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ORIGINAL RESEARCH ARTICLE

Smart museum and visitor satisfaction

Siyang Liu*, Jian Guo

Dalian Art College, Dalian 116600, China

*** Corresponding author:** Siyang Liu, liusiyang@dac.edu.cn

ABSTRACT

The digitization of museums has not only changed the way people view exhibitions but also transferred some rights to the hands of visitors to meet their needs for personalized services. Through a review of literature, we found that research related to smart museums presents an increasing trend in the recent 15 years. Progress has been made in the definition of smart museums, intelligent system construction, and intelligent narrative and service. However, there are few studies on systems of assessment criteria for smart museums, let alone on the relationship between how smart a museum is and a visitor's satisfaction with the experience offered at the museum. Our purpose in this study was to establish assessment criteria for smart museums, and then to use the assessment criteria to explore the relationship between degree of museum intelligence and visitor satisfaction. We collected survey data from 602 visitors at Beijing's Palace Museum and ran an exploratory factor analysis on the data. The results showed that six factors of museum intelligence, taken as assessment criteria, were positively correlated with visitor satisfaction. The technology integration factor had the greatest correlation, while module performance had the greatest impact on visitor satisfaction.

Keywords: smart museum; assessment criteria; visitor satisfaction; museum intelligence; user experience

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1. Introduction

A smart space (or iSpace) is a world in which the context of information and communication technology disappears into the physical objects and domains of our lives and work[1]. The essential requirement of an intelligent space is the natural interaction between the space and the user, including the user's subconscious gestures, actions, and behaviors[2]. The Internet of Things has completely changed the way of visiting traditional museums, and static cultural spaces have become intelligent due to the definition of innovative models of sensors and services[3]. Artifacts are transformed into intelligent objects of the Internet of Things, making decisions autonomously, sensing the environment, communicating with other objects, accessing existing Internet resources, and interacting with people[4].

Smart museums are a new generation of museums after traditional and digital museums[5], but their connotation still includes three aspects: protection, management, and service. Smart technology can control the operation, exhibition, environment, communication capacity, and information service from inside to outside[6] while helping visitors through technology and equipment to receive information and customized services, thus improving the visiting experience[7]. The information service of a smart museum is not limited to providing record-based descriptions of exhibits to nearby visitors[8]. At the same time, visitors can collaborate in using or creating knowledge of cultural heritage[9]. The construction of intelligent systems will promote a comprehensive change in museum management, operation, and service on the basis of information construction, making the mode of museum management more refined.

Research on the relationship between visitor satisfaction and the smart museum evaluation system will aid in facility and service optimization, precise marketing, academic research promotion, policy formulation guidance, and social influence enhancement, all of which have significant academic and practical implications.

2. Literature reviews

Zachila et al.[10] provide a report on current work to create a smart museum (SM) ontology that satisfies five goals. Wang[11] investigates a workable strategy to fully utilize the function of the smart museum and offers some recommendations for the spatial design of the smart museum. Smart museums are based on technology and devices that may allow us to better understand and change user behavior through interactive narratives. From the perspective of technology and equipment alone, intelligence can be divided into perception, application, and network. Porter and Heppelmann[12] introduced a model for "smart, connected products" constructed on a progression of capabilities, each building upon the previous one. These functions fall into four parts: monitoring, control, optimization, and autonomy.

Sparacino's concept of the smart museum focuses on the understanding of visitors' behaviors, feelings, and needs[2]. She argues that smart spaces need to be supported by three forms of intelligence: perceptual, interpretive, and narrative. The requirement for measuring intelligence in an entertainment space is that it provides a layered intelligent model with a unified mathematical representation including narrative intelligence. Based on an understanding of spatial intelligence in the human brain, intelligence is measured in meeting users' actions, behaviors, preferences, and needs[13]. One advantage is that the service object, as the main body of research, supports the user's perspective to understand the environment, content, and exhibits.

Other scholars have also tried to analyze intelligence from the perspective of information services, among whom Korzun and his team defined the service intelligence level of an intelligent museum into three layers. Information expansion to the edges is one layer, IoT-aware information exchange is another, and semantic enrichment is the third[14].

