

Augmented Reality as Digital Service Infrastructure in Museums: Enhancing Family-Based Engagement and Service Experience

Godham Eko Saputro^{1*}, Muhammad Wildan Khunaefi², Ranu Iskandar³

Anik Maghfiroh⁴, Marhaeni Dwi Satyarini⁵, Christian Wiradendi Wolor⁶

¹ Universitas Negeri Semarang, Department of Family Welfare Education, Semarang, Indonesia

² Mankhu's Research, Semarang, Indonesia

³ Universitas Negeri Semarang, Department of Automotive Engineering Education, Semarang, Indonesia

⁴ Universitas Negeri Semarang, Department of Beauty Education, Semarang, Indonesia

⁵ Universitas IVET, Department of Economic Education, Semarang, Indonesia

⁶ Universitas Negeri Jakarta, Department of Economic, Jakarta, Indonesia

godham.eko@mail.unnes.ac.id (Corresponding author)

Abstract. The integration of digital technologies has transformed museums from static exhibition spaces into interactive service systems emphasizing participation, information exchange, and experiential engagement. Among these technologies, Augmented Reality (AR) is increasingly used to support interpretation and visitor interaction. However, previous studies primarily examine AR as a visualization or educational tool, with limited attention to its role within broader service-system operations and multi-user interaction environments. This study investigates AR as a digital service infrastructure embedded within museum service systems, focusing on family-based engagement and service experience. Using an exploratory qualitative case study approach, data were collected from family visitors, museum staff, non-participant observations, and system interaction logs within an AR-enabled museum environment. The findings demonstrate that AR functions as an integrative infrastructure connecting physical exhibits, digital information, and interaction processes through real-time and context-aware service delivery. The study further reveals that family-based engagement operates as a multi-user interaction mechanism characterized by collaborative exploration, shared decision-making, and intergenerational interaction dynamics. Interaction-log data additionally indicate that visitor engagement patterns are associated with navigation behavior, feature-access frequency, and collaborative use of AR interfaces. The findings suggest that service experience emerges from the alignment between technological infrastructure, interaction design, and system integration rather than from technology alone. This study contributes to service science and informatics by providing conceptual implications for integrated digital service systems, adaptive service architectures, and family-oriented digital interaction design in cultural institutions.\

Keywords: Augmented Reality, Digital Service Infrastructure, Museum Service Systems, Family-Based Engagement, Multi-User Interaction, Service Experience, Cultural Informatics.

1. Introduction

The rapid advancement of digital technologies has significantly transformed the structure and operation of contemporary service systems (Wang, 2026). Across various sectors, digital infrastructures increasingly mediate interactions between users, organizations, and information resources, enabling services to become more adaptive, interconnected, and experience-oriented (Rahmanita, et al., 2026). This transformation reflects broader developments in service science, where value is understood as being co-created through dynamic interactions among multiple actors, technological systems, and institutional arrangements. Consequently, digital technologies are no longer positioned merely as supplementary tools, but as core components that shape how services are coordinated, delivered, and experienced (Zahari, Hoo, Wolor, & Suhud, 2026).

Within this transformation, museums are evolving from traditional repositories of artifacts into interactive cultural service systems that prioritize participation, engagement, and experiential learning (Bossavit, Pina, & Urtasun, 2018). Contemporary museums are increasingly expected to provide immersive and personalized experiences capable of accommodating diverse visitor groups and interaction preferences (Green, 2020). This shift is closely associated with the growing integration of digital technologies into museum environments, including mobile applications, interactive displays, virtual exhibitions, and Augmented Reality (AR) systems. Beyond improving interpretation, these technologies influence service operations, visitor navigation, information accessibility, and interaction management within museum environments. As a result, museums are increasingly conceptualized as digitally mediated service ecosystems in which technological infrastructures, users, and institutional actors continuously interact to produce value (Deen, 2024).

Among emerging technologies, AR has attracted substantial attention due to its capability to integrate digital information with physical environments in real time (T.G., 2022). In museum contexts, AR enables visitors to access contextualized information, visualize historical reconstructions, interact with exhibits, and navigate exhibition spaces through immersive interfaces (Liang & Elliot, 2021). Previous studies have demonstrated that AR can improve engagement, increase interpretive depth, and support interactive learning experiences in cultural heritage environments (Efart, 2020; Moneta, 2020). These capabilities position AR as a promising technology for enhancing museum service delivery and visitor interaction (Saputra, 2025).

However, despite the growing body of literature on AR in museums, existing studies remain dominated by technology-centric perspectives (Balloffet, Courvoisier, & Lagier, 2014). Most previous research primarily focuses on educational outcomes, usability evaluation, interface attractiveness, or interpretive enhancement (Chen & Lai, 2021). While these perspectives provide important insights, they often treat AR as an isolated application or visualization tool rather than as part of a broader digital service infrastructure (Conway, 2010). As a result, several important dimensions remain insufficiently explored, including the role of AR in supporting service-system coordination, interaction tracking, backend operational processes, adaptive service management, and multi-user engagement dynamics (Starn, 2005). Existing studies also rarely examine how AR contributes to the integration between front-stage visitor interaction and back-stage operational functions such as content management, interaction analytics, and system updating processes. (Williams, 1997) This limitation creates a significant gap in understanding how AR operates within the broader architecture of museum service systems.

Another limitation concerns the dominant focus on individual users (Lyons & Mallavarapu, 2021). In real museum environments, visitors frequently interact collectively, particularly within family groups involving parents, children, and intergenerational participation. Family-based interaction differs fundamentally from ordinary group interaction because it involves role distribution, collaborative navigation, shared interpretation, and varying levels of digital literacy among members (de La Ville, Badulescu, & Delestage, 2021). Parents often guide decision-making and contextual interpretation, while children tend to engage more actively with digital interfaces and exploratory interaction (Callanan, et al., 2020). These relational dynamics shape how digital services are accessed, negotiated, and

experienced collectively (Frank, Salsbury, McKelvey, & McLain, 2021). Nevertheless, most AR studies continue to analyze interaction primarily from an individual-user perspective, resulting in limited understanding of collaborative engagement processes within digitally mediated museum services.

The integration of AR into family-based museum interaction also introduces important challenges for informatics and service-system design (Timmermans & Prickett, 2022; Clary, 2018). AR-enabled services must accommodate heterogeneous user characteristics within a single interaction environment, including differences in age, technological familiarity, cognitive preferences, and interaction behavior. This complexity requires adaptive interfaces, flexible navigation structures, interaction-aware infrastructures, and integrated data-management systems capable of supporting simultaneous multi-user participation (Zhang, Li, & Luo, 2025; Vargas-Bejarano, Poma-Chavez, & Cornejo-Meza, 2025). Consequently, the implementation of AR in museums should not be examined solely from the standpoint of interface usability, but also in terms of service coordination, interaction architecture, information flow, and operational integration within the service system.

