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Smart Museum Dimensions: Museum Visitor Satisfaction Analysis

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Keywords:
Smart museum, Visitor satisfaction; Customer satisfaction index (CSI), Importance–performance analysis (IPA), Smart tourism.

Abstract.
This research aims to examine the validity of smart museum indicators and identify priority indicators that influence visitor satisfaction at the Sonobudoyo Museum, Yogyakarta. Unlike previous studies that mainly evaluate smart tourism at the destination level, this study focuses on a single cultural museum by assessing smart museum attributes from the perspective of visitors' expectations and experiences. This study uses a descriptive quantitative approach by distributing questionnaires to 200 respondents at the Sonobudoyo Museum. The research instrument includes six dimensions of a smart museum: technology utilisation, interactivity, adaptability, systematic efficiency, technology integration, and affordability. Data were analysed using the Customer Satisfaction Index (CSI) method to measure overall satisfaction levels and Importance–Performance Analysis (IPA) to map indicators that require improvement based on the comparison of visitors' expectations and experiences. The research results show that the level of visitor satisfaction falls into the "Very Satisfied" category with a CSI score of 84.83%. However, the IPA analysis identified 12 indicators that do not meet visitor expectations. The main findings indicate a significant gap in the aspects of device maintenance, the security sensor function that disrupts comfort, and the limited accessibility for disabled and elderly visitors. On the other hand, the ease of accessing information through QR codes and data privacy guarantees are the main strengths of this museum. These findings suggest that smart museum development should not only emphasize technology adoption, but also prioritize reliability, comfort, accessibility, and visitor-centred digital service improvement.

Kata Kunci:
Museum pintar, Kepuasan pengunjung; Indeks Kepuasan Pelanggan (CSI), Analisis Kepentingan-Kinerja (IPA), Pariwisata pintar.

Abstrak.
Penelitian ini bertujuan untuk menguji validitas indikator smart museum dan mengidentifikasi indikator prioritas yang memengaruhi kepuasan pengunjung di Museum Sonobudoyo, Yogyakarta. Berbeda dari penelitian sebelumnya yang umumnya mengevaluasi smart tourism pada tingkat destinasi, penelitian ini berfokus pada satu museum budaya dengan menilai atribut smart museum berdasarkan ekspektasi dan pengalaman pengunjung. Penelitian ini menggunakan pendekatan kuantitatif deskriptif dengan menyebarkan kuesioner kepada 200 responden di Museum Sonobudoyo. Instrumen penelitian mencakup enam dimensi smart museum, yaitu pemanfaatan teknologi, interaktivitas, adaptabilitas, efisiensi sistematis, integrasi teknologi, dan keterjangkauan. Data dianalisis menggunakan metode Customer Satisfaction Index (CSI) untuk mengukur tingkat kepuasan secara keseluruhan dan Importance–Performance Analysis (IPA) untuk memetakan indikator yang memerlukan perbaikan berdasarkan perbandingan antara harapan dan pengalaman pengunjung. Hasil penelitian menunjukkan bahwa tingkat kepuasan pengunjung berada pada kategori "Sangat Puas" dengan skor CSI sebesar 84,83%. Namun, hasil analisis IPA mengidentifikasi 12 indikator yang belum memenuhi ekspektasi pengunjung. Temuan utama menunjukkan adanya kesenjangan signifikan pada aspek pemeliharaan perangkat, fungsi sensor keamanan yang mengganggu kenyamanan, serta keterbatasan aksesibilitas bagi pengunjung disabilitas dan lanjut usia. Di sisi lain, kemudahan akses informasi melalui QR code dan jaminan privasi data menjadi kekuatan utama museum ini. Temuan ini menunjukkan bahwa pengembangan smart museum tidak hanya perlu menekankan adopsi teknologi, tetapi juga harus memprioritaskan keandalan, kenyamanan, aksesibilitas, dan peningkatan layanan digital yang berpusat pada pengunjung.

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1. Introduction

The development of information and communication technology (ICT) has driven fundamental transformations in the global tourism sector through advancements in technology, economy, and society (Gretzel et al., 2015). The concept of smart tourism emerges as the application of technology to create interconnected ecosystems, linking various stakeholders and enhancing operational efficiency (Buhalis & Yang, 2023). In this spectrum, there is a significant scale difference between a smart destination, which refers to a wide area (multiple objects), and a smart museum, which is a single, more specific object (single object) (Dzúriková et al., 2022; Ivars-Baidal et al., 2021). As an evolution of traditional museums, smart museums leverage digital transformation not only to display collections but also to build deeper connections and interactions with visitors through integrated system intelligence (Liu & Guo, 2024; Zhang et al., 2022). A smart museum should therefore be understood not merely as a museum that adopts digital devices, but as an institution that integrates technology, data, interactivity, personalization, and connectivity to enhance visitor experience, learning, interpretation, and cultural engagement (Pérez, 2023) Contemporary smart museums increasingly rely on digital interpretation, immersive media, sensor-based systems, mobile connectivity, and data-driven services to create more responsive, inclusive, and meaningful cultural experiences. Thus, the "smartness" of a museum should be evaluated not only through the availability of technology, but also through the extent to which such technology is perceived as useful, usable, reliable, and relevant by visitors.

Although the implementation of technology aims to enhance competitiveness and tourist experiences, in practice, obstacles often arise that trigger dissatisfaction. Issues such as suboptimal touchscreen interfaces, lack of cultural learning opportunities, and dependence on technology that distances visitors from the essence of museum collections have become frequently encountered phenomena (Fan et al., 2024; Li, 2024; Ting et al., 2013). This indicates that the use of technology in museums does not automatically improve visitor experience, particularly when digital facilities are not aligned with visitors' needs, usability, and expectations. These issues have also been identified in several museums in Yogyakarta that have undergone digital transformation, where visitors still complain about the digital guidance system being difficult to understand and the lack of adequate supporting facilities (Amanda et al., 2018; Saputra & Roychansyah, 2022). The decline in the quality of this experience risks reducing visitor interest and hindering the sustainability of museums as cultural preservation institutions (Annechini et al., 2020; Romanelli, 2021). Therefore, the implementation of smart museum technology requires a visitor-centred evaluation, because technological sophistication alone does not guarantee satisfaction when the system fails to support comfort, interpretation, accessibility, and meaningful engagement with museum collections.

In the city of Yogyakarta, the local government has promoted digital transformation through smart culture policies in museums such as the Vredeburg Fort Museum, the TNI AD Dharma Wiratama Museum, and the Intro Living Kotagede Museum, which use virtual reality (VR), augmented reality (AR), and video mapping technology (Aini, 2022; Firosya, 2023; Maulana, 2024; Pandu, 2024; Pratiwi, 2023; Sunendra, 2023). However, the Sonobudoyo Museum stands out as the only institution that explicitly claims its position as a smart museum through communication strategies on social media (Instagram @sonobudoyo, 2023a, 2023b). Although data shows that museums with digital technology tend to have higher visitor numbers (Cornellia & Hermawan, 2020; Wicaksono, 2023), the success of a museum should not be measured solely by the quantity of visitors, but also by the extent to which the technology truly meets information needs and provides practical value for visitors. Therefore, evaluating smart museums requires attention not only to the availability of digital technology, but also to how visitors perceive the importance and performance of each digital service attribute. This is particularly relevant for cultural museums, where technology must support heritage interpretation rather than replace the authenticity, educational value, and emotional meaning of the museum experience.

Current research shows a theoretical inconsistency in measuring the effectiveness of smart museums. First, previous research often used general smart tourism indicators designed for large-scale destinations, making them less accurate when applied to the specific context of museums (Amanda et al., 2018; Saputra, 2022). Second, although the latest smart museum dimension model has been developed, the model remains exploratory and has not yet been tested for confirmatory validity in real cases in destinations with cultural characteristics like Yogyakarta (Liu & Guo, 2024). Lastly, previous studies tend to focus on evaluating the overall positive impact of technology, but overlook in-depth mapping of which elements are most crucial for visitors (Al Saffar, 2024; Liu & Guo, 2024; Pérez, 2023). In other words, the existing literature has not adequately explained which specific smart museum attributes should be prioritized when visitor expectations and actual experiences do not align. Moreover, previous studies have shown mixed findings regarding the role of technology in museum experiences. Some studies suggest that digital technology can enhance tourist engagement, interpretation quality, and learning experience (Wang & Azizurrohman, 2024; Haleem et al., 2022), while other studies indicate that excessive or poorly designed technology may reduce the authenticity of museum visits, distract visitors from original collections, and create dissatisfaction when the system is difficult to use (Nikolaou, 2024; Taylor, 2024). These contrasting findings indicate that smart museum technology should not be treated as universally beneficial; rather, its value depends on how visitors evaluate its usefulness, ease of use, accessibility, and performance within the museum environment.

