

Integration of Sensor Technology in Branding and Disseminating Intangible Cultural Heritage

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Intangible cultural heritages (ICHs) have been affected by globalization and modernization, requiring innovative preservation and transmission methods. In this study, we investigated how to integrate sensor technologies into ICH branding and promotion in three representative sites: a museum, an indigenous art center, and a traditional village. Motion detectors, augmented reality applications, and Bluetooth audio guides were deployed to enhance visitor engagement and cultural appreciation. Data were collected from 150 participants through surveys and interviews by experts, with reliability confirmed by Cronbach's alpha (0.763). The results demonstrated moderate-to-high visitor satisfaction, with mean scores of 3.52 for engagement and experience, 3.48 for personalization and accessibility, 3.50 for branding and perception of the ICH, and 3.49 for preservation and cultural sensitivity. A one-sample t-test confirmed significantly positive perceptions of sensor-integrated branding [$t(149) = 8.76, p < 0.001$]. One-way analysis of variance (ANOVA) results revealed significant differences in the branding and perception of the ICH ($F = 3.82, p = 0.024$) and preservation and cultural sensitivity ($F = 1.84, p = 0.029$) across different educational backgrounds. These findings show the potential of sensor technologies to create immersive, personalized, and data-driven cultural experiences while also identifying barriers, such as cost, technical reliability, and cultural authenticity. The results of this study contribute to sensor technology development by proposing an engagement index that synthesizes motion, orientation, and proximity data, offering a novel framework for quantifying visitor interaction and refining cultural branding strategies.

1. Introduction

Intangible cultural heritages (ICHs) present the traditions, expressions, knowledge, and skills of a community and its cultural identity, by showcasing singing, dancing, traditions, rituals, festivals, handicrafts, and the philosophy of nature and the universe.⁽¹⁾ Unlike monuments and artifacts, ICHs have been changed by communities over the years, reflecting their background and differences. Since they are rooted in life, ICHs represent diversity, togetherness, and the environment.

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However, the existence of ICHs has been threatened in the modern era. Globalization, urbanization, migration, and modernization have fostered cultural blending but have also led to the erosion of traditional identities. For example, indigenous languages, one of the ICHs, are rapidly disappearing. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) estimates that more than half of the approximately 7000 languages globally could disappear by 2100. With diverse rural practices, the number of people involved in traditional arts and crafts preservation is decreasing since the younger generation is leaving their hometowns.⁽²⁾

Sustaining ICHs requires active intergenerational participation within communities. However, inadequate infrastructure has accelerated the decline of cultural traditions. Most ICH forms have been transmitted through experiential practice and oral tradition, rather than preserved in written records. Although an ICH serves as an important marker of community identity, its transmission is constrained by static, two-dimensional documentation methods. Conventional approaches to ICH branding rely on passive observation, which fails to capture the inherently kinesthetic qualities of oral traditions and ritual practices. In particular, knowledge of medicinal plants is increasingly at risk, as elders often pass away without transferring their expertise to younger generations.

To preserve ICHs, sensor-integrated systems for enhancing visitor engagement are required. These support personalized cultural branding strategies. The preservation of ICHs also demands actively passing down traditions, adapting them to modern contexts, and ensuring their relevance. Communities must sustain and evolve their heritage to prevent its significance from fading. This perspective aligns with UNESCO's 2003 Convention for the Protection of Intangible Cultural Heritage, which emphasizes community engagement, cultural diversity, and the continuous evolution of ICHs over time.⁽¹⁾ Digital technology plays an essential role in protecting and promoting ICHs. Digital archives facilitate the transmission of multimedia presentations and intangible cultural practices to the public.⁽³⁾ However, challenges, such as inaccuracy, diminished cultural significance, and the risk of exploitation for tourism or profit must be addressed. Therefore, innovative methods need to be provided to ensure accessibility, authenticity, and continuous community oversight.