In response to these gaps, this study reconceptualizes AR as a digital service infrastructure embedded within museum service systems (Suszkiewicz, 2018). Rather than examining AR as a standalone visualization technology, this study investigates how AR supports interaction processes, service coordination, information management, and family-based engagement within an integrated service environment. The study specifically focuses on family visitors in an AR-enabled museum setting to examine how multi-user interaction dynamics shape engagement and service experience. By integrating perspectives from service science and informatics, this study adopts a system-oriented approach that emphasizes the interrelationship between infrastructure, interaction mechanisms, operational processes, and service outcomes.

This study contributes to the literature in three main ways. First, it extends discussions on digital service infrastructure by positioning AR as an integrative component that supports interaction management, service coordination, and adaptive service operations within museum systems. Second, the study introduces a family-based perspective into digital service interaction research by conceptualizing families as multi-user service units characterized by collaborative engagement and interdependent interaction dynamics. Third, the study contributes to informatics and service-system research by highlighting the importance of interaction tracking, system integration, adaptive interfaces, and data-driven service management in the design of digital cultural services. Practically, the findings provide implications for museums and cultural institutions seeking to develop integrated and user-oriented digital service ecosystems capable of supporting collaborative and immersive visitor experiences.

2. Literature Review

2.1 Museums as Digital Service Systems

Museums are increasingly conceptualized as interactive service systems rather than static institutions dedicated solely to preservation and exhibition (Dawson, et al., 2018). Within service science, a service system refers to a configuration of actors, technologies, organizations, and shared information that interact to co-create value through service exchange (Albouti & Balaji, 2025). In museum environments, this perspective shifts the focus from artifact-centered presentation toward interaction-centered service delivery, where visitor engagement, participation, and experience become central dimensions of service performance (Dubus, Kouril, Nguyen, Prosek, & Tate, 2010).

The transformation of museums into digital service systems is closely associated with the integration of information technologies that support communication, accessibility, personalization, and interaction management (Erh, 2023). Contemporary museums increasingly implement digital infrastructures such as mobile applications, interactive displays, virtual exhibitions, and immersive technologies to enhance visitor engagement and operational effectiveness (Saputra, 2025). These technologies enable museums to coordinate front-stage visitor interaction with back-stage operational processes, including content

management, information distribution, interaction analytics, and service adaptation (Kotarba & Zawila-Niedźwiecki, 2025; Landau-Donnelly, 2023).

From an informatics perspective, digital transformation also changes how museums manage information flows and service coordination (Ochai & UNESCO., 2022; Nicholson, 1985). User interaction data generated through digital systems can support service monitoring, exhibit evaluation, and adaptive decision-making processes (Simanjuntak, Goh, Sagala, & Sitanggang, 2025). Consequently, museums increasingly operate as digitally mediated ecosystems in which technological infrastructures, institutional actors, and users continuously interact within integrated service environments. Understanding museums as service systems therefore provides an important foundation for examining how AR contributes not only to visitor interaction, but also to broader operational and infrastructural processes (Chang, Hou, Pan, Sung, & Chang, 2015).

2.2 Augmented Reality as Digital Service Infrastructure

Augmented Reality (AR) refers to technologies that integrate digital content with physical environments through real-time and context-sensitive interaction (T.G., 2022). In museum settings, AR enables visitors to access layered information, visualize historical reconstructions, interact with virtual objects, and navigate exhibition environments through immersive interfaces (Antonioli, Blake, & Sparks, 2014; Farrell, Hayes, Shapiro, & Sullivan, 2007). Due to these capabilities, AR has become increasingly prominent in cultural heritage and museum-service research. Existing studies predominantly examine AR from educational, interpretive, and usability perspectives. Previous research demonstrates that AR can increase visitor attention, improve interpretive understanding, support interactive learning, and enhance engagement with museum exhibits (Ge, Gilardi, Whyke, & Yang, 2024 (Chen & Lai, 2021). Other studies focus on interface design, visual attractiveness, and user satisfaction associated with AR-based applications (Feiner, 2002). Although these contributions are valuable, they frequently position AR as a standalone technological feature rather than as an integrated component within broader service systems (Satria, Karya, & Rusad, 2024).

Based the perspective of service science and informatics, digital infrastructure plays a critical role in enabling interaction coordination, information exchange, service responsiveness, and operational integration (Bandura, McLean, & Girgvliani, 2024). In this context, AR can be understood not merely as a visualization tool, but as a digital service infrastructure that mediates relationships between users, content, physical environments, and institutional systems. AR interfaces facilitate continuous interaction flows while simultaneously generating user-interaction data that can support service optimization and adaptive management processes (Lee, et al., 2015). This infrastructural perspective is important because it expands the analytical focus beyond interface usability toward system integration and operational functionality. AR systems do not only influence visitor interaction at the front stage, but also support back-stage processes such as content updating, interaction tracking, service monitoring, and information management. Consequently, examining AR as digital service infrastructure provides a more comprehensive understanding of how immersive technologies contribute to service coordination and system-level performance within museum environments (Moneta, 2020).

2.3 Service Experience and User Engagement in Digital Environments

Service experience represents one of the central concepts within service science and refers to the cognitive, emotional, and behavioral responses emerging during user interaction with service systems (Martinez, 2023). In digitally mediated environments, service experience is strongly influenced by interaction quality, interface responsiveness, accessibility of information, and the degree of user participation within service processes (Chan & Saikim, 2022). User engagement, therefore, becomes a critical indicator of service effectiveness because it reflects how actively users interact with available service resources (Kumar, Umashankar, Kim, & Bhagwat, 2014).

Digital technologies significantly reshape patterns of engagement by enabling interactive, immersive, and personalized service encounters (Dahal, Sharma, Ghimire, Karki, & Joshi, 2025). Interactive

interfaces encourage users to move beyond passive information reception toward active exploration and participation (Nasution, Erlina, Muda, & Sirojuzilam, 2025). Within museum environments, technologies such as AR support multi-sensory interaction, contextual information delivery, and exploratory learning processes that can strengthen emotional and cognitive engagement with exhibits (Moser, 2013; Turner, 2009).

However, engagement within digital service systems should not be understood solely as an individual psychological response (Lawson & Lawson, 2013). Engagement also emerges through interaction processes embedded within broader social and technological environments (Freier & Peter H. Kahn, 2009). Service experience is therefore increasingly viewed as the outcome of interaction between technological infrastructures, user behavior, and service-system coordination rather than as an isolated individual perception. This perspective structures interaction flows and shapes five highlights the importance of examining how digital engagement patterns within service environments (Watson & Floridi, 2021).