From a theoretical perspective, the evaluation of smart museum services can be linked to the Technology Acceptance Model (TAM), which explains that users' acceptance of technology is influenced by perceived usefulness and perceived ease of use (Davis, 1989). In the context of museums, digital facilities such as interactive screens, virtual reality, augmented reality, and digital guidance systems will provide meaningful value only when visitors perceive them as useful, accessible, and capable of enriching their cultural experience. In addition, this study is also informed by the expectation–performance logic of satisfaction, which argues that satisfaction emerges when perceived performance meets or exceeds prior expectations. This perspective is relevant because visitors' evaluation of smart museum attributes depends not only on the existence of technology, but also on whether its actual performance corresponds to what visitors consider important. Therefore, the effectiveness of smart museum implementation should not only be assessed from the availability of digital technology, but also from visitors' evaluation of its usefulness, performance, and relevance to their needs. By combining technology acceptance logic with expectation–performance evaluation, this study positions smart museum satisfaction as a result of the interaction between technological attributes, visitor expectations, and perceived service performance

To address this gap, this study adopts a dimensional evaluation perspective to investigate how the characteristics of smart museums influence visitors' perceptions and satisfaction. By integrating the smart museum dimension model into the Importance–Performance Analysis (IPA) method (Aprilia et al., 2022; Praseptiawan et al., 2022), this study aims to test the validity of existing indicators and identify priority elements that require strategic improvements. IPA is considered appropriate because it compares the level of importance and performance of each service attribute, allowing researchers to identify which elements should be maintained, improved, or reconsidered (Martilla & James, 1977). The use of IPA is particularly suitable for this study because the objective is not merely to measure overall satisfaction, but to diagnose specific smart museum attributes that require managerial attention. While the Customer Satisfaction Index (CSI) provides a general measure of visitor satisfaction, IPA offers a more strategic and attribute-based mapping by classifying smart museum indicators into different priority quadrants. Unlike general satisfaction measurement, IPA provides a strategic mapping of service attributes into different quadrants, making it useful for formulating managerial priorities in smart museum development. Accordingly, this study contributes to the smart museum literature by empirically contextualizing smart museum dimensions in an Indonesian cultural museum setting, linking technology acceptance with expectation–performance evaluation, and offering practical priorities for improving digital services. Through this approach, it is hoped that museum managers can refine their digital service strategies to more effectively promote positive tourist behaviour and enhance sustainable cultural tourism experiences.

2. Literature Review

2.1. Dimensions in Tourism Research

Dimensions are components found in tourism products, such as the components of tourism products which are attraction, accessibility, amenities, and ancillary services, commonly referred to as the 4A framework (Cooper et al., 1993). The dimensions of a smart destination differ from those of a general destination (Buhalis, 2000). Like the study by Huertas et al. (2019), which discusses the dimensions of smart destinations (6SA), which include smart attractions, smart accessibility, smart amenities, smart ancillary services, smart activities, and smart packages. However, within that dimension, there are no clear indicators to measure the level of a smart destination. Thus, a new dimension was developed encompassing governance, sustainability, innovation, accessibility, connectivity, intelligence, information, and online marketing with 72 indicators (Ivars-Baidal et al., 2021).

Although the dimensions and indicators of smart destinations have been developed, the measurement is still limited to the city or regional scale. Such as, measuring the smart destination level in the city of Valencia in Spain and the region of Banská Bystrica in Slovakia (Dzúriková et al., 2022; Ivars-Baidal et al., 2021). This indicates that existing smart destination indicators are more appropriate for evaluating multiple tourism objects within a wider destination system rather than a single attraction with specific operational, interpretive, and experiential characteristics. Therefore, the dimensions of a smart destination (multiple objects) will differ if adopted in research on a single tourist attraction (single object) such as a museum (Liu & Guo, 2024; Pérez, 2023; Zhang et al., 2022). A museum represents a distinctive tourism setting because it combines cultural preservation, education, interpretation, visitor engagement, and heritage experience. Consequently, the measurement of a smart museum requires a more specific dimensional framework that can capture how technology supports both museum management and visitor experience at the single-object level.

2.2. Smart Museum Definition

Museum, in general, is defined by The International Council of Museums (ICOM, 2022) as a permanent non-profit institution that serves the public by researching, collecting, preserving, interpreting, and exhibiting tangible and intangible heritage, where the institution is open to the public, easily accessible, and inclusive to promote diversity and sustainability, and operates and communicates ethically, professionally, and involves community participation to offer a variety of educational, entertainment, reflection, and knowledge-sharing experiences.

The definition of a museum in general is different from that of a smart museum. As stated by Pérez (2023), a smart museum is a museum that comprehensively integrates inclusive strategies and Information and Communication Technology (ICT) at all functional levels to achieve efficient and sustainable management. This explanation indicates that the definition of a smart museum emphasises the goal of efficiency in management. Pérez (2023) stated that not all museums can achieve the maximum level of "smart," so "smart" can be understood as a museum that has undergone digital transformation. In line with this perspective, from the visitors' side, a smart museum is a museum that undergoes digital transformation with an emphasis on the museum's intelligence to provide a more immersive experience (Liu & Guo, 2024; Zhang et al., 2022). Thus, the concept of a smart museum involves two complementary orientations. The first is managerial orientation, which focuses on efficiency, integration, data management, and sustainability. The second is experiential orientation, which focuses on how visitors perceive, use, and benefit from technology during their museum visit. In this study, the smart museum is approached primarily from the visitor perspective because the success of smart museum implementation depends not only on the presence of technology, but also on whether visitors experience the technology as useful, accessible, comfortable, and relevant to their cultural visit.

2.3. Technology at Smart Museum

Advanced technology is used in smart museums with the aim of enhancing visitor experience. For example, Virtual Reality (VR) enables digital representations of museum collections and virtual tours that can significantly improve experience and accessibility for visitors (Kramar et al., 2021). More specifically, sensor integration allows interconnected museum systems to collect data in real time and provide personalized experiences, such as navigation guidance and lighting adjustments based on visitor movement (Korzun et al., 2017; Marchenkov et al., 2017).

Table 1. Technology at the Smart Museum

Technology	Functions
Quick Response (QR) Code	A bridge between the real world and the digital realm, this code allows for more detailed information access and interaction through scanning codes that contain data (e.g., websites, text, and audio) (Ovallos-Gazabon et al., 2020; Thinley et al., 2024).
Digital Information Media (Monitor Screen/Smart TV)	The delivery of information using videos, animations, or interactive graphics can enrich the visitor experience and help them interact directly with the collection objects (Chen, 2023; Wang & Zhu, 2022).
Interactive diorama	Multisensory interactions, including touch, audio, and visual, to enhance visitor engagement (Claisse et al., 2018; Guedes et al., 2020).
Virtual Reality (VR)	VR provides realistic 3D visualisations that allow visitors to explore cultural and historical environments in a new way (Khalloufi et al., 2024; Zheng et al., 2024)
Augmented Reality (AR) in Photobooth	AR technology allows visitors to take photos with virtual graphic elements or effects that are directly integrated into the physical environment, creating a unique and engaging experience (Nazhar, 2021; Wu et al., 2023).
Museum Collection Security Sensor	Sensor systems to detect visitor presence and monitor sensitive areas around the collection (Ovallos-Gazabon et al., 2020).
Video Mapping	Projecting dynamic multimedia content onto the surfaces of real objects, creating an engaging and immersive visual illusion (Nikolakopoulou et al., 2022; Pahrulroji et al., 2021).
Automatic Door Sensor	This sensor works by detecting movement when visitors approach the door, automatically opening to provide access without the need for physical contact (Handojo et al., 2020; Šveb Dragija & Jelinčić, 2022).
Interactive Game	Utilising technology and creative design, interactive games can provide an enjoyable educational experience (Ovallos-Gazabon et al., 2020).

In addition, various smart museum technologies, such as QR codes, digital information media, interactive dioramas, Augmented Reality (AR), security sensors, video mapping, automatic door sensors, and interactive games, can support different aspects of museum experience. QR codes allow visitors to access more detailed information through their own devices. Digital information media and interactive dioramas can enrich interpretation through visual, audio, and multisensory elements. VR and AR can provide immersive and engaging experiences, while sensor-based technologies can support visitor movement, safety, and interaction with museum spaces.

However, the relationship between technology and visitor experience is not always linear or automatically positive. While digital technologies may enhance learning, engagement, accessibility, and entertainment, poorly designed or poorly maintained technologies may also create discomfort, confusion, distraction, and dissatisfaction. For instance, VR devices that are difficult to operate, interactive screens with unclear instructions, sensors that produce disturbing alarms, or digital maps that fail to support navigation may weaken the overall museum experience. Therefore, smart museum technology should be evaluated not only based on its availability, but also based on its performance, usability, reliability, inclusiveness, and ability to support meaningful engagement with museum collections. This perspective is important because cultural museums must ensure that technology strengthens, rather than replaces, the authenticity and interpretive value of heritage collections. The use of technology in this museum has been widely implemented, as explained in Table 1.

