storytelling, and gamification, which enhance immersion and participation.

HCD focuses on crafting intuitive, accessible experiences tailored to user needs. For example, the "ReACH" project employed HCD to create digital interfaces that allowed users to interact with artifact reproductions,

making them accessible to a broader audience and improving the visitor experience [17]. Interactive storytelling immerses users in heritage narratives by encouraging active exploration. For instance, the "Pure Land: Inside the Mogao Grottoes" project, as mentioned in the previous subchapter, used VR to allow users to virtually explore Buddhist frescoes, offering a deeper understanding of the cultural significance. Gamification incorporates elements such as challenges and rewards, making learning enjoyable. The "Museu do Fado" in Portugal used interactive installations where visitors learned about Fado music through challenges, increasing engagement and educational value [18].

However, challenges arise, particularly in culturally sensitive environments. Ensuring narrative integrity is critical, as interactive methods can sometimes oversimplify complex histories. Collaboration efforts with cultural experts and stakeholders are vital, as seen in the digital twin reconstruction of Notre Dame Cathedral, where historians ensured historical accuracy, as mentioned earlier in the research background. Cultural sensitivity is key to successful digital heritage design. The "Flanders Fields" project in Belgium, as also mentioned in the research background, exemplified how involving local narratives in design ensures respectful and authentic representation. Sustainability, both ecological and technological, is essential for long-term preservation. Projects like the Mosul Museum employ 3D scanning and digital archives to safeguard artifacts despite physical destruction, ensuring future access [19].

Ethical considerations, such as preventing commodification and protecting data privacy, are paramount. The "ReACH" project, as mentioned before, developed global access guidelines while protecting cultural ownership, helping maintain the dignity of cultural heritage in the digital age.

2.4. Practical Implementation Strategies and Research Gaps

Implementing phygital cultural heritage experiences requires a thoughtful alignment with key design principles to ensure user engagement and respect for cultural integrity. Core strategies include stakeholder engagement, iterative development, user training, and sustainability planning. However, notable gaps remain in scalability and cultural authenticity across different contexts.

Stakeholder engagement is vital for preserving cultural authenticity by actively involving cultural experts and local communities. A notable example is the "Flanders Fields" project, as has been referred to in the research background, where local stakeholders were integrated to ensure both the physical and digital elements accurately reflected cultural values. This approach guarantees that the representation remains culturally grounded and trustworthy. Iterative development focuses on continually refining prototypes through user feedback, ensuring the longevity and relevance of digital heritage projects. The "Google Arts & Culture" platform exemplifies this by regularly updating virtual museum tours based on user interaction [20]. User training broadens access to digital heritage by lowering barriers to technology use. Institutions like the Smithsonian provide digital literacy workshops, ensuring that users of all backgrounds can engage with interactive exhibits [21].

Sustainability involves addressing both environmental and financial challenges. Projects such as the "Virtual Multimodal Museum (ViMM)" prioritize scalable and cost-effective solutions to ensure the long-term viability of digital heritage experiences [22]. However, challenges arise in adapting these approaches to diverse cultural contexts, especially in preserving narrative fidelity and cultural sensitivity, particularly in non-Western settings. Phygital experiences must accommodate oral traditions and non-material heritage, which remain underrepresented in current models. Research also reveals gaps in ethical guidelines for digital reproduction, with particular concerns about commodifying cultural heritage. Without the proper context, displaying artifacts online may lead to the exploitation of cultural symbols. For instance, reproducing

indigenous artifacts raises significant issues regarding cultural ownership and potential misuse. Projects like ReACH provide ethical frameworks that promote global access while respecting the cultural values of the communities involved.

3. METHODS

3.1. Research Design

This study employed a mixed-methods approach, utilizing both qualitative and quantitative research methodologies to thoroughly investigate the design principles for phyigital cultural heritage experiences.

a. Qualitative Research Methods: The qualitative aspect of the research was conducted through an in-depth literature review and the collection of open-ended feedback in the survey [23].

- Literature Review: Sources were selected based on their relevance to digital technologies in cultural heritage, with a focus on peer-reviewed articles and case studies from reputable journals. Thematic analysis was used to extract key insights, which informed the development of the survey questions and provided a conceptual framework for understanding phyigital heritage experiences.

- Optional Survey Feedback: In addition to quantitative ratings, respondents were encouraged to share qualitative insights through open-ended responses. These responses were analyzed using thematic coding to identify recurring themes, challenges, and suggestions for improving phyigital heritage projects.

b. Quantitative Research Methods: Quantitative data were collected through a structured survey distributed to cultural heritage professionals.