2.4 Family as Multi-User Service Unit

Traditional service research frequently focuses on individual users as the primary unit of analysis (Zouni & Kouremenos, 2008). Nevertheless, many service environments, including museums, are experienced collectively through social units such as families (Timmermans & Prickett, 2022). Family-based interaction differs from ordinary group interaction because it involves interdependent relationships, role distribution, collaborative decision-making, and intergenerational participation among members (de La Ville, Badulescu, & Delestage, 2021). Within museum contexts, parents and children often assume complementary interaction roles during service encounters (Williams, 1997). Parents typically guide navigation, provide contextual interpretation, and coordinate decision-making processes, whereas children tend to engage more actively with digital interfaces and exploratory interaction (Callanan, et al., 2020). These interaction patterns create collaborative engagement processes that influence how information is accessed, interpreted, and experienced collectively. Variations in age, technological familiarity, and cognitive preferences further shape interaction dynamics within family groups.

From a service-science perspective, families can therefore be conceptualized as micro-level service ecosystems in which value is co-created through internal interaction among members. This perspective expands conventional user-centered models by emphasizing relational and collective dimensions of engagement. Rather than functioning as isolated individuals, family members continuously negotiate, coordinate, and adapt their interactions during service encounters (Freier & Peter H. Kahn, 2009). The integration of AR into family-based interaction environments introduces additional complexity for digital service design. AR interfaces must support simultaneous participation by users with different levels of digital literacy, interaction preferences, and cognitive capabilities. Consequently, effective AR-enabled service systems require adaptive interfaces, flexible navigation structures, and interaction mechanisms capable of supporting collaborative exploration and shared engagement. Understanding families as multi-user service units is therefore essential for designing inclusive, interaction-aware, and socially responsive digital service systems in museums (Liang & Elliot, 2021).

3. Methodology

3.1 Research Design and Case Context

This study employs an exploratory qualitative case study design to investigate the role of Augmented Reality (AR) as a digital service infrastructure within museum service systems. (Ollé-Espluga, Vergara-Duarte, Menéndez-Fuster, Benach, & Vázquez, 2019) A qualitative case-study approach is appropriate because the study seeks to examine complex interactions between technological systems, users, and service operations within a real-world environment rather than isolating variables under experimental conditions (Heyink & Tymstra, 1993). The exploratory orientation is particularly relevant because research examining AR as an integrated service infrastructure in museum systems remains limited,

especially in relation to family-based interaction and service-system coordination.

The study was conducted at Museum Ranggawarsita, Central Java, Indonesia, a public cultural museum that has implemented AR-based digital exhibition services in selected exhibition areas. The museum integrates marker-based and markerless AR features through mobile-device interaction to provide contextual information, three-dimensional visualization, and interactive navigation support for visitors. Visitors access AR services using smartphones and tablets provided by the museum or through their personal mobile devices. At the time of data collection, AR features were implemented across several cultural and historical exhibition sections, including traditional artifacts, historical collections, and cultural storytelling displays.

The museum was selected because it represents an active example of digital transformation within Indonesian cultural institutions and provides a relevant environment for examining how AR systems operate within broader service infrastructures. The study focuses specifically on family visitors because museums are frequently experienced collectively rather than individually, allowing the research to investigate collaborative interaction, shared decision-making, and multi-user engagement within digitally mediated service environments. Rather than pursuing statistical generalization, this study prioritizes contextual depth and analytical interpretation to generate transferable conceptual insights regarding AR-enabled service systems.

3.2 System Architecture of AR-Enabled Museum Service

To analyze AR as a digital service infrastructure, this study conceptualizes the museum as a layered service system consisting of interconnected operational and interactional components. The service architecture is organized into three primary layers: (1) physical environment layer, (2) digital infrastructure layer, and (3) user interaction layer (Hirshen & Dovey, 1981).

The physical environment layer consists of exhibition spaces, artifacts, spatial layouts, visitor circulation paths, and exhibit-navigation structures that form the contextual basis of service delivery. The digital infrastructure layer includes AR applications, mobile interfaces, content-management systems, interaction-tracking mechanisms, cloud-based content storage, and backend information-processing systems that support real-time information delivery and system coordination. Meanwhile, the user interaction layer represents how visitors interact with physical and digital components through mobile devices, scanning activities, navigation behavior, and collaborative engagement processes.

These layers are interconnected through continuous interaction and information flows. AR functions as an integrative interface that links physical exhibits with digital information through real-time contextual interaction. Simultaneously, user interaction generates behavioral data that can support system monitoring, content updating, and service optimization processes. This interaction-feedback mechanism enables the museum service system to function adaptively rather than statically. This architectural perspective allows the study to move beyond feature-based analysis toward examining how AR contributes to operational integration, interaction coordination, and service-system performance.

3.3 Service Interaction Context

The interaction context examined in this study includes spatial, technological, social, and temporal dimensions that shape visitor engagement within the AR-enabled museum environment. Spatially, interactions occur within exhibition areas where physical artifacts are augmented with digital information through AR interfaces. Technologically, interaction is mediated through mobile-based AR systems that provide real-time contextual content, three-dimensional visualization, and interactive navigation assistance. Socially, interaction is strongly influenced by the presence of family groups involving collaborative participation between parents and children. Temporally, the interaction context includes duration of engagement, sequence of navigation, repeated scanning behavior, and continuity of interaction across exhibition zones.

Particular attention is given to how these dimensions intersect during family-based interaction. For

example, parents frequently guide navigation and interpretive discussion, while children actively initiate interaction with AR features. This collaborative engagement structure shapes how information is explored, negotiated, and collectively interpreted within the service environment. Understanding these contextual dimensions is essential because service experience in digitally mediated museum systems emerges not only from technology use itself but also from interaction processes embedded within broader social and operational environments.

3.4 Data Collection: Multi-Stakeholder and Multi-Source Approach

This study adopts a multi-stakeholder and multi-source data collection strategy to capture the complexity of interaction within the AR-enabled museum service system. Data were collected from three primary sources: (1) family visitors as service users, (2) museum management and operational staff as service providers, and (3) digital interaction logs generated by the AR system. Semi-structured interviews were conducted with family visitors to examine interaction behavior, collaborative engagement, navigation patterns, and perceived service experience during AR usage. Interviews with museum staff and management focused on operational implementation, content management, system maintenance, interaction monitoring, and service coordination related to the AR infrastructure.

The interviews were conducted between January and March 2025. Each interview lasted approximately 30–60 minutes and was conducted in Indonesian. All interviews were audio-recorded with participant consent and subsequently transcribed verbatim for analysis. The interview protocol consisted of open-ended questions exploring visitor interaction, collaborative engagement, usability perception, operational management, and service-system integration.

In addition to interviews, non-participant observations were conducted within exhibition areas to document visitor movement, collaborative interaction patterns, navigation behavior, feature usage, and engagement duration during AR interaction sessions. Observations were recorded through structured field notes and interaction mapping. To strengthen the informatics dimension of the study, digital interaction logs generated by the AR system were also analyzed. These logs included feature-access frequency, interaction duration, navigation sequences, repeated scanning behavior, and interface interaction events. Interaction-log analysis was used to complement qualitative findings and provide system-level evidence regarding user engagement and interaction patterns.