2.4. Smart Museum Dimensions

Previous studies have identified the dimensions of a smart museum based on the perspectives of curators, managers, and museum experts. These dimensions are considered important components for assessing a museum's technological capabilities (Liu & Guo, 2024). Liu and Guo (2024) identify six dimensions of a smart museum: technology-enabled, interactivity, adaptability, systematic efficiency, technology integration, and affordability. Each dimension consists of attributes and indicators that explain specific characteristics of smart museum implementation. Therefore, the smart museum dimension model can be used to evaluate how technological capability contributes to visitor satisfaction.

Previous research has mainly focused on smart museum management (Pérez, 2023), visitor experience with museum technology, and visitor satisfaction (Zhang et al., 2022). However, several studies still rely on smart destination dimensions, which are not fully specific to the single-object context of museums. According to Liu and Guo (2024), a smart museum as a single object requires specific indicators that reflect museum characteristics, visitor interaction, and technology-based interpretation. Based on this limitation, Liu and Guo (2024) developed a model linking smart museum dimensions with visitor satisfaction.

Nevertheless, the application of this model remains limited. First, the model has largely been developed from expert and institutional perspectives, while empirical evaluation from the visitor perspective remains relatively underexplored. Second, the suitability of the indicators in different cultural museum contexts has not been sufficiently examined. Third, previous research tends to identify factors that shape satisfaction, but provides limited diagnostic explanation regarding which specific indicators require improvement from the visitor perspective. Therefore, this study does not merely adopt the smart museum dimension model; it empirically contextualizes the model in the setting of Sonobudoyo Museum by examining visitors' expectations and experiences of each smart museum indicator.

Based on previous research on smart museum dimensions and visitor satisfaction, three main factors have been identified as shaping satisfaction: usefulness, acceptance, and technology performance (Liu & Guo, 2024). Technology usefulness refers to the extent to which technology improves effectiveness, efficiency, and satisfaction when visitors use smart museum facilities. Liu and Guo (2024) identify ease of use, task suitability, and comfort of use as important aspects of usefulness because they shape the quality of interaction between visitors and museum technology. Technology acceptance refers to whether the design and function of technology are sufficient to meet visitors' needs and expectations. Meanwhile, technology performance includes the operational quality, reliability, responsiveness, and integration of digital facilities in the museum environment.

These three factors indicate that smart museum satisfaction is not determined by technological sophistication alone. Instead, satisfaction depends on whether visitors perceive the technology as useful, acceptable, and well-performing in supporting their museum visit. The model proposed by Liu and Guo (2024) explains that six smart museum dimensions generate three main factors that shape visitor satisfaction at the Beijing Palace Museum, China. In contrast to that previous context, this study applies the model to assess smart museum dimensions based on visitors' expectations and experiences at the Sonobudoyo Museum.

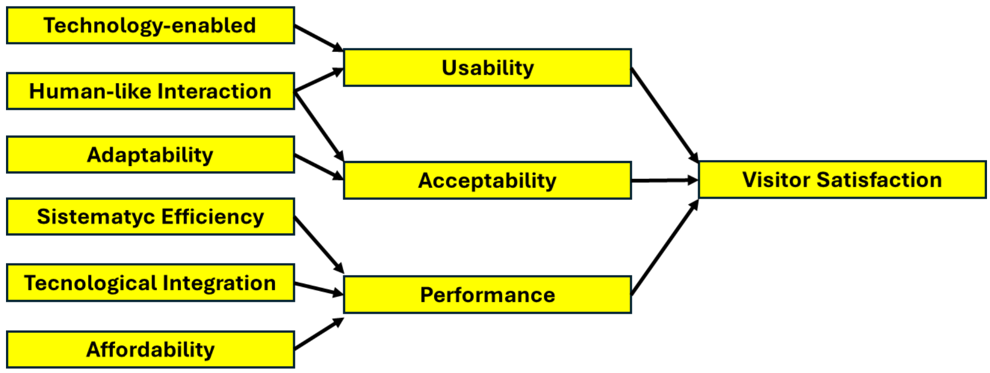

Figure 1. Smart Museum Dimension Model and Visitor Satisfaction
Source: Liu & Guo (2024)

2.5. Visitor Satisfaction in Smart Museums

Satisfaction is a function of product evaluation and customer expectations. Dissatisfaction arises when expectations and anticipations are not fulfilled (Kotler et al., 2022). In tourism, visitor satisfaction is achieved when the services provided meet or exceed visitors' expectations (Damanik & Yusuf, 2022). If the museum experience meets or exceeds expectations, visitors will feel satisfied or very satisfied. Conversely, if the experience falls below expectations, visitors may feel disappointed.

Expectations refer to visitors' perceptions of how tourism activities or museum experiences should unfold at a destination (Maghrifani et al., 2019). Visitor expectations can influence satisfaction because visitors tend to evaluate their experience based on what they consider important before or during the visit. Understanding visitor expectations is crucial for the sustainability of tourism destinations and cultural institutions because visitors rely on what they expect when judging service quality and experience (Buhalis, 2000). According to Maghrifani et al. (2019), expectations can vary depending on visitor characteristics, motivation, and situational conditions, while perceived experience may depend on the quality of services encountered during the visit.

In the context of a smart museum, visitors may expect technology-based facilities that enable digital interaction, personalized information, ease of access, comfort, and meaningful interpretation (Damanik et al., 2023). If the experience perceived by visitors meets these expectations, their educational, recreational, and cultural needs are more likely to be fulfilled. Thus, indicators of smart museum dimensions can shape visitor satisfaction.

Visitor experience is defined as an internal and subjective response that occurs through direct or indirect contact with services, objects, environments, and technologies (Rageh et al., 2013). In a smart museum, visitor experience begins when visitors enter the museum environment and continues as they interact with digital facilities, interpret collections, use navigation systems, and form post-visit responses such as recommendation intention, willingness to revisit, and willingness to pay more (Zhang et al., 2022). In this study, visitor experience refers specifically to visitors' experience when interacting with the technologies used in the smart museum.

This study uses the term "visitors" consistently to refer to museum visitors, including visitors who visit Sonobudoyo Museum. This terminology is used because the museum context involves both tourism and cultural visitation, and the evaluation focuses on visitor experience with smart museum attributes. In this study, visitor satisfaction is measured using the Customer Satisfaction Index (CSI), which compares visitors' experiences with their expectations (Fornell et al., 2020). Visitor satisfaction is assessed based on indicators of smart museum dimensions. For example, in the technology-enabled dimension, visitors evaluate whether their experience with digital facilities meets their expectations regarding usability, privacy, and maintainability. If the perceived experience exceeds expectations, satisfaction increases; if it falls below expectations, dissatisfaction may occur.

According to the concept of visitor satisfaction, two variables are central: expectations and experiences. Previous research has also shown that expectations and experiences influence visitor satisfaction in tourism and museum settings (Liu & Guo, 2024; Rahmawati et al., 2023; Zhang et al., 2022). The level of satisfaction can therefore be calculated by comparing visitors' expectations and experiences regarding smart museum dimensions (Liu & Guo, 2024). This study uses categorization to interpret satisfaction levels more specifically rather than merely classifying visitors as satisfied or dissatisfied (Burns & Neisner, 2006). This categorization is widely used in studies employing CSI as a data analysis technique (Fečiková, 2004; Praseptiawan et al., 2022) and is also relevant for descriptive research (Montinaro & Chirico, 2006).

2.6. Technology Acceptance and Expectation-Performance Evaluation

The evaluation of smart museum services can be strengthened through the Technology Acceptance Model (TAM), which explains that technology acceptance is influenced by perceived usefulness and perceived ease of use (Davis, 1989). In a smart museum context, perceived usefulness refers to the extent to which digital technology helps visitors obtain information, understand collections, navigate museum spaces, and enrich their cultural experience. Perceived ease of use refers to the extent to which visitors consider museum technology easy to access, understand, and operate.

TAM is relevant to this study because smart museum facilities, such as QR codes, VR, AR photobooths, interactive dioramas, digital maps, and sensor-based systems, will only contribute to satisfaction when visitors perceive them as useful and easy to use. Technology that is sophisticated but difficult to operate may not generate satisfaction, especially when it interrupts interpretation, comfort, or accessibility. Therefore, the smartness of a museum should be assessed through visitors' acceptance and evaluation of technological attributes rather than through technological availability alone.

In addition to TAM, this study is informed by the expectation–performance logic of satisfaction. This perspective explains that satisfaction emerges when perceived performance meets or exceeds prior expectations. In the context of smart museums, visitors evaluate not only whether a technology exists, but also whether its actual performance corresponds to what they consider important. For example, a digital map may be available, but it will not contribute strongly to satisfaction if visitors perceive it as unable to support navigation or activity planning. Similarly, a security sensor may function technically, but it may reduce satisfaction if it creates noise or discomfort.

