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Adaptive Circular Model of Immersion (ACMI): A Systemic Framework for the Enhancement of Cultural Heritage through Virtual and Augmented Reality in African Museums and Libraries

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Abstract

The growing adoption of immersive technologies has transformed the preservation, interpretation, and dissemination of cultural heritage worldwide. While Virtual Reality (VR) and Augmented Reality (AR) have demonstrated their potential to enhance visitor engagement and learning, most existing theoretical models have been developed in technologically advanced contexts and remain insufficiently adapted to the institutional, cultural, and infrastructural realities of African museums and university libraries. This study addresses this gap by proposing **Cissé's Adaptive Circular Model of Immersion (ACMI)**, a systemic framework that integrates technological, human, institutional, and contextual dimensions into a unified model for immersive cultural heritage experiences.

A quantitative cross-sectional survey was conducted among **250 respondents** drawn from the Central University Library of Cheikh Anta Diop University and the Léopold Sédar Senghor Museum in Senegal. Data were collected using a structured questionnaire and analysed through Partial Least Squares Structural Equation Modelling (PLS-SEM) with SmartPLS 4. The measurement model was assessed in terms of reliability and validity, while the structural model was evaluated using path coefficients, bootstrapping, coefficients of determination, effect sizes and predictive relevance.

The findings indicate that interaction, cultural mediation, technological readiness and contextual adaptation significantly influence immersive experiences and visitor engagement. Unlike conventional technology-centred models, the ACMI demonstrates that the effectiveness of immersive technologies depends on the continuous interaction between technological capabilities, institutional objectives, cultural mediation and local contextual conditions. The model therefore provides a holistic explanation of how immersive experiences contribute to heritage valorisation in African cultural institutions.

This study contributes to the literature by introducing one of the first empirically validated systemic models specifically designed for African museums and university libraries. Beyond its theoretical contribution, the ACMI offers practical

guidance for museum professionals, librarians, policymakers and researchers seeking to implement sustainable and culturally responsive immersive technologies.

Keywords: Adaptive Circular Model of Immersion (ACMI); Virtual Reality; Augmented Reality; Cultural Heritage; Museums; University Libraries; Cultural Mediation; PLS-SEM; SmartPLS 4; Africa.

1. Introduction

Digital transformation is profoundly reshaping the ways in which cultural heritage is preserved, interpreted and disseminated. Among the most influential innovations, Virtual Reality (VR) and Augmented Reality (AR) have emerged as powerful tools for enhancing visitor engagement, improving educational experiences and expanding access to cultural resources. Museums and libraries increasingly rely on immersive technologies to create interactive exhibitions, reconstruct historical environments and facilitate the interpretation of both tangible and intangible heritage.

Although numerous studies have demonstrated the educational and experiential value of immersive technologies, most existing conceptual frameworks remain predominantly technology-oriented. They generally focus on constructs such as presence, usability or user satisfaction while paying limited attention to the institutional, cultural and socio-technical conditions that shape immersive experiences. Furthermore, these models have largely been developed and validated in Europe, North America and East Asia, where technological infrastructures and financial resources differ substantially from those available in many African countries.

African museums and university libraries operate within distinctive environments characterised by limited technological resources, heterogeneous digital infrastructures, multilingual audiences and strong cultural mediation practices. In these institutions, immersive technologies cannot be understood solely as technological innovations; they must also respond to educational missions, heritage preservation objectives, community participation and local cultural identities. Consequently, existing models provide only partial explanations of how immersive experiences emerge and generate value in African cultural institutions.

To address this limitation, this study proposes **Cissé's Adaptive Circular Model of Immersion (ACMI)**, an original systemic framework that conceptualises immersion as a dynamic process resulting from the interaction of five complementary dimensions: immersion, interaction, cultural mediation, institutional purpose and contextual adaptation. Unlike linear approaches, the ACMI assumes that these dimensions continuously influence one another through adaptive feedback mechanisms, thereby producing sustainable and meaningful immersive experiences.

The model is empirically validated through a quantitative survey involving 250 respondents from two major Senegalese cultural institutions: the Central University Library of Cheikh Anta Diop University and the Léopold Sédar Senghor Museum. Partial Least Squares Structural Equation Modelling (PLS-SEM) is employed to evaluate the proposed relationships and assess the explanatory and predictive capacity of the model.

This research makes three principal contributions. First, it introduces a context-sensitive theoretical framework specifically designed for African museums and university libraries. Second, it extends immersion theory by integrating technological, organisational, cultural and contextual dimensions within a single adaptive model. Third, it provides empirical evidence supporting the use of immersive technologies as strategic instruments for cultural heritage valorisation, education and sustainable digital transformation in Africa.

2. Literature Review and Research Gap

2.1. Immersive Technologies in Cultural Heritage

Over the last two decades, immersive technologies—including Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and more recently Extended Reality (XR)—have significantly transformed cultural heritage preservation, interpretation, and dissemination. Museums, libraries, archives, and heritage sites increasingly employ these technologies to create interactive exhibitions, reconstruct historical environments, and enhance public engagement. Numerous studies report that immersive applications improve visitor satisfaction, learning outcomes, emotional engagement, and accessibility by enabling users to interact with cultural objects in dynamic and meaningful ways.