One such innovative method is to embed sensors in ICHs. Sensors and augmented reality (AR) enable users to interact with ICHs.⁽⁴⁾ The related technologies foster meaningful emotional and educational outcomes. For example, AR applications revive traditional rituals in a virtual space. When visitors approach an exhibition in a museum, motion sensors activate an audio-visual presentation and provide relevant information. Also, sensors are used to monitor environmental parameters to ensure the safe preservation of artifacts (Fig. 1).⁽⁵⁾ Digital archives with motion capture display historical dances or handicraft skills. New technologies help museums, libraries, and cultural institutions reach their visitors effectively and preserve ICHs.⁽⁶⁾

Although sensor technologies are useful in preserving ICHs, issues exist in integrating them, including high costs, technical requirements, and the need for regular maintenance and experts. While sensor technologies help sustain community traditions, they must not disrupt traditional practices.⁽⁸⁾ Small cultural organizations cannot afford such advanced technologies. To address these challenges, a close cooperation between cultural, technological, and communal institutions is essential.

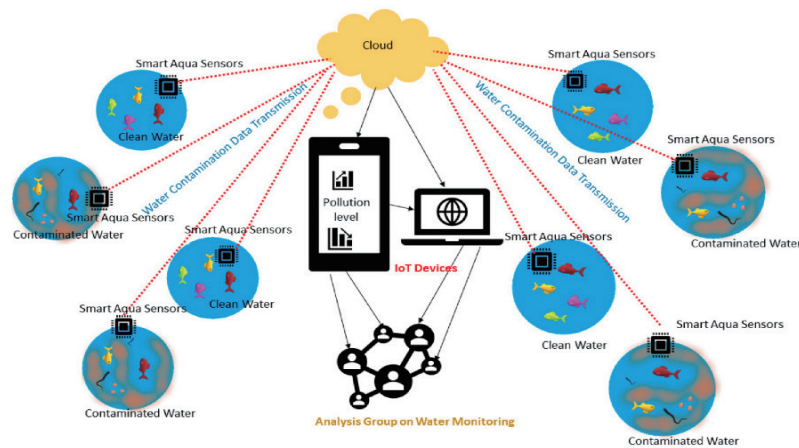


Fig. 1. (Color online) Environment monitoring using IoT and sensors.⁽⁷⁾

Therefore, the integration of sensor technologies into the branding and promotion of ICHs is examined in this study. Specifically, we examine how devices such as motion detectors and AR systems can enhance visitor engagement with an ICH and affect the branding strategies of cultural institutions. In addition, we identify technological, cultural, and financial barriers that hinder the adoption of sensor-based approaches in ICH preservation and transmission. A framework was developed to integrate sensor data, including motion, orientation, and proximity, and quantify visitor engagement. The results were used to evaluate and refine cultural branding practices, enabling dynamic, participatory, and sustainable modes of ICH transmission.

This article is organized as follows. The description on how to use sensors and collect data is given in Sect. 2. In Sect. 3, we present the uses of sensors for ICH branding and promotion. Section 4 showcases the examples of successful integration of sensors. Section 5 concerns the analysis of the results and discussion of issues and recommendations. Finally, Sect. 6 concludes this article.

2. Methods

This study was conducted at three representative sites: a museum exhibiting traditional crafts, an indigenous art center, and a village presenting ancestral rituals. At each site, sensor technologies were deployed to enhance promotion and exhibition effectiveness. The sensor-based infrastructure primarily consisted of motion detectors, AR applications, and audio guide systems.

Infrared motion sensors were installed to activate localized multimedia, including videos, interactive displays, and soundscapes, using passive infrared (PIR) technology owing to its lightweight design and low power consumption. AR applications, accessible via tablets and smartphones, enabled visitors to experience traditional performances, rituals, and craft-making processes through digital overlays. These applications incorporated 3D models, animated visuals, and supplementary information to enrich engagement. Location-based audio guides, powered by Bluetooth Low Energy (BLE) beacons and GPS modules, provided context-specific

narratives, allowing visitors to access detailed explanations of ICH practices. Interviews and storytelling sessions were also integrated to deepen cultural understanding. Sensors were implemented near exhibits and performance areas to facilitate immersive appreciation (Table 1).