- Survey Structure: The survey was divided into five sections, each corresponding to one of the identified design principles (Human-Centered Design, Technological Integration, Narrative Fidelity, Cultural Sensitivity, and Sustainability). Each section contained three Likert scale questions, allowing participants to rate their agreement with various statements on a scale from 1 (Strongly Disagree) to 5 (Strongly Agree).

- Data Collection: The survey was distributed electronically to participants, and responses were collected over one week.

- Data Analysis: The quantitative data were analyzed using JASP software, with descriptive statistics calculated for each survey item. The Content Validity Ratio (CVR) was also employed to assess the necessity of each item, ensuring the reliability of the survey results [24].

By integrating both qualitative insights from the literature and survey feedback with quantitative data from the survey, the study aimed to provide a holistic understanding of how design principles impact the development of phyigital cultural heritage experiences.

3.2. Data Collection and Sampling Strategy

This study employed a mixed-methods approach, integrating both qualitative and quantitative research methods to develop and validate a comprehensive set of design principles for phyigital cultural heritage experiences. Data was collected through a combination of a literature review and a structured survey. These methods were chosen to ensure that the identified design principles were supported both by theoretical insights and empirical validation from professionals.

a. Literature Review: The literature review served as the qualitative component of the study, aimed at

identifying key design principles and challenges associated with phygital cultural heritage. Key terms such as “cultural heritage,” “preservation,” “phygital experiences,” “user experience,” “interactive storytelling,” “digital technologies,” “immersive technologies,” “design principles,” and “sustainability” were used to guide the review.

The sources included peer-reviewed journals, case studies, and reports that focused on the integration of digital technologies like augmented reality (AR), virtual reality (VR), and digital twins into cultural heritage. The literature review provided a theoretical foundation for the study, offering insights into key principles such as Human-Centered Design, Technological Integration, Narrative Fidelity, Cultural Sensitivity, and Sustainability. These insights informed the development of the survey, ensuring that the questions were aligned with both the research question and the hypothesis.

b. Survey Design: Building on the insights gained from the literature review, a structured survey was developed to gather quantitative and qualitative data from professionals involved in phygital cultural heritage projects. The survey was divided into five sections, each corresponding to one of the identified design principles, with each section divided into five parts (A–E): The Main Survey (A, B, C): Participants were asked to rate their agreement with statements related to each design principle on a 5-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree). This allowed for the collection of quantitative data about the perceived importance and relevance of the principles. Optional Feedback (D): Open-ended questions encouraged participants to share qualitative insights based on their professional experience, providing additional depth and context to the quantitative findings. Content Validation (E): The final part of each section involved evaluating the necessity of each survey item. Participants were asked to rate items as "essential," "useful but not essential," or "not necessary" for assessing the relevant design principle. This process was crucial for refining the survey’s focus and ensuring content validity.

The survey questions were designed to empirically test the hypothesis that balancing technological innovation with cultural authenticity is essential for creating immersive and sustainable phygital cultural heritage experiences. A sample survey question table is provided in Table 1: Survey Questions and Structure.

Table 1. Survey Questions and Structure

Section 1: Human-Centered Design	
1A	To what extent do you agree that prioritizing user needs is essential for creating accessible phygital cultural heritage experiences?
1B	To what extent do you agree that iterative design (repeated cycles of design, testing, and refinement) is crucial for improving user experience in phygital cultural heritage projects?
1C	How important is it to incorporate feedback from diverse user groups early in the design process for phygital cultural heritage experiences?
1D	Please provide any examples or experiences you have related to the importance of Human-Centered Design in your work or experience with (phygital) cultural heritage projects.
1E	Do you consider this section essential for evaluating Human-Centered Design as a design principle?
Section 2: Technological Integration	
2A	To what extent do you agree that the seamless incorporation of technologies like VR and AR enhances cultural heritage experiences without overshadowing them?
2B	How important is it to ensure that the selected technologies are scalable and flexible enough to adapt to future developments in cultural heritage projects?
2C	To what extent do you agree that the technology used should not only be innovative but also user-friendly and intuitive for a wide range of audiences?
2D	What challenges have you encountered in the integration of advanced technologies into cultural heritage projects/settings/objects?
2E	Do you consider this section essential for evaluating Technological Integration as a design principle?
Section 3: Narrative Fidelity	
3A	How important is it to maintain authenticity in storytelling when designing digital cultural heritage experiences?
3B	To what extent do you agree that involving cultural experts and historians in the design process is essential for maintaining narrative fidelity in digital heritage projects?
3C	How critical is it to ensure that digital representations do not oversimplify or alter the cultural narratives they aim to preserve?