Equipment and smart technology provide both an opportunity and a guarantee for change of museums. Smart technology has a broad impact on the visitor experience. Among them, accessibility and interactivity affect the experience enhanced by smart technologies. There is a significant correlation between tourists' perceived value of smart technology and their satisfaction[15]. Siountri et al.[16] examine the interconnection and interoperability of BIM, IoT, Blockchain and advanced digital technologies in the demanding environment of a museum, where efficient, secure monitoring and management are critical factors that should be satisfied. In a study on the most recent developments in WiFi vision, He et al. examined how common WiFi devices' channel state information (CSI) is used for perception, recognition, and detection. To serve as a guide for decision-making, they built an intelligent museum environment parameter rating evaluation system[17]. By including a weighted clustering center function, Guo et al.[18] suggested a museum environment parameter data rating evaluation approach built on an enhanced K-Means clustering algorithm. BLE beacons for indoor placement in an interactive IoT-based smart museum are studied by Spachos and Plataniotis. The presentation of an indoor geolocation system aims to improve visitor satisfaction in museums. The BLE beacon is a promising option for an interactive smart museum, according to experimental results on distance estimate, position, and detection accuracy[19].

3. Materials and methods

3.1. Assessment factors selection and analysis

In this study, we calculated the variance contribution rate of each dimension through ANOVA, then used it as the calculated weight for each dimension to obtain a formula for calculating intelligence. Using this formula, we can calculate the total score of "intelligence" based on each dimension's performance.

To further conceptualize the smart museum's evaluation factors and obtain an overview of these energies of smart museums, we consulted two sources of information. First, we conducted exploratory face-to-face interviews with seven experts. All respondents have a background in display design or interaction design and have at least eight years of experience as designers or curators in the industry. Respondents were asked the following three questions:1) "What do you think about museum industry after the COVID-19 Epidemic?" 2) "What is the smart museum to you?" 3) "What factors do you think that can evaluate the smart museum?" All seven respondents gave available answers to these three questions to gain insight into experts' opinions on museum intelligence.

We operate on each dimension using the traditional reflection measurement perspective to ensure that within a dimension the indicators have a common theme and thus reflect the same basic structure. In this way, we can measure museum intelligence as a third-order structure. After each first-order dimension and second-order attribute, third-order indicators can be used to measure museum intelligence, forming a multiple-item scale. Through the content analysis of the existing literature, we sorted out a total of 34 indicators to evaluate the intelligence of museums, and then refined and classified these indicators through expert interviews. Finally we obtained 28 indicators, 20 attributes and 6 dimensions. Now, we examined all the dimensions and indicators one by one in **Table 1**.

Table 1. Dimensions, attributes and statements.

Dimensions	Attributes	Item Statements
1. Technology-enabled (3 Items)	01. Usability	01. The museum is using advanced technology to exhibit the artifacts.
	02. Privacy	02. The museum ensures its visitors their safety and their non-unauthorized use of personal information.
	03. Maintainability	03. The museum is maintained and upgraded.
2. Human-like Interaction (8 Items)	04. Input	04. The instructions in the interaction are accurate.
		05. The task guidance during interaction is easy to understand.
		06. The interaction interface and flow are concise.
	05. Cooperativity	07. The ability to cooperate, in particular with other machines.
	06. Output	08. The process of interaction is as natural as communicating with people.
		09. The artifacts can introduce themselves to the visitors.
		10. The museum can use asynchronous or synchronous to exchange information.
		11. The museum can collaborate with visitors to achieve semantic enrichment.
3. Adaptability (4 Items)	07. Real-time feedback	12. The museum system responds to the visitor requirements immediately.
	08. Context-aware	13. The devices can exploit emerging technologies to infer the current activity state of the user and the characteristics of their environment.
	09. Upgradeability	14. The museum can upgrade hardware and software appropriately to achieve better performance.
	10. Customizability	15. The museum system directly adapts its behavior to the visitor requirements.