AR platforms utilize device-based CMOS image sensors for visual simultaneous localization and mapping, combined with inertial measurement units, such as gyroscopes and accelerometers, to track visitor orientation and viewpoints. BLE beacon-powered audio guides delivered spatially relevant information, thereby enhancing the comprehension of both the sites and their intangible heritage. Three sensor-integrated platforms were employed to capture visitor interaction: PIR motion sensors for the proximity-based triggering of multimedia; AR platforms leveraging CMOS image sensors and IMUs for spatial orientation tracking; and audio guides functioning via BLE beacons (using the received signal strength indicator as a distance sensor) and GPS modules for outdoor ritual sites.⁽⁹⁾ Raw data from these sensors were correlated with survey responses to validate the relationship between physical interaction and perceived brand value.⁽¹⁰⁾

Before data collection, a pilot test was conducted to optimize sensor configurations and refine the digital materials presented to visitors. Adjustments to sensor placement and functionality were made on the basis of pilot outcomes. Data collection involved 150 participants recruited through random sampling among visitors who interacted with at least one sensor-based installation. The sample included visitors at all three sites, with demographic representation as follows: 42% aged 18–35, 38% aged 36–55, and 20% aged over 55; 55% female and 45% male. Approximately 65% reported low to moderate prior knowledge of the specific ICH. All participants provided informed consent and completed the post-visit evaluation survey.

A questionnaire survey on a five-point Likert scale was used (Table 2), and the reliability of the survey results was tested using Cronbach's alpha. Four experts were invited to this study. The expert group comprised two senior scholars specializing in ICH and two associate professors with expertise in computer science and control engineering. Collectively, the experts contributed interdisciplinary perspectives from the humanities and information sciences. Their professional backgrounds included leadership roles in research centers and academic departments, as well as advanced training in literature, computer science, and control theory. This diverse expertise ensured that the study integrated cultural, technological, and methodological insights into the analysis. The experts observed interviews to assess visitor satisfaction, sensor usability, and the impact of sensor technologies on the memory retention and brand recognition of the ICH, and analyzed visitor reactions and group behaviors in relation to different sensor types. The results of the survey were analyzed to assess the engagement and experience, personalization and accessibility, branding and perception of the ICH, and preservation and cultural sensitivity. By

Table 1
Sensor-derived interaction data collected in this study.

Platform	Sensor	Mean raw interaction time (min)	Average daily trigger frequency
PIR platform	Pyroelectric infrared	4.2	142 triggers
AR platform	CMOS/IMU	6.5	88 sessions
Audio guide	BLE	5.8	115 zone entries

IMU: inertial measurement unit.

Table 2
Items included in questionnaire used in this study.

Variable	Items
Engagement and experience	<ol style="list-style-type: none"> 1. The interactive sensors in the exhibits engaged me effectively. 2. The sensor-enabled exhibits created an emotional connection with the cultural heritage. 3. The motion and AR features enhanced my overall experience. 4. The sensor technology encouraged me to explore the exhibits more deeply. 5. The interactive exhibit experience was enjoyable and memorable.
Personalization and accessibility	<ol style="list-style-type: none"> 1. The sensor-based content felt personalized to my interests and preferences. 2. The technology accommodated different learning styles and accessibility needs. 3. I was able to interact with the exhibits at my own pace. 4. The audio guides and adaptive features helped me navigate the site effectively. 5. The sensor technology made the cultural experience inclusive for all visitors.
Branding and perception of ICH	<ol style="list-style-type: none"> 1. The use of sensor technology improved my overall perception of this institution's brand. 2. The technology effectively communicated the cultural significance of the heritage. 3. I would recommend this site to others because of its use of sensor technology. 4. The sensor technology increased my interest in learning more about this cultural heritage. 5. The exhibits felt relevant to contemporary audiences through the use of sensor technology.
Preservation and cultural sensitivity	<ol style="list-style-type: none"> 1. The sensor technology contributed to preserving and transmitting ICH. 2. The use of technology in the exhibits felt respectful toward the cultural traditions. 3. The sensor-enhanced exhibits helped me better understand the values and significance of ICH. 4. I felt the technology struck an appropriate balance between innovation and cultural tradition. 5. I trust this institution's commitment to responsibly using technology for cultural preservation.

integrating sensor-derived metrics with visitor feedback, a robust methodological framework for evaluating the role of sensor technologies in enhancing ICH branding and transmission was established.

Survey and interview data were processed using the Statistical Package for the Social Sciences version 27. Statistical analyses, including correlation analysis, t-tests, and analysis of variance (ANOVA), were performed to evaluate the effects of sensor technologies on cultural branding and ICH transmission. Ethical standards were strictly observed throughout the study. All participants were assured of privacy protection and the right to withdraw at any time. The research protocol was reviewed and approved by the Institutional Review Board of Wenhua College, China.