3D	Can you share an instance where narrative fidelity was successfully maintained or compromised in a digital heritage project?
3E	Do you consider this section essential for evaluating Narrative Fidelity as a design principle?
Section 4: Cultural Sensitivity	
4A	To what extent do you agree that accurately representing cultural narratives and values is critical in phyigital cultural heritage experiences?
4B	How important is it to include the community or cultural group represented in the digital project in the decision-making process to ensure cultural sensitivity?
4C	How important is it to regularly update digital content to reflect the evolving cultural values and sensitivities of the communities represented?
4D	What strategies do you employ, or do you think should be employed, to ensure cultural sensitivity in digital heritage projects?
4E	Do you consider this section essential for evaluating Cultural Sensitivity as a design principle?
Section 5: Sustainability	
5A	How important is it for digital heritage projects to plan for long-term viability and use eco-friendly practices?
5B	To what extent do you agree that incorporating eco-friendly technologies and practices is vital for the long-term sustainability of digital heritage projects?
5C	To what extent do you agree that sustainable practices in digital heritage projects should include both environmental and financial sustainability?
5D	What measures have you, or should be taken to ensure the sustainability of a digital heritage project?
5E	Do you consider this section essential for evaluating Sustainability as a design principle?
Additional Section:	
-	Are there any other essential design principles or considerations that you believe are crucial for creating effective phyigital cultural heritage experiences but are not covered in the previous sections? Please explain.

c. Content Validation using CVR: To ensure the validity of the survey items, Lawshe's Content Validity Ratio (CVR) was employed. This technique evaluates the relevance of each survey item based on expert feedback. Seven experts in the fields of cultural heritage, digital media, and UX design were selected for this purpose. They were asked to evaluate each item as "essential," "useful but not essential," or "not necessary." The Content Validity Ratio was calculated using the formula:

$$CVR = \frac{n_e - (N/2)}{N/2} \quad (1)$$

Where n_e is the number of experts who rated the item as "essential" and N is the total number of experts. The CVR values range from -1 to +1, with positive values indicating that more than half of the experts deemed the item essential. All CVR values were retained for the final survey.

d. Sampling Strategy, Rationale, and Survey Distribution: This study employed purposive homogeneous sampling to gather data from cultural heritage professionals and experts with relevant experience in digital heritage projects [25]. The primary research objective is to develop and validate design principles for phyigital cultural heritage experiences, which requires feedback from individuals who have practical knowledge of the intersection between cultural heritage and digital technologies.

Homogeneous sampling was chosen because it ensures that participants share common professional experience and expertise in this specific field. By selecting individuals with a deep understanding of phyigital heritage, the study can focus on collecting highly relevant and informed feedback. This is critical to the study's goals, as it ensures that the participants can effectively evaluate the design principles based on their direct involvement in similar projects. This method allows for a more focused analysis by limiting the inclusion of participants who may lack sufficient familiarity with the specific challenges of integrating digital technologies into cultural heritage. Consequently, this approach improves the reliability of the data by reducing extraneous variability and increases the validity of the results by ensuring that they are grounded in real-world practice.

Focusing on a homogeneous group of experts enhances the reliability of the study by ensuring that the feedback is consistent and based on relevant experiences. This targeted sampling approach minimizes the risk of introducing bias or irrelevant data from participants without the necessary expertise. Furthermore, the validity of the study is strengthened by collecting data from professionals who are best positioned to assess the

practical applicability of the design principles. This alignment between the sample group and the research objectives ensures that the study's findings are both theoretically and practically robust. By using homogeneous sampling, the study guarantees that the data collected is directly applicable to the research objectives and the development of design principles that are sustainable, user-centered, and technologically integrated within phygital cultural heritage projects.

The survey was distributed electronically via email and the WhatsApp chat app. Participants were given one week to complete the survey, and responses were guaranteed anonymity to encourage honest and reflective feedback. This method of distribution ensured accessibility and convenience for participants across various geographical locations.

3.3. Data Analysis, Integrity, and Limitations

Thematic analysis was selected as the primary method for analyzing the qualitative data gathered from both the literature review and the survey's open-ended responses. This method allows for the identification, analysis, and reporting of patterns (themes) within the data, making it particularly well-suited for a study that seeks to explore complex interactions between cultural heritage and digital technologies [26]. Thematic analysis was chosen because of its flexibility and its ability to accommodate both deductive and inductive approaches. This study used the thematic analysis to explore key design principles such as Human-Centered Design, Technological Integration, and Cultural Sensitivity, which were identified during the literature review and subsequently validated through the survey. The method's flexibility made it ideal for identifying recurring themes across diverse data sources, allowing the study to address the research questions and hypothesis effectively.