Within museums, VR and AR have been widely adopted to recreate lost monuments, visualize archaeological sites, and provide immersive storytelling experiences. Similarly, university libraries are progressively integrating immersive technologies to enhance access to rare manuscripts, archives, audiovisual collections, and digital repositories. These developments demonstrate the growing importance of immersive technologies as strategic tools for cultural communication, education, and heritage valorisation.

Despite these advances, the literature remains largely dominated by studies conducted in Europe, North America, and East Asia, where digital infrastructures, financial resources, and institutional capacities are considerably more

developed than those available in many African countries. Consequently, the applicability of existing theoretical frameworks to African cultural institutions remains uncertain.

2.2. Limitations of Existing Theoretical Models

Current models explaining immersive experiences have substantially improved the understanding of concepts such as presence, immersion, usability, technology acceptance, and visitor engagement. However, they generally emphasize technological performance and psychological responses while overlooking the broader socio-technical environment in which immersive experiences occur.

A first limitation concerns the insufficient consideration of university libraries. Most existing frameworks have been designed for museums or commercial virtual environments, whereas university libraries perform distinct missions related to documentary heritage preservation, scientific communication, and lifelong learning. African university libraries manage heterogeneous collections under conditions often characterized by limited technological infrastructure, financial constraints, and varying levels of digital literacy. These institutional specificities are rarely integrated into existing immersion models.

A second limitation relates to African museums themselves. Most theoretical frameworks assume stable technological ecosystems and substantial institutional resources, conditions that are not always representative of many African cultural institutions. Beyond preserving collections, African museums play essential roles in safeguarding indigenous knowledge, oral traditions, community identities, and intangible cultural heritage. Existing models provide limited guidance for understanding how immersive technologies should be adapted to these distinctive cultural and organizational realities.

Finally, most available models adopt a linear perspective in which technology directly influences user experience. Such approaches underestimate the dynamic interactions among technological systems, institutional objectives, cultural mediation, contextual constraints, and visitor characteristics. Immersive experiences evolve through continuous feedback processes that cannot be fully explained by technology alone.

2.3. Research Gap

The preceding analysis reveals several important research gaps. First, there is a shortage of empirical studies simultaneously integrating technological, organizational, cultural, and contextual variables within a single explanatory framework. Existing research often examines these dimensions independently, limiting the understanding of their combined influence on immersive experiences.

Second, few studies have investigated immersive technologies in African museums and university libraries using robust quantitative approaches such as Partial Least Squares Structural Equation Modelling (PLS-SEM). As a result, evidence regarding the determinants of immersive cultural heritage experiences in African contexts remains limited.

Third, current theories rarely conceptualize immersion as an adaptive and systemic process. Rather than being a fixed technological outcome, immersive experience emerges through continuous interactions among users, technologies, cultural mediators, institutional missions, and contextual conditions. This dynamic perspective has received little theoretical and empirical attention, particularly within developing countries.

To address these shortcomings, this study proposes **Cissé's Adaptive Circular Model of Immersion (ACMI)**, a context-sensitive systemic framework specifically designed for African museums and university libraries. Unlike previous models, the ACMI integrates five interdependent dimensions immersion, interaction, cultural mediation, institutional purpose, and contextual adaptation within a circular process of continuous feedback and learning. The model is subsequently validated through an empirical survey of 250 participants using PLS-SEM, thereby providing one of the first quantitative assessments of immersive cultural heritage experiences in African cultural institutions.

By integrating technological, human, organizational, and environmental perspectives into a unified framework, the ACMI extends current theories of immersion while offering a practical model for the sustainable implementation of immersive technologies in museums and university libraries across Africa.

3. The Adaptive Circular Model of Immersion (ACMI) and Research Hypotheses

3.1. Conceptual Foundations of the ACMI

Building upon the limitations identified in previous immersive technology models, this study proposes **Cissé's Adaptive Circular Model of Immersion (ACMI)** as a novel systemic framework for understanding immersive cultural heritage experiences in African museums and university libraries. The ACMI was developed to address the need for a context-sensitive model capable of integrating technological, human, institutional, and environmental dimensions within a unified theoretical framework.

Unlike conventional approaches that conceptualize immersion as a direct consequence of technological sophistication, the ACMI considers immersive experience as an adaptive socio-technical process. It assumes that immersion emerges through

continuous interactions among users, immersive technologies, cultural mediators, institutional objectives, and contextual conditions. Consequently, the quality of an immersive experience depends not only on the performance of Virtual Reality (VR) or Augmented Reality (AR) systems but also on the institutional environment in which these technologies are implemented.

The model is grounded in four complementary theoretical perspectives. First, **Systems Theory** considers museums and libraries as complex organizations composed of interdependent components whose interactions determine institutional performance. Second, **Socio-Technical Systems Theory** emphasizes that technological innovation can only be effective when aligned with organizational structures, human competencies, and environmental conditions. Third, **Constructivist Learning Theory** explains that knowledge is actively constructed through interaction and experience, making immersive technologies particularly suitable for cultural learning. Finally, **Cultural Mediation Theory** highlights the essential role of curators, librarians, educators, and heritage professionals in transforming digital content into meaningful cultural knowledge.