3. Sensor Technology

3.1 Immersive storytelling

Sensor technologies have transformed storytelling, creating immersive experiences at cultural and historical sites. Traditional ICH presentations are provided on 2D displays in guided tours, preventing visitors from actively participating in learning exhibits.⁽¹¹⁾ Motion detectors, gesture recognition sensors, and AR devices promote visitors' engagement by enabling the interactive appreciation of exhibits. When detecting visitor approaches, motion sensors activate multimedia presentations, such as heritages, cultural dances, or rituals, in digital animations on-screen. This allows visitors to see cultural development and listen to explanations, which increases visitors' interest in history (Fig. 2).



Fig. 2. (Color online) Immersive experience using motion sensors.

3.2 Personalized experiences

Sensor technologies help museums design exhibits and programs effectively to match visitors' preferences, which significantly enhances ICH branding. The data from the sensors are used to create and improve dynamic content on the basis of visitor movements and interactions, which ensures a personalized experience. Sensors track visitor locations, triggering customized audio-visual displays to provide relevant information. Students can especially benefit as this approach fosters their engagement in learning. Sensor-driven exhibitions enable museums to attract a diverse range of visitors, including younger generations accustomed to technology. Integrating sensor technologies into ICHs ensures accessibility, an immersive experience, and emotional and intellectual interactions, which facilitates the preservation and dissemination of ICHs.^(12,13)

3.3 Interactive exhibitions and visitor engagement

Interactive sensors provide immersive, hands-on experiences for visitors (Fig. 3). Touch sensors, cameras, and pressure mats track visitor gestures, allowing them to interact with exhibits dynamically. For instance, virtual artifacts can be manipulated through hand movements, haptic technology lets visitors engage in craft-making, and storytelling is activated by stepping on floor markers. These interactive experiences encourage visitors to collaborate and participate in activities and discussions. The sensor's contribution to the exhibition helps preserve cultural authenticity. The change from viewing exhibitions as static displays to experiencing them through interactions aligns with modern trends that prioritize visitor engagement. Integrating sensor technologies into the ICH allows visitors to connect their emotions to the heritage.



Fig. 3. (Color online) Interactive exhibition.

3.4 AR and virtual reality (VR)

Integrating AR and VR with sensor technologies enhances ICH branding and transmission. AR overlays digital content, such as 3D replicas, animations, and historical details, onto real exhibits. AR allows visitors to experience traditional dances, oral storytelling, and rituals in a virtual environment. VR immerses visitors in cultural activities, enabling them to interact with virtual exhibits and explore their history and hidden stories. Integrating sensors ensures seamless navigation in digital environments by tracking the movement, gestures, and viewpoints of visitors.⁽¹⁴⁾ VR helps visitors attend indigenous ceremonies, fostering meaningful participation. The integration of AR, VR, and sensor technologies allows visitors to experience the heritage that no longer exists in the present (Fig. 4).

3.5 Environmental monitoring

Sensor technologies enable the protection of ICHs by enabling real-time environmental monitoring. Traditional textiles, musical instruments, and rituals are largely affected by physical and climate factors. At ICH sites, sensors are used to monitor temperature, humidity, illumination, and air quality for the preservation of cultural artifacts. IoT-connected sensors enable efficient management by providing real-time alerts about potential risks. Environmental data are also used to enhance the interactive experience of exhibits and raise awareness of the importance of ICH preservation. Sensors are used for conservation and visitor engagement as well as for the dissemination of ICHs.

3.6 Data-driven branding

By leveraging data from sensors, visitor behavior and interests in ICHs can be understood, which enables the development of unique and effective branding strategies for ICHs. The analysis results of sensor data are used to identify popular exhibits, visitor movement patterns,



Fig. 4. (Color online) Example of VR experience in cultural activity (drumbeating).

and narratives that resonate with visitors. For instance, sensor data highlight the busiest areas, which is useful for layout adjustments and audio guide content organization. The real-time adaptability made possible by using sensor data allows cultural institutions to refine marketing strategies to enhance visitor experiences and promotional effects. Data analytics helps target visitors with specific interests and enables the improvement of resource allocation and stakeholder engagement. It is important to ensure data privacy and adherence to ethical guidelines to foster visitor trust through transparent policies. Sensor-data analytics helps enhance ICH branding and its promotion.