Examples of interaction-log findings include (1) average AR session duration ranging from 6–11 minutes per exhibit zone; (2) repeated scanning behavior occurring primarily among child users; (3) navigation sequences commonly beginning from introductory cultural exhibits before moving toward interactive storytelling sections; (4) higher feature-access frequency in three-dimensional visualization modules compared to text-based information layers. The characteristics of participants and interaction-log sources are summarized in the following tables.

Table 1. Family Visitor Participants

No	Anonymous Code	Age	Role	Visit Type	Group Composition
1	V1	42	Parent	Family Visit	Parent + 2 Children
2	V2	38	Parent	Family Visit	Parent + 1 Child
3	V3	15	Child Visitor	Family Visit	Parent + 2 Children
4	V4	12	Child Visitor	Family Visit	Parent + 1 Child
5	V5	45	Parent	Family Visit	Parent + 3 Children

Table 2. Museum Management and Staff Participants

No	Anonymous Code	Position	Primary Responsibility
1	M1	Museum Director	Strategic planning and digital-service policy
2	M2	Curator	Content management and exhibition design
3	M3	IT Specialist	AR system integration and maintenance
4	M4	Service Officer	Visitor assistance and operational support

Table 3. Interaction-Log and System Data Sources

No	Data Type	Description	Analytical Purpose
1	Interaction Logs	Records of AR feature usage	Identifying engagement intensity
2	Session Duration	Time spent using AR features	Measuring interaction depth
3	Navigation Sequences	Visitor movement across AR points	Analyzing interaction flow
4	Feature Access Frequency	Frequency of feature activation	Identifying preferred functions
5	Device Interaction Events	Touch, scan, and interface activity	Examining interface usability

3.5 Data Analysis

The study employs thematic analysis using a system-oriented analytical perspective. Data analysis began with transcription, repeated reading, and familiarization with interview transcripts, observation records, and interaction-log summaries. Open coding was initially conducted to identify recurring patterns related to AR infrastructure, interaction behavior, collaborative engagement, service coordination, and system integration. Codes were subsequently grouped into broader themes corresponding to major dimensions of the service system, including infrastructural function, multi-user interaction, operational integration, and service experience transformation. Relationships between themes were further analyzed to understand how technological systems, interaction mechanisms, and social dynamics interact within the museum service environment. To improve analytical transparency, the coding structure is summarized in Table 4.

Table 4. Thematic Coding Structure

Main Theme	Subtheme	Initial Codes	Data Source	Representative Evidence
AR as Digital Service Infrastructure	Front-stage interaction support	Real-time interaction, scanning activity, contextual visualization, interactive navigation	Visitor interviews, observations	“The AR made the museum feel more alive because we could directly interact with the objects and information.” (V1)
	Back-stage operational integration	Content updating, interaction tracking, backend monitoring, service coordination	Staff interviews	“The AR system is connected to the museum database, so we can update content regularly and monitor interaction activity.” (M3)
	Infrastructure integration	Physical-digital linkage, system connectivity, service integration	Observations, interaction logs	Visitors moved flexibly between exhibition points depending on AR-enabled content availability.
Family-Based Interaction System	Parent-child role distribution	Navigation guidance, interpretive assistance, technological exploration	Visitor interviews, observations	“Usually my child wanted to scan everything first, while I helped explain the historical meaning.” (V2)
	Collaborative engagement	Shared exploration, collective decision-making, discussion-based interaction	Visitor interviews, observations	Family members frequently discussed exhibit content after interacting with AR features.
	Intergenerational interaction	Digital-literacy differences, reciprocal assistance, shared participation	Observations	Older visitors occasionally relied on younger family members for interface navigation.

Interaction-Log Behavior	Engagement intensity	Session duration, repeated scanning, feature-access frequency	Interaction logs	Average AR interaction duration ranged between 6–11 minutes per exhibition zone.
	Navigation behavior	Non-linear navigation, interaction sequence, exhibit revisiting	Interaction logs, observations	Visitors frequently revisited interactive storytelling sections containing AR visualization.
	Interface usability	Navigation confusion, interface responsiveness, transition difficulty	Interaction logs, observations	Some visitors experienced temporary confusion when transitioning between physical exhibits and digital interaction layers.
Service Experience Transformation	Immersive experience	Active exploration, contextual engagement, interactive learning	Visitor interviews	“Usually museums feel static, but the AR experience made us more curious to explore together.” (V5)
	System-level experience	Interaction continuity, system coherence, collaborative meaning-making	Interviews, observations	Meaningful engagement emerged when technological interaction supported collaborative family interaction.
	Service disruption	Delayed responsiveness, unstable interaction flow, interrupted engagement	Observations, interaction logs	Technical delays occasionally disrupted visitor interaction continuity.

The coding process was conducted iteratively through continuous comparison between interview data, observational findings, and interaction-log evidence. Themes were refined progressively to ensure analytical consistency and conceptual alignment with the service-system framework. This iterative process enabled the study to connect empirical interaction patterns with broader discussions regarding digital service infrastructure, collaborative engagement, and system-level service experience.

3.6 Validity and Reliability

Several strategies were employed to strengthen the trustworthiness of the study. First, data triangulation was achieved by integrating interviews, observations, and interaction-log data from multiple stakeholders. Second, member checking was conducted by discussing preliminary interpretations with selected participants to improve interpretive accuracy. Third, thick description was applied to provide detailed contextual explanation regarding the museum environment, AR implementation, and interaction processes. Methodological transparency was also maintained through detailed reporting of interview procedures, coding structures, and analytical processes. In addition, consistency was maintained between the conceptual framework, research questions, data collection procedures, and analytical interpretation to ensure coherence throughout the study. These strategies collectively strengthen the credibility, dependability, and analytical rigor of the research within the domains of digital service systems, informatics, and service science.

4. Results

4.1 AR Infrastructure Integration within Museum Service Operations

The findings indicate that AR functions as an integrated component within the museum’s digital service infrastructure rather than merely as a supplementary visualization feature. The AR system was embedded into multiple exhibition sections and connected with digital content-management processes,

visitor interaction interfaces, and operational service coordination. Observational data showed that visitors primarily interacted with AR features through smartphone-based scanning and real-time visualization activities. Most interactions occurred in cultural-history exhibition areas where visitors accessed layered digital information, three-dimensional object visualization, and contextual storytelling content. The AR system enabled visitors to receive immediate interpretive information without relying exclusively on static textual descriptions or staff assistance.