Table 1. (*Continued*).

Dimensions	Attributes	Item Statements
4. Systematic Efficiency (5 Items)	11. Autonomy	16. The ability to make independent decisions based on observations, to plan, to draw conclusions and to make judgments concerning consequences.
		17. The ability to learn and eliminate mistakes.
		18. Visitors feel they have mastered the system quickly.
	12. Learnability	19. Museum devices or applications can be easily picked up and understood by the user.
	13. Intuitiveness	20. Visitors can interact with the museum devices, website or app effectively by applying knowledge unconsciously.
5. Technological Integration (4 Items)	14. Compatibility	21. The website or app can be used on different personal devices, systems, and browsers.
	15. Collaboration	22. Visitors can use museum technology tools to collaborate with others or share info with others effectively.
	16. Constructiveness	23. Visitor can use museum technology tools to connect new information to their knowledge.
	17. Goal-orientation	24. Visitors can use technology tools to set visiting goals, plan activities, monitor progress.
6. Affordability (4 Items)	18. Time	25. The museum can save visitor's touring time.
	19. Expense	26. The cost of getting to the museum, admission, equipment rental, catering, membership, and purchase of souvenirs are reasonable.
		27. Museums can push product information according to the consumption habits and preferences of visitors.
	20. Workload	28. The museum can plan the display route and choose the narrative mode according to the person's physical strength.

3.2. Assessment criteria

3.2.1. Technology-enabled

If a whole museum can run automatically, the development of digitization comes from the continuous innovation of technology, which plays an increasingly important role in all aspects of museums' intellectualization. Many museums use information and technological means to remain competitive. This dimension includes usability, privacy, and maintainability. Usability refers to the extent to which connected devices, websites, and apps are easy to use. Museums should ensure visitors' safety and privacy by ensuring that they do not use personal information without authorization. Maintainability refers to capacity for required maintenance upgrade.

3.2.2. Human-like interaction

To the degree a museum device or exhibit communicates and interacts with users naturally and humanly, this interaction includes input and output. Input can quantify performance and appropriateness of modality by accuracy, synchronicity, and degree of coverage for the user's behavior[20]. Output can be measured through intelligibility, comprehensibility, and ability to convey specific information. On the user side, interaction performance can be quantified by the user's effort and freedom in interacting with the system. Cooperativity can be quantified by the speed/pace, simplicity, fluency, and naturalness of interactions[20].

3.2.3. Adaptability

Adaptability is the ability to be adapted to users' required functions, or to enhance performance[21,22]. This dimension includes extensibility of functions (achieved by designing a potential extension of functions), upgradeability of modules (their need for upgrades, new technologies, and changes in requirements), and customizability of components (ease of adaptation for individual customers' requirements and preferences)[23].

3.2.4. Systematic efficiency

Systematic efficiency includes autonomy, effectiveness, learnability, and intuitiveness. Autonomy is generally considered the condition or quality of self-calibration, self-diagnostics, fault-tolerance, and self-tuning[24]. Machine autonomy in the field of artificial intelligence identifies five essential statements[25], of which two can measure the performance of automation in a smart museum. One statement concerns the ability to make independent decisions based on observations, along with the ability to plan, to draw conclusions, and to make judgments concerning consequences. The other statement concerns the ability to learn and eliminate mistakes.

Effectiveness is defined as the accuracy and completeness with which specified users can reach specified goals in particular environments[18,26]. Learnability is defined as the speed and facility with which users feel they have been able to master a system[18,26]. Intuitiveness is the extent to which the user is able to interact with a technical system through unconscious application of knowledge[18,27].

3.2.5. Technological integration

Technology integration refers to mobile devices such as computers, smartphones, tablets, digital cameras, as well as social media platforms and networks, software applications, the Internet, and other technical resources, as they deliver and manage information in museums. The ultimate goal of technology integration is to redefine how we teach and learn and do things we have never done before[28].

Compatibility refers to the ability of a museum's website and app to function on any computer or smartphone[16].