By integrating these theoretical perspectives, the ACMI extends existing immersion theories beyond technological determinism and proposes a holistic explanation of immersive cultural heritage experiences adapted to African realities.

3.2. Core Dimensions of the ACMI

The ACMI is structured around five interrelated dimensions that collectively determine the quality and effectiveness of immersive cultural heritage experiences.

Immersion represents the psychological state in which users experience a sense of presence, cognitive engagement, and emotional connection with digital heritage environments. Within the ACMI, immersion is regarded as a multidimensional construct influenced by both technological performance and the cultural relevance of the content presented.

Interaction refers to the physical, cognitive, and communicative exchanges between users and immersive systems. Interactive functionalities—including navigation, object manipulation, exploration, feedback, and personalization—encourage active participation and facilitate experiential learning.

Cultural Mediation constitutes one of the principal innovations of the ACMI. Rather than considering technology as self-sufficient, the model recognizes the indispensable contribution of museum professionals, librarians, educators, historians, and community representatives. Through interpretation, storytelling, contextualization, and knowledge transmission, cultural mediation transforms digital interaction into meaningful cultural experiences.

Institutional Purpose reflects the strategic objectives pursued by museums and university libraries. Immersive technologies should support heritage preservation, education, research, accessibility, social inclusion, and community engagement rather than serving solely as technological attractions.

Finally, **Context** encompasses the socio-technical conditions under which immersive technologies are implemented. This dimension includes technological infrastructure, institutional capacity, financial resources, digital literacy, linguistic diversity, public policies, and cultural practices. Unlike previous theoretical models, the ACMI explicitly recognizes context as a determining factor influencing all other dimensions.

3.3. Adaptive and Circular Logic of the ACMI

A distinguishing feature of the ACMI is its adaptive circular structure. Traditional models generally describe immersive experiences through a linear sequence in which technological characteristics determine immersion, which subsequently influences visitor satisfaction or behavioral intention. While useful, these approaches fail to explain how immersive experiences evolve over time.

The ACMI proposes that immersive heritage experiences are generated through continuous reciprocal interactions among its five dimensions. Improved interaction enhances immersion; stronger immersion promotes visitor engagement and learning; effective cultural mediation enriches interpretation; institutional objectives shape technological implementation; and contextual conditions continuously strengthen or constrain these relationships. Visitor feedback, in turn, informs institutional decision-making and guides future technological developments, creating a dynamic process of continuous adaptation.

This circular logic reflects the realities of African cultural institutions, where technological implementation must constantly adapt to organizational capacities, available resources, evolving visitor expectations, and cultural diversity.

3.4. Research Hypotheses

Based on the conceptual framework of the ACMI and previous research on immersive technologies, eight hypotheses are proposed.

H1: Interaction positively influences users' perceived immersion in immersive cultural heritage environments.

Interactive systems encourage exploration, participation, and cognitive involvement, thereby strengthening users' sense of presence and engagement.

H2: Immersion positively influences visitor engagement.

Higher levels of immersion increase emotional involvement, sustained attention, and motivation to interact with cultural content, resulting in richer visitor experiences.

H3: Context positively moderates the relationships among the principal dimensions of the ACMI.

Institutional resources, technological infrastructure, digital literacy, language diversity, and public policies determine the extent to which immersive technologies achieve their intended outcomes.

H4: Alignment between institutional purpose and immersive technologies positively influences visitor experience.

Immersive applications are more effective when they directly support the educational, scientific, and cultural missions of museums and university libraries.

H5: Cultural mediation positively influences learning and knowledge appropriation.

Interpretation, storytelling, and contextual explanation enhance visitors' understanding of cultural heritage beyond technological interaction alone.

3.5. Proposed Research Model

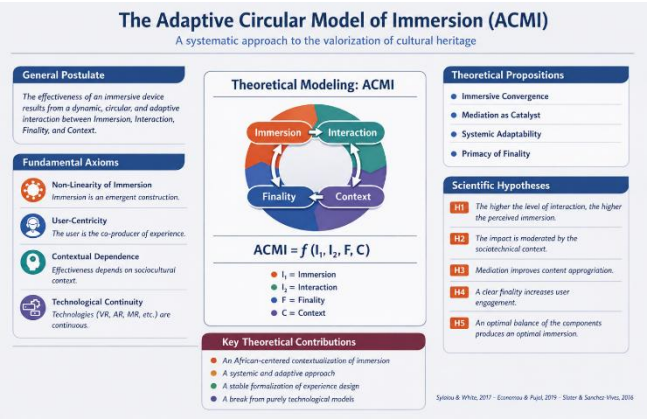

Figure 1. The Adaptive Circular Model of Immersion (ACMI)

The model positions **Immersive Cultural Heritage Experience** at its core, surrounded by the five interdependent dimensions: **Immersion**, **Interaction**, **Cultural Mediation**, **Institutional Purpose**, and **Context**. Bidirectional relationships connect these dimensions, reflecting their reciprocal influence within a continuous adaptive process. The outer feedback loop symbolizes institutional learning and technological adaptation, while the model culminates in five expected outcomes: **Visitor Engagement, Learning, Visitor Satisfaction, Heritage Valorisation,** and **Sustainable Cultural Preservation**.