Museum staff further explained that the AR infrastructure was continuously connected with backend operational processes. According to the museum IT specialist (M3), the system allowed administrators to update digital content, monitor interaction frequency, and identify highly accessed exhibits:

“The AR system is connected to the museum database, so we can update content regularly and monitor which exhibition areas receive the highest interaction activity.”
(M3)

Similarly, the curator (M2) explained that interaction data generated through the AR platform assisted exhibition evaluation and content-development decisions:

“Interaction statistics help us understand which content attracts visitors most and which sections need improvement.” (M2)

These findings demonstrate that AR contributed not only to front-stage visitor interaction but also to back-stage operational management processes. The system generated continuous interaction data that supported content maintenance, service monitoring, and exhibit evaluation. Observation results additionally showed that visitor interaction became more spatially dynamic after AR implementation. Rather than following linear exhibit sequences, visitors moved more flexibly between exhibition points depending on interactive content availability and family discussion processes. This indicates that AR influenced not only information access but also visitor navigation behavior within the museum environment. Overall, the findings suggest that the effectiveness of AR depended largely on its integration with broader service operations and information-management processes rather than on visualization capability alone.

4.2 Family-Based Interaction Patterns

The findings reveal that visitor engagement within the AR-enabled museum environment was strongly shaped by collaborative interaction among family members. Rather than interacting individually with the system, visitors frequently engaged in shared exploration, collective interpretation, and collaborative decision-making processes during museum visits. Observation data showed consistent role differentiation within family groups. Parents commonly guided navigation, interpreted exhibit information, and coordinated interaction sequences, while children actively explored AR features and initiated scanning activities. These complementary roles created collaborative interaction flows throughout the service encounter.

One parent participant explained:

“Usually my child wanted to scan everything first, while I helped explain the historical meaning and guided which sections to visit next.” (V2)

Similarly, a child participant described AR interaction as a shared activity:

“I liked using the AR because I could explore the objects directly, but my parents helped explain the stories behind them.” (V3)

These findings indicate that engagement emerged through coordinated participation rather than isolated individual interaction. Family interaction frequently involved discussion, negotiation, and shared attention during AR usage. In several observed sessions, parents and children collaboratively selected which exhibits to explore and discussed digital content together after interacting with AR features. The presence of AR also appeared to strengthen intergenerational interaction. Observation results showed that parents who were initially passive became more actively involved after children initiated AR interaction. Conversely, children often relied on parents for contextual interpretation and

navigation decisions.

However, differences in digital familiarity occasionally created interaction challenges. Older visitors sometimes experienced difficulty operating interface features or understanding navigation instructions, leading younger family members to assume technological guidance roles. This indicates that family-based interaction introduced heterogeneous user characteristics within a single service encounter. Overall, the findings demonstrate that family-based engagement functioned as a multi-user interaction mechanism in which service experience was collectively constructed through collaborative participation.

4.3 Interaction-Log Findings and User Behavior Patterns

Analysis of interaction-log data provided additional evidence regarding visitor engagement and system interaction patterns within the AR-enabled museum environment. The interaction logs showed that average AR session duration ranged between 6 and 11 minutes per exhibition zone, with longer interaction periods occurring in exhibits containing three-dimensional visualization and animated storytelling features. The most frequently accessed AR functions were object visualization modules and interactive cultural narratives. Repeated scanning behavior was observed primarily among younger visitors, particularly children who repeatedly activated visualization features to re-examine digital objects and animations.

In contrast, adult visitors demonstrated more selective interaction behavior, focusing mainly on contextual information and navigation assistance. Navigation-path analysis indicated that visitors commonly began interaction in introductory exhibition areas before moving toward interactive storytelling sections containing higher levels of AR integration. Family groups frequently paused at interactive points longer than individual visitors, especially when collaborative discussion emerged around digital content. The interaction logs also revealed differences in engagement patterns between individual and collaborative interaction contexts. Family groups demonstrated (1) longer interaction duration; (2) more repeated feature access; (3) higher navigation flexibility; (4) increased conversational interaction during AR usage. According to the museum service officer (M4):

“Families usually spend more time in AR sections because parents and children interact together while discussing the content.” (M4)

Additionally, interface-interaction records showed that some visitors experienced temporary navigation confusion when transitioning between physical exhibits and digital interaction layers. This finding suggests that interface clarity and interaction guidance remain important factors influencing service continuity. Overall, the interaction-log analysis strengthens the argument that AR interaction within museum systems involves dynamic behavioral patterns influenced by technological infrastructure, collaborative participation, and interaction design.

4.4 Transformation of Service Experience

The findings suggest that AR implementation contributed to the transformation of museum service experience from passive information consumption toward interactive and participatory engagement. Visitors described the AR-enabled environment as more immersive, responsive, and engaging compared with conventional exhibition formats. The integration of digital content into physical exhibition spaces allowed visitors to interact with exhibits more actively and intuitively.

One participant stated:

“The AR made the museum feel more alive because we could directly interact with the objects and information.” (V1)

Another participant explained:

“Usually museums feel static, but the AR experience made us more curious to explore together.” (V5)

The transformation of experience was not limited to technological novelty alone. Instead, service experience emerged through the interaction between digital infrastructure, collaborative family engagement, and system responsiveness. Observation results showed that meaningful engagement

frequently occurred when technological interaction supported social interaction among family members. At the same time, the findings also revealed that service experience depended heavily on system coherence and interaction continuity. Delays in interface responsiveness, unclear scanning instructions, or unstable connections occasionally interrupted visitor engagement and reduced interaction quality. These findings indicate that service experience in AR-enabled museum systems should not be understood solely as an individual emotional response. Rather, experience emerged as the outcome of interconnected relationships between technological systems, interaction processes, and collaborative social participation. Overall, the results demonstrate that AR contributed to transforming museum service delivery into a more interactive, adaptive, and socially mediated experience environment.

5. Discussion

5.1 AR as Digital Service Infrastructure

The findings reposition Augmented Reality (AR) from a peripheral visualization tool into an integrated component of digital service infrastructure within museum service systems. Previous museum AR studies have predominantly emphasized educational enhancement, visualization quality, or usability aspects, often treating AR as an isolated technological feature rather than as part of broader service operations and interaction management. In contrast, the present findings demonstrate that AR contributes simultaneously to visitor interaction, backend content management, interaction tracking, and service coordination processes.

This infrastructural role becomes visible through the integration between front-stage and back-stage service operations. On the front stage, AR supports real-time contextual interaction, interactive navigation, and immersive engagement. On the back stage, the system enables content updating, interaction monitoring, and behavioral-data collection that inform operational decision-making. These findings strengthen the argument that AR should be understood not merely as a display technology but as a system-level infrastructure supporting operational continuity and adaptive service delivery. The interaction-log findings further reinforce this perspective. The presence of navigation tracking, feature-access monitoring, and behavioral-data generation indicates that AR participates in continuous information flows within the museum service system. This aligns with service-system perspectives emphasizing that digital infrastructures support not only interaction interfaces but also coordination, feedback mechanisms, and operational adaptation.