Collaboration describes the degree to which technology is used to facilitate, enable, or enhance visitors' opportunities to share information and create knowledge with peers and experts outside the museum. Visitors use technology to collaborate with others rather than working individually at all times[29].

Constructiveness means that visitors use technology to connect new information with their previous knowledge, rather than passively receiving[29].

Goal-orientation addresses visitors' use of technology to set goals, plan activities, monitor progress, and evaluate results before and during visits to museums, rather than simply visiting without reflection[29].

3.2.6. Affordability

Affordability involves stakeholders such as museums, communities, visitors, and even countries. We focused on what visitors can afford in smart museums. Affordability is subjective. An item can be considered unaffordable if it costs more time and money than expected. If good design should feature affordability, this affordability in design refers to money and includes the user's time, cost, and workload.

Time in this sense refers to the time it takes for visitors to complete their visits to museums. Whether visiting a site or browsing a website, visitors want to visit within a time range they can afford. Saving time, like affordability, is a relative, subjective concept.

Expenses include travel expenses, admission tickets, equipment rental fees, catering, and cost of souvenirs. A museum's location, the date of visiting, and visitor consumption have significant impacts on expenditure, so it is not easy to compare them horizontally.

Workload includes cognitive costs (such as necessary information-processing capacity and resources)[30] and physical effort required to visit.

3.3. Study site

The reason why we chose the Palace Museum as a case study is that it is the most visited national museum in China every year, with the number of visitors exceeding 9 million in 2019, which makes it easy for us to conduct online and offline surveys of visitors. Secondly, it is one of the earliest museums in China that use VR and AR technology to display cultural relics and has already established a digital resource system that covers all types of cultural relics and all commonly used data types. As the digital museum with the highest degree of intelligence in China, it has the basic conditions for the construction of a smart museum. Last but not the least, the Palace Museum and Huawei Technologies signed a strategic cooperation agreement to jointly carry out cooperation in 5G application demonstration, building museum smart area, and holding artificial intelligence competition.

3.4. Data collection

We received a total of 602 questionnaires, of which 515 were valid, and the effective rate was 85.5%. All participants have visited the Palace Museum at least once. To avoid affecting visitors' judgment on each item, we did not inform respondents in advance that the focus of this survey was on museum intelligence.

The main part of the questionnaire was composed with reference to the six dimensions of the museum, and participants were asked to evaluate their visits and experiences on each dimension. The scale adopted self-assessment on a seven-point Likert scale to measure from 1 = "completely inconsistent" to 7 = "perfectly consistent." There were two satisfaction measures derived from the American Customer Satisfaction Index (ACSI), also measured on a seven-point scale.

3.5. Data analysis

Reliability refers to the degree of consistency or stability in measured results (i.e., data). Consistency reflects the relationship between questions within a test, examining whether each question measures the same content or trait. Stability is the coefficient of reliability between repeated measurements at different times for the same group of subjects using a measurement tool (e.g., the same questionnaire).

We analyzed our data for reliability and found that the overall Cronbach's Alpha was 0.961; the Cronbach's Alpha values for the six factors are shown in **Table 2**. We can see that the Cronbach's Alpha values for all latent variables were above 0.7, indicating high reliability.

Table 2. Reliability analysis of the six factors.

Variable	Number of Items	Cronbach's Alpha
F1. Technology-enabled	3	0.751
F2. Human-like Interaction	8	0.876
F3. Adaptability	4	0.878
F4. Systematic Efficiency	5	0.845
F5. Technological Integration	4	0.873
F6. Affordability	4	0.768

Table 3. Validity analysis of the data.

KMO and Bartlett's test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.971
Bartlett's Test of Sphericity	Approx. Chi-Square	8982.496
	df	378
	Sig.	0.000

Table 4. Variance analysis of each factor to visitor satisfaction.