3.7 Collaborative design and community involvement enabled by deploying sensors

To integrate new technologies in creating immersive experiences and branding ICHs, experts, communities, and institutions need to collaborate. Sensor technologies positively affect user acceptance and perception owing to their superiority. Such technological advancements also help maintain cultural values and traditional narratives. For example, gesture recognition sensors enable digital simulations to preserve ICHs. The sensor-enhanced branding strategy enhances trust and acceptance through community involvement, and mitigates concerns about misrepresentation. Technological skills empower residents to create content and sustain cultural heritage in their villages. Following ethical principles, technologies enhance community engagement in safeguarding and sharing heritage. Through such collaborative design, ICH branding can be enhanced.

3.8 Gamification and educational applications

Sensor technologies contribute to the gamification of ICH exhibitions, making cultural experiences dynamic and engaging. Incorporating challenges, rewards, and stories in sensor-based games increases the participation of young visitors. Sensors are used to track movements and provide instant feedback to encourage skill development to preserve and disseminate ICHs. For example, AR-powered treasure hunts guide visitors through historical sites, presenting

cultural elements. These immersive experiences foster the visitor's engagement, learning, and connections to ICHs. Sensor-driven educational tools accommodate diverse educational needs by presenting ICHs in a virtual environment. By gamification and sensor technology, entertainment is integrated with ICHs, which creates connections to ICHs and raises their brand recognition.

4. Case Studies

We conducted case studies that feature how sensor technologies have been used to maintain and present ICHs. The cases showcase music and dance in various sensory ways: experience in the museum, ritual re-creation in VR, and costume culture. These cases show the value of sensor technologies in personalizing ICHs. Sensor technologies help visitors to be involved in cultural activities, pass traditions down, and make ICHs accessible. The key factors and problems in the successful implementation of sensors in museums and galleries were identified through the case studies, showing a future direction for improving ICH branding.⁽¹⁵⁾

4.1 i-Treasures project

Advanced sensors are essential to the i-Treasures project, which strives to safeguard and present ICHs. In this project, an open-source platform was constructed with sensors and devices to record and analyze music, dance, and crafts. Through the digitization of content, the i-Treasures project captures the movements and sensations in ICH experiences, revealing new patterns and connections.

In the project, researchers investigated musical styles by motion capture and analyzed sounds to discover rare Corsican "Cantu in Paghjella" and Sardinian "Canto a Tenore", which have since been passed down. The project helps to better understand how these customs developed and spread in different areas. Additionally, the i-Treasures project has provided educational resources by sensorimotor learning so that children can learn uncommon skills through virtual exercises. The project led to the formation of the hubs of local schools in Wuhan, China, using technology to preserve ICHs. Owing to the combination of cultural knowledge and advanced sensor technology, the i-Treasures project has proven that sensor technologies contribute to the preservation and promotion of ICHs. They support meaningful activities and facilitate the sharing of ideas to bring people together and contribute to the community's growth. The use of sensors in the project illustrates how ICHs can be appreciated in real life beyond mere documentation, helping students and the public to learn more about ICHs.

4.2 AR and motion detection in museum

AR and motion detection rely on sensor technologies to create immersive museum experiences. Using infrared cameras, an application enables children to engage with an Aboriginal puppet and Arabic writing simply by moving their bodies in VR. The application was designed to help children explore ICHs through gamification and motion capture. Sensors

enhance visitor engagement and provide a valuable experience. Gesture-based interactions provided a deeper level of immersion than traditional exhibits. The museum's system focuses on the sustainability and interoperability of ICHs. This system highlights how sensor technologies shape new models that prioritize cultural sensitivity and accessibility. Through AR and motion detection, traditions are recorded online and transformed into interactive, meaningful experiences. The seamless implementation of sensor technologies underscores the importance of kinesthetic activities and the cultural continuity of ICHs.

4.3 VR and interactive storytelling

The preservation and promotion of the Old Bridge Diving tradition in Mostar, Bosnia, and Herzegovina demonstrate how VR, storytelling, and sensor technology can enhance cultural experiences. This tradition, where residents dive into the river from the historic bridge, is gradually fading as fewer people participate. To address this, researchers developed a VR simulation technique that replicates the diving experience using 360-degree environments and interactive storytelling. Sensors track participants' movements and gaze, fostering identification with the diver and enhancing their engagement. This immersive method strengthens the emotional connections of participants, making the tradition accessible and widely appreciated. VR increased viewers' emotional attachment and understanding of the significance of old bridge diving in the Bosnian culture. By offering a virtual experience, those unable to witness the ceremony become aware of the tradition. This highlights how sensor-integrated VR ensures the preservation and continuity of ICHs across different regions, engages visitors, and enhances their recognition and branding.