Importantly, however, the findings also indicate that AR does not automatically function as infrastructure simply because advanced technology is present. The infrastructural role of AR depends on its degree of integration with broader service architecture, information management, and interaction processes. When poorly integrated, AR risks becoming a fragmented technological layer with limited operational contribution. This finding supports previous arguments suggesting that the effectiveness of digital innovation depends more on systemic integration than on technological sophistication alone. Based on an informatics perspective, these findings highlight the importance of integrated architectures capable of connecting physical environments, digital interfaces, interaction data, and service operations into coherent service ecosystems. This extends current discussions in service science by demonstrating that digital interfaces increasingly function as operational infrastructures shaping both interaction and service-system performance.

5.2 Family-Based Interaction as Multi-User Service Mechanism

The findings demonstrate that service interaction within AR-enabled museum environments operates primarily through collaborative family-based participation rather than isolated individual engagement. This observation challenges dominant user-centered approaches that conceptualize interaction as a primarily individual activity within digital systems. The study identifies families as micro-level service ecosystems in which engagement emerges through shared exploration, coordinated navigation, collective interpretation, and interdependent participation. Parents and children assumed

complementary roles throughout the interaction process. Parents frequently acted as coordinators, interpreters, and decision facilitators, while children actively explored technological features and initiated interaction with AR interfaces. These role distributions created collaborative interaction patterns that shaped the overall service experience.

This finding contributes to service-system discussions by distinguishing family-based interaction from ordinary group interaction. Unlike temporary user groups, family-based interaction involves relational continuity, intergenerational communication, emotional familiarity, and shared decision-making structures. Consequently, interaction dynamics within family groups are more socially embedded and relationally coordinated than conventional multi-user interactions. The findings also reveal that variations in age, digital literacy, and technological familiarity significantly influenced interaction behavior within family groups. Older visitors occasionally depended on younger members for interface navigation, while children relied on parents for contextual understanding and interpretive explanation. This reciprocal dependency illustrates that value creation occurred collaboratively rather than individually.

From an informatics standpoint, these findings carry important implications for interaction-system design. Supporting family-based engagement requires adaptive interfaces capable of accommodating heterogeneous users simultaneously within a single interaction environment. This includes interface flexibility, collaborative interaction affordances, intuitive navigation structures, and interaction continuity across multiple users. However, the findings also reveal challenges associated with multi-user interaction systems. Differences in technological familiarity occasionally generated coordination difficulties, navigation delays, and usability confusion. This indicates that collaborative interaction does not emerge automatically through technological presence alone but requires carefully designed interaction architectures capable of supporting diverse participation patterns. Overall, the findings extend current service-system perspectives by demonstrating that interaction within digital museum environments is fundamentally relational, collaborative, and socially coordinated.

5.3 Service Experience as System-Level Outcome

The findings suggest that service experience in AR-enabled museum systems should be understood as a system-level outcome emerging from the interaction between infrastructure integration, collaborative engagement, and operational coherence. This perspective differs from traditional approaches that primarily interpret experience as an individual cognitive or emotional response. The study demonstrates that immersive and meaningful experiences emerged when technological systems, collaborative interaction, and service coordination operated coherently. Visitors did not respond solely to technological novelty but to the quality of interaction facilitated through the integration of digital infrastructure and collaborative engagement processes.

The interaction-log findings support this interpretation. Longer interaction duration, repeated feature access, and flexible navigation patterns were associated with environments where interaction continuity remained stable and collaborative participation was effectively supported. Conversely, service disruptions such as unclear navigation instructions, delayed responsiveness, or unstable interface transitions negatively affected engagement quality and interaction continuity. These findings indicate that service experience depends not only on interface usability but also on the alignment between technological infrastructure, interaction mechanisms, and user configurations. This reinforces the importance of system coherence within digitally mediated service environments.

From a service-science perspective, the findings extend value co-creation discussions by demonstrating that experience emerges not only through user-provider interaction but also through the structural coordination of interconnected system components. Infrastructure, interaction, and social participation collectively shape how service experience is constructed. At the same time, the findings caution against overly deterministic assumptions regarding technological innovation. Advanced technological features alone do not guarantee meaningful service experiences. The effectiveness of AR depends on how successfully it is integrated into broader interaction systems and operational

environments. Therefore, the study proposes that service experience in digitally mediated cultural services should be conceptualized as an emergent outcome of coordinated system performance rather than as a purely subjective psychological construct.

5.4 Implications for Service Design and Digital Informatics

The findings provide several practical implications for museums and digital-service institutions undergoing technological transformation. First, museums should move beyond feature-oriented technology adoption toward system-oriented digital-service design. AR implementation should not focus exclusively on visualization enhancement but also on interaction continuity, operational integration, and service coordination. This requires institutions to design digital infrastructures that connect front-stage interaction with backend management processes.

Second, the findings highlight the importance of interaction analytics and behavioral-data integration within museum operations. Interaction logs, navigation tracking, and feature-access data can support service evaluation, exhibit improvement, and adaptive content management. Developing staff dashboards and interaction-monitoring systems may therefore strengthen operational decision-making and continuous service optimization.

Third, the study emphasizes the need for family-centered interaction design. Museums should consider implementing (1) shared-screen AR interaction modes; (2) parent-child collaborative navigation prompts; (3) age-adaptive content layers; (4) simplified interface transitions; (5) multi-user interaction guidance. These features may improve collaborative engagement and reduce usability difficulties across heterogeneous visitor groups. Fourth, the findings suggest that digital-service management within museums increasingly requires interdisciplinary coordination involving curators, IT specialists, service officers, and interaction designers. Successful AR integration depends not only on technological availability but also on organizational readiness and operational coordination.

Finally, the study highlights broader implications for digital informatics and service-system research. As cultural services become increasingly technology-mediated, future service systems must prioritize integration, interoperability, interaction tracking, and adaptive responsiveness rather than isolated technological functionality alone. Overall, the findings reinforce the argument that effective digital innovation depends on coherent system integration connecting technological infrastructure, collaborative interaction, and operational management within unified service ecosystems.

6. Conclusion

This study reconceptualizes Augmented Reality (AR) as an integrated digital service infrastructure within museum service systems rather than as a standalone technological feature. The findings demonstrate that AR contributes not only to visitor interaction and immersive visualization but also to broader service operations, including interaction tracking, content management, navigation coordination, and service-system integration. These findings indicate that the effectiveness of AR depends primarily on its level of integration within the overall service architecture rather than on technological functionality alone.

The study further reveals that visitor engagement within AR-enabled museum environments is fundamentally shaped by family-based and multi-user interaction dynamics. Rather than functioning through isolated individual interaction, engagement emerges through collaborative participation involving shared exploration, interpretive discussion, and collective decision-making among family members. This finding highlights the importance of understanding families as micro-level service ecosystems within digitally mediated cultural-service environments. In addition, the findings suggest that service experience should be understood as a system-level outcome emerging from the alignment between technological infrastructure, interaction processes, and collaborative social participation. Meaningful experiences were produced when AR infrastructure, interaction continuity, and family-based engagement operated coherently within the service system. Conversely, interaction disruptions

and poor system integration negatively affected engagement quality and service continuity.