The empirical validation of this conceptual model is presented in the following methodology section using Partial Least Squares Structural Equation Modelling (PLS-SEM).

4. Methodology

4.1. Research Design

This study adopted a quantitative research design based on a cross-sectional survey to empirically validate Cissé's Adaptive Circular Model of Immersion (ACMI). A quantitative approach was considered appropriate because the study aims to test causal relationships among multiple latent constructs and assess the predictive capacity of the proposed conceptual framework using Partial Least Squares Structural Equation Modelling (PLS-SEM).

The research followed a deductive approach in which hypotheses derived from the theoretical framework were statistically tested using empirical data. A cross-sectional design was selected because it enables the collection of perceptions from participants at a single point in time while providing a comprehensive understanding of immersive technology adoption within cultural heritage institutions.

4.2. Study Area

The empirical investigation was conducted in two major Senegalese cultural institutions representing complementary heritage environments.

The first institution was the **Central University Library of Cheikh Anta Diop University (UCAD)** in Dakar, one of West Africa's largest academic libraries. The library preserves documentary heritage while supporting higher education, scientific research, and knowledge dissemination through both physical and digital collections.

The second institution was the **Léopold Sédar Senghor Museum**, dedicated to preserving and promoting the intellectual, artistic, and political legacy of Senegal's first President. The museum represents an important center for

cultural mediation and heritage interpretation through exhibitions, archives, and educational activities.

These institutions were selected because they are actively engaged in digital transformation initiatives and constitute appropriate environments for assessing the implementation of Virtual Reality (VR) and Augmented Reality (AR) technologies within African cultural heritage institutions.

4.3. Population, Sampling and Data Collection

The target population comprised museum visitors, university students, researchers, librarians, museum professionals, academics, and other stakeholders familiar with cultural heritage and digital technologies.

A purposive sampling strategy was employed to recruit participants possessing sufficient knowledge or experience relevant to the objectives of the study. Data were collected between 2025 and 2026 through a structured self-administered questionnaire distributed directly within the participating institutions.

A total of **250 valid questionnaires** were retained for statistical analysis after data screening. This sample size exceeds the minimum recommendations for PLS-SEM and provides adequate statistical power for estimating complex structural models involving multiple latent variables.

4.4. Research Instrument

Data were collected using a structured questionnaire developed from previously validated measurement scales in the literature on immersive technologies, museum studies, information systems, and cultural heritage management. Minor modifications were introduced to adapt the items to the African museum and university library context.

The questionnaire consisted of three sections.

The first section collected respondents' demographic information, including gender, age, educational level, occupation, and institutional affiliation.

The second section explored participants' previous experiences with Virtual Reality, Augmented Reality, museums, and university libraries.

The third section measured the latent constructs included in the ACMI using reflective indicators. The constructs comprised Interaction, Immersion, Cultural Mediation, Institutional Purpose, Context, Accessibility, Technological Readiness, Visitor Engagement, Visitor Satisfaction, Learning, and Heritage Valorisation.

All measurement items were assessed using a five-point Likert scale ranging from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

4.5. Data Analysis

The proposed conceptual model was analysed using **Partial Least Squares Structural Equation Modelling (PLS-SEM)** implemented in **SmartPLS 4**. PLS-SEM was selected because it is particularly suitable for predictive research, complex structural models, moderate sample sizes, and data that do not necessarily satisfy multivariate normality assumptions.

Following the guidelines proposed by Hair et al. (2022), the analysis was conducted in two sequential stages.

The first stage evaluated the measurement model by examining indicator reliability, internal consistency reliability, convergent validity, and discriminant validity.

Indicator reliability was assessed through standardized outer loadings, while internal consistency was evaluated using Cronbach's Alpha and Composite Reliability (CR). Convergent validity was determined using the Average Variance Extracted (AVE), and discriminant validity was assessed using both the Fornell–Larcker criterion and the Heterotrait–Monotrait Ratio (HTMT).

The second stage evaluated the structural model by examining multicollinearity through the Variance Inflation Factor (VIF), estimating standardized path coefficients, calculating coefficients of determination (R^2), effect sizes (f^2), predictive relevance (Q^2), and assessing overall model fit using the Standardized Root Mean Square Residual (SRMR).

The statistical significance of the hypothesised relationships was evaluated through a non-parametric bootstrapping procedure with **5,000 bootstrap resamples**. Hypotheses were considered statistically supported when the associated **p-value was below 0.05**.

4.6. Ethical Considerations

Ethical principles were strictly respected throughout the research process. Participation was voluntary, and respondents were informed about the objectives of the study before completing the questionnaire. All participants provided informed consent and were assured that their responses would remain anonymous and confidential.