4.4 Interactive exhibition of Ming Dynasty costume

The exhibition digitally preserved over 40 garments, highlighting their social significance, symbolic meanings, and craftsmanship.⁽¹⁶⁾ In the project, high-resolution photographs, 3D data, and patterns were collected for analysis. The results were used to produce highly detailed 3D replicas, allowing visitors to explore the intricate designs via touchscreens and AR, helping them to understand and experience traditional garment-making techniques. 3D models and interactive exhibitions allow visitors to explore this costume culture. Digital exhibits provide valuable references, fostering knowledge-sharing and creative inspiration. Sensors in the exhibits play a crucial role in sustaining traditional cultural expressions for education, marketing, and public engagement.

These case studies highlight the applications of sensor technologies in promoting and disseminating ICHs. The sensor technologies used for ICH branding enable immersive, personalized experiences by connecting tradition to modern innovation, such as multisensory exhibitions, kinesthetic learning, VR storytelling, and digital costume displays.

5. Results and Discussion

The questionnaire survey data were tested for reliability. Cronbach's alpha coefficient was 0.763, showing that the data were appropriate for assessing how visitors perceive the benefit of using sensors in ICH branding and dissemination. Contributions of sensor technologies to the visitor's engagement and experience, personalization and accessibility, and the branding and perception of the ICH were measured in the assessment.

The overall mean score was 3.52 [standard deviation (*SD*) = 0.71] in visitor's engagement and experience, suggesting that the participants had moderately positive opinions on the use of sensor technologies in the museum. Personalization and accessibility scored 3.48 (*SD* = 0.64), suggesting the participants felt that the technology was tailored well to diverse age groups. The branding and perception of the ICH scored 3.50 (*SD* = 0.75), indicating that the interactive features positively affected their perception of sensor technologies. The participants had a positive view of preservation and cultural sensitivity using sensor technologies, scoring 3.49 (*SD* = 0.74). The scores varied significantly, ranging from 1.40 to 5.00 (Table 3). While the participants generally find sensor technologies useful, they expect further improvements to benefit them and enhance cultural activities. To determine if the observed mean score of 3.5 was statistically significant, a one-sample t-test was conducted against a test value of 3.0 (neutral). The results indicated a significant positive perception of the sensor-integrated branding [$t(149) = 8.76, p < 0.001$]. The high *SD* (0.7) and the broad range of responses (1.4 to 5.0) indicated the heterogeneous nature of the visitor population. A post-hoc analysis revealed that previous experience in technology was a significant predictor of satisfaction; visitors with high digital literacy scores accounted for the majority of the scores of 4.0–5.0. This variance suggests that while sensor technology is highly effective for younger demographics, supplementary traditional methods remain necessary for older populations to ensure inclusive ICH transmission.⁽¹⁷⁾

While the average engagement score of 3.5 indicated a moderate-to-high level of success, considering initial technology adoption, the use of IMU-based AR and BLE-based audio guides was a new experience for many participants. In human–computer interaction, the first interactions with sensor systems often exhibit high variance as users navigate the learning curve.⁽¹⁸⁾ Therefore, the mean score in this study serves as a baseline for branding efficiency, which is expected to increase as the technology becomes more ubiquitous.

To explore the impact of educational background on the perception of sensor technologies, a one-way ANOVA was performed. 150 participants were categorized into three groups on the basis of their highest level of education. Through the analysis, it was determined whether the

Table 3
Descriptive statistics of questionnaire survey results.