Other potential methods, such as content analysis and grounded theory, were considered but found to be less appropriate for this study. Content analysis, while useful for categorizing data into predefined categories, is less suited for exploring the depth of meaning behind participants' feedback. Grounded theory, which is often used to generate new theories, was also not ideal for this study, as the research was focused on validating existing design principles rather than building new theoretical frameworks. Thematic analysis provided the balance needed between flexibility and structure, making it the most suitable method for this research.

Thematic analysis directly supports the testing of the hypothesis by systematically identifying patterns in the qualitative data that either confirm or challenge the proposed design principles. For instance, recurring themes such as "Cultural Sensitivity" and "Narrative Fidelity" emerged as critical factors in creating authentic and sustainable phygital heritage experiences. By mapping these themes to the research objectives, thematic analysis reveals how professionals perceive the importance of these principles and their relevance in practical settings. This process enables a deeper understanding of how technological innovations can be balanced with cultural preservation, thus providing evidence to test the hypothesis.

Despite its strengths, thematic analysis presents certain limitations. One of the main challenges is the potential for researcher bias, as the process of identifying themes can be subjective. Although measures were taken to mitigate bias, such as cross-referencing codes and seeking external validation, there is always a risk of overemphasizing certain themes based on the researcher's perspective. Additionally, thematic analysis may miss some nuances in the data, particularly when dealing with complex issues like cultural authenticity, where subtle differences in interpretation can be important. Furthermore, the method does not allow for the quantification of theme frequency, which could provide more detailed insights into the relative importance of different factors.

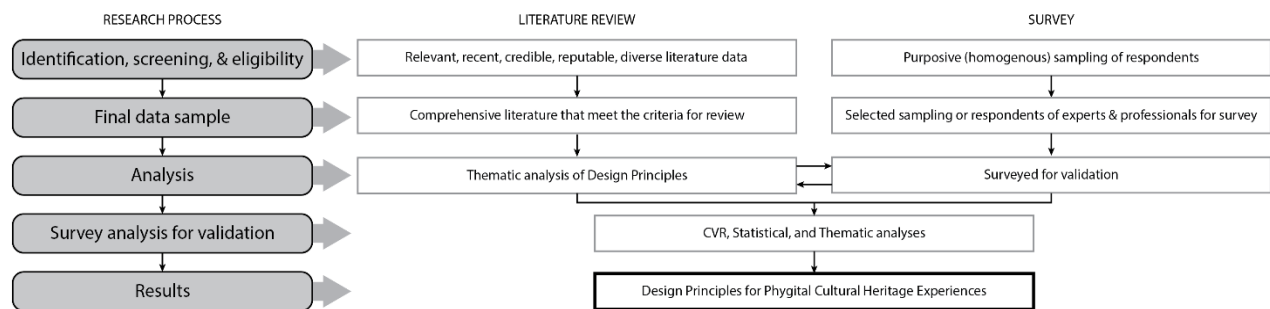


Figure 1. Research process

The survey data were analyzed in two phases: (1) Content Validation Analysis: The CVR results were analyzed to determine which survey items were considered essential by the expert panel. (2) Main Survey Data Analysis: For the items validated through the CVR process, descriptive statistics were used to summarize and analyze the responses using JASP software for its ease of use and comprehensive statistical capabilities. This included calculating the mean rating, standard deviation, and agreement rate for each design principle. Open-ended responses were thematically analyzed to identify key patterns and insights that complemented the quantitative findings.

Triangulation of data sources, including document analysis and survey results, was employed to enhance the reliability and validity of the findings. Ethical considerations, such as informed consent and confidentiality, were rigorously observed. The study was conducted within an academic environment, with potential limitations including biases in document selection and the challenges of interpreting qualitative data. The overall process can be summarized in Figure 1.

3.4. Ethical Considerations

This study followed strict ethical guidelines to ensure participant privacy, confidentiality, and autonomy, especially given the nature of the data collected from identified professionals through a structured survey. Participation in the survey was entirely voluntary. All participants were informed about the purpose of the research, the voluntary nature of their involvement, and their right to withdraw at any time. No incentives were provided, and participants were free to skip any questions they were uncomfortable answering. Although the participants were known to the researcher, their responses were treated with complete anonymity. Identifiable information was not included in the analysis or reporting of results. In cases where participants provided optional feedback, any information that could reveal their identity was removed to ensure confidentiality. This ensured that participants felt comfortable providing honest feedback while maintaining an ethically sound approach to data collection.

