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User Perceptions in the Evaluation and Design of Smart Libraries

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Abstract

Smart libraries represent an important integration of digital and intelligent technologies into public cultural spaces and have substantial potential to meet the public's growing demand for digital cultural services. However, how digital systems, service processes, and spatial environments jointly shape user evaluations and usage intention remains poorly understood. To address this gap, we integrated the information systems success model (ISSM) with the technology acceptance model (TAM) to develop a user-perception framework comprising system quality, information quality, service quality, and environmental quality. Survey data from 352 users with prior experience of smart libraries were analysed using partial least squares structural equation modelling. The integrated model showed good explanatory power for user satisfaction, attitude towards use, and usage intention in smart libraries. System quality and information quality were positively associated with perceived ease of use, perceived usefulness and user satisfaction, with information quality showing relatively larger path coefficients for perceived ease of use and perceived usefulness. Service quality and environmental quality were positively associated with perceived usefulness and user satisfaction but showed no significant association with perceived ease of use. Perceived usefulness, attitude towards use, and user satisfaction were each positively associated with usage intention, whereas perceived ease of use did not directly predict attitude towards use. These findings indicate that user evaluations of smart libraries are shaped not by technological ease of use alone, but by the combined effects of digital facilities, information organisation, service touchpoints, and the spatial environment. On the basis of these findings, we propose four design strategies: optimising smart facilities and interactive interfaces; coordinating information classification with wayfinding systems; integrating service nodes with digital service scenarios; and improving functional zoning and indoor environmental quality. These strategies provide an evidence base for the spatial design and service-environment renewal of smart libraries.

Keywords: smart library; usage intention; information system success model; technology acceptance model

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1. Introduction

As a vital hub for knowledge dissemination and cultural education, libraries play a fundamental role in information services and the development of social culture. Urban public cultural service facilities are increasingly undergoing digital transformation and

intelligent upgrading amid the fast development of digital networks and artificial intelligence technologies. Against this backdrop, traditional libraries are increasingly integrating digital technologies and intelligent systems, evolving toward the development stage of smart libraries [1]. In 2021, the 14th Five-Year Development Plan (2021–2025) of the Library Society of China emphasised promoting the concept of intelligent transformation across libraries of all levels and types, and advancing the construction of smart library systems. Meanwhile, the library system, as an essential institution for information and knowledge services, has undergone profound transformation. Many urban libraries are actively exploring digital integration pathways to build new types of public reading spaces characterised by openness, interactivity, and intelligence. Against this trend, an increasing number of small urban libraries are seeking transformation into smart libraries, gradually becoming vital public cultural service providers within urban communities [2]. As a new type of cultural venue integrating digital technology with traditional reading spaces, smart libraries, characterised by intelligent devices, self-service operations, and online–offline interaction, offer residents more convenient and diverse reading experiences and public services.

Existing research on smart libraries mainly falls into two categories: the application of information technologies and the study of user behaviours. For instance, Xu and Shang [3] proposed a blockchain-based service architecture for smart libraries, while Zhou [4] developed a framework integrating the Internet of Things and Software-Defined Networking. In terms of user behaviour, Shahzad et al. [5] established an empirical framework for leveraging artificial intelligence tools to enhance learning experiences and promote sustainable smart library services in academic contexts, and Liu [6] proposed a personalised document recommendation method based on user behaviour perception technology. In recent years, growing attention in library and information science has been directed toward the view that future smart library research should place greater emphasis on user experience and satisfaction with intelligent services [7,8]. Research on smart libraries in China began relatively late and has primarily focused on construction pathways, development models, and technological implementation [9–11]. As a public-oriented information service space, the core value of smart libraries lies in meeting diverse user needs; however, empirical studies from the user perspective remain limited. In particular, systematic and structured theoretical models and empirical validations are still lacking regarding users' behavioural patterns, perceptual experiences, and usage intentions [12]. Moreover, previous studies have typically conceptualised smart libraries as digital platforms or information service systems, focusing primarily on technological functions, information resources, and service performance. Far less attention has been paid to how smart facilities are embedded within physical spaces and how digital systems and the built environment jointly shape the user experience. Previous studies have revealed that, despite the widespread construction and promotion of smart libraries across China, their practical operation often suffers from low utilisation rates, limited public awareness, monotonous functional experiences, unsatisfactory service quality, and insufficient levels of intelligence [12]. These findings point to a persistent mismatch in smart library development, where infrastructure advances more quickly than user experience. Therefore, to facilitate the optimisation and upgrading of smart libraries, it is essential to return to the user perspective, gain a deeper understanding of users' perceptual experiences and behavioural responses during use, and systematically examine their usage intentions, satisfaction, and influencing mechanisms. This approach provides both a theoretical foundation for optimising service systems and reconfiguring smart library spaces, as well as empirical support for administrative decision making and policy formulation.

TAM is a well-established theoretical framework that has been extensively used to understand how users come to accept and adopt new technologies [13]. At the core of

the model is the idea that how useful and easy a technology is perceived to be affects both users' intention to adopt it and their subsequent usage [14]. A major strength of TAM is that it offers a systematic framework for analysing how external variables affect system usage behaviour [15]. The ISSM is widely employed to evaluate user responses to information systems. ISSM offers a multidimensional and integrative perspective, enabling researchers to systematically analyse how different quality dimensions of an information system affect user satisfaction and behavioural outcomes [16]. In recent years, TAM has been increasingly applied to studies of user behaviour in library information services and digital reading technologies, yielding a series of significant findings [17–19]. Meanwhile, researchers in digital library studies have begun to recognise the potential of ISSM in library and information science research [20–22]. Therefore, this study integrates the ISSM and TAM within a unified theoretical framework and employs structural equation modelling to examine the structural relationships among multiple variables, thereby elucidating the mechanisms and key factors underlying users' intention to use smart libraries. This study extends the application of the ISSM and TAM to physical public cultural spaces by incorporating indoor environmental factors into the analysis of smart library use. By further revealing the interplay between digital systems and the built environment, it provides empirical evidence to inform the planning, spatial renewal, and operational optimisation of smart libraries.

2. Conceptual Framework and Hypothesis Development

2.1. Theoretical Foundations

2.1.1. Information Systems Success Model

In 1992, DeLone and McLean developed the ISSM, which has since become a widely adopted framework for evaluating information systems success. In 2003, the model was refined by the same authors, who added service quality as an additional dimension. The ISSM has been widely used and supported by empirical evidence across a variety of contexts and fields. For example, Yakubu and Dasuki [23] investigated the determinants of students' adoption of e-learning systems. Iqbal and Rafiq [24] investigated determinants of successful user experiences in digital library environments. Al-Shargabi et al. [25] confirmed significant associations between ISSM constructs and the adoption of e-learning systems. As integrated public service platforms combining information services, reading experiences, and intelligent interaction, smart urban libraries encompass information access, resource use, interactive experience, and cultural engagement. These features align with the ISSM dimensions of content provision, system support, and service feedback, making the model suitable for evaluating their effectiveness.

Moreover, the ISSM has been applied primarily to the evaluation of digital platforms and information systems [26,27]. Smart libraries, however, are not purely digital service platforms operating through online systems; rather, they represent hybrid digital–physical service environments in which smart devices, digital resources, and physical spaces are closely integrated [10]. When using smart-library services, users interact not only with information systems but also with physical environmental conditions, including spatial layout, facility configuration, lighting, and the acoustic environment. Accordingly, explaining users' evaluations of smart libraries solely in terms of system, information, and service quality may not fully capture their experiences within the physical setting in which these services are used. Environment–behaviour research regards the built environment not as a passive backdrop for human activity, but as an active component of person–environment interaction that can shape users' cognitive evaluations, spatial experiences, and behavioural responses. Research on built environments further suggests that interactions between occupants and building systems are jointly shaped by environmental conditions, individual

perceptions, and behavioural processes [28], with environmental influences on behaviour often operating through processes of perception and evaluation [29]. In smart libraries, environmental quality does not directly alter the operational logic of digital systems. Instead, by strengthening the capacity of the physical environment to support user activities, it may influence perceptions of service convenience, functional value, and overall experience, thereby shaping technology-acceptance behaviour. Previous studies across libraries [30,31], hotels [32,33], and learning environments [34,35] have likewise shown that the quality of physical space is an important component of environmental attractiveness and users' intention to use such spaces and services. On this basis, we argue that user acceptance in smart libraries, as a representative form of service environment integrating digital technologies with the built environment, cannot be explained solely by information-system attributes. We therefore extend the ISSM by incorporating environmental quality, thereby bringing physical-environmental factors into the evaluation of digital services and broadening the explanatory scope of the model to hybrid digital–physical environments.