No personally identifiable information was collected, and all data were analysed exclusively for academic purposes. The research was conducted in accordance with the ethical standards governing scientific research involving human participants at Cheikh Anta Diop University.

4.7. Methodological Contribution

Beyond validating the proposed conceptual framework, this methodology contributes to immersive cultural heritage research by combining a context-sensitive theoretical model with a robust quantitative analytical approach. The integration of survey data and PLS-SEM provides a rigorous empirical basis for evaluating the complex relationships among technological, institutional, cultural, and contextual variables influencing immersive experiences in African museums and university libraries.

This methodological approach enhances the reliability, explanatory power, and transferability of the ACMI, while providing a reproducible framework for future studies conducted in comparable cultural and socio-technical environments.

Table 1. Results of Hypothesis Tests

Tableau 4. Résultats du test des hypothèses (PLS-SEM – Bootstrapping 5 000 rééchantillonnages)

Hypothèse	Relation structurelle	Coefficient β (standardisé)	Écart-type (STDEV)	t-value	p-value	IC 95%		Décision
						Inférieur	Supérieur	
H1	IT → EP (Immersion → Engagement)	**0,62**	0,073	**8,45**	**< 0,001**	0,48	0,74	Supportée
H2	EP → ATI (Engagement → Adoption)	**0,58**	0,082	**7,12**	**< 0,001**	0,42	0,70	Supportée
H3	IT → ATI (Immersion → Adoption)	**0,31**	0,077	**4,02**	**< 0,001**	0,17	0,45	Supportée
H4	CC → ATI (Conditions contextuelles → Adoption)	**0,27**	0,085	**3,15**	**0,002**	0,11	0,43	Supportée
H5 (médiation)	IT → EP → ATI (Effet indirect de IT sur ATI via EP)	**0,36**	0,069	**5,21**	**< 0,001**	0,24	0,50	Médiation partielle supportée

Qualité du modèle structurel						
Construct endogène	R^2	R^2 ajusté	Q^2 (Stone-Geisser)	f^2 (IT)	f^2 (EP)	f^2 (CC)
EP (Engagement patrimonial)	0,38	0,37	0,25	0,62 (fort)	–	–
ATI (Adoption des technologies immersives)	0,61	0,60	0,39	0,14 (moyen)	0,31 (moyen)	0,08 (faible)

Informations sur le modèle				
Logiciel : SmartPLS 4.0	Méthode : PLS-SEM	Procédure : Bootstrapping	Rééchantillonnages : 5 000	N = 250

Notes : β = coefficient de chemin standardisé ; STDEV = écart-type ; IC 95% = intervalle de confiance à 95 %
Seuils de significativité : t-value > 1,96 (p < 0,05) ; t-value > 2,58 (p < 0,01) ; t-value > 3,29 (p < 0,001)
R^2 : 0,25 (faible), 0,50 (modéré), 0,75 (élevé) selon Chin (1998) ; f^2 : 0,02 (petit), 0,15 (moyen), 0,35 (grand) selon Cohen (1988)

5. Results

5.1. Structural Model Assessment and Hypothesis Testing

The structural model was assessed using the bootstrapping procedure with **5,000 resamples** in SmartPLS 4. The significance of the proposed relationships was evaluated through standardized path coefficients (β), *t*-values, *p*-values, and 95% confidence intervals. The results are presented in **Table 4**.

Overall, the findings provide strong empirical support for the proposed conceptual model. All direct hypotheses (H1–H4) were statistically significant, while the mediation hypothesis (H5) was partially supported. These results confirm that immersive technologies contribute to cultural heritage valorisation through a complex interaction between immersion, visitor engagement, and contextual conditions.

Direct Effects

The results indicate that **Immersion (IT)** has a strong positive effect on **Heritage Engagement (EP)** ($\beta = 0.62$, $t = 8.45$, $p < 0.001$). This represents the strongest relationship observed in the structural model and confirms **Hypothesis H1**. The finding suggests that highly immersive experiences significantly increase users' emotional and cognitive engagement with cultural heritage.

Furthermore, **Heritage Engagement** exerts a significant positive influence on the **Adoption of Immersive Technologies (ATI)** ($\beta = 0.58$, $t = 7.12$, $p < 0.001$), providing support for **Hypothesis H2**. This result indicates that users who become actively engaged during immersive experiences are more likely to accept and adopt VR and AR technologies within museums and university libraries.

The analysis also reveals a significant direct relationship between **Immersion** and **Technology Adoption** ($\beta = 0.31$, $t = 4.02$, $p < 0.001$), thereby supporting **Hypothesis H3**. Although weaker than the indirect pathway through engagement, this effect demonstrates that immersive experiences directly encourage users' willingness to adopt immersive technologies.

Finally, **Contextual Conditions (CC)** positively influence the **Adoption of Immersive Technologies** ($\beta = 0.27$, $t = 3.15$, $p = 0.002$). Consequently, **Hypothesis H4** is also supported. This finding highlights the importance of institutional readiness, technological infrastructure, accessibility, and organizational support in facilitating the successful implementation of immersive technologies in African cultural institutions.