4. RESULTS

4.1. Overview of Design Principles and their Implementation as a Framework

Thematic analysis was used to identify five key themes as seen in Figure 2: Human-Centered Design, Technological Integration, Narrative Fidelity, Cultural Sensitivity, and Sustainability, which are essential for phyigital cultural heritage experiences. The process involved several steps: 1) Familiarization: Thoroughly reviewing the literature to understand the content. 2) Coding: Noting significant patterns related to design and technology use in cultural heritage. 3) Theme Identification: Grouping related codes into broader categories

like user engagement and ethical use of technology. 4) Reviewing Themes: Refining and ensuring a distinct, accurate representation of the data. 5) Defining Themes: Naming and describing each theme to reflect its essence and relevance to the study. These themes emerged from systematic analysis, ensuring they are well-grounded in both theory and practical application for designing engaging and sustainable phygital cultural heritage experiences.

The thematic analysis identified five key design principles to guide the creation of immersive, culturally authentic, and sustainable phygital cultural heritage experiences, aligned with the research question on balancing technological innovation and cultural authenticity. These will be validated through surveys of cultural heritage professionals:

a. Human-Centered Design: This addresses the research question of ensuring intuitive and accessible phygital experiences by proposing that technology should prioritize user needs. It supports the hypothesis that technology must serve users to maintain engagement and authenticity.

b. Technological Integration: This principle answers how advanced technologies can enhance cultural experiences without compromising authenticity. It supports the hypothesis that technology should complement, not dominate, cultural narratives.

c. Narrative Fidelity: Focuses on maintaining the integrity of cultural stories, addressing the research question on balancing innovation and authenticity, reinforcing the hypothesis that storytelling must remain authentic to cultural heritage.

d. Cultural Sensitivity: This principle aligns with the hypothesis by emphasizing the need for continuous community involvement and respect for cultural values, ensuring authentic representation in phygital experiences.

e. Sustainability: Addresses the hypothesis by proposing long-term viability through eco-friendly and adaptable solutions, ensuring that phygital heritage projects can endure over time despite financial and technological constraints.

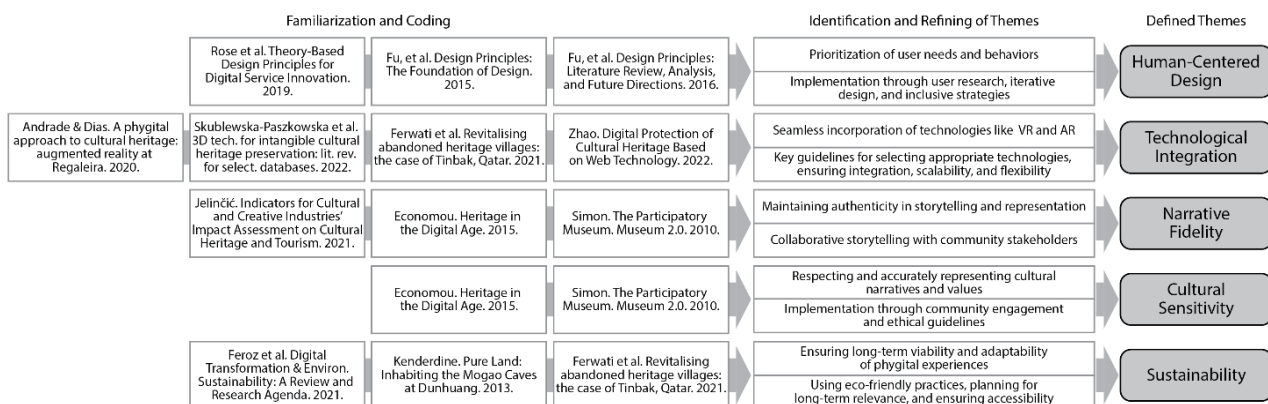


Figure 2. Thematic analysis results

4.2. Survey Results

In the survey, respondents evaluated the importance and applicability of the five key design principles for phygital cultural heritage experiences. These principles, which are derived from the extensive literature review,

have been identified as essential for balancing innovation with cultural authenticity in digital heritage projects.

The survey was structured into five sections, each corresponding to one of these design principles. For each principle, participants were asked to rate various aspects on a Likert scale, provide qualitative feedback, and evaluate the necessity of each item through content validation questions (CVR). The questions were directly informed by the literature review, which highlighted key challenges and strategies associated with each principle. For instance, questions related to Human-Centered Design focused on user needs and iterative design processes, ensuring that phygital experiences are intuitive and accessible. Those under Technological Integration assessed the seamless incorporation of new technologies without overshadowing cultural content. Narrative Fidelity questions emphasized the importance of maintaining the accuracy and authenticity of cultural stories when presented in digital formats. Cultural Sensitivity questions explored the ethical representation of cultural narratives, ensuring that digital portrayals are respectful and involve community engagement. Finally, questions related to Sustainability examined the long-term viability of digital heritage projects, including the use of eco-friendly practices and strategies for ensuring that these projects remain relevant and accessible over time.