2.1.2. Technology Acceptance Model

Developed by Davis et al. in 1989 [36], TAM was derived from the Theory of Reasoned Action. It provides a well-developed theoretical basis for analysing how people come to accept and use new information technologies [36]. The model identifies two key determinants of users' acceptance: perceived usefulness (PU) and perceived ease of use (PEOU). PU denotes the perceived ability of a new technology to improve work efficiency and quality, whereas PEOU captures users' perceptions of how effortless the technology is to operate. Users' PEOU enhances PU, and these perceptions collectively influence usage attitudes, which subsequently translate into behavioural intentions. TAM has demonstrated broad applicability across diverse fields, including Internet services [37], information systems [38], and e-learning [39].

To enhance the explanatory power of TAM, scholars from various disciplines have extended the model by incorporating additional variables or integrating it with other theoretical frameworks [40]. These extended versions of TAM have been widely recognised and empirically validated. An example is provided by Wei et al. [41], who incorporated TAM and the TPB to explain the uptake of BIM in Chinese green building projects. Attuquayefio et al. [42] integrated ISSM, Self-Determination Theory, and TAM2 to propose and test a comprehensive model investigating student satisfaction with online learning systems in tertiary education contexts within developing countries. In parallel, several researchers have introduced TAM into studies on learning and reading environments [43]. Wang et al. [44] applied TAM and Task–Technology Fit Theory to explore university students' continued learning intention in novel electronic learning spaces. Al-Adwan A. S. et al. [45] employed an extended TAM framework to analyse the antecedents of students' behavioural intention toward metaverse-based learning platforms.

2.2. Model Development and Hypotheses Formulation

2.2.1. Model Development

Previous studies have shown that combining ISSM and TAM offers a solid basis for understanding the mechanisms behind users' behavioural intentions [46,47]. On this basis, the current research develops a research model of users' intention to use smart libraries by integrating ISSM and TAM, while incorporating "environmental quality" as an additional dimension to capture the spatial characteristics of smart libraries (Figure 1).

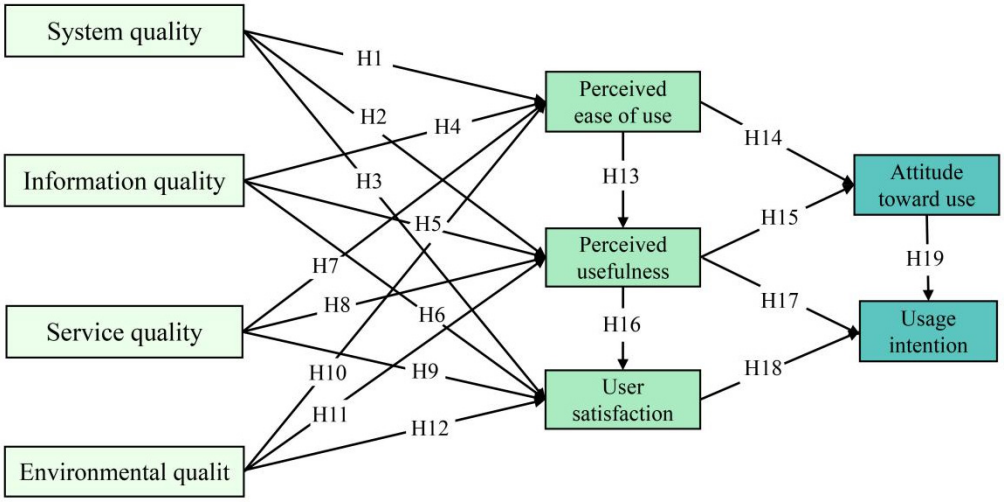


Figure 1. Conceptual framework of the study.

2.2.2. Hypotheses Development

(1) System quality

System quality (SYQ) describes the extent to which an information system demonstrates desirable technical and functional attributes, including flexibility, reliability, ease of operation, and response speed. In this study, SYQ denotes the technical performance of smart libraries, encompassing system stability, interface usability, and responsiveness during user interaction. The positive effects of SYQ on PEOU and PU have been well established across multiple domains, including library services [48], art exhibition platforms [49], and electronic learning platforms [50]. Misra et al. [51] found that SYQ significantly influences users' continuance intention toward digital library systems. Similarly, Shahzad A. et al. [52] also provided evidence that higher SYQ was associated with greater e-learning system use and stronger user satisfaction (US). On the basis of the above reasoning, the expected relationships are outlined below.

H1. *SYQ is assumed to contribute positively to PEOU.*

H2. *SYQ is assumed to contribute positively to PU.*

H3. *SYQ is assumed to contribute positively to US.*

(2) Information quality

Information quality (IQ) is characterised by completeness, accuracy, relevance, timeliness, and authority [53]. In this study, IQ refers to the comprehensiveness, accuracy, and practical value of information available in smart libraries. High-quality information contributes to stronger trust in new technologies while increasing perceived usefulness [54], thereby promoting users' intention to adopt the system [55]. IQ is frequently considered a central element shaping users' satisfaction and their intention to adopt emerging technologies [56]. For instance, Alyoussef [20] found that IQ is positively correlated with PEOU and PU. Similarly, Alzahrani et al. [57] found that IQ was an important predictor of Malaysian users' satisfaction and behavioural intention toward digital library platforms. On the basis of the above reasoning, the expected relationships are outlined below.

H4. *IQ is assumed to contribute positively to PEOU.*

H5. *IQ is assumed to contribute positively to PU.*

H6. *IQ is assumed to contribute positively to US.*

(3) Service quality

Service quality (SEQ) reflects users' perceptions of the technical and interpersonal support provided during their interaction with an information system, including staff competence, service attitude, and responsiveness. In this study, SEQ represents the reliability of service operations and the quality of assistance provided by on-site or remote staff during users' interaction with smart urban libraries. Numerous studies have demonstrated that SEQ positively influences users' perceptions and satisfaction. For instance, Al-Adwan et al. [50] reported that SEQ positively influenced PU in the context of electronic learning platforms. Wu et al. [58] reported a positive relationship between SEQ and PEOU among users of university open course platforms. Parasuraman et al. [59] confirmed that higher perceived SEQ leads to greater user satisfaction. Wang and Shieh [60] further demonstrated that library SEQ significantly affects user satisfaction. Iqbal et al. [61] found that SEQ may enhance users' satisfaction with digital library platforms. On the basis of the above reasoning, the expected relationships are outlined below.

H7. *SEQ is assumed to contribute positively to PEOU.*

H8. *SEQ is assumed to contribute positively to PU.*

H9. *SEQ is assumed to contribute positively to US.*

(4) Environmental quality

Environmental quality (EQ) refers to the physical conditions and spatial atmosphere provided by a facility, including aspects such as spatial layout, lighting, noise control, and visual comfort. In this study, EQ represents users' perceived rationality of spatial layout, clarity of wayfinding signage, and environmental comfort, encompassing both physical and sensory experience dimensions in the context of smart urban libraries. A substantial body of research has indicated that EQ positively affects users' perceptions and satisfaction. For example, well-designed spatial arrangements, appropriate lighting conditions, and a pleasant atmosphere have been found to enhance users' overall experience and sense of satisfaction [62,63]. Xu and Hu [10] and He and Mao [12] found that EQ strongly influences satisfaction with smart libraries. On the basis of the above reasoning, the expected relationships are outlined below.