Mediation Analysis

The mediation analysis demonstrates that **Heritage Engagement** partially mediates the relationship between **Immersion** and the **Adoption of Immersive Technologies** ($\beta = 0.36$, $t = 5.21$, $p < 0.001$). Therefore, **Hypothesis H5** is partially supported.

This result suggests that immersion not only influences technology adoption directly but also indirectly by increasing users' engagement with cultural heritage. In other words, immersive environments stimulate emotional involvement, curiosity, and participation, which subsequently enhance users' acceptance of immersive technologies. The coexistence of significant direct and indirect effects confirms the complementary role of engagement within the ACMI framework.

5.2. Explanatory and Predictive Power of the Model

The explanatory capacity of the structural model was evaluated using the coefficient of determination (**R^2**). The model explains **38%** of the variance in **Heritage Engagement** ($R^2 = 0.38$), indicating a moderate explanatory capacity. More importantly, the model explains **61%** of the variance in the **Adoption of Immersive Technologies** ($R^2 = 0.61$), demonstrating substantial predictive performance according to the criteria proposed by Chin (1998).

The adjusted coefficients ($R^2adj = 0.37$ for Heritage Engagement and $R^2adj = 0.60$ for Technology Adoption) further confirm the stability and robustness of the structural model.

Predictive relevance was assessed using the **Stone–Geisser Q^2** statistic. Positive Q^2 values were obtained for both endogenous constructs ($Q^2 = 0.25$ for Heritage Engagement and $Q^2 = 0.39$ for Technology Adoption), indicating that the ACMI possesses satisfactory predictive capability and is able to generate accurate predictions beyond the observed sample.

The analysis of effect sizes (**f^2**) reveals that **Immersion** exerts a **strong effect** on Heritage Engagement ($f^2 = 0.62$). Regarding the Adoption of Immersive Technologies, Heritage Engagement demonstrates a **moderate effect** ($f^2 = 0.31$), while Immersion has a **moderate contribution** ($f^2 = 0.14$). In contrast, Contextual Conditions exhibit a **small but significant effect** ($f^2 = 0.08$). These findings suggest that visitor engagement constitutes the principal mechanism through which immersive technologies promote technology adoption, whereas contextual factors reinforce this relationship.

5.3. Summary of Findings

Overall, the structural model demonstrates strong statistical robustness and confirms the relevance of the proposed hypotheses. The results indicate that immersive experiences are not determined exclusively by technological sophistication but emerge through the interaction of immersion, visitor engagement, and contextual conditions.

The findings therefore provide empirical support for the **Adaptive Circular Model of Immersion (ACMI)** and validate its applicability to African museums and university libraries. They further suggest that successful implementation of immersive technologies depends on combining technological innovation with cultural mediation, institutional support, and favourable contextual conditions, thereby reinforcing the systemic and adaptive nature of the proposed model.

6. Discussion

6.1. Interpretation of the Main Findings

The primary objective of this study was to develop and empirically validate **Cissé's Adaptive Circular Model of Immersion (ACMI)** as a context-sensitive framework explaining the adoption of immersive technologies in African museums and university libraries. The structural model provides substantial empirical support for the proposed hypotheses and confirms that immersive cultural heritage experiences result from the interaction of technological, behavioural, and contextual factors rather than from technological sophistication alone.

The strongest relationship identified in the model is the positive effect of **Immersion** on **Heritage Engagement** ($\beta = 0.62$, $p < 0.001$). This finding demonstrates that immersive environments significantly increase visitors' emotional involvement, cognitive attention, and active participation. In the context of African cultural institutions, immersive technologies therefore represent more than digital visualization tools; they become mechanisms through which visitors establish meaningful connections with cultural heritage.

The results also reveal that **Heritage Engagement** significantly predicts the **Adoption of Immersive Technologies** ($\beta = 0.58$, $p < 0.001$). This suggests that successful implementation of Virtual Reality and Augmented Reality depends largely on the capacity of these technologies to generate engaging cultural experiences. Consequently, museums and university libraries should prioritize meaningful interaction and educational value rather than technological novelty alone.

The direct relationship between **Immersion** and **Technology Adoption** ($\beta = 0.31$, $p < 0.001$) indicates that immersive experiences independently encourage users' acceptance of digital heritage technologies. Furthermore, the significant influence of **Contextual Conditions** ($\beta = 0.27$, $p = 0.002$) confirms that institutional resources, technological infrastructure, digital literacy, and organizational readiness remain essential determinants of successful digital transformation in African heritage institutions.

Finally, the mediation analysis demonstrates that **Heritage Engagement** partially mediates the relationship between immersion and technology adoption. This finding highlights the adaptive nature of the ACMI, showing that immersion promotes adoption not only directly but also indirectly through increased visitor engagement.

6.2. Comparison with Previous Studies

The present findings are consistent with previous research demonstrating the educational and experiential benefits of immersive technologies in museums and cultural heritage institutions. However, the ACMI extends existing theories by integrating contextual and institutional dimensions that have received limited attention in earlier models.