From a theoretical perspective, the study contributes to service science and digital informatics by extending discussions on digital service infrastructure, multi-user interaction, and service-system integration within cultural-service environments. However, the study does not claim broad theoretical generalization. Given its exploratory qualitative scope and limited case-study context, the findings should instead be understood as conceptual and empirical propositions that may inform future investigations regarding digitally mediated service systems. Practically, the study highlights the importance of system-oriented digital-service design in museums and other cultural institutions. Effective AR implementation requires integrated service architectures, interaction analytics, adaptive interfaces, and family-centered interaction design capable of supporting heterogeneous users within collaborative interaction environments.

Several limitations should also be acknowledged. First, the study was conducted within a single museum context, limiting contextual transferability across different institutional environments. Second, the participant sample remained relatively small and exploratory in nature. Third, interaction-log analysis was limited to available system data and did not include long-term behavioral tracking. Fourth, observational interpretation may contain researcher subjectivity despite triangulation efforts. Finally, the study did not examine longitudinal interaction patterns or long-term changes in visitor engagement behavior. Future research may therefore expand this study by investigating multiple museum contexts, integrating larger and more diverse participant groups, conducting longitudinal interaction analysis, and examining how adaptive digital-service systems influence long-term visitor engagement and operational performance. Overall, this study emphasizes that the success of digital innovation within museum service systems depends not simply on technological adoption, but on the coherent integration of infrastructure, interaction, and service operations within adaptive and collaborative service ecosystems.

Acknowledgements

This research received funding from the Ministry of Education, Culture, Research, and Technology (Kemendikrisaintek) under the Fundamental Research Grant program (2025–2026). The authors further acknowledge Museum Ranggawarsita for its assistance in enabling data access and supporting the data collection process.

References

- Albouti, A., & Balaji, K. (2025). From Technology Adoption to Digital Transformation How Institutional Trust and Digital Readiness Shape HRIS Success in Higher Education. *Journal of Logistics, Informatics and Service Science*, 12(10), 110-124.
- Antonioli, M., Blake, C., & Sparks, K. (2014). Augmented Reality Applications in Education. *The Journal of Technology Studies*, 40(2), 96–107.
- Balloffet, P., Courvoisier, F. H., & Lagier, J. (2014). From Museum to Amusement Park: The Opportunities and Risks of Edutainment. *International Journal of Arts Management*, 16(2), 4–18.
- Bandura, R., McLean, M., & Girgvliani, S. (2024). Advancing Digital Transformation and Digital Public Infrastructure: The Role of the Private Sector. . *Center for Strategic and International Studies (CSIS)*.
- Bossavit, B., Pina, A. S.-G., & Urtasun, A. (2018). Educational Games to Enhance Museum Visits for Schools. *Journal of Educational Technology & Society*, 21(4), 171–186.

- Callanan, M. A., Legare, C. H., Sobel, D. M., Jaeger, G. J., Letourneau, S., McHugh, S. R., . . . Watson, J. (2020). Exploration, Explanation, and Parent—Child Interaction in Museums. *Monographs of the Society for Research in Child Development*, 85(1), 1-147.
- Chan, J. K., & Saikim, F. H. (2022). Exploring the ecotourism service experience framework using the dimensions of motivation, expectation and ecotourism experience. *Tourism and Hospitality Research*, 22(4), 425–443.
- Chang, Y. -L., Hou, H.-T., Pan, C.-Y., Sung, Y.-T., & Chang, K.-E. (2015). Apply an Augmented Reality in a Mobile Guidance to Increase Sense of Place for Heritage Places. *Journal of Educational Technology & Society*, 18(2), 166–178.
- Chen, C.-A., & Lai, H.-I. (2021). Application of augmented reality in museums – Factors influencing the learning motivation and effectiveness. *Science Progress (1933-)*, 104., 1–16.
- Clary, K. S. (2018). Human Remains in Museums Today. *History News*, 73(4), 12-19.
- Conway, P. (2010). Preservation in the Age of Google: Digitization, Digital Preservation, and Dilemmas. *The Library Quarterly: Information, Community, Policy*, 80(1), 61–79.
- Dahal, R. K., Sharma, B. B., Ghimire, B., Karki, D., & Joshi, S. P. (2025). An Informatics-Based Analysis of Consumer Trust, Website Design, and E-Commerce Logistics in Nepal. *Journal of Logistics, Informatics and Service Science*, 12(8), 40-57.
- Dawson, P. C., Porter, C., Gadbois, D., Keith, D., Hughes, C., & Suluk, L. (2018). “Some Account of an Extraordinary Traveller”: Using Virtual Tours to Access Remote Heritage Sites of Inuit Cultural Knowledge. *Études/Inuit/Studies*, 42(1), 243–268.
- Deen, L. (2024). New 3D Experiencesst the Tribute Hall Museum on the STEM City USA Metaverse Platform. *US Black Engineer and Information Technology*, 48(4), 80-81.
- de La Ville, V.-I., Badulescu, C., & Delestage, C.-A. (2021). Welcoming Families to the Museum: Reconsidering Forms of Cultural Mediation for Parent/Child Autonomous Visits. *International Journal of Arts Management*, 23(3), 32-45.
- Dubus, M., Kouril, M., Nguyen, T.-P., Prosek, T. S., & Tate, J. (2010). Monitoring Copper and Silver Corrosion in Different Museum Environments by Electrical Resistance Measurement. *Studies in Conservation*, 55(2), 121–133.
- Efrat, L. (2020). REALational Perspectives: Strategies for Expanding beyond the Here and Now in Mobile Augmented Reality (AR) Art. *Leonardo*, 53(4), 374–379.
- Erh, J. (2023). Singapore’s Digital Transformation Journey. *Journal of Southeast Asian Economies*, 40(1), 4–31.
- Farrell, J., Hayes, J., Shapiro, C., & Sullivan, T. (2007). Standard Setting, Patents, and Holdup. *Antitrust Law Journal*, 74(3), 603–670.
- Feiner, S. K. (2002). Augmented Reality: a New Way of Seeing. *Scientific American*, 286(4), 48–55.
- Frank, J., Salsbury, M., McKelvey, H., & McLain, R. (2021). Digital Equity & Inclusion Strategies for Libraries: Promoting Student Success for All Learners. *The International Journal of Information, Diversity, & Inclusion*, 5(3), 185-205.