H10. *EQ is assumed to contribute positively to PEOU.*

H11. *EQ is assumed to contribute positively to PU.*

H12. *EQ is assumed to contribute positively to US.*

(5) Perceived ease of use

PEOU reflects users' perception that a system can be operated easily and with little effort. For the purposes of this research, PEOU reflects users' belief that the smart library system can be used easily and with minimal effort. Prior research has shown that PEOU positively affects PU [20,64,65]. Furthermore, PEOU has been shown to directly affect users' behavioural intention and attitude toward using new technologies such as metaverse-based learning platforms [45], digital libraries [66], and e-learning systems [67]. On the basis of the above reasoning, the expected relationships are outlined below.

H13. *PEOU is assumed to contribute positively to PU.*

H14. *PEOU is assumed to contribute positively to ATU.*

(6) Perceived usefulness

PU refers to users' perception that a system can enhance their performance in work-related tasks. For this research, PU refers to users' perception that smart libraries help improve efficiency in reading, learning, and information acquisition. A substantial body of empirical research has confirmed the effect of PU on user satisfaction and intention to use. Hong et al. [68], for instance, reported that both PU and PEOU had direct effects on users' intention to adopt digital library systems. Riady et al. [66] reported that PU was the strongest predictor of users' adoption intention toward digital libraries. Evidence from Atukunda et al. [69] suggests that users who perceived e-learning systems as more useful also tended to report higher satisfaction. Foroughi et al. [70] reported that PU significantly affects users' attitudes toward adopting artificial intelligence technologies. On the basis of the above reasoning, the expected relationships are outlined below.

H15. *PU is assumed to contribute positively to ATU.*

H16. *PU is assumed to contribute positively to US.*

H17. *PU is assumed to contribute positively to UI.*

(7) User satisfaction

User satisfaction (US) reflects the affective response individuals form after interacting with an information system or technological service [71]. It is commonly regarded as an important signal of continued usage and a factor that shapes the likelihood of ongoing use. In this study, US denotes users' emotional responses during their interaction with smart urban libraries, where positive experiences motivate continued use to fulfil daily reading and information needs. Prior studies have consistently confirmed the relationship and underlying mechanisms between US and usage intention. For instance, Nascimento et al. [72] revealed that when deciding whether to continue using smartwatches, users primarily consider their satisfaction with the device. Riady et al. [21] identified US as the most influential predictor of users' intention to use digital libraries. Cidral et al. [73] further demonstrated that US is a significant driver of e-learning system usage. On the basis of the above reasoning, the expected relationships are outlined below.

H18. *US is assumed to contribute positively to UI.*

(8) Attitude toward use

Attitude toward use (ATU) can be understood as users' overall positive orientation and degree of interest in adopting a given system or technology. In this study, ATU is defined as users' emotional and cognitive approval of their experience while using smart libraries. Previous research suggests that ATU contributes positively to users' behavioural intention toward system adoption [74,75]. On the basis of the above reasoning, the expected relationships are outlined below.

H19. *ATU positively influences UI.*

(9) Usage intention

Usage intention (UI) is defined as an individual's overall behavioural tendency towards a system or service after having experienced it. In this study, UI serves as the dependent variable and does not refer to users' initial intention to adopt urban smart libraries. Rather, it captures the broader behavioural tendency formed on the basis of prior use experience, encompassing preferences for personal use, intentions for future use, and the social tendency to recommend the service to others.

2.3. Research Framework

First, this study integrates the ISSM and TAM to develop a user acceptance model for smart libraries and formulate the corresponding hypotheses. Second, the proposed model is tested using partial least squares structural equation modelling (PLS-SEM) and survey data from 352 respondents with prior experience of using smart libraries. Finally, the empirical findings are translated into evidence-based recommendations for the interior environmental design of smart libraries, and the study's limitations and directions for future research are discussed.

3. Data and Methods

3.1. Questionnaire Design

As this study relied on cross-sectional self-reported survey data, the possibility of common method bias cannot be entirely excluded. To mitigate this risk, several procedural measures were incorporated into the questionnaire design and administration. These included context-specific adaptation of established scales, refinement of survey items through expert review and user pretesting, anonymous data collection, and the exclusion of invalid or anomalous responses to improve measurement quality.

3.1.1. Measurement Item Sources and Construct Definition

The questionnaire comprised two sections. The first collected demographic information, including gender, age, educational attainment, and frequency of smart-library use. The second assessed factors associated with users' use of smart libraries. Scale development followed the theoretical distinctions among quality dimensions established in the ISSM. According to the DeLone and McLean framework, system quality primarily reflects the performance characteristics of an information system, including reliability, operability, and responsiveness; information quality concerns the accuracy, completeness, and effective organisation of system outputs; and service quality captures users' experiences of obtaining service support and assistance. Unlike conventional digital information systems, smart libraries integrate intelligent facilities, digital resources, service systems, and physical environments. Consequently, some indicators may, in their observable form, appear to span more than one quality dimension. To maintain theoretical consistency within the measurement model, indicators were assigned to constructs not according to the physical medium through which they were manifested, but according to their primary role in shaping users' quality evaluations. Where a spatial element primarily supported information recognition, resource access, or interaction with digital services, it was treated as reflecting the spatial realisation of information-system or service functions. By contrast, elements that primarily shaped users' overall evaluations of spatial comfort, environmental atmosphere, or suitability for activities were classified as environmental quality. More specifically, factors primarily affecting users' judgements of system performance, interaction convenience, and support for task completion were assigned to system quality; those primarily affecting the efficiency of information access, recognition, and use were assigned to information quality; and those reflecting the accessibility of assistance and service support were assigned to service quality. Environmental quality, introduced as a contextual extension of the ISSM,

was operationalised with reference to the spatial characteristics of smart libraries and relevant research on environmental experience, including spatial organisation, environmental comfort, and visual experience.

During item development, the measures were divided into two categories according to their source. The first comprised adapted items derived from established scales and semantically adjusted to the smart-library context; the second comprised newly developed items designed to capture the integration of digital technologies with the physical environment in smart libraries. This approach was intended to preserve the conceptual integrity of the constructs while ensuring that the measures captured users' actual experiences in smart-library settings.

3.1.2. Expert Review and Item Refinement

After the initial item pool was developed, five experts from relevant fields were invited to assess the content validity of the questionnaire. Experts were selected according to three criteria: (1) their research or professional practice was related to smart-library development, information-system applications, public-space design or user-experience research; (2) they had relevant academic publications or practical project experience; and (3) they were able to evaluate the interrelationships among digital systems, user services, and spatial environments from an interdisciplinary perspective.

The experts evaluated the initial items on three aspects: whether each item accurately reflected its intended theoretical construct, whether its content was necessary and representative, and whether conceptual redundancy or overlap existed across items. The initial questionnaire comprised 32 measurement items. Based on the expert feedback, several items were revised or removed, resulting in a final set of 30 items. The two deleted items were removed primarily for two reasons. First, some items substantially overlapped with existing indicators and therefore provided little additional measurement information. For example, the information-quality item stating that "information resources meet users' diverse needs" overlapped substantially with the existing item measuring resource richness and was therefore removed. Second, some items had limited explanatory value in the specific context of smart-library use and did not contribute substantively beyond the existing measures. For example, the environmental-quality item stating that "the overall spatial environment reflects intelligent and modern characteristics" captured users' general impressions of the smart library but did not meaningfully extend the measurement domain of environmental quality and was therefore removed. The resulting formal scale therefore contained 30 measurement items.

3.1.3. Questionnaire Pretesting and Scale Refinement

Following the expert review, a pretest was conducted with 10 smart-library users to assess questionnaire comprehensibility, item clarity, and response burden. After completing the questionnaire, participants provided feedback on item comprehension and any difficulties encountered during completion. The pretest indicated that all items were readily understood, with no evident ambiguity or problematic redundancy identified. Questionnaire completion time recorded during the pretest was used solely to assess questionnaire length and ease of completion and was not used as a criterion for determining valid responses in the formal survey. Before the formal analyses, data-quality screening was conducted to assess questionnaire completeness, response consistency, and anomalous response patterns.