Item	Mean Standard Deviation (mean ± SD)	F	P
F1. Technology-enabled	16.2951 ± 3.1657	21.622	0.000**
F2. Human-like Interaction	41.6796 ± 7.61298	17.113	0.000**
F3. Adaptability	20.1029 ± 4.6070	24.561	0.000**
F4. Systematic Efficiency	25.5631 ± 5.1847	20.304	0.000**
F5. Technological Integration	20.3087 ± 4.6929	26.216	0.000**
F6. Affordability	20.2757 ± 4.1902	33.256	0.000**

As shown in **Table 3** above, the test validity of KMO and Bartlett's test is 0.971, the test chi-square value is 8982.496, and the corresponding significance P-value is 0.000. The closer the KMO and Bartlett test values are to 1, the better the validity of the scale is. It shows that the questionnaire is effective.

The number of the appropriateness of KMO sampling is 0.971, indicating that factor analysis has a good effect. The variance analysis results of the six factors on satisfaction are shown in **Table 4**. The F-test statistics of F1, F2, F3, F4, F5, and F6 are 21.622, 17.113, 24.561, 20.304, 26.216, and 33.256, and the corresponding Test *P*-value is 0.000. The null hypothesis should be rejected, and it is believed that all factors have significant differences in satisfaction.

As shown in **Table 5**, the correlation coefficients obtained from the correlation analysis among various factors, and the corresponding significant *P* values are all 0.000. Since all correlations are significant at 0.01 level, it is considered that there is a strong correlation among various factors.

Table 5. Correlation analysis.

Correlation								
			F1	**F2**	**F3**	**F4**	**F5**	**F6**
Spearman Rho	F1	Correlation Coefficient	1.000	0.687**	0.610**	0.598**	0.598**	0.571**
	F2	Correlation Coefficient	0.687**	1.000	0.781**	0.755**	0.768**	0.724**
	F3	Correlation Coefficient	0.610**	0.781**	1.000	0.787**	0.726**	0.731**
	F4	Correlation Coefficient	0.598**	0.755**	0.787**	1.000	0.783**	0.755**
	F5	Correlation Coefficient	0.598**	0.768**	0.726**	0.783**	1.000	0.775**
	F6	Correlation Coefficient	0.571**	0.724**	0.731**	0.755**	0.775**	1.000

**. At level 0.01 (double tails), the correlation is significant.

We defined an intelligent museum to lay a foundation for establishing subsequent evaluation dimensions. We then determined six key factors by which to evaluate the intelligentization of museums, defining attributes and indicators on the six factors, and established a complete evaluation system. Then, combining these six factors and their correlation coefficients, we proposed a calculation method for evaluating intelligence. We finally determined the formula for intelligence evaluation as follows:

$$I = 0.3284F1 + 0.31F2 + 0.3449F3 + 0.3431F4 + 0.3753F5 + 0.3353F6 \quad (1)$$

However, just working out a museum's intelligence score is of little use except with museum government ratings. It is necessary to evaluate museum intelligentization, especially to explore its influence on visitor satisfaction, which is of great significance to establish evaluation systems and construction of museums.

We therefore proved that the six dimensions have a positive impact on museum's intelligence. Humanized interaction with tourists is more in line with visitors' psychological needs. Besides, more adaptable, systemically efficient, and more affordable interactions will place lower demands on visitors and leave impressions of more natural interactions. Technology is the foundation of building a museum with intelligence, and technology integration is designed to meet visitors' needs at different levels in real time. It is therefore not surprising that this factor has the most significant impact on visitor satisfaction.

Due to the large sample of datas we collected, the six factors significance after our analysis is decisive, however prone to errors. We therefore reused factor analysis to extract common factors.

Table 6. Total variance explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	13.761	49.148	49.148	13.761	49.148	49.148	6.016	21.487	21.487
2	1.513	5.405	54.553	1.513	5.405	54.553	5.542	19.794	41.280
3	1.054	3.766	58.319	1.054	3.766	58.319	4.771	17.039	58.319

Extraction Method: Principal Component Analysis.

The total variance obtained by factor analysis is explained, as shown in **Table 6**. The total variance reflects the total proportion of the extracted data information to the original information. The analysis results showed that three common factors were extracted by taking the eigenvalue more significant than one as the extraction condition, and the variance contribution rate was obtained as 49.148%, 5.405%, and 3.766%, respectively. Its cumulative contribution rate reached 58.319%. As **Table 7** shows, for the three common factors proposed, the corresponding component matrix is:

Table 7. Rotated component matrix[a].