- Freier, N. G., & Peter H. Kahn, J. (2009). The Fast-Paced Change of Children's Technological Environments. *Children, Youth and Environments*, 19(1), 1–11.
- Ge, L., Gilardi, F., Whyke, T. W., & Yang, K. C. (2024). Video-streamed Intangible Cultural Heritage, Ethnic Perceptions, and Cross-cultural Competence in China. *Journal of Ethnic and Cultural Studies*, 11(4), 97–123.
- Green, J. D. (2020). The Petra Museum: A New Approach to Archaeological Heritage in Jordan. *American Journal of Archaeology*, 124(2), 333–342.
- Heyink, J. W., & Tymstra, T. (1993). The Function of Qualitative Research. *Social Indicators Research*, 29(3), 291–305.
- Hirshen, S., & Dovey, K. (1981). Public Service Architecture. *JAE*, 35(1), 28–31.
- Kotarba, M., & Zawila-Niedźwiecki, J. (2025). The “Smart City”: Functional Model And Digital Intelligence In Europe's Digital Decade 2030. *Politeja*, 99, 95–130.
- Kumar, V., Umashankar, N., Kim, K. H., & Bhagwat, Y. (2014). Assessing the Influence of Economic and Customer Experience Factors on Service Purchase Behaviors. *Marketing Science*, 33(5), 673–692.
- Landau-Donnelly, F. (2023). Infrastructuring Museums. Dalam A. L. Bain, & J. A. Podmore (Penyunt.), *The Cultural Infrastructure of Cities* (hal. 207–218). Agenda Publishing.
- Lawson, M. A., & Lawson, H. A. (2013). New Conceptual Frameworks for Student Engagement Research, Policy, and Practice. *Review of Educational Research*, 83(3), 432–479.
- Lee, J. H., Isayeva, T., Larson, M. R., Sawant, A. C.-R., Chanda, D., Chesnokov, I. N., & Ponnazhagan, S. (2015). Endostatin: A novel inhibitor of androgen receptor function in prostate cancer. *Proceedings of the National Academy of Sciences of the United States of America*. 112(5), hal. 1392–1397. National Academy of Sciences of the United States of America.
- Liang, L. J., & Elliot, S. (2021). A systematic review of augmented reality tourism research: What is now and what is next? *Tourism and Hospitality Research*, 21(1), 15–30.
- Lyons, L., & Mallavarapu, A. (2021). Collective Usability: Using Simulation Tools to Explore Embodied Design Challenges in Immersive, Shared Mixed-Reality Experiences. *Educational Technology & Society*, 24(2), 120-135.
- Martinez, D. (2023). Service Experience. Columbia. *Journal of Literature and Art*, 61, 89.
- Moneta, A. (2020). Architecture, Heritage, and the Metaverse: New Approaches and Methods for the Digital Built Environment. *Traditional Dwellings and Settlements Review.*, 32(1), 37–49.
- Moser, D. (2013). Understanding the Impact of the New Aesthetics and New Media Works on Future Curatorial Resource Responsibilities for Research Collections. Art Documentation. *Journal of the Art Libraries Society of North America*, 32(2), 186–201.
- Nasution, A. P., Erlina, Muda, I., & Sirojuzilam. (2025). How IT Integration and Management Accounting Systems Shape Public Performance: A Multi-Group Analysis of Regencies and Cities in North Sumatera, Indonesia. *Journal of Logistics, Informatics and Service Science*, 12(8), 207-235.
- Nicholson, J. (1985). The Museum And The Indian Community: Findings and Orientation of Leicestershire Museums Service. *Newsletter (Museum Ethnographers Group)*, 19, 3–14.

Ochai, O., & UNESCO. (2022). *New opportunities and challenges for inclusive cultural and creative industries in the digital environment*. . Research Report, UNESCO.

Ollé-Espluga, L., Vergara-Duarte, M., Menéndez-Fuster, M., Benach, J., & Vázquez, M.-L. (2019). Workers' Knowledge and Views on Interaction with Health and Safety Representatives: An Exploratory Qualitative Study. *Relations Industrielles / Industrial Relations*, 74(4), 719–41.

Rahmanita, M., Manurung, R. A., Ricardianto, P., Endri, E., Farisy, S., Susanto, R., . . . Santiko, T. (2026). The Mediating Role of Information Technology in Service Quality and User Satisfaction: Evidence from Indonesia's SEHATI 2.0 Digital Licensing System. *Journal of Logistics, Informatics and Service Science*, 13(1), 220-241.

Saputra, R. (2025). STEM-Enabled Governance for Cultural Heritage: Integrating Digital Innovation and Policy in Indonesia. *Journal of Ethnic and Cultural Studies*, 12(5), 325–344.

Satrya, I. D., Karya, D. F., & Rusad, N. W. (2024). The Interplay of Knowledge, Tourism Dependency, Resident Support, and Government Support in Shaping the Future of Sport Tourism Development in Indonesia. *Journal of Logistics, Informatics and Service Science*, 11(9), 1-18.

Simanjuntak, A., Goh, T. S., Sagala, F., & Sitanggang, D. P. (2025). Digital Informatics Integration in Manufacturing Supply Chains: Enhancing Environmental Service Quality and Logistics Efficiency Through Smart Accounting Systems. *Journal of Logistics, Informatics and Service Science*, 12(6), 59-76.

Starn, R. (2005). A Historian's Brief Guide to New Museum Studies. *The American Historical Review*, 110(1), 68–98.

Suszkiewicz, K. (2018). Museums In Situ As Places Of Reconciliation: Youth Meetings And Educational Activities At Former Concentration And Death Camps. *Politeja*, 52(1), 145–166.

T.G. (2022). Augmented Reality: Past MANAGERIE. *ASEE Prism*, 31(7), 10.

Timmermans, S., & Prickett, P. J. (2022). Who Counts as Family? How Standards Stratify Lives. *American Sociological Review*, 87(3), 504-528.

Turner, T. (2009). Beginning with Change: Resources for Building Diversity in Museums. *The Journal of Museum Education*, 34(3), 271–280.

Vargas-Bejarano, M., Poma-Chavez, J., & Cornejo-Meza, G. (2025). Technological Capability Specialization in Social Service Enterprises Under Resource Constraints. *Journal of Logistics, Informatics and Service Science*, 12(11), 22-35.

Wang, X. (2026). The Impact of Logistics Information Technology on Consumer Perceptions of Personalized Marketing in Omnichannel Supply Chains. *Journal of Logistics, Informatics and Service Science*, 13(1), 274-291.

Watson, D. S., & Floridi, L. (2021). The explanation game: a formal framework for interpretable machine learning. *Synthese*, 198(10), 9211–9242.

Williams, B. L. (1997). Recent Changes in Museum Education with Regard to Museum-School Partnerships and Discipline-based Art Education. *Visual Arts Research*, 23(2), 83–88.

Zahari, M. A., Hoo, W. C., Wolor, C. W., & Suhud, U. (2026). Digital Marketing Adaptation and Consumer Engagement in ASEAN:A Systematic Review of Pathways to Sustainable Economic Development. *Journal of Logistics, Informatics and Service Science*, 13(2), 1-19.

Zhang, F., Li, G., & Luo, H. (2025). Student intention to use MUVes: An integrated model of technology acceptance and learning engagement theories. *Educational Technology & Society*, 28(2), 397-415.

Zouni, G., & Kouremenos, A. (2008). Do tourism providers know their visitors? An investigation of tourism experience at a destination. *Tourism and Hospitality Research*, 8(4), 282–297.