As the formal survey was administered in Chinese, measurement items adapted from English-language sources were translated using a translation–back-translation procedure to ensure semantic equivalence. First, a researcher proficient in English-language academic

literature and familiar with information-systems and design research translated the original English items into Chinese. A second independent researcher then back-translated the Chinese version into English. The research team compared the original and back-translated English versions and resolved any semantic discrepancies through discussion and revision to ensure conceptual equivalence with the original scales. To reduce potential acquiescence bias, one negatively worded item was included: "I am unwilling to recommend the smart library to others." This item was reverse-coded before analysis so that all items were scored in the same direction, with higher scores indicating stronger usage intention. Although recommendation intention is conceptually distinct from personal usage intention, previous studies of technology and service acceptance suggest that users' willingness to recommend a service can reflect a positive behavioural response formed after use [41]. Accordingly, in this study, recommendation intention is treated as part of the broader behavioural tendency that develops after users have experienced a smart library and is therefore included as a reflective indicator of the latent construct of usage intention. To further assess whether the assignment of this indicator affects the substantive conclusions, we conducted a robustness check during the structural-model analysis by re-estimating the model after removing the item, "I am unwilling to recommend the smart library to others." The final measurement scale is presented in Table 1. Previous empirical studies have suggested that Likert scales with a greater number of response categories, such as seven-point scales, may provide better reliability and validity than scales with fewer response options, such as four- or five-point scales [76]. Accordingly, all observed variables in this study were measured using a seven-point Likert scale.

Table 1. Measurement items and sources.

Variable	Measurement Item	Questionnaire Item	Source	Development Method
System quality	SYQ1	The smart library interface is clearly organised and aesthetically pleasing, with simple and intuitive operation flows that enable efficient task completion through smooth interaction.	[2,62,77,78]	Adapted
	SYQ2	Smart facilities, such as self-service kiosks and interactive displays, are appropriately located and provide sufficient operational space for convenient access and use.		
	SYQ3	The smart facilities operate reliably, with stable network connectivity and timely system responses.		
Information quality	IQ1	The smart library offers a wide range of online learning resources, including e-books, audiobooks, and video courses, effectively meeting diverse reading and learning needs.	[8,79–83]	Adapted
	IQ2	The digital resources of the smart library are regularly updated to reflect current social issues and emerging developments in various fields.		
	IQ3	Resource classification, interface hierarchy and spatial wayfinding are organised in a clear and consistent manner.		
	IQ4	Signage, displays, and digital interfaces use clear and consistent typography, graphics, colour schemes, and layouts, making information easy to identify.		
Service quality	SEQ1	Service facilities, such as self-service checkout and return kiosks and identity-verification devices, are secure, reliable and conveniently located.	[8,84–89]	Adapted
	SEQ2	Service desks, assistance points, and technical-support stations are clearly visible and enable users to obtain help easily when needed.		
	SEQ3	Digital and virtual service facilities are adequately provided and well integrated with reading, learning, and social-interaction spaces.		

Table 1. *Cont.*

Variable	Measurement Item	Questionnaire Item	Source	Development Method
Environmental quality	EQ1	Lighting, acoustic conditions, temperature, and air circulation create a comfortable environment for reading and learning.	[62,90]	Newly developed
	EQ2	The functional zoning, circulation routes, and arrangement of furniture and facilities are appropriately planned.		
	EQ3	Interior colours, materials, furniture, and decorative elements are visually coordinated and create an appropriate spatial atmosphere.		
	EQ4	Interior decorative and cultural elements reflect the distinctive identity of the library and are well coordinated with its smart facilities and overall spatial environment.		
Perceived ease of use	PEOU1	I find the operation of the smart library simple and convenient, including functions such as reservation, borrowing, and information retrieval.	[36,91,92]	Adapted
	PEOU2	I can easily learn and understand how to use the smart library and its operating procedures.		
	PEOU3	I have no difficulty finding the services or resources I need in the smart library.		
	PEOU4	Even without assistance, I am able to complete all operations in the smart library smoothly.		
Perceived usefulness	PU1	Using the smart library improves my reading efficiency.	[36,92,93]	Adapted
	PU2	The smart library enables me to acquire and utilise knowledge resources more efficiently.		
	PU3	Using the smart library is beneficial for broadening my access to information and knowledge.		
User satisfaction	US1	Using the smart library gives me a sense of enjoyment.	[8,94]	Adapted
	US2	Overall, I feel highly satisfied when using the smart library.		
	US3	My needs are fully met when using the smart library.		
Attitude toward use	ATU1	Using the smart library is a wise choice.	[95–97]	Adapted
	ATU2	I have a positive impression of the smart library.		
	ATU3	I hold a positive attitude toward using the smart library.		
Usage intention	UI1	Compared with traditional libraries, I prefer to use the smart library for reading.	[8]	Adapted
	UI2	I am unwilling to recommend the smart library to others (reverse-coded).		
	UI3	If there is a smart library nearby, I am willing to use it.		

3.2. Data Collection

This study aimed to examine the factors influencing users' intention to use smart libraries. The study was conducted in Jiaxing, Zhejiang Province, China, one of the regions in which smart reading spaces were introduced relatively early. On-site questionnaire surveys were conducted at 22 smart libraries in Jiaxing between 16 July and 27 September 2025. Given the strongly context-dependent nature of smart-library services and the higher concentration of user visits at weekends, data collection was conducted primarily on weekends to facilitate the recruitment of participants with direct experience of using smart libraries. Given the place-based nature of smart-library use, data were collected using an on-site intercept sampling approach. During data collection, eligible users were approached in active-use areas, including library entrances, self-service zones, and major reading spaces. Participants were eligible if they (1) had prior experience using a smart library, (2) were able to complete the questionnaire independently, and (3) voluntarily agreed to participate and to the anonymous use of their survey data. To reduce potential bias arising from the

concentration of respondents at a single site, data were collected across all 22 smart libraries, and the distribution of valid responses by location was recorded (Table 2, Figure 2).

Table 2. Distribution of collected questionnaires across survey sites.

Smart Library	Number of Valid Responses	Smart Library	Number of Valid Responses
Smart Reading Room (CIFI Guangyaocheng Branch)	15	Smart Reading Room (Furun Road Branch)	18
Shancheng Smart Reading Room	14	Smart Reading Room (Changshui Subdistrict Library Branch)	14
Yunshang Smart Reading Room	13	Smart Reading Room (Yingcai Apartment Branch)	18
Smart Reading Room (Greentown Liu'an Hefeng Phase II Branch)	18	Smart Reading Room (Fengnan Street Branch)	17
Smart Reading Room (Chengbei Road Branch)	15	Smart Reading Room (Yuxiandai Street Branch)	20
Smart Reading Room (Shaonian Road Branch)	18	Smart Reading Room (Daqiao North Road Branch)	15
Smart Reading Room (Yunhai Road Branch)	17	Smart Reading Room (Yashan Middle Road Branch)	15
Smart Reading Room (Vanke Huancuiyuan Branch)	14	Hanfang Smart Reading Room	17
Smart Reading Room (Jiaxing Library, Xincheng Subdistrict)	15	Jing'an Smart Reading Room	17
Smart Reading Room (Taifu World City Branch)	13	Jing'an Smart Reading Room (Haining People's Square Branch)	17
Total	352		

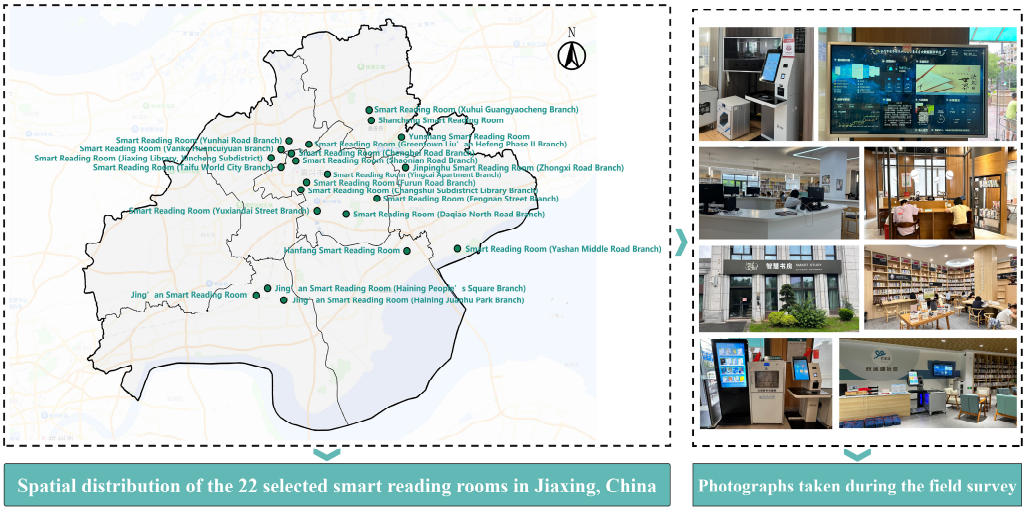


Figure 2. Current development of smart reading rooms in Jiaxing.