Table 2. Survey Results

Principle Expert	Human-Centered Design					Technological Integration					Narrative Fidelity					Cultural Sensitivity					Sustainability									
	A	B	C	Avg	CVR	A	B	C	Avg	CVR	A	B	C	Avg	CVR	A	B	C	Avg	CVR	A	B	C	Avg	CVR					
1	5	5	5	5	E	5	5	5	5	E	5	5	4	4.67	E	5	5	4	4.67	U/NE	4	4	4	4	U/NE					
2	5	5	3	4.33	E	5	5	4	4.67	E	5	5	5	5	E	4	5	3	4	U/NE	4	3	4	3.67	U/NE					
3	4	5	5	4.67	E	4	5	5	4.67	E	4	4	4	4	E	4	5	5	4.67	E	5	4	5	4.67	E					
4	5	5	5	5	E	5	5	5	5	E	5	5	5	5	E	5	5	5	5	E	5	5	5	5	E					
5	5	5	5	5	E	5	5	5	5	E	4	5	4	4.33	E	4	5	4	4.33	E	5	5	5	5	E					
6	5	5	5	5	E	4	4	5	4.33	E	5	5	5	5	E	5	5	4	4.67	E	5	5	5	5	U/NE					
7	4	5	4	4.33	E	4	5	5	4.67	E	5	5	5	5	E	5	5	4	4.67	E	3	3	4	3.33	U/NE					
Avg rating						4.763					4.714					4.573					4.381									
Rt cnstcy						0.252					0.405					0.318					0.706									
Exp agree						1					1					1					0.429					-0.143				
% agree						100					100					100					71					43				
Qualitative feedback	<p>Keywords: accessibility, inclusivity, user experience, complexity Key Issues: Many participants highlighted the lack of inclusive design in cultural heritage projects, particularly for visually impaired users. Complex interfaces often led to user frustration and disengagement, with respondents stressing the importance of intuitive design that prioritizes accessibility across diverse user groups.</p>					<p>Keywords: user-friendly, cost, infrastructure, scalability Key Issues: Respondents reported difficulties with integrating new technologies into older structures (e.g., PCU Library) and cited high costs associated with hardware (e.g., VR headsets) and software development. They emphasized the need for user-friendly systems to ensure technology enhances engagement rather than detracting from it. Scalability and adapting technology to diverse environments were also raised as concerns.</p>					<p>Keywords: authenticity, conflicting narratives, historical accuracy, stakeholder engagement Key Issues: Preserving authentic storytelling was considered critical, with examples like the Viking VR project lauded for their historical accuracy. However, projects that deal with contested histories (e.g., Indonesia’s G30S-PKI event) face challenges in balancing multiple perspectives and narrative accuracy. Stakeholder involvement was viewed as essential in navigating these complexities.</p>					<p>Keywords: community engagement, misrepresentation, cultural respect, ethical guidelines Key Issues: Ensuring cultural accuracy and respect was a major concern, with respondents emphasizing the need for early and ongoing engagement with local communities. They noted the risk of misrepresentation and cultural commodification if ethical guidelines are not followed, or local stakeholders are not regularly consulted. Projects were seen as more successful when they incorporated local input throughout development.</p>					<p>Keywords: long-term viability, budget constraints, eco-friendly practices, future-proofing Key Issues: The financial feasibility of sustainable practices was a significant concern, especially for smaller institutions. While eco-friendly technologies and future-proofing were seen as critical, budget constraints made it difficult to implement these solutions. Participants suggested that sustainable approaches often conflict with the high costs of maintaining digital infrastructure over the long term.</p>									
Other feedback	<p>Principles Management: A framework/meta-principle is needed to help manage and balance competing priorities. Openness to Future Developments: Projects must stay adaptable to evolving technologies to remain relevant. Business Considerations: Importance of cost-effective planning and financial sustainability for smaller institutions. Public Consultation: Stakeholder involvement is essential for ensuring projects align with community needs. Expert Involvement in Architecture: Ensuring historical accuracy and structural integrity (for projects involving physical spaces) through expert collaboration.</p>																													

*Avg: Mean score from a 1-5 Likert scale; CVR: E = Essential; U/NE = Useful but Not Essential; NN = Not Necessary; Average rating: High (near 5.0) = strong importance; Low (near 3.0) = moderate importance; SD: Low = high agreement; High = varied responses; CVR score: 1 = full consensus, lower/negative = less agreement; % agreement: Higher values reflect stronger consensus on importance.