By integrating technology acceptance and expectation–performance evaluation, this study positions visitor satisfaction as the result of interaction between smart museum attributes, visitors' perceived importance, and perceived performance. This theoretical framing responds to the need for a more analytical approach in smart museum research, where technology should be evaluated not merely as an innovation, but as an experiential service attribute that must be useful, usable, reliable, and inclusive.

2.7. Importance-Performance Analysis

Importance–Performance Analysis (IPA) is a method used to identify the alignment or gap between expectation and experience (Fečiková, 2004). IPA helps identify indicators that require improvement because their performance does not meet visitors' expectations (Praseptiawan et al., 2022). This method asks respondents to assess two aspects: the level of importance, which reflects visitors' expectations, and the level of performance, which reflects visitors' actual experiences. The average values of these two assessments are then analyzed using a Cartesian diagram that divides indicators into four quadrants.

IPA is particularly relevant for smart museum evaluation because smart museum attributes may not have equal levels of importance and performance from the visitor perspective. Some technologies may be perceived as highly important but perform poorly, making them urgent priorities for improvement. Other technologies may perform well but have lower importance, indicating possible over-allocation of resources. Therefore, IPA provides a more diagnostic and strategic interpretation than general satisfaction measurement alone.

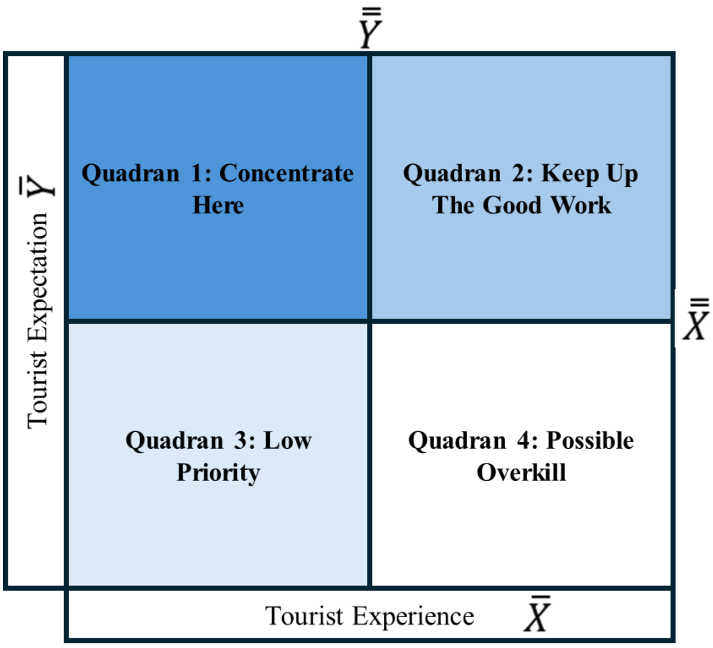

Figure 2. Quadrants on the Cartesian Diagram
Source: Martilla & James (1977)

In this study, IPA complements the Customer Satisfaction Index (CSI). CSI provides an overall measure of visitor satisfaction with smart museum implementation, while IPA identifies which specific smart museum indicators should be maintained, improved, or reconsidered. This combination is useful because a high overall satisfaction score may still conceal specific weaknesses in certain attributes, such as accessibility for elderly or disabled visitors, maintenance of devices, sensor comfort, or digital navigation. Thus, IPA is not only a statistical mapping technique, but also a managerial decision-support framework for prioritizing improvements in smart museum development.

3. Methods

This research is a quantitative study with a descriptive approach. A descriptive quantitative approach was considered appropriate because the study aimed to measure visitors' evaluations of smart museum attributes and identify priority indicators for improving smart museum services at the Sonobudoyo Museum. The analysis was conducted in three stages. First, instrument testing was conducted to examine whether the indicators of each smart museum dimension were valid and reliable for use in the context of the Sonobudoyo Museum. Second, the Customer Satisfaction Index (CSI) was used to measure the overall level of visitor satisfaction with smart museum implementation. Third, Importance–Performance Analysis (IPA) was applied to identify smart museum attributes that require managerial priority based on the gap between visitors' expectations and experiences. Thus, CSI was used to provide an overall satisfaction index, while IPA was used to produce a more diagnostic mapping of smart museum indicators that should be maintained, improved, or reconsidered. The combination of CSI and IPA was used because overall satisfaction scores may not fully reveal which specific smart museum attributes perform below visitors' expectations. Therefore, CSI provides a general satisfaction index, while IPA offers attribute-level diagnostic information for determining improvement priorities.

The selection of museum research locations is based on the criteria of smart museums, specifically museums that have undergone digital transformation, with a focus on the application of smart technology. Furthermore, the selected museum is a cultural museum, as this relates to the role of museums in the preservation of culture in tourism. Thus, the Sonobudoyo Museum was chosen as the research location. In this study, the Sonobudoyo Museum was considered suitable because it applies several technology-based facilities that can be evaluated by visitors, including QR code-based information access, digital information media, interactive dioramas, virtual reality, augmented reality, video mapping, automatic door sensors, collection security sensors, and interactive games. These facilities represent relevant smart museum attributes because they are directly related to visitor interaction, information access, interpretation, accessibility, and technology-based experience within the museum environment.

The population in this study consists of visitors who have visited museums in the city of Yogyakarta. The population in this study cannot be determined because the research is limited to the period from March to May 2025. Therefore, non-probability sampling was used so that the population did not have the same opportunity to fill out the questionnaire. The questionnaire was distributed accidentally to visitors encountered during the research period. The inclusion criteria for respondents were visitors or visitors who had visited the Sonobudoyo Museum during the data collection period, had seen or used at least one smart museum facility, were able to evaluate their expectations and experiences, and were willing to complete the questionnaire voluntarily. These criteria were applied to ensure that respondents had sufficient experience to assess the smart museum indicators used in this study. The determination of the sample size is not based on the population, so it is determined using the rule of thumb approach from Hair et al. (2019), which is 5-10 times the number of attributes. In this study, there are 20 attributes, so the expected number of respondents is 10 x 20 =

200 respondents. This also aligns with the requirements for social science research related to technology, which is expected to have a minimum of 200 respondents (Dash & Paul, 2021). The instruments used include six dimensions of the smart museum (Liu & Guo, 2024). The research instrument was adapted and modified from the smart museum dimension model proposed by Liu and Guo (2024). The adaptation was conducted by adjusting the indicators to the technological facilities available at the Sonobudoyo Museum, while maintaining the six main dimensions of the smart museum: technology-enabled, interactivity, adaptability, systematic efficiency, technology integration, and affordability. Thus, the instrument was not developed entirely from the beginning, but was based on an existing theoretical model and contextualized according to the empirical setting of the Sonobudoyo Museum.

The distribution of the questionnaire was conducted directly to visitors, with the hope that they still remember their experience regarding the smart museum dimensions. Additionally, an online questionnaire was used to facilitate completion after the visitors' visit, with the expectation of not disrupting their subsequent activities. The questionnaire contains data related to tourist characteristics such as demographic data. Furthermore, the collected data also includes information related to the assessment of the smart museum dimensions, which are evaluated based on 27 statements. This assessment was conducted using a 5-point Likert scale to obtain more detailed responses. Each statement was assessed from two perspectives: the level of importance, which represents visitors' expectations, and the level of performance, which represents visitors' actual experiences when interacting with smart museum facilities. The demographic section included information on age, gender, education level, occupation, number of visits, travel expenditure, and region of origin. All respondents were informed that their participation was voluntary and that the data collected would be used only for academic purposes.

Before the main data collection, an instrument test was conducted on 30 respondents to examine the validity and reliability of the questionnaire. Validity testing was conducted by comparing the calculated correlation value of each item with the critical r-table value. An item was considered valid when the calculated r-value was greater than the r-table value at the selected significance level. Reliability testing was conducted using Cronbach's Alpha to assess the internal consistency of the instrument. A Cronbach's Alpha value of 0.70 or above was considered acceptable for social science research. After the instrument was declared valid and reliable, the questionnaire was distributed to 200 respondents for the main data collection.

The data analysis consisted of descriptive statistics, CSI calculation, and IPA mapping. Descriptive statistics were used to describe respondent characteristics and the average score of each smart museum indicator. CSI was used to calculate the overall level of visitor satisfaction by comparing the importance and performance scores. IPA was then used to map each indicator into four quadrants based on the average importance and performance values. Quadrant I indicates attributes with high importance but low performance and therefore requires immediate improvement. Quadrant II indicates attributes with high importance and high performance that should be maintained. Quadrant III indicates attributes with low importance and low performance, while Quadrant IV indicates attributes with low importance but high performance, suggesting possible over-allocation of resources.