Depending on the fieldwork schedule, data collection was conducted for approximately 5–6 h per day. To acknowledge participants' time and encourage participation, respondents who completed the questionnaire received a compensation of RMB 20. Before formal data collection, the study protocol was reviewed and approved by the Medical Ethics Committee of Jiangnan University (approval no. JNU202506RB067). Before participation, respondents were informed of the study purpose, the anonymous handling of their data, and their right to participate voluntarily and withdraw at any time. The survey was administered only after informed consent had been obtained [98]. To ensure

data quality, all returned questionnaires were screened for validity before formal analysis. First, questionnaires with incomplete responses were excluded. Response patterns were then examined for indicators of low-quality data, including invariant responding, clearly patterned responses, and duplicate submissions. Questionnaires with unusually short completion times were additionally reviewed manually, with validity assessed in conjunction with response consistency and the completeness of demographic information. Only questionnaires that met the predefined quality criteria for completion time, response patterns, and item completeness were retained for subsequent analyses. A total of 360 questionnaires were distributed, of which 352 valid responses were retained for analysis.

Because respondents were drawn from 22 different smart libraries, their evaluations could potentially be influenced by site-specific factors such as spatial conditions, smart-facility configurations, and service models. We therefore examined whether the data exhibited a meaningful nested structure. Individual users were treated as the level-1 units of analysis, with smart libraries treated as the level-2 clustering units. Intraclass correlation coefficients (ICCs) were calculated for each latent construct to assess the extent of clustering attributable to survey site. The ICCs were 0.006 for SYQ, 0.026 for IQ, 0.017 for SEQ, and 0.001 for EQ. The corresponding values for PEOU, PU, US, ATU, and UI were 0.046, 0.008, −0.008, −0.004, and −0.020, respectively. These results indicate that between-library variance was minimal and that variability in the constructs arose predominantly at the individual-user level rather than from systematic differences across libraries. Overall, no substantial library-level clustering effect was evident. Accordingly, subsequent structural-model analyses at the individual level were considered appropriate.

3.3. Sample Characteristics

Among the valid responses, male participants (52.3%) slightly outnumbered female participants (47.7%). Most respondents were under the age of 30, accounting for 73.9% of the sample. In addition, most participants held a bachelor's degree or higher (67.9%), and over 90% reported visiting smart libraries at least five times per year (Table 3).

Table 3. Sample demographic characteristics.

Characteristic	Category	Number	Percentage (%)
Gender	Male	184	52.3
	Female	168	47.7
Age	20 years old or below	36	10.2
	21–30 years old	224	63.7
	31–40 years old	56	15.9
	Above 40 years old	36	10.2
Education Level	High school or below/Vocational school	48	13.6
	Junior college	65	18.5
	Bachelor's degree	170	48.3
	Master's degree or above	69	19.6
Annual Visit Frequency	More than 7 times	179	50.8
	6 times	86	24.4
	5 times	66	18.8
	Fewer than 5 times	21	6.0

4. Results and Analysis

PLS-SEM was used to test the proposed hypotheses. Structural equation modelling can broadly be implemented using covariance-based structural equation modelling (CB-SEM) or variance-based PLS-SEM. Although both approaches can be used to analyse structural

relationships among latent constructs, they differ in their primary objectives and analytical emphasis. CB-SEM is primarily suited to confirmatory testing of established theoretical models, with an emphasis on reproducing the observed covariance matrix and assessing overall model fit. By contrast, PLS-SEM places greater emphasis on explaining relationships among latent constructs and predicting endogenous variables, making it particularly suitable for theory extension, complex models, and prediction-oriented research.

The choice of PLS-SEM was guided by the study objectives, model characteristics, and analytical requirements. First, this study does not simply replicate or validate the ISSM or the TAM. Instead, it extends these established frameworks by incorporating environmental quality to develop an integrated user-acceptance model tailored to the smart-library context. The analysis therefore focuses not only on whether established theoretical relationships are supported, but also on how different quality dimensions jointly contribute to user satisfaction, attitude towards use, and usage intention. Second, the model includes multiple exogenous quality dimensions—system quality, information quality, service quality, and environmental quality—which influence attitude towards use and usage intention through perceived ease of use, perceived usefulness, and user satisfaction. This structure captures the multifactorial nature of user acceptance in smart libraries and places particular emphasis on evaluating the explanatory contributions of different antecedents to key endogenous constructs, rather than focusing solely on overall model fit. PLS-SEM is therefore well aligned with the study objective of identifying influential factors while maximising the explained variance of endogenous constructs and assessing users' behavioural intentions. In addition, the data were obtained from actual smart-library users, and the focal outcomes, such as user satisfaction and usage intention, reflect behavioural tendencies emerging from users' service experiences. Compared with an approach centred primarily on global model fit, PLS-SEM enables the explanatory contribution of different quality dimensions to be assessed through path coefficients, coefficients of determination (R^2), effect sizes (f^2), and predictive-performance measures. PLS-SEM therefore provides an appropriate analytical framework for explaining and predicting user acceptance in smart libraries.

To ensure the reliability of the structural-model estimates, the adequacy of the sample size was further assessed. Given the use of PLS-SEM, the required sample size was determined with reference to the complexity of the structural model and the maximum number of predictors associated with any endogenous construct. In the proposed model, PU and US each have five predictors, representing the highest predictive complexity among the endogenous constructs. Accordingly, five predictors were used as the basis for estimating the minimum required sample size. An a priori power analysis was conducted using G*Power 3.1, with the significance level set at $\alpha = 0.05$, statistical power at 0.80, and the anticipated effect size at $f^2 = 0.15$, corresponding to a medium effect. The analysis indicated a minimum required sample size of 92. The final sample of 352 valid responses therefore substantially exceeded this minimum requirement, providing sufficient statistical power for structural-model estimation and hypothesis testing.

4.1. Assessment of Common Method Bias

Common method bias was assessed using Harman's single-factor test and a full-collinearity VIF assessment. For Harman's single-factor test, all measurement items were entered simultaneously into an exploratory factor analysis, and factors were extracted using an unrotated principal component procedure. Six factors with eigenvalues greater than 1 were extracted, accounting for 72.614% of the total variance. The first factor had an eigenvalue of 11.924 and explained 39.746% of the total variance, indicating that no single factor accounted for the majority of the variance. Common method bias was further examined using a full-collinearity assessment. The VIF values for all latent constructs

ranged from 1.379 to 2.460, all below the recommended threshold of 5. Taken together, these results suggest that common method bias was unlikely to substantially affect the study findings.

4.2. Measurement Model Assessment

Before hypothesis testing, the measurement model underwent a preliminary evaluation of its reliability and validity. Cronbach's alpha coefficients fell between 0.790 and 0.884, with all values above the recommended cutoff of 0.700. Composite reliability coefficients fell between 0.877 and 0.917, with all values exceeding 0.700, confirming that the constructs met the recommended reliability standard [99]. Convergent validity was evaluated from two aspects: AVE and indicator loadings for the reflective constructs. All AVE values fell within the range of 0.674–0.786 and remained higher than the threshold of 0.50. These findings indicate that the constructs achieved an acceptable level of convergent validity [100] (Table 4).