	Component		
	1	2	3
Q1	0.375	0.155	0.611
Q2	0.137	0.222	0.718
Q3	0.273	0.184	0.652
Q4	0.284	0.172	0.716
Q5	0.228	0.244	0.648
Q6	0.235	0.320	0.650
Q7	0.432	0.181	0.412
Q8	0.668	0.198	0.306
Q9	0.531	0.260	0.457
Q10	0.616	0.249	0.272
Q11	0.666	0.346	0.329
Q12	0.700	0.276	0.325
Q13	0.701	0.360	0.258
Q14	0.542	0.395	0.351
Q15	0.700	0.401	0.225
Q16	0.633	0.439	0.173
Q17	0.628	0.509	0.175
Q18	0.220	0.530	0.424
Q19	0.160	0.593	0.431
Q20	0.340	0.637	0.215
Q21	0.363	0.649	0.243
Q22	0.344	0.687	0.242

Table 7. (*Continued*).

	Component		
	1	**2**	**3**
Q23	0.366	0.637	0.340
Q24	0.487	0.575	0.270
Q25	0.129	0.557	0.492
Q26	0.224	0.566	0.124
Q27	0.416	0.578	0.181
Q28	0.494	0.561	0.177

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]

a. Rotation converged in 7 iterations.

According to the composition matrix, the results are as follows:

$$\begin{gathered} x_3 = 0.611Q1 + 0.718Q2 + 0.652Q3 + 0.716Q4 + 0.648Q5 + 0.65Q6 \\ x_1 = 0.432Q7 + 0.668Q8 + 0.531Q9 + 0.616Q10 + 0.666Q11 + 0.7Q12 + 0.701Q13 \\ +0.542Q14 + 0.7Q15 + 0.633Q16 + 0.628Q17 \\ x_2 = 0.53Q18 + 0.593Q19 + 0.637Q20 + 0.649Q21 + 0.687Q22 + 0.637Q23 \\ +0.575Q24 + 0.557Q25 + 0.566Q26 + 0.578Q27 + 0.561Q28 \end{gathered} \quad (2)$$

As shown in **Table 8**, the regression analysis method was adopted to save each item as a variable, and the regression analysis was carried out according to the components of each item and other items. And the correlation coefficient of the regression model obtained is 0.81 and *R* square is 0.657, indicating a good fitting effect of the model.

The variance test was carried out on the obtained regression equation model, and the value of test statistic *F* was 325.578, and its corresponding test *P*-value was 0.000 < 0.05. Therefore, the null hypothesis should be rejected, and the model was considered reasonable through the variance test model.

Table 8. Regression analysis model summary.

Model	*R*	*R* Square	Adjusted *R* Square	Std.Error of the Estimate
1	0.518a	0.268	0.266	0.98088
2	0.690b	0.476	0.474	0.83096
3	0.810c	0.657	0.655	0.67318

a. Predictors: (Constant), REGR factor score 2 for analysis 1

b. Predictors: (Constant), REGR factor score 2 for analysis 1, REGR factor score 1 for analysis 1

c. Predictors: (Constant), REGR factor score 2 for analysis 1, REGR factor score 1 for analysis 1, REGR factor score 3 for analysis 1

Table 9. Regression analysis results between 6 factors and visitor satisfaction.

Coefficients[a]						
Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
		B	**Std.Error**	**Beta**		
1	(Constant)	5.304	0.043	-	122.711	0.000
	REGR factor score 2 for analysis 1	0.593	0.043	0.518	13.702	0.000
2	(Constant)	5.304	0.037	-	144.850	0.000
	REGR factor score 2 for analysis 1	0.593	0.037	0.518	16.174	0.000
	REGR factor score 1 for analysis 1	0.522	0.037	0.456	14.241	0.000

Table 9. (*Continued*).