4. Results

The distribution of the questionnaire was conducted by the researcher over 3 days, from February 26 to 28, 2025, with 30 initial respondents used for the research instrument test. The instrument test was conducted on 30 respondents to determine the validity and reliability of the statement items. Thus, the instrument used is valid and reliable. Next, 200 questionnaires were distributed for the final data collection in April 2025. The pilot test was important to ensure that the questionnaire items were suitable for measuring visitors' expectations and experiences regarding smart museum attributes. The validity test results indicate that all statement items had correlation values above the required threshold, suggesting that the items were appropriate for further analysis. Reliability testing was also conducted to examine the internal consistency of the instrument before the main survey was administered.

Table 2. Respondent Characteristics

Demographic Variable		**Frequency**	**Percentage (%)**
Age	• 15 - 25 years old (Generation Z)	99	49.5 %
	• 26 - 40 years old (Millennial / Generation Y)	97	48.5 %
	• 41 - 56 years old (Generation X)	4	2 %
Gender	• Male	71	35.5 %
	• Female	129	64.5 %
Education	• Graduate Studies	3	1.5 %
	• Bachelor's degree	90	45 %
	• Diploma	58	29 %
	• Senior High School/Vocational School Equivalent	49	24.5 %
Occupation	• Civil Servant/Army/Police	18	9 %
	• Private Employee	106	53 %
	• Entrepreneur	22	11 %
	• Student/University Student	54	27 %
Number of visits	• 1 time	94	47 %
	• 2 times	48	24 %
	• 3 times	42	21 %
	• 4 times	12	6 %
	• 5 times	4	2 %
Tourist Expenses	• Rp. 0 - Rp. 50.000	91	45.5 %
	• Rp. 50.001 - Rp. 200.000	70	35 %
	• Rp. 200.001 - Rp. 500.000	31	15.5 %
	• Rp. 500.001 - Rp. 1.000.000	5	2.5 %
	• > Rp. 1.000.000	3	1.5 %
Region of Origin	• Jawa Barat	59	29.5 %
	• Jawa Tengah	57	28.5 %
	• Jawa Timur	33	16.5 %
	• D.I.Yogyakarta	14	7 %
	• DKI Jakarta	21	10.5 %
	• Aceh	1	0.5 %
	• Bali	4	2 %
	• Sumatera Utara	1	0.5 %
	• Sulawesi Selatan	1	0.5 %
	• Kepulauan Riau	1	0.5 %
	• Banten	6	3 %
	• Bengkulu	1	0.5 %
	• Sumatera Barat	1	0.5 %

Source: Author's Analysis (2025)

Table 3. Validity and Reliability Test Results

Dimension	Code	Attribute	Statement	R count Expectation	R count Experience
Technology-enabled	TE1	Usability	The museum's website/application/QR code is clearly visible to visitors.	0.883	0.787
	TE2	Privacy	The policy that visitors' personal data is not shared with anyone other than the museum management when filling out the Visitor Satisfaction QR survey.	0.827	0.531
	TE3	Maintainability	Maintenance of the museum's VR devices and interactive dioramas.	0.834	0.703
Interactivity	INT1	Input	Comprehension of the user guide for the museum's VR and interactive dioramas.	0.766	0.666
	INT2		The process/workflow for using the museum's VR and interactive dioramas.	0.803	0.760
	INT3	Cooperativity	Functionality of the game controllers and touch sensors.	0.863	0.820
	INT4	Output	Interaction with the interactive diorama via touch, motion, or sound inputs.	0.780	0.697
	INT5		The availability of descriptive information about the museum's collection on digital screens (monitors/TVs).	0.854	0.490
	INT6		Information about the museum's collection is delivered through various methods, such as sound, video, and touch sensors.	0.814	0.603
	INT7		The museum's collection security sensors are functional.	0.823	0.752
Adaptability	ADA1	Real-time feedback	The speed/responsiveness of the sensors (door sensor/collection security sensor/sensor for video mapping).	0.848	0.581
	ADA2	Context-aware	The functionality of the door sensors and video mapping in the museum.	0.805	0.843
	ADA3	Upgradeability	The technology used in the museum is the latest/most current technology.	0.766	0.799
	ADA4	Customizability	Information on the interactive diorama is available in multiple languages.	0.807	0.636
Systematic Efficiency	EFS1	Autonomy	The sensor technology (e.g., door sensor, collection security sensor, video mapping sensor) detects tourist movement.	0.868	0.463
	EFS2		The accuracy of the AR technology in the museum's photobooth when detecting a user.	0.867	0.752
	EFS3		Mastery of the VR / game in the museum.	0.865	0.736
	EFS4	Learnability	The ease of use of the museum's devices (VR/AR/website).	0.855	0.798
	EFS5	Intuitiveness	The ease of access to the museum's devices (VR/AR/website).	0.834	0.764
Technology Integration	ITG1	Compatibility	The museum's website can be accessed via various devices (laptop/tablet/mobile phone).	0.877	0.476
	ITG2	Collaboration	The AR technology in the photobooth has a photo-sharing feature accessible via QR code/website.	0.896	0.480
	ITG3	Constructiveness	The interactive diorama / digital information (monitor/TV) enhances tourist knowledge.	0.737	0.752
	ITG4	Goal-orientation	The activity planning feature on the museum's digital map.	0.813	0.711
Affordability	AFF1	Time	The digital map displays a route that provides a short estimated travel time to the destination.	0.840	0.486
	AFF2	Expense	The museum offers a reasonable price for all the provided services and technology facilities.	0.846	0.595
	AFF3		The digital information board provides interesting information about products (souvenirs or services).	0.817	0.786
	AFF4	Workload	The museum is easily accessible for visitors with physical limitations (e.g., the elderly or disabled).	0.786	0.787

Source: Author's Analysis (2025)

The characteristics of the respondents were analysed based on demographic data that included variables such as age, gender, education level, type of occupation, number of visits to the museum, expenditure while travelling, and place of origin. Table 2 presents the results of the frequency distribution test for each respondent characteristic at the Sonobudoyo Museum.

The respondent profile shows that the sample was dominated by Generation Z and Millennial visitors, accounting for 98% of the total respondents. This demographic pattern is important because younger visitors are generally more familiar with digital interfaces, mobile-based information access, and self-guided technology use. Therefore, the interpretation of the results should consider the possibility that the high satisfaction score may partly reflect the technological familiarity of younger visitors.

4.1. Frequency Distribution Analysis

Average scores for each statement and dimension were categorized on five-level scales for tourist expectations. The results indicate that visitors deem the Sonobudoyo Museum's smart museum development 'very important' and, overall, reported 'very good' experiences. Notably, eight indicators received 'good,' rather than 'very good,' experience ratings (Table 4.). This result indicates that, although visitors generally perceived smart museum development as important and experienced it positively, several attributes still require attention. The difference between "very good" and "good" ratings suggests that certain technologies may be available but have not yet delivered an optimal experience from the visitor perspective.

4.2. Customer Satisfaction Index (CSI)

Overall visitor satisfaction scored 84.83% on the CSI, which falls into the very satisfied category for the implementation of smart museum technology at the Sonobudoyo Museum (Table 4.). Nevertheless, a 15.17% satisfaction gap remained, indicating that some aspects of smart museum implementation had not fully met visitors' expectations. Next, an Importance–Performance Analysis (IPA) was conducted to determine the level of conformity between the expectations and experiences of visitors on each indicator. This finding shows that a high CSI score does not necessarily indicate the absence of service problems. Instead, the remaining satisfaction gap suggests that some smart museum attributes still require improvement, particularly in relation to technology reliability, accessibility, and visitor comfort.

4.3. Importance-Performance Analysis (IPA)

Based on Table 4, the results of the analysis of the level of conformity between visitors' expectations and experiences show that the average level of conformity is 97.62%. Thus, indicators with a level of conformity above this value are items with experience values that exceed visitors' expectations. Out of 27 indicators, 12 indicators have experiences that do not meet visitors' expectations or are unsatisfactory, while 15 indicators have experiences that meet visitors' expectations or are satisfactory. The unsatisfactory indicators demonstrate that the smart museum experience is not uniform across all technological attributes. Some technologies may function well as general facilities, but they still require improvement when assessed from the perspective of importance and performance. This supports the use of IPA as a diagnostic tool because it identifies specific attributes that need managerial attention, even when the overall satisfaction level is high.