Table 4. Reliability and convergent validity.

Variable	Item	Factor Loading	Cronbach's Alpha	CR	AVE
SYQ	SYQ1	0.895	0.845	0.907	0.764
	SYQ2	0.855			
	SYQ3	0.872			
IQ	IQ1	0.855	0.850	0.899	0.690
	IQ2	0.830			
	IQ3	0.786			
	IQ4	0.850			
SEQ	SEQ1	0.876	0.812	0.888	0.727
	SEQ2	0.833			
	SEQ3	0.847			
EQ	EQ1	0.853	0.839	0.892	0.674
	EQ2	0.807			
	EQ3	0.807			
	EQ4	0.816			
PEOU	PEOU1	0.887	0.884	0.920	0.741
	PEOU2	0.842			
	PEOU3	0.833			
	PEOU4	0.881			
PU	PU1	0.908	0.864	0.917	0.786
	PU2	0.898			
	PU3	0.853			
US	US1	0.893	0.854	0.912	0.774
	US2	0.867			
	US3	0.880			
ATU	ATU1	0.869	0.790	0.877	0.704
	ATU2	0.832			
	ATU3	0.816			
UI	UI1	0.878	0.820	0.893	0.735
	UI2	0.836			
	UI3	0.857			

Discriminant validity was further examined through the Fornell–Larcker approach. Table 5 reports the correlation matrix, in which the bold diagonal entries denote the square roots of the AVEs. The bold diagonal values exceeded the inter-construct correlations,

providing evidence of adequate discriminant validity. As a complementary assessment of discriminant validity, the heterotrait–monotrait ratio (HTMT) criterion was further examined [101]. The HTMT results reported in Table 6 show that the highest value obtained was 0.801, well under the conservative benchmark of 0.900 [102], indicating satisfactory discriminant validity. Taken together, the measurement-model assessment indicates that all latent constructs demonstrate satisfactory internal consistency reliability, convergent validity, and discriminant validity, supporting the overall reliability and validity of the measurement model.

Table 5. Correlations and discriminant validity (Fornell–Larcker criterion).

	SYQ	**IQ**	**SEQ**	**EQ**	**PEOU**	**PU**	**US**	**ATU**	**UI**
SYQ	0.874								
IQ	0.434	0.831							
SEQ	0.508	0.447	0.852						
EQ	0.412	0.388	0.422	0.821					
PEOU	0.545	0.581	0.44	0.385	0.861				
PU	0.539	0.591	0.527	0.516	0.593	0.887			
US	0.568	0.609	0.555	0.566	0.603	0.689	0.88		
ATU	0.337	0.41	0.298	0.333	0.43	0.63	0.475	0.839	
UI	0.28	0.385	0.341	0.366	0.379	0.595	0.541	0.567	0.858

Table 6. HTMT.

	SYQ	**IQ**	**SEQ**	**EQ**	**PEOU**	**PU**	**US**	**ATU**	**UI**
SYQ									
IQ	0.512								
SEQ	0.611	0.538							
EQ	0.488	0.456	0.512						
PEOU	0.63	0.668	0.517	0.445					
PU	0.629	0.689	0.625	0.603	0.676				
US	0.669	0.714	0.666	0.665	0.694	0.801			
ATU	0.414	0.5	0.373	0.406	0.512	0.762	0.578		
UI	0.333	0.459	0.416	0.436	0.444	0.703	0.646	0.702	

4.3. Structural Model Evaluation

The structural model was further evaluated using the coefficient of determination (R^2) and the cross-validated redundancy measure (Q^2). R^2 represents the proportion of variance in each endogenous construct explained by the model and therefore reflects its explanatory power. The R^2 values for PEOU, PU, US, ATU, and UI were 0.455, 0.546, 0.621, 0.402, and 0.442, respectively, indicating that the model explained a substantial proportion of variance in the endogenous constructs. Predictive relevance was further assessed using the Stone–Geisser Q^2 statistic [103]. Q^2 values were obtained using the blindfolding procedure with an omission distance of 7. Q^2 values greater than 0 indicate predictive relevance for the corresponding endogenous construct [103]. The Q^2 values for PEOU, PU, US, ATU, and UI were 0.331, 0.420, 0.468, 0.275, and 0.314, respectively. All values exceeded 0, indicating predictive relevance for the endogenous constructs.

The significance of the structural paths was assessed using bootstrap resampling. Specifically, 5000 bootstrap resamples were generated from the original sample to obtain standard errors, t statistics, and significance levels for the path coefficients. Confidence intervals were estimated using the percentile bootstrap method, and 95% confidence intervals were reported. A structural path was considered statistically significant when $p < 0.05$ and its 95% bootstrap confidence interval did not include zero.

In the final stage, the structural model was examined to test the proposed relationships among the variables associated with users' intention to use smart libraries (Table 7, Figure 3). The analysis supported 16 of the 19 proposed hypotheses, with 3 not being validated. Specifically, SYQ was positively associated with PEOU, PU, and US, lending support to H1–H3. IQ positively affected PEOU, PU, and US, thereby supporting H4–H6. SEQ was positively associated with PU and US, which provides evidence in favour of H8 and H9. However, SEQ did not significantly affect PEOU, so H7 was not supported. EQ was positively associated with PU and US, which provides evidence in favour of H11 and H12. However, EQ did not exert a significant effect on PEOU, meaning that H10 failed to gain empirical support. By contrast, PEOU positively predicted PU, thereby confirming H13. However, the effect of PEOU on ATU did not reach significance, so H14 failed to gain empirical support. By contrast, PU showed positive effects on ATU, US, and UI, thereby supporting H15–H17. The analysis also revealed that both US and ATU were significant antecedents of UI, with US showing a direct positive effect, thereby lending support to H18 and H19.

Table 7. Structural model path estimates.

Path	β	STDEV	t	*p*	BT = 5000 95%CI	F^2	Hypothesis
SYQ -> PEOU	0.306	0.063	4.840	<0.001	[0.176, 0.423]	0.11	Supported
SYQ -> PU	0.146	0.051	2.875	0.004	[0.045, 0.245]	0.02	Supported
SYQ -> US	0.161	0.052	3.117	0.002	[0.057, 0.258]	0.042	Supported
IQ -> PEOU	0.383	0.046	8.400	<0.001	[0.293, 0.473]	0.193	Supported
IQ -> PU	0.251	0.063	3.973	<0.001	[0.127, 0.374]	0.083	Supported
IQ -> US	0.229	0.045	5.084	<0.001	[0.146, 0.320]	0.085	Supported
SEQ -> PEOU	0.080	0.049	1.653	0.098	[−0.019, 0.179]	0.008	Not supported
SEQ -> PU	0.157	0.057	2.737	0.006	[0.045, 0.270]	0.035	Supported
SEQ -> US	0.131	0.033	4.001	<0.001	[0.066, 0.193]	0.028	Supported
EQ -> PEOU	0.077	0.053	1.448	0.148	[−0.021, 0.187]	0.008	Not supported
EQ -> PU	0.208	0.048	4.314	<0.001	[0.115, 0.304]	0.070	Supported
EQ -> US	0.204	0.040	5.116	<0.001	[0.131, 0.288]	0.076	Supported
PEOU -> ATU	0.087	0.054	1.596	0.111	[−0.023, 0.192]	0.008	Not supported
PEOU -> PU	0.218	0.063	3.469	0.001	[0.096, 0.342]	0.057	Supported
PU -> ATU	0.579	0.059	9.788	<0.001	[0.462, 0.696]	0.364	Supported
PU -> UI	0.248	0.053	4.670	<0.001	[0.143, 0.352]	0.045	Supported
PU -> US	0.293	0.043	6.798	<0.001	[0.209, 0.378]	0.108	Supported
US -> UI	0.226	0.054	4.162	<0.001	[0.119, 0.332]	0.048	Supported
ATU -> UI	0.303	0.055	5.461	<0.001	[0.189, 0.410]	0.099	Supported

To further assess the model's out-of-sample predictive performance, PLSpredict was applied to the structural model. PLSpredict evaluates predictive performance for endogenous constructs using a cross-validation procedure. In this study, 10-fold cross-validation with 10 repetitions was employed, and out-of-sample predictive performance was assessed by comparing prediction errors between the training and holdout samples. Q^2_predict was used to evaluate predictive relevance, with values greater than zero indicating out-of-sample predictive relevance. The Q^2_predict values for PEOU, PU, ATU, US, and UI were 0.437, 0.504, 0.208, 0.565, and 0.199, respectively. All values exceeded zero, indicating that the model exhibits predictive relevance for the key endogenous constructs.