Coefficients[a]						
Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
		B	**Std.Error**	**Beta**		
3	(Constant)	5.304	0.030	-	178.800	0.000
	REGR factor score 2 for analysis 1	0.593	0.030	0.518	19.965	0.000
	REGR factor score 1 for analysis 1	0.522	0.030	0.456	17.579	0.000
	REGR factor score 3 for analysis 1	0.487	0.030	0.425	16.405	0.000
a. Dependent variable: Visitor satisfaction						

It can be seen from **Table 9** above, with satisfaction as the dependent variable and each factor and factor as the independent variable, the regression equation obtained by stepwise regression analysis is:

$$y = 0.593x_2 + 0.522x_1 + 0.487x_3 + 5.304 \tag{3}$$

Y represents visitor satisfaction, x_1, x_2, and x_3 represent the extracted common factors 1, 2, and 3. As shown in the above equation: The evaluation value is positively correlated with x_1, x_2, and x_3; the most relevant factor is common factor x_2. The *T*-test values of each coefficient are all of which have passed the *t*-test of coefficient, so the equation is considered to be reasonable.

3.6. Common factors

After re-extracting common factors on the six dimensions, we found that component 1 had the most significant influence on variables from the assessment criteria items 7 to 17. Component 2 had the most significant influence on variables from the assessment criteria items 18 to 28, and component 3 had the most significant influence on the first six items. Finally, by combining the corresponding relations between factors and variables, we renamed each factor comprehensively, as Usability, Acceptability, and Performance.

3.6.1. Usability

According to the ISO definition, usability refers to "the degree of effectiveness, efficiency, and satisfaction with which a specific user uses a product in a specific usage environment to achieve a specific goal." Based on Eason 1984's usability model, we considered three usability aspects: ease of use, task matching, and pleasure of use, influenced by quality of interactions[27]. All three can affect visitor satisfaction[22].

3.6.2. Acceptability

Acceptability refers mainly to whether a design is good enough to meet all the needs and requirements of users and other potential stakeholders. It is often used to measure the acceptability of teaching, law, and healthcare to target users. Acceptability may be represented as a purely economic measure, relating the number of potential users to the target group's quantity.

3.6.3. Performance

Performance covers considerable content and, according to the variance in calculated contribution rates, it also has the most significant impact on tourist satisfaction. We ranked used factor scores, the top five attributes being collaboration, compatibility, constructiveness, intuition, and learnability, all of which could be classified as aspects of the museum's performance as operating system.

4. Results

According to our data, autonomy of systematic efficiency is summarized in the usability module. Because autonomy can also describe adaptability, we redivided autonomy into adaptability dimension. However, technology-enabled dimension and input attributes of human-like interaction belonged to the same module, input still placed among interaction factors due to the differences in attributes' meanings. The Performance module contained six factors, and this module also had the greatest impact on tourist satisfaction.

Figure 1 illustrates the relationship between various dimensions of measuring museum intelligence and visitor satisfaction. As a result, museums can improve the visitor satisfaction by upgrading museum infrastructure and services through key dimensions of museum intelligence, thereby increasing their competitiveness.

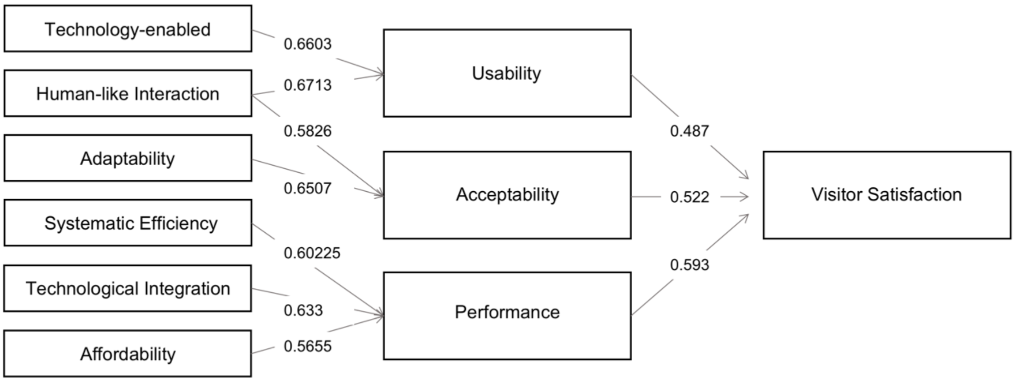

Figure 1. The relationship model of the museum intelligence assessment criteria and visitor satisfaction.