Table 4. Analysis Results

Code	Avg. Expectation (MIS)	Desc.	Avg. Experience (MSS)	Desc.	WF	WS	Level of conformity	Desc.
TE1	4.44	Very Important	4.45	Very Good	0.04	0.17	100.23%	Satisfactory
TE2	4.37	Very Important	4.34	Very Good	0.04	0.16	99.31%	Satisfactory
TE3	4.31	Very Important	4.03	Good	0.04	0.14	93.50%	Unsatisfactory
INT1	4.31	Very Important	4.26	Very Good	0.04	0.16	98.84%	Satisfactory
INT2	4.28	Very Important	4.22	Very Good	0.04	0.16	98.60%	Satisfactory
INT3	4.36	Very Important	4.22	Very Good	0.04	0.16	96.79%	Unsatisfactory
INT4	4.35	Very Important	4.34	Very Good	0.04	0.16	99.77%	Satisfactory
INT5	4.41	Very Important	4.29	Very Good	0.04	0.16	97.28%	Unsatisfactory
INT6	4.36	Very Important	4.24	Very Good	0.04	0.16	97.25%	Unsatisfactory
INT7	4.41	Very Important	4.20	Good	0.04	0.15	95.24%	Unsatisfactory
ADA1	4.38	Very Important	4.25	Very Good	0.04	0.16	97.03%	Unsatisfactory
ADA2	4.42	Very Important	4.32	Very Good	0.04	0.16	97.74%	Satisfactory
ADA3	4.39	Very Important	4.34	Very Good	0.04	0.16	98.86%	Satisfactory
ADA4	4.32	Very Important	4.24	Very Good	0.04	0.16	98.15%	Satisfactory
EFS1	4.37	Very Important	4.19	Good	0.04	0.15	95.88%	Unsatisfactory
EFS2	4.27	Very Important	4.21	Very Good	0.04	0.15	98.59%	Satisfactory
EFS3	4.21	Very Important	4.16	Good	0.04	0.15	98.81%	Satisfactory
EFS4	4.38	Very Important	4.28	Very Good	0.04	0.16	97.72%	Satisfactory
EFS5	4.28	Very Important	4.17	Good	0.04	0.15	97.43%	Unsatisfactory
ITG1	4.30	Very Important	4.19	Good	0.04	0.15	97.44%	Unsatisfactory
ITG2	4.32	Very Important	4.24	Very Good	0.04	0.16	98.15%	Satisfactory
ITG3	4.32	Very Important	4.28	Very Good	0.04	0.16	99.07%	Satisfactory
ITG4	4.38	Very Important	4.16	Good	0.04	0.15	94.98%	Unsatisfactory
AFF1	4.29	Very Important	4.27	Very Good	0.04	0.16	99.53%	Satisfactory
AFF2	4.37	Very Important	4.25	Very Good	0.04	0.16	97.25%	Unsatisfactory
AFF3	4.35	Very Important	4.27	Very Good	0.04	0.16	98.16%	Satisfactory
AFF4	4.41	Very Important	4.16	Good	0.04	0.15	94.33%	Unsatisfactory
Average	**4.35**	**Very Important**	**4.25**	**Very Good**			**97.62%**	
Σ	**117.29**		**114.51**		**1.00**	**4.24**	**CSI**	**84.83%**

MIS = Mean Importance Score; MSS = Mean Satisfaction Score; WF = Weight Factor; WS = Weighted Score

Source: Author's Abalysis (2025)

Cartesian diagram to see which indicators need to be improved in Figure 3. The Cartesian diagram provides a visual mapping of smart museum indicators based on their importance and performance scores. This mapping helps identify which indicators should be prioritized for improvement, maintained as strengths, considered low priority, or reviewed because of possible over-allocation of resources.

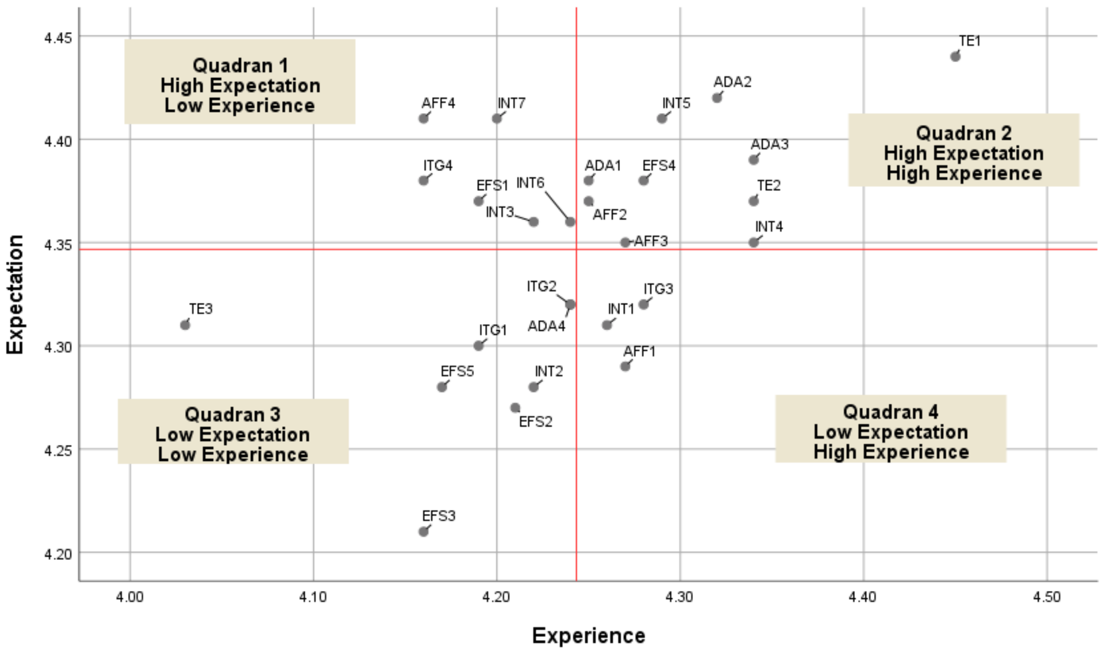

Figure 3. Results of the Analysis on the Cartesian Diagram
Source: Author's Analysis (2025)

5. Discussion

The findings indicate that the implementation of smart museum technology at the Sonobudoyo Museum has generally generated positive visitor experiences. However, the results demonstrate that the mere presence of technology does not guarantee visitor satisfaction. Rather, satisfaction is influenced by how visitors perceive the usefulness, usability, reliability, accessibility, and overall quality of technological services. This finding supports both the Technology Acceptance Model (TAM) and the expectation–performance perspective, which emphasize that technology must deliver meaningful value and meet visitor expectations to produce positive evaluations.

Although the CSI result indicates a high level of overall satisfaction, the IPA analysis reveals several attributes that still require improvement. Therefore, the effectiveness of smart museum implementation should be evaluated beyond aggregate satisfaction scores. Specific attributes, including device maintenance, security sensors, digital navigation, and accessibility, continue to exhibit performance gaps relative to visitor expectations.

In terms of technology utilisation, the high expectations of visitors have generally been met very well, especially in terms of ease of access to information through personal devices (TE1), which is in line with Wang & Zhu (2022). The museum's success in maintaining tourist data privacy (TE2) also builds trust, which is an important foundation for smart tourism (Kang & Su, 2022). However, there is a significant gap in the aspect of device maintenance (TE3), where visitors' high expectations for the availability of VR and interactive dioramas are not fully realised due to operational constraints such as damaged or limited devices, which could potentially become a problem in the future. These findings suggest that the effectiveness of smart museum services depends not only on technological availability but also on operational reliability. Advanced facilities can contribute positively to visitor experiences only when they are consistently functional and well maintained. Consequently, technological capability should be viewed as a combination of innovation, maintenance, and service readiness.

The dimension of interactivity is considered very important by visitors, and most of their experiences are rated as very good. However, one indicator, namely the function of the collection security sensors (INT7), shows a lower experience despite the technology functioning properly (Koukopoulos & Koukoulis, 2018). This is due to the frequent ignoring of sensor alarms and their repeated triggering by some visitors, which ultimately creates noise pollution and disturbs the atmosphere of the museum for other visitors who comply with the rules (Oquendo & Santos, 2020). This result shows a form of human–technology friction in the smart museum experience. Although the security sensor may function technically, its repeated alarm sound can reduce comfort and disturb the contemplative atmosphere expected in a cultural museum. This finding challenges the assumption that technological functionality is always equivalent to experiential quality. In the museum context, technology must operate in harmony with visitor comfort, spatial atmosphere, and cultural interpretation.

Visitors have very high expectations for the adaptability of technology at the Sonobudoyo Museum and generally have a very positive experience. The use of the latest technology (ADA3) and the functionality of door sensors and video mapping (ADA2) are highly appreciated. However, there are a few notes on the response speed of sensors (ADA1), which visitors still consider to be somewhat slow. In fact, high-speed sensors are a crucial element in providing a smooth, contactless access experience (Šveb Dragija & Jelinčić, 2022). This indicates that adaptability in smart museums should be understood not only as the presence of updated technology, but also as the ability of technology to respond quickly and appropriately to visitor movement and needs.