The survey provided valuable insights into how the five key design principles relate to the research question and hypothesis. Table 2 presents both quantitative ratings and qualitative feedback that support the hypothesis:

the integration of technological innovation, narrative fidelity, and cultural sensitivity is crucial for creating authentic and sustainable phygital cultural heritage experiences.

a. Human-Centered Design: The principle of Human-Centered Design received the highest level of agreement, with an average rating of 4.761 and a standard deviation of 0.318, indicating strong consensus among participants. All experts rated this principle as "essential" (CVR: 1.0), and 100% of respondents agreed on its importance. Several respondents emphasized the need for designs that prioritize user needs, with one participant stating, "Many cultural heritage projects lack accessibility features, which disengages certain visitor groups, particularly the visually impaired." Another highlighted the significance of intuitive design, citing frustration in previous projects where "the user interface was too complex, leading to a poor user experience."

Relation to Hypothesis: The strong quantitative agreement and consistent qualitative feedback support the hypothesis by reinforcing the idea that intuitive, Human-Centered Design is essential for enhancing user engagement in phygital cultural heritage projects. The feedback directly shows that aligning design with user needs leads to better experiences, supporting the argument that technological innovation should serve users rather than hinder them.

b. Technological Integration: Technological Integration also received unanimous support, with an average rating of 4.763 and a low standard deviation of 0.252, indicating that participants strongly agreed on its importance. All experts rated this principle as essential (CVR: 1.0), and 100% of respondents agreed on its importance. One participant noted, "In the redesign of the PCU Library, integrating new technology was challenging because preserving the original architectural features limited what could be done." Another respondent highlighted the importance of user-friendly technologies, stating, "Some of the technology, especially VR, was difficult to navigate, which reduced the overall engagement." **Relation to Hypothesis:** The high level of agreement and the qualitative feedback emphasize that seamless technological integration is critical. Specific examples of challenges in balancing technology with heritage preservation validate the hypothesis that technology must enhance, not overwhelm, cultural narratives. This is consistent with the idea that technological innovation can coexist with narrative fidelity if properly managed.

c. Narrative Fidelity: The principle of Narrative Fidelity had a high average rating of 4.714 and a standard deviation of 0.405, with 100% agreement among respondents. The CVR score of 1.0 reflects a consensus among experts that maintaining authentic storytelling is essential. One respondent pointed out, "In projects like the Viking VR project, narrative fidelity was achieved through careful recreation of historical details, ensuring that the user experienced a historically accurate version of the story." However, another noted the challenge of maintaining narrative fidelity in the face of conflicting historical accounts, as seen in the different versions of Indonesia's G30S-PKI (1965 coup attempt) event. **Relation to Hypothesis:** This feedback provides concrete examples of both success and challenges in maintaining narrative fidelity. The balance between technology and authentic storytelling, highlighted by participants, supports the hypothesis that phygital heritage experiences must preserve cultural narratives to remain authentic and meaningful.

d. Cultural Sensitivity: Cultural Sensitivity received an average rating of 4.573 with a standard deviation of 0.318, reflecting more varied responses than the previous principles. Only 71% of respondents fully agreed on its importance, and the CVR score was 0.429, indicating some disagreement among experts. The qualitative responses reflected the complexity of implementing cultural sensitivity. One participant remarked, "Involving community leaders early in the project helps ensure that cultural representations are accurate and respectful," while another warned, "Without regular consultation with local stakeholders, projects can easily misrepresent or commodify the cultural elements they seek to preserve." **Relation to Hypothesis:** The variability in quantitative responses is echoed in the qualitative feedback, where participants noted the practical challenges

of implementing cultural sensitivity. This complexity underscores the hypothesis that cultural sensitivity is crucial but difficult to execute, particularly in diverse or contested cultural contexts. The feedback also suggests that ongoing community engagement is key to achieving authenticity in these projects.

e. Sustainability: Sustainability had the lowest average rating at 4.381, with a much higher standard deviation of 0.706, reflecting significant disagreement among participants. Only 43% of respondents agreed on its importance, and the CVR was negative (-0.143), indicating that some experts did not consider it essential. Several participants expressed concerns about the feasibility of sustainability practices, with one respondent stating, “The high cost of maintaining digital infrastructure makes it difficult for smaller institutions to adopt sustainable practices.” Another highlighted the importance of future-proofing projects: “Planning for technological advancements is crucial for long-term sustainability, but it often conflicts with budget constraints.” **Relation to Hypothesis:** The low level of agreement on sustainability highlights a key challenge in applying this principle. While the hypothesis posits that sustainability is vital for the long-term success of phygital heritage experiences, the feedback suggests that financial and technical constraints make it difficult to implement effectively. This divergence points to the need for more flexible, context-specific strategies for sustainability in cultural heritage projects.