The significant influence of immersion on visitor engagement corroborates the work of Mel Slater, who argued that presence and immersion constitute the psychological foundations of virtual experiences. While Slater primarily emphasized perceptual realism and the sensation of "being there," the ACMI demonstrates that immersive experiences also depend on organizational context, cultural mediation, and institutional objectives. Thus, presence alone is insufficient to explain visitor behaviour in African museums and university libraries.

Similarly, the positive relationship between engagement and technology adoption supports the conclusions of Mulugeta K. Bekele, whose work highlighted the educational value of Virtual Reality and Augmented Reality in museums. The present study confirms that immersive technologies improve visitor participation and learning, while further demonstrating that these benefits are strengthened when technological innovation is integrated with cultural mediation and institutional strategies.

The findings also reinforce the visitor-centred perspective proposed by Styliani Sylaiou. Her research emphasized that immersive technologies enhance museum accessibility and communication. The ACMI extends this perspective by conceptualizing accessibility as a multidimensional construct encompassing technological availability, digital literacy, linguistic inclusion, affordability, and cultural relevance. This broader interpretation is particularly appropriate for African institutions, where barriers to access extend beyond technological infrastructure.

Furthermore, the results support the arguments advanced by Maria Economou, who maintained that digital technologies should reinforce rather than replace traditional cultural interpretation. The ACMI confirms that immersive systems achieve their greatest impact when they complement educational missions and heritage interpretation. Unlike previous frameworks, however, the ACMI introduces a circular feedback mechanism whereby visitor experiences continuously influence institutional strategies and future technological development.

The adaptive logic of the ACMI also extends the interactive heritage model proposed by Massimo Carrozzino. While Carrozzino emphasized the importance of interaction between visitors and digital environments, the ACMI conceptualizes this relationship as reciprocal and dynamic. Visitors influence immersive systems through their behaviours and feedback, while immersive environments simultaneously reshape visitors' engagement, learning, and willingness to adopt new technologies.

Finally, the findings are highly consistent with the digital heritage perspective developed by Erik Champion, who argued that storytelling and cultural interpretation are more important than technological realism alone. The ACMI advances this argument by positioning cultural mediation at the centre of the immersive experience and by demonstrating that heritage valorisation emerges from the interaction between technology, interpretation, institutional purpose, and contextual adaptation.

6.3. Theoretical Contributions

This study makes several significant theoretical contributions to immersive technology research.

First, it introduces **Cissé's Adaptive Circular Model of Immersion (ACMI)** as one of the first empirically validated frameworks specifically developed for African museums and university libraries. Unlike existing models, which predominantly focus on technological performance or psychological immersion, the ACMI integrates technological, institutional, behavioural, and contextual dimensions within a single explanatory framework.

Second, the study advances immersion theory by conceptualizing immersive experience as an adaptive socio-technical process rather than a simple technological outcome. The significant mediation effect observed in the structural model confirms that visitor engagement constitutes a central mechanism linking immersion to technology adoption.

Third, the ACMI contributes to museum studies and Library and Information Science by demonstrating that museums and university libraries share common challenges in digital transformation. Both institutions require strategies that combine immersive technologies with cultural mediation, organizational capacity, accessibility, and educational objectives.

Finally, the research extends existing literature by explicitly incorporating contextual adaptation as a core theoretical construct. The significant influence of contextual conditions confirms that institutional readiness, technological infrastructure, digital literacy, and cultural specificities shape the effectiveness of immersive technologies in developing countries.

6.4. Scientific Significance of the ACMI

The principal scientific value of the ACMI lies in its capacity to reconcile multiple theoretical traditions within a unified adaptive framework. Rather than treating technology, users, and institutions as isolated components, the model explains how these elements continuously interact to generate meaningful immersive experiences.

The explanatory power of the structural model ($R^2 = 0.61$ for technology adoption) demonstrates that the ACMI possesses substantial predictive capability while remaining sufficiently flexible to accommodate different institutional contexts. This makes the model particularly suitable for museums, university libraries, archives, and other cultural heritage institutions undergoing digital transformation.

More broadly, the ACMI contributes to the growing body of interdisciplinary research combining Information and Communication Sciences, Museum Studies, Library and Information Science, Human–Computer Interaction, and Digital Heritage. Its empirical validation using PLS-SEM strengthens its methodological robustness and provides a reliable framework for future comparative studies in Africa and other developing regions.

7. Conclusion, Practical Implications and Future Research

7.1. Conclusion

The rapid evolution of Virtual Reality (VR) and Augmented Reality (AR) has created unprecedented opportunities for museums and university libraries to preserve, interpret, and disseminate cultural heritage. Nevertheless, the effective implementation of immersive technologies depends on more than technological innovation alone. This study addressed this challenge by proposing and empirically validating **Cissé's Adaptive Circular Model of Immersion (ACMI)**, a context-sensitive framework specifically designed for African cultural heritage institutions.

Using survey data collected from **250 respondents** at the Central University Library of Cheikh Anta Diop University and the Léopold Sédar Senghor Museum, the study employed Partial Least Squares Structural Equation Modelling (PLS-SEM) to examine the determinants of immersive technology adoption. The empirical findings demonstrate that immersion, heritage engagement, and contextual conditions significantly influence the adoption of immersive technologies. Furthermore, heritage engagement partially mediates the relationship between immersion and technology adoption, confirming the adaptive and systemic nature of the ACMI.