In terms of systematic efficiency, visitors considered it very important, with experiences varying between good and very good. The most satisfying indicator was the accuracy of AR technology in the *photobooth* in detecting users (EFS2), which succeeded in creating a unique and interesting experience (Wu et al., 2023). In addition, the ease of learning and understanding the devices (EFS4 and EFS3) was also rated highly, indicating that the museum succeeded in providing an intuitive interface design and clear navigation, in line with the importance of user-friendly features (Guedes et al., 2023). This finding strengthens the relevance of perceived ease of use in technology acceptance, because visitors are more likely to evaluate smart museum facilities positively when the technology can be learned and operated without excessive effort.

In terms of technology integration, visitors had a satisfying experience, especially in two aspects. First, the feature of sharing photos from the AR photobooth via QR codes (ITG2) was rated very good because it extended the visitors' experience and provided low-cost digital souvenirs (Pérez-Sanagustín et al., 2016). Second, the use of interactive dioramas and digital monitors to enhance knowledge (ITG3) was also highly appreciated, proving that dynamic information delivery through videos or animations can significantly enrich visitors' experiences (Chen, 2023). These findings show that technology integration can strengthen visitor engagement when digital features are connected to personal experience, social sharing, and knowledge enhancement. However, integration should not only emphasize technological novelty, but also ensure that each digital feature supports interpretation and visitor movement within the museum.

Overall, the accessibility dimension was considered very important by visitors, and most of their experiences were rated very good, covering aspects of time, cost, and product information. However, there is one area that requires attention, namely the accessibility indicator for visitors with physical limitations (AFF4), such as the elderly and people with disabilities. The experience on this indicator was only rated ‘good,’ indicating that the Sonobudoyo Museum has not yet fully met visitors' expectations regarding inclusivity and ease of access for all groups. This finding highlights the importance of integrating inclusivity into smart museum development. Technological advancement alone is insufficient when access barriers remain for elderly visitors and individuals with disabilities. Therefore, accessibility should be regarded as a core component of smart museum quality rather than a supplementary feature.

The level of visitor satisfaction with the implementation of smart museum technology at the Sonobudoyo Museum is classified as very satisfied, with a Customer Satisfaction Index (CSI) score of 84.83%. This result confirms the findings of Zhang et al. (2022) that the use of advanced technology can indeed enhance visitor satisfaction. However, there is still a gap of 15.17%, indicating that some visitors are not fully satisfied, a condition that can be understood given that tourist expectations will continue to rise with technological advancements (Fornell et al., 2020). The level of conformity analysis (Table 2) also identified 12 specific indicators whose suitability levels are still unsatisfactory. Therefore, it is still necessary to ensure relevance and provide a better experience in the future. (Al Saffar, 2024).

The demographic composition of respondents should also be considered when interpreting these findings. The sample was heavily dominated by Generation Z and Millennial visitors, who represented 98% of the total respondents. This concentration may have influenced the high satisfaction score because younger visitors are generally more accustomed to digital technology, mobile-based interaction, QR code access, and independent exploration. Consequently, the results may reflect the preferences and technological readiness of younger visitors more strongly than those of older visitors, elderly visitors, or visitors with disabilities. Future studies should therefore involve a more balanced generational composition to examine whether smart museum technologies provide equally satisfying experiences across different visitor groups.

5.1. Quadrant 1 (Concentrate Here)

The indicators situated in Quadrant 1 delineate the highest priority areas for corrective action by the Sonobudoyo Museum, as they are characterized by high tourist expectations but low perceived performance. A primary issue concerns the security sensors (EFS1, INT7), the implementation of which frequently disrupted the comfort of other visitors and failed to engender a sense of security (Kollmann, 2007; J. Xu & Pan, 2024). Furthermore, the static digital map (ITG4) lacks the expected functionality for activity planning, thereby impeding effective navigation and diminishing tourist engagement (Al Khalifa & Jiwane, 2025). Problems were also identified with interactive technologies, where devices such as game controllers were often non-functional due to maintenance challenges (INT3) (Vosinakis et al., 2020), and their inconsistent deployment across the museum (INT6) created a fragmented and underwhelming experience (Kamariotou et al., 2021). Finally, accessibility for visitors with disabilities and the elderly (AFF4) remains inadequate, indicating an urgent need to enhance the museum's inclusivity. These findings indicate that Quadrant 1 attributes should become the main focus of managerial intervention because they represent services that visitors consider important but have not yet performed at the expected level.

5.2. Quadrant 2 (Keep Up the Good Work)

Quadrant 2 highlights the museum's principal strengths, where tourist experiences successfully met or exceeded their high expectations. This success is evident in the ease of information access via QR codes or the website (TE1), which aligns with the importance of digital connectivity (Liu & Guo, 2024), and in the assurance of data privacy (TE2), which successfully engendered tourist trust, a recurring issue in smart tourism (Kang & Su, 2022). The responsive functionality of sensors for automatic doors and video mapping (ADA1, ADA2), coupled with the user-friendly interactive dioramas (INT4), proved effective in creating a satisfying multisensory experience and increasing tourist engagement (Ji et al., 2024), particularly for the predominant Generation Y and Z cohorts

(Kumraksa & Monpanthong, 2024). Moreover, the affordable ticket prices (AFF2) were a significant driver of satisfaction (W. Xu et al., 2024), supported by appealing product information on digital media (AFF3) that effectively incentivized visitors to engage with additional services. These attributes should be maintained because they represent smart museum features that successfully combine technological performance with visitor expectations.

5.3. Quadrant 3 (Low Priority)

Indicators within Quadrant 3 are not considered priorities for improvement, as they possess both low tourist expectations and low perceived performance. This includes immersive technologies like VR and AR, where visitors held low expectations regarding device maintenance (TE3), the ease of mastering VR games (EFS3), and the features of the AR photobooth (EFS2, ITG2). This low expectation can be attributed to the inherent complexity of VR, which remains unfamiliar to a broad segment of the public (Gao & Foulen, 2025), and the perception that AR features are less enriching than other interactions (Suess & Barton, 2022). Likewise, the museum's website accessibility (EFS5, ITG1) was rated poorly, as visitors do not consider it a primary channel of interaction, likely attributable to a lack of promotion or engaging features (Cristobal-Fransi et al., 2021). Finally, the multilingual feature on interactive dioramas (ADA4) was deemed unimportant due to the predominantly domestic composition of the respondent pool. Although these indicators are categorized as low priority, they should not be ignored completely. Instead, the museum may improve them gradually after addressing the more urgent indicators in Quadrant 1.

5.4. Quadrant 4 (Possible Overkill)

The indicators in Quadrant 4 suggest a potential over-allocation of resources to areas where perceived performance significantly exceeds tourist expectations, which are themselves low. For instance, while the knowledge-enhancing interactive dioramas (ITG3) were highly satisfactory, the primary tourist motivation appears to be oriented more toward entertainment than in-depth education (Saifuddin, 2020). Similarly, the user-friendly technology guides (INT1) performed well but were perceived as non-essential by the predominantly self-reliant Generation Z and Y demographic, who are accustomed to intuitive, independent exploration (Coman et al., 2020). Lastly, the time-saving digital map (AFF1) also registered high performance against low expectations, as many visitors preferred to enjoy a leisurely-paced visit along the prescribed route, a phenomenon that aligns with the 'ant tourist' concept of appreciating the journey itself (Liu et al., 2020). Overall, the quadrant analysis demonstrates that smart museum development should prioritize service effectiveness rather than technological expansion alone. Immediate attention should be directed toward attributes in Quadrant 1, where visitor expectations exceed perceived performance. These findings reinforce the importance of using visitor evaluations as the basis for strategic decision-making in smart museum management.

6. Conclusions

According to IPA, several indicators failed to meet visitor satisfaction. Specifically, six indicators (AFF4, EFS1, INT3, INT6, INT7, and ITG4) were identified in Quadrant 1, representing critical areas that require enhancement to further elevate visitor satisfaction at the Sonobudoyo Museum. Therefore, despite the high overall satisfaction, targeted improvements are crucial for museum management to better meet visitor expectations, thereby enhancing the overall experience to be more optimal and inclusive. This involves prioritizing aspects where the visitor experience is still lacking. Indicators requiring urgent improvement, as identified in Quadrant 1, include accessibility for people with disabilities, security sensors, digital maps, interactive technologies like game controllers, and the delivery of collection information, all of which are currently not optimal. Ultimately, continuous evaluation and adaptive management strategies will be key for Museum Sonobudoyo to not only sustain high visitor satisfaction but also to progressively enhance its smart museum offerings in alignment with evolving tourist needs and technological advancements.

These findings suggest that the Sonobudoyo Museum has successfully developed several strengths as a smart museum, particularly in information access, data privacy, and interactive digital experience. However, the museum still needs to address critical weaknesses related to accessibility, sensor comfort, device maintenance, and digital navigation. Therefore, the main managerial implication is that smart museum development should move beyond the provision of advanced technology toward a more visitor-centred, inclusive, and experience-oriented digital service strategy.