To further evaluate predictive performance, prediction errors were examined at the indicator level by comparing the PLS-SEM model with a linear model (LM) benchmark. For most indicators, the PLS-SEM model yielded lower prediction errors, as measured by the root mean square error (RMSE) and mean absolute error (MAE), than the LM benchmark. Overall, the lower prediction errors observed for most indicators provide further evidence of the model's out-of-sample predictive performance (Table 8).

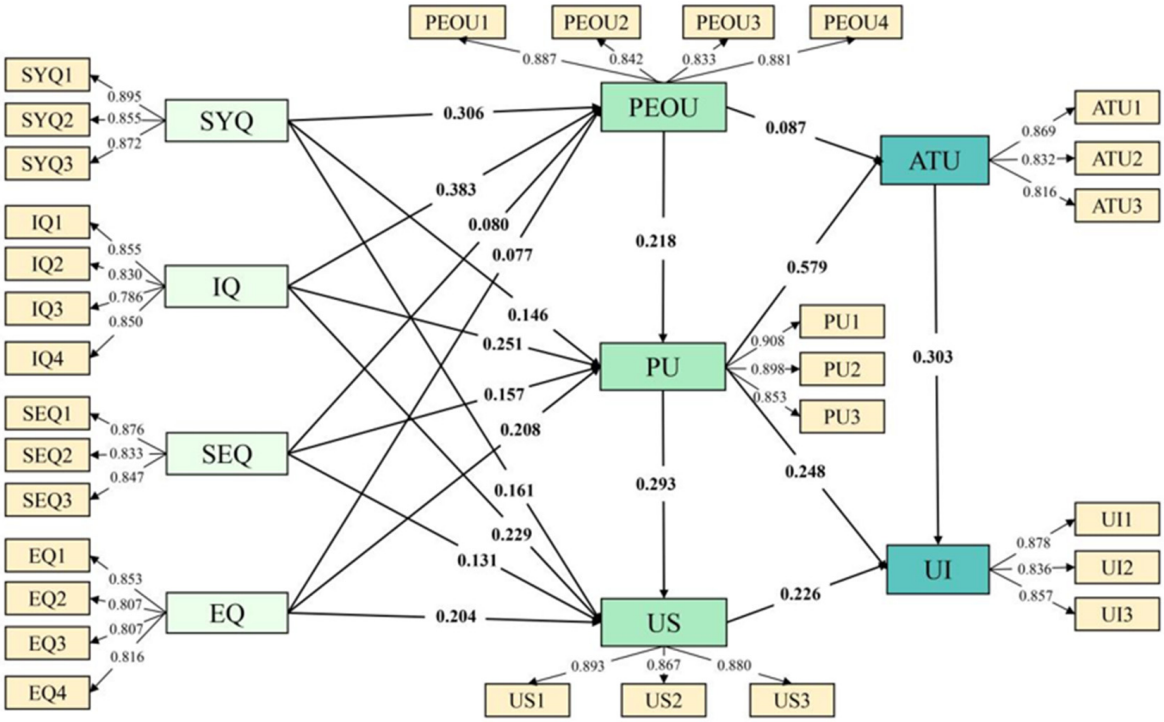


Figure 3. PLS-SEM structural model results.

Table 8. PLSpredict results.

Indicator	Q^2_predict	PLS-RMSE	LM-RMSE	PLS-MAE	LM-MAE
PEOU1	0.353	1.325	1.348	1.067	1.082
PEOU2	0.305	1.184	1.213	0.916	0.944
PEOU3	0.272	1.159	1.177	0.918	0.939
PEOU4	0.359	1.196	1.214	0.959	0.979
PU1	0.450	1.039	1.049	0.807	0.807
PU2	0.391	1.129	1.132	0.886	0.901
PU3	0.340	1.112	1.108	0.859	0.866
ATU1	0.126	1.251	1.269	1.020	1.030
ATU2	0.153	1.160	1.174	0.922	0.938
ATU3	0.157	1.240	1.262	1.002	1.016
US1	0.457	1.086	1.099	0.759	0.775
US2	0.418	1.163	1.171	0.855	0.870
US3	0.438	1.121	1.139	0.788	0.800
UI1	0.157	1.351	1.360	1.053	1.054
UI2	0.100	1.329	1.344	1.057	1.069
UI3	0.181	1.183	1.212	0.937	0.964

To assess the potential influence of including UI2 as an indicator of usage intention, we conducted an additional robustness check based on indicator removal. With the original structural model otherwise unchanged, UI2 was removed from the usage-intention construct and the model parameters were re-estimated to examine the stability of the main structural paths before and after its exclusion.

As shown in Table 9, after removing UI2, the effects of PU, US, and ATU on UI remained consistent in direction with those in the original model, and all paths remained statistically significant ($p < 0.001$). Specifically, the PU → UI path coefficient changed from 0.248 to 0.267, the US → UI coefficient from 0.226 to 0.202, and the ATU → UI coefficient from 0.303 to 0.281, indicating only minor changes in effect size. The R^2 for usage intention decreased from 0.442 to 0.413, suggesting that the model retained substantial explanatory

power after UI2 was excluded. Taken together, these results indicate that including UI2, which captures recommendation intention, as an indicator of the latent usage-intention construct, does not materially alter the main structural relationships or the substantive conclusions of the study.

Table 9. Robustness check results after excluding UI2.

Path	Original Model β	Original Model t	Original Model *p*	β After Excluding UI2	t After Excluding UI2	*p* After Excluding UI2
PU → UI	0.248	4.670	<0.001	0.267	4.480	<0.001
US → UI	0.226	4.162	<0.001	0.202	3.632	<0.001
ATU → UI	0.303	5.461	<0.001	0.281	4.880	<0.001

4.4. Mediation Effect Testing

To further clarify the mechanisms through which smart-library quality factors influence UI, mediation analyses were conducted. Beyond direct effects, mediation analysis helps explain how external quality factors influence UI through users' cognitive evaluations and attitudinal processes. Bootstrap analysis was performed in SmartPLS 4.0 using 5000 resamples, and the significance of indirect effects was assessed using 95% confidence intervals. An indirect effect was considered statistically significant when its bootstrap confidence interval did not include zero. The mediation and total-effect results are presented in Tables 10 and 11, respectively.

Table 10. Results of mediation analysis.