5. Discussion

The development of an evaluation method for smart museums holds significant theoretical and practical implications. From a theoretical perspective, this approach assists scholars and researchers in gaining a deeper understanding of how digital technologies impact cultural institutions and visitor experiences, thereby offering novel research avenues within relevant academic disciplines. From a practical standpoint, this method equips museums with tangible tools and strategies to enhance their digital content, interactivity, and visitor engagement, consequently augmenting the appeal and sustainability of museums.

This paper delves into the concept of an intelligent museum and evaluates museum intelligence as six dimensions: technology-enabled, human-like interaction, systematic efficiency, technological integration, and affordability. Our research offers opportunities and insights for museum designers and curators. Our conceptualization of museum intelligence can inform the conception of intelligent museums. Our results indicate that the six dimensions of museum intelligence can be condensed into three modules, all of which have a positive impact on tourist satisfaction. Designers and engineers can draw ideas from these areas when building intelligent museums.

In a smart museum's infrastructure phase, it is necessary to clearly define and establish a standard and rigorous method to evaluate its intelligence. Our intelligent assessment system and intelligence calculation formula for museums can exactly meet this need. However, just working out a museum's intelligence score is of little use except with museums' government ratings. It is necessary to evaluate museums' intellectualization, especially to explore its influence on visitors' satisfaction, which is of great significance to establish evaluation systems and construction of museums.

Due to the infancy of the smart museum, not only visitors but also many professionals have doubts or even a limited understanding of museums' intellectual development. As a result, some options were not fully understood during the questionnaire survey. Therefore, our results are mainly for museums' intelligent development services, and further research is needed.

A significant part of our future work should focus on overcoming these limitations to provide a more natural and holistic system for assessing museums' intellectualization. Therefore, the following work should be carried out from the following three aspects: 1) The first is to verify the validity and reliability of the museum's intelligent evaluation model extensively and test the universality of the intelligent formula. We obtain the relationship model between museum intelligence and user satisfaction utilizing exploratory factor analysis. However, it is unclear whether it is accurate or not, so it is necessary to conduct further investigation of users and experts. Confirmatory factor analysis can be used to test whether the relationship between each factor and tourist satisfaction conforms to the theoretical relationship in the model; 2) The second aspect is to expand and deepen the understanding of museum intelligence. Although this study has delved into the concept of museum intelligence and its dimensions, there is still room for further exploration. For example, how does museum intelligence affect visitor behavior and experience? What are the specific ways and mechanisms? This requires more in-depth research and case studies to enhance our understanding of museum intelligence. In addition, we can also explore new technologies and methods to help museums improve their intelligence level continuously; 3) The third aspect is to examine the marginal impact of intelligence level on tourist satisfaction. Based on current research findings, the six factors that constitute the measurement standard of museum intelligence are positively correlated with user satisfaction. This correlation indicates that as the level of museum intelligence increases, user satisfaction also increases. However, as the concept of a smart museum is still in its early stages of development, both visitors and some professionals lack a clear understanding of it. Therefore, the next step is to enhance subjects' understanding of what an intelligent museum is through prototype design and experiments, then compare a traditional museum to an experimental smart museum to further investigate the relationship between the level of intelligence and tourist satisfaction. Finally, the evaluation system for intelligent museums should be standardized and perfected.

Author contributions

Conceptualization, SL and JG; methodology, SL; software, SL; validation, SL; formal analysis, SL; investigation, SL; resources, SL; data curation, SL; writing—original draft preparation, SL; writing—review and editing, JG; visualization, JG; funding acquisition, SL and JG. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

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