The findings should also be interpreted within the demographic characteristics of the respondents, which were dominated by Generation Z and Millennials. This limitation suggests that future research should involve more diverse age groups and visitor segments to provide a broader understanding of smart museum satisfaction.

Theoretically, this study contributes by empirically contextualizing the smart museum dimension model, which was previously exploratory, in the setting of an Indonesian cultural museum. The results of this study confirm that dimensions are valid indicators for measuring a single object tourist attraction (Liu & Guo, 2024). This addresses the theoretical inconsistencies in previous research that often imposed broad-scale smart tourism indicators (destinations) into the specific context of museums. However, the theoretical contribution of this study should be understood as empirical contextualization rather than full causal theory testing. This study does not test causal relationships among technology acceptance constructs, but it extends the discussion of smart museum dimensions by examining how visitors evaluate the importance and performance of each attribute in a cultural museum setting.

Furthermore, this research reinforces the visitor satisfaction theory by demonstrating that expectations and experiences are key variables in the digital museum ecosystem. The finding that the Customer Satisfaction Index (CSI) score reached 84.83% supports the literature stating that the use of advanced technologies such as VR, AR, and sensors is directly correlated with increased satisfaction. This study provides empirical evidence that technology is not merely an accessory, but rather a determinant factor in shaping the value perception for modern visitors, particularly Generation Z and Millennials. The use of the Importance–Performance Analysis (IPA) method in the context of smart museums also enriches the literature on mapping crucial indicators for visitors.

This study also highlights the potential mismatch between technological functionality and experiential quality. The case of security sensors demonstrates that technically effective systems may still generate negative perceptions when they disrupt visitor se noise pollution. This provides a new perspective that the evaluation of smart museums should not only focus on system functionality but also on the harmony of human-technology interaction. Finally, this study provides a foundation for future research on digital inclusivity in cultural institutions. The low assessment of accessibility for people with disabilities (AFF4) in the IPA analysis indicates that the theory of smart museums should place greater emphasis on aspects of diversity and universal accessibility, rather than just cutting-edge innovation. This theoretical implication emphasises that the concept of a "smart" museum should also include social intelligence in serving various groups of visitors with different physical needs.

In addition, this study contributes to the integration of technology acceptance and expectation–performance perspectives in smart museum research. The findings show that visitors' satisfaction with smart museum technology is shaped not only by perceived technological sophistication, but also by usefulness, ease of use, comfort, accessibility, and the alignment between expectations and actual experiences. This provides a more nuanced theoretical understanding that smart museum evaluation should combine technological, experiential, and inclusive dimensions.

Practically, this research provide a roadmap for the management of the Sonobudoyo Museum to prioritise improvements on indicators in Quadrant 1 (Concentrate Here), particularly on the security sensor system and digital navigation. The management needs to evaluate the sensitivity of the sensor alarms to avoid disturbing the comfort of other visitors, as well as update the static digital map (ITG4) to a more interactive navigation system to facilitate activity planning within the museum. These improvements are necessary to ensure that digital services contribute positively to visitor experiences and operational effectiveness. In practical terms, the museum should conduct regular sensor calibration, adjust alarm intensity, and provide clearer visitor guidance near sensitive collection areas so that security technology can protect collections without reducing visitor comfort. The digital map should also be developed into a more interactive and user-oriented navigation tool, including route recommendations, estimated walking time, facility locations, and accessibility information for elderly visitors and visitors with disabilities.

Museum management must also pay serious attention to the maintenance of technological devices (maintainability). Considering that devices such as game controllers and interactive dioramas often experience malfunctions or inconsistent performance, regular maintenance procedures and more responsive system updates are necessary. Improving performance in these aspects, which have high expectations but low performance, will directly close the dissatisfaction gap of 15.17% identified in this study. Therefore, the museum should establish a preventive maintenance schedule, assign responsible technical staff, and provide a reporting mechanism that allows visitors or museum officers to quickly report malfunctioning devices. Consistent operational performance is essential because visitors evaluate digital services based on their actual functionality rather than their technological sophistication alone.

From an inclusivity perspective, Sonobudoyo Museum needs to revamp its technological facilities to be more friendly for the elderly and people with disabilities. The practical implications include providing digital navigation paths specifically for wheelchairs or interactive device interfaces that can be adjusted for the speech-impaired or hearing-impaired. By improving accessibility aspects (AFF4), the museum not only meets the smart culture policy standards of the local government but also expands its market share to a more diverse segment of visitors. Accessibility improvements should include ramps, clear wayfinding, wheelchair-friendly routes, readable digital interfaces, audio descriptions, captions, visual instructions, and staff assistance for visitors who require additional support. Inclusivity should therefore be embedded within the smart museum framework, ensuring that all visitor groups can benefit equally from both physical and digital services.

Lastly, the management can maintain the affordable pricing strategy (AFF2) and the ease of information access through QR codes (TE1), as these two elements have proven to be the main strengths that satisfy visitors. The effectiveness of the AR photobooth and digital diorama in enhancing visitor knowledge should also be maintained as promotional tools on social media. By combining the maintenance of current strengths and strategic improvements on existing weaknesses, Sonobudoyo Museum can strengthen its position as a pioneer of sustainable smart museums in Yogyakarta. However, the museum should also consider visitor segmentation in designing future digital services, because the respondent profile was dominated by Generation Z and Millennial visitors who are generally more familiar with digital technology. Future managerial strategies should therefore ensure that smart museum services are not only attractive for younger visitors, but also understandable, comfortable, and accessible for older visitors, families, elderly visitors, and visitors with disabilities.

Finally, this study has several limitations that should be considered in interpreting the findings. First, data on tourist expectations and experiences were collected concurrently post-visit, deviating from the ideal theoretical condition where expectations are measured pre-visit. This was necessitated by the constraint of a unified questionnaire and the technical difficulty of tracking respondents post-exit from the museum. This condition may have influenced the way respondents evaluated their expectations because post-visit responses can be affected by the actual experience they had already encountered. Further on-site challenges included the fact that not all respondents comprehended the "smart museum" concept, requiring the researcher to provide additional explanation and assistance. Additionally, some prospective respondents declined to participate due to time constraints. Future research should consider separating the measurement of expectations and experiences by collecting expectation data before the visit and performance or experience data after the visit. This approach would allow a more precise comparison between initial expectations and actual visitor experiences.

A further limitation pertains to the accessibility indicator (AFF4), which was administered to the general tourist population rather than being specifically targeted at visitors with disabilities, defined as individuals with activity limitations resulting from impairments in bodily function (Altman, 2014), or elderly visitors over the age of 65 with potential physical limitations arising from frailty, cognitive decline, and higher comorbidity (Pagan, 2020). The accidental sampling method used for the questionnaire distribution could potentially introduce bias into these responses. Nevertheless, the high level of expectation recorded for this indicator can be interpreted as a reflection of the general importance placed on inclusivity at the Sonobudoyo Museum. Future studies should involve visitors with disabilities and elderly visitors as specific respondent groups to obtain a more accurate understanding of accessibility barriers in smart museum environments. Such research could examine not only physical accessibility but also digital accessibility, including interface readability, audio-visual support, navigation assistance, and the usability of interactive technologies for visitors with different abilities.

Another limitation relates to the demographic composition of the respondents. The sample was heavily dominated by Generation Z and Millennial visitors, which may have influenced the findings, particularly in relation to technology acceptance, digital familiarity, and perceived ease of use. Younger visitors may evaluate QR codes, AR photobooths, digital maps, and interactive devices more positively because they are generally more accustomed to mobile-based and self-guided technologies. Therefore, the findings may not fully represent the perceptions of older visitors, elderly visitors, or visitors with lower levels of digital literacy. Future research should use a more balanced generational sample to examine whether smart museum technologies are equally effective across different visitor segments.

This study is also limited by its descriptive quantitative design and the use of CSI and IPA as diagnostic tools. Although these methods are useful for measuring satisfaction and identifying improvement priorities, they do not explain causal relationships among smart museum dimensions, technology acceptance, visitor experience, and satisfaction. Future studies may employ structural equation modelling, experimental designs, or mixed-method approaches to examine the causal mechanisms underlying smart museum satisfaction. Qualitative interviews could also be used to explore why certain technologies are perceived as useful, disruptive, difficult, or inclusive by different visitor groups.

Finally, this research is contextually limited to the Sonobudoyo Museum as a single case. Consequently, the findings may not be directly generalizable to museums with different cultural contexts, technological infrastructures, visitor demographics, or management systems. Future studies could conduct comparative analyses across different types of museums, such as cultural museums, art museums, history museums, and science museums, to examine whether the smart museum dimension model can be applied consistently across various institutional contexts.

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