Variable	<i>N</i>	Minimum score	Maximum score	Mean score	<i>SD</i>
Engagement and experience	150	1.40	5.00	3.5227	0.70883
Personalization and accessibility	150	2.00	5.00	3.4813	0.64135
Branding and perception of ICH	150	1.40	5.00	3.4960	0.75181
Preservation and cultural sensitivity	150	2.00	5.00	3.4893	0.73623
Valid <i>N</i> (listwise)	150				

branding and perception of the ICH were enhanced or if they were contingent on the visitor's academic background. The ANOVA results showed the participants' various aspects. The personalization and accessibility of sensor technologies showed no significant differences between the participants and the experts, with an F -value of 0.649 and a p -value of 0.847. Engagement and experience with sensor technologies also showed similar scores between groups (an F -value of 0.832 and a p -value of 0.653). A difference in the perception of preservation and cultural sensitivity was observed between the groups (an F -value of 1.842 and a p -value of 0.029) (Table 4). The inclusion of the branding and perception of the ICH revealed a significant difference (an F -value of 3.82 and a p -value of 0.024) depending on the level of education. Visitors with postgraduate education perceived sensor-based branding as more authentic and efficient than did visitors with secondary education.⁽¹⁹⁾ This confirms the necessity of tailoring sensor-based content to the specific educational profiles of the target audience.

To test the significance of differences between groups across multiple dependent variables, multivariate ANOVA (MANOVA) was employed. This analysis utilized Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root to assess the simultaneous impact of sensor-integrated branding while accounting for intercorrelations between variables.

Wilks' Lambda represents the proportion of total variance not explained by the independent variables; a lower value indicates a greater effect of sensor technology. Pillai's Trace, the most robust metric against violations of variance–covariance homogeneity, measures the sum of explained variance. Hotelling's Trace is used to determine the overall strength of the multivariate effect through the sum of eigenvalues, while Roy's Largest Root identifies the most dominant trend by focusing on the first eigenvector.⁽²⁰⁾ The MANOVA results revealed that the branding and perception of the ICH was the only variable that showed a statistically significant multivariate effect ($p = 0.024$). This indicates that while the technology's impact on general engagement or personalization might vary, its effect on how the cultural brand is perceived is statistically consistent across demographic groups. Conversely, engagement and experience, and personalization and accessibility did not reach statistical significance ($p > 0.05$). Notably, as shown in Table 5, Roy's Largest Root for personalization (0.058) was close to the significance

Table 4
One-way ANOVA results.

Variable		Sum of squares	Degree of freedom (DF)	Mean square	F	p
Personalization and accessibility	Between groups	4.725	17	0.278	0.649	0.847
	Within groups	56.563	132	0.429		
	Total	61.288	149			
Engagement and experience	Between groups	7.249	17	0.426	0.832	0.653
	Within groups	67.614	132	0.512		
	Total	74.863	149			
Branding and perception of ICH	Between groups	14.45	17	0.85	1.881	0.024*
	Within groups	59.664	132	0.452		
	Total	74.114	149			
Preservation and cultural sensitivity	Between groups	15.485	17	0.911	1.842	0.029
	Within groups	65.278	132	0.495		
	Total	80.763	149			

Table 5
Multivariate test results.

	Effect	Value	<i>F</i>	Hypothetical DF	Error DF	Significance level
Intercept	Pillai's Trace	0.985	1570.947 ^b	2	49	0.000
	Wilks' Lambda	0.015	1570.947 ^b	2	49	0.000
	Hotelling's Trace	64.120	1570.947 ^b	2	49	0.000
	Roy's Largest Root	64.120	1570.947 ^b	2	49	0.000
Engagement and experience	Pillai's Trace	0.475	0.973	32	100	0.518
	Wilks' Lambda	0.578	0.967 ^b	32	98	0.527
	Hotelling's Trace	0.640	0.960	32	96	0.537
	Roy's Largest Root	0.426	1.331 ^c	16	50	0.216
Personalization and accessibility	Pillai's Trace	0.548	1.257	30	100	0.200
	Wilks' Lambda	0.521	1.259 ^b	30	98	0.199
	Hotelling's Trace	0.788	1.260	30	96	0.199
	Roy's Largest Root	0.546	1.820 ^c	15	50	0.058
Branding and perception of ICH	Pillai's Trace	0.747	1.528	32	132	0.024
	Wilks' Lambda	0.417	1.514	32	132	0.024
	Hotelling's Trace	1.513	1.499	32	132	0.024
	Roy's Largest Root	0.861	1.921	17	132	0.024
Preservation and cultural sensitivity	Pillai's Trace	1.217	1.142	136	100	0.242
	Wilks' Lambda	0.153	1.120 ^a	136	98	0.277
	Hotelling's Trace	3.110	1.098	136	96	0.315
	Roy's Largest Root	1.610	1.184 ^b	68	50	0.267

a: exact statistic, b: upper bound on *F*-score that yields a lower bound on the significance level.

threshold, suggesting a marginal trend. Finally, preservation and cultural sensitivity showed no significant interaction effect, implying that the role of sensors in dissemination is currently perceived similarly regardless of the visitor's specific background.