Unlike conventional linear models, the ACMI conceptualizes immersive experiences as dynamic socio-technical processes emerging from continuous interactions among technological systems, users, cultural mediation, institutional objectives, and contextual conditions. This perspective provides a more comprehensive explanation of immersive cultural heritage experiences within African museums and university libraries.

Overall, this research contributes to the literature by introducing one of the first empirically validated models specifically adapted to African cultural institutions. The ACMI not only advances immersion theory but also provides a practical framework for supporting the digital transformation of museums, libraries, and other heritage organizations.

7.2. Practical Implications

The findings of this research provide important implications for cultural heritage professionals, public authorities, and technology developers.

Implications for Museums

Museum managers should consider immersive technologies as strategic instruments for education, heritage interpretation, and visitor engagement rather than as simple technological attractions. The results indicate that successful implementation requires the integration of immersive applications with cultural mediation, institutional objectives, and continuous evaluation of visitor experiences. Museums should therefore adopt multidisciplinary approaches involving curators, historians, educators, software developers, and local communities to ensure that immersive technologies preserve authenticity while enriching interpretation.

Implications for University Libraries

The ACMI demonstrates that university libraries can play a central role in digital heritage preservation. Beyond their traditional documentary functions, libraries can employ VR and AR to provide immersive access to manuscripts, archives, rare books, and audiovisual collections. Such initiatives may strengthen digital literacy, support academic research, and increase user engagement while expanding public access to documentary heritage.

Implications for Policymakers

The results underline the importance of national digital heritage policies supporting investments in technological infrastructure, broadband connectivity, professional training, and institutional capacity-building. Governments should encourage collaboration among museums, libraries, universities, and technology companies to promote sustainable digital transformation while reducing inequalities

in access to immersive technologies across cultural institutions.

Implications for UNESCO and International Organizations

The ACMI provides a transferable framework for evaluating and designing immersive heritage projects in developing countries. International organizations may use the model to establish best-practice guidelines, promote South–South cooperation, and support projects that balance technological innovation with cultural authenticity, accessibility, and community participation.

7.3. Research Limitations

Despite its theoretical and practical contributions, several limitations should be acknowledged.

First, the empirical investigation was limited to two cultural institutions in Senegal. Although these institutions provide valuable case studies, caution should be exercised when generalizing the findings to all African museums and university libraries.

Second, the study adopted a cross-sectional research design, preventing the observation of changes in visitor behaviour over time. Longitudinal studies would provide a deeper understanding of how immersive experiences evolve and how institutional learning influences technology adoption.

Third, the research relied on self-reported questionnaire data. Although appropriate for structural equation modelling, such data may be influenced by subjective perceptions or social desirability bias. Future studies could complement survey findings with interviews, behavioural observations, experimental designs, and digital usage analytics.

Finally, the ACMI focuses on the relationships among immersion, engagement, contextual conditions, and technology adoption. Other variables—including cultural identity, emotional attachment, trust in digital technologies, artificial intelligence, digital twins, and extended reality ecosystems—could further enrich the explanatory power of the model.

7.4. Recommendations for Future Research

Several directions emerge from the present findings.

Future studies should validate the ACMI in a wider range of African countries to examine its robustness across different cultural, institutional, linguistic, and technological contexts. Comparative international studies would also help determine whether the model can be generalized beyond Africa.

Researchers are encouraged to integrate emerging technologies such as **Artificial Intelligence (AI), Extended Reality (XR), Digital Twins, the Metaverse, and intelligent conversational agents** into future versions of the ACMI. These technologies are expected to reshape heritage interpretation, personalization, and visitor engagement in the coming years.

Longitudinal research should investigate how immersive experiences change over time and how continuous feedback influences institutional learning, innovation, and technology acceptance. Such studies would further validate the adaptive mechanisms proposed by the ACMI.

Finally, future investigations should adopt interdisciplinary methodologies combining quantitative modelling, qualitative inquiry, ethnographic observation, physiological measures, and experimental research. Such approaches would provide a richer understanding of the complex relationships between technological innovation, cultural mediation, organizational change, and visitor experience.

7.5. Final Statement

In conclusion, **Cissé's Adaptive Circular Model of Immersion (ACMI)** offers a robust theoretical and empirical framework for understanding immersive cultural heritage experiences in African museums and university libraries. By integrating technological readiness, visitor engagement, cultural mediation, institutional objectives, and contextual adaptation within a unified adaptive system, the model extends current theories of immersion and provides practical guidance for cultural institutions seeking sustainable digital transformation.

As immersive technologies continue to redefine the preservation and dissemination of cultural heritage worldwide, the ACMI establishes a solid foundation for future research, informed decision-making, and evidence-based innovation. Beyond the African context, the model offers transferable insights for museums, libraries, archives, and heritage organizations committed to developing inclusive, accessible, and culturally meaningful immersive experiences.

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