The survey results provide strong support for the hypothesis that a balance of technological innovation, narrative fidelity, and cultural sensitivity is crucial for creating authentic, sustainable phygital cultural heritage experiences. Human-Centered Design, Technological Integration, and Narrative Fidelity received high ratings and clear qualitative examples that show how these principles contribute to user engagement and authenticity. However, Cultural Sensitivity and Sustainability revealed complexities and challenges, particularly in practical implementation, suggesting that these areas need further refinement and community involvement to be successfully integrated into future projects. Overall, the survey demonstrates that while technological innovation is key to creating engaging phygital experiences, these innovations must align with user needs and preserve the integrity of cultural narratives to ensure authenticity and sustainability.

5. DISCUSSIONS

The results of this study validate the significance of the five identified design principles—Human-Centered Design, Technological Integration, Narrative Fidelity, Cultural Sensitivity, and Sustainability—in creating phygital cultural heritage experiences. However, several challenges were identified, particularly with Cultural Sensitivity and Sustainability, suggesting that more nuanced, context-specific strategies are necessary for effective implementation.

a. Human-Centered Design: Human-Centered Design received unanimous support from participants, highlighting its importance in enhancing user engagement and accessibility. The findings strongly align with the hypothesis that designs prioritizing user needs are essential for successful phygital experiences. Participants emphasized that accessibility is often lacking, particularly for underserved groups such as the visually impaired. This reinforces the need for intuitive, inclusive designs that meet diverse user needs, supporting the argument that technological innovation must enhance user engagement rather than complicate it.

b. Technological Integration: Technological Integration also received high levels of support, affirming that technology should complement cultural heritage without overshadowing it. Feedback from participants highlighted challenges in integrating advanced technologies like VR into existing structures while maintaining historical integrity. These findings support the hypothesis that technological innovation must coexist with cultural preservation, ensuring that technology enhances rather than detracts from the cultural narrative.

c. Narrative Fidelity: Maintaining Narrative Fidelity was viewed as essential, with a strong consensus among participants that authenticity in storytelling is critical. The example of the Viking VR project highlighted the successful preservation of historical accuracy, while other projects, like those involving contested histories, faced challenges in maintaining narrative fidelity. This supports the hypothesis that phygital experiences must prioritize authentic storytelling to preserve cultural integrity, especially when dealing with sensitive or contested historical events.

d. Cultural Sensitivity: Cultural Sensitivity presented more variability in responses, reflecting the complexities involved in accurately representing diverse cultural narratives. Participants noted the importance of early and continuous community engagement to ensure respectful representation. While cultural sensitivity is important for authenticity, the feedback suggests that it can be difficult to implement in practice, particularly when balancing innovation with respect for cultural values. These challenges indicate a need for more flexible frameworks that allow for ongoing dialogue with stakeholders.

e. Sustainability: Sustainability was the most contested principle, with participants expressing concerns about its practical feasibility, particularly in terms of cost and long-term viability. The high financial burden associated with maintaining digital heritage projects was a key issue raised. These challenges highlight the need for context-specific strategies to ensure that phygital heritage projects remain sustainable over time. While sustainability is important, the feedback indicates that it must be balanced with financial constraints and technological advancements to be realistically implemented.

f. Managing Conflicting Priorities: Several participants raised concerns about potential conflicts between principles, particularly between Technological Integration and Cultural Sensitivity. To address this, a Principles Management Strategy could help balance competing priorities, ensuring that cultural authenticity is maintained while embracing innovation. This framework could assist in resolving tensions between different design principles and provide clearer guidelines for project implementation.

6. CONCLUSION

This study validated five key design principles for phygital cultural heritage experiences: Human-Centered Design, Technological Integration, Narrative Fidelity, Cultural Sensitivity, and Sustainability. The results largely support the hypothesis that balancing technological innovation with cultural preservation is essential for creating engaging and authentic phygital experiences. However, practical challenges in implementing Cultural Sensitivity and Sustainability suggest that these principles require more flexible, context-specific approaches to be effectively applied.

While Human-Centered Design, Technological Integration, and Narrative Fidelity received strong support, highlighting their importance in enhancing user engagement and maintaining cultural authenticity, the variability in responses for Cultural Sensitivity and Sustainability suggests that these areas need further exploration. The introduction of a Principles Management Strategy could help balance these competing priorities and ensure that cultural heritage projects remain both innovative and respectful of cultural values.

Future research should focus on refining these principles and developing practical strategies for their implementation across diverse cultural and technological contexts. This will ensure that phygital heritage projects are not only innovative and engaging but also sustainable and culturally respectful over the long term.

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