Table 6 shows the present status of sensor technologies used at the study sites. The motion sensors were installed in 10 places, and the duration of visitor interaction to interact with the multimedia was 4.2 min on average. The engagement score was 3.7, and 78% of the participants were satisfied with the engagement through sensor technologies. AR devices were used in eight places, with an average interaction time of 6.5 min and the highest engagement score of 4.1. The survey indicated an 85% satisfaction rate for AR devices. Audio guides with location sensors were installed in 12 places. The participants spent 5.8 min and scored their engagement as 3.9 with a satisfaction rate of 82%.

Motion detectors provided interesting and responsive environments that prompted visitors to explore in more detail. Because of its 3D visuals and relevant details, AR allowed the participants to enjoy and explore ICHs immersively. Audio guides effectively delivered cultural stories in accordance with each visitor's learning needs. The results showed that sensor technologies enhanced the participants' enthusiasm, appreciation for culture, and satisfaction at ICH sites.

Using sensors, game developers can create interactive and personalized experiences for the greater involvement of users. The participants understood the culture better and were satisfied with using motion detectors, AR, and audio guides. Traditional methods based on sculptures and explanations were less appealing than the methods with sensor technologies. The results of this study showed that advanced technologies promote and preserve ICHs (Table 7).

Table 6
Observation results in this study.

Device	Mean interaction time (min) ^a	Engagement score (1.0–5.0) ^b	Satisfaction rate (%) ^c
PIR platform	4.2	3.7	78
AR device	6.5	4.1	85
Audio guide	5.8	3.9	82

a: mean interaction time = *entry time*/*exit time*, b: engagement score = *trigger frequency* × *dwelt time*/*total session duration*, c: percentage of participants who scored 4 or 5.

Table 7
Results for traditional methods and sensor-enhanced methods in promoting and disseminating ICHs.

Variable	Sensor-enhanced method	Traditional method
Engagement	Interactive, immersive	Moderate – passive viewing
Personalization	Experiences tailored via sensor data	One-size-fits-all presentations
Accessibility	Supports diverse learning styles	Limited accommodation
Understanding culture	Enhanced through AR and audio guides	Dependent on static displays
Satisfaction	Higher owing to dynamic interactions	Lower owing to limited interaction

6. Conclusions

We examined the integration of sensor technologies into the branding and dissemination of ICHs across three representative sites. By deploying motion detectors, AR applications, and BLE beacon-powered audio guides, the research revealed that sensor technologies significantly enhance visitor engagement, personalization, and cultural appreciation. Quantitative analysis results showed the reliability of survey data (Cronbach's alpha = 0.763) and revealed moderately positive perceptions, with mean scores of 3.52 for engagement and experience, 3.48 for personalization and accessibility, 3.50 for the branding and perception of ICH, and 3.49 for preservation and cultural sensitivity. A one-sample t-test indicated a statistically significant positive perception of sensor-integrated branding [$t(149) = 8.76, p < 0.001$]. Furthermore, one-way ANOVA results indicated significant differences across educational backgrounds, particularly in branding and perception ($F = 3.82, p = 0.024$) and preservation and cultural sensitivity ($F = 1.84, p = 0.029$), underscoring the importance of tailoring sensor-based content to diverse audiences.

By introducing an engagement score, motion, orientation, and proximity data were assessed using a measure of visitor interaction. This method integrates sensor-derived technical metrics with subjective visitor feedback, enabling cultural institutions to refine branding strategies by referring to objective, real-time data. Beyond its immediate application to ICHs, the engagement score offers a methodological advancement for evaluating audience engagement in sensor-driven environments more broadly. In further studies, high implementation costs, technical maintenance requirements, and the need to balance innovation with cultural authenticity and inclusivity must be explored.

Overall, the results of this study confirmed that sensor technologies can play a transformative role in safeguarding and transmitting an ICH, ensuring its relevance for future generations while advancing the scientific development of sensor-based engagement systems.

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