Path	Indirect Effect β	STDEV	t	*p*	BT = 5000 95%CI	Result
SYQ → PU → UI	0.036	0.015	2.425	0.015	[0.010, 0.068]	Significant Mediation
IQ → PU → UI	0.062	0.020	3.072	0.002	[0.026, 0.105]	Significant Mediation
SEQ → PU → UI	0.039	0.018	2.220	0.026	[0.010, 0.079]	Significant Mediation
EQ → PU → UI	0.052	0.016	3.192	0.001	[0.023, 0.087]	Significant Mediation
SYQ → US → UI	0.036	0.015	2.507	0.012	[0.011, 0.068]	Significant Mediation
IQ → US → UI	0.052	0.014	3.801	<0.001	[0.027, 0.080]	Significant Mediation
SEQ → US → UI	0.030	0.011	2.596	0.009	[0.011, 0.055]	Significant Mediation
EQ → US → UI	0.046	0.016	2.910	0.004	[0.020, 0.082]	Significant Mediation
PEOU → PU → UI	0.054	0.020	2.753	0.006	[0.020, 0.097]	Significant Mediation
PU → ATU → UI	0.175	0.036	4.816	<0.001	[0.107, 0.248]	Significant Mediation
PEOU → PU → ATU → UI	0.038	0.014	2.737	0.006	[0.014, 0.068]	Significant Serial Mediation
SYQ → PU → ATU → UI	0.026	0.010	2.479	0.013	[0.007, 0.048]	Significant Serial Mediation
IQ → PU → ATU → UI	0.044	0.015	2.983	0.003	[0.019, 0.076]	Significant Serial Mediation
SEQ → PU → ATU → UI	0.028	0.012	2.334	0.020	[0.008, 0.054]	Significant Serial Mediation
EQ → PU → ATU → UI	0.037	0.011	3.216	0.001	[0.017, 0.062]	Significant Serial Mediation

The external quality factors exerted indirect effects on UI through PU. The indirect effects of SYQ on UI through PU (β = 0.036, t = 2.425, p = 0.015) and of IQ on UI through PU (β = 0.062, t = 3.072, p = 0.002) were significant. Significant indirect effects were also observed for SEQ (β = 0.039, t = 2.220, p = 0.026) and EQ (β = 0.052, t = 3.192, p = 0.001). The results indicate that the effects of SYQ, IQ, SEQ, and EQ on users' usage intention are not primarily direct. Rather, these factors influence usage intention indirectly through users' cognitive evaluations of the value and utility of smart libraries, together with subsequent psychological responses such as satisfaction and attitude towards use, thereby contributing to the formation of usage intention.

Table 11. Total effects of the structural model.

Path	Total Effect β	STDEV	t	*p*	BT = 5000 95%CI
SYQ → UI	0.149	0.031	4.760	<0.001	[0.087, 0.209]
IQ → UI	0.226	0.034	6.702	<0.001	[0.160, 0.292]
SEQ → UI	0.117	0.031	3.744	<0.001	[0.060, 0.182]
EQ → UI	0.159	0.032	4.917	<0.001	[0.098, 0.224]
PEOU → UI	0.133	0.037	3.587	<0.001	[0.061, 0.206]
PU → UI	0.490	0.049	9.965	<0.001	[0.388, 0.581]
US → UI	0.226	0.054	4.162	<0.001	[0.119, 0.332]
ATU → UI	0.303	0.055	5.461	<0.001	[0.189, 0.410]

US also mediated the relationships between the quality factors and UI. SYQ, IQ, SEQ, and EQ each exerted significant indirect effects on UI through US. The indirect effect for SYQ → US → UI was significant (β = 0.036, t = 2.507, $p = 0.012$), as was that for IQ → US → UI (β = 0.052, t = 3.801, $p < 0.001$). The corresponding indirect effects for SEQ (β = 0.030, t = 2.596, $p = 0.009$) and EQ (β = 0.046, t = 2.910, $p = 0.004$) were also significant. These results suggest that smart-library quality factors not only shape users' evaluations of system value, but also influence UI by fostering satisfaction with the overall service experience.

The cognition–attitude–behaviour pathway proposed within the TAM framework was also examined. PEOU exerted a significant indirect effect on UI through PU (β = 0.054, t = 2.753, $p = 0.006$), while PU also exerted a significant indirect effect on UI through ATU (β = 0.175, t = 4.816, $p < 0.001$). Serial mediation analysis further showed that PEOU influenced UI through the sequential pathway PEOU → PU → ATU → UI (β = 0.038, t = 2.737, $p = 0.006$). This finding is consistent with the TAM proposition that UI is not shaped solely by perceived operational ease, but develops through users' evaluations of technological value and the subsequent formation of attitudes.

Finally, the serial mediating role of PU and ATU in the relationships between the quality factors and UI was examined. Significant serial indirect effects on UI through PU and ATU were observed for SYQ (β = 0.026, t = 2.479, $p = 0.013$), IQ (β = 0.044, t = 2.983, $p = 0.003$), SEQ (β = 0.028, t = 2.334, $p = 0.020$) and EQ (β = 0.037, t = 3.216, $p = 0.001$). These findings indicate that the effects of multidimensional smart-library quality on UI are partly transmitted through users' evaluations of usefulness and the formation of favourable attitudes. Overall, the mediation analyses reveal that the effects of external quality factors on UI are transmitted partly through cognitive evaluation and subsequent psychological responses, particularly PU, US, and ATU.

5. Design Implications for Integrated Quality Enhancement in Smart Libraries

Building on the relationships identified by the structural model, this study further draws on the Code for Design of Library Buildings (JGJ 38) [104] and relevant architectural design principles to translate the empirical findings into conceptual design proposals for system facilities, information wayfinding, service nodes, and spatial environments, thereby providing design implications for smart-library practice.

5.1. Smart-Facility Layout and Interactive-Interface Optimisation

The results show that SYQ significantly affects PEOU, PU, and US, indicating that smart facilities in libraries not only provide information services but also shape users' evaluations of the overall spatial service experience through the clarity, efficiency, and convenience of their use.

From a design-translation perspective, SYQ concerns not only equipment performance but also the alignment between smart facilities and users' activity flows. Self-service borrowing and return machines, information-retrieval terminals, and interactive facilities can therefore be arranged in relation to users' movement patterns and spatial functions to improve facility visibility and ease of access. For example, drawing on the usability and user-interaction principles of ISO 9241 [105], frequently used facilities may be positioned near entrances and major circulation nodes, whereas facilities requiring sustained interaction may be located in more stable areas of user activity. At the same time, facility interfaces and spatial wayfinding systems should maintain informational consistency, using coherent forms of information presentation to reduce the cognitive burden associated with transitions between digital interfaces and the physical environment. Smart-facility design should also accommodate the needs of different user groups by adopting appropriate operating heights, interaction modes, and assistive functions to improve usability and accessibility (Figure 4).

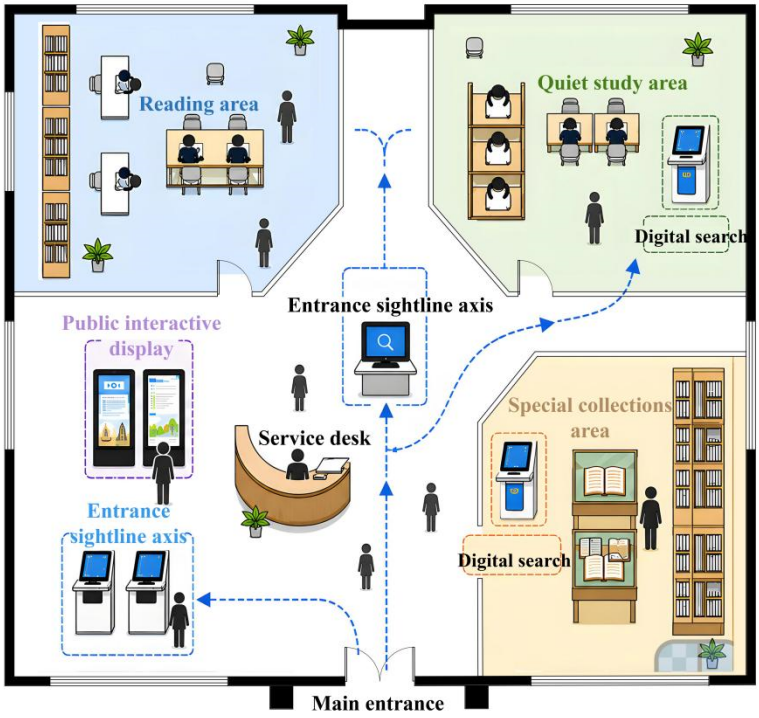


Figure 4. Conceptual illustration of smart-facility layout.

5.2. Information Organisation and Wayfinding-System Design

IQ had significant positive effects on PEOU, PU, and US, with comparatively larger path coefficients for PEOU and PU than those of the other quality dimensions. These findings suggest that information design in smart libraries should extend beyond the provision of information resources to integrate digital interfaces, spatial wayfinding, and physical resource organisation into a coherent information environment.

In design practice, mobile platforms, retrieval terminals, electronic displays, physical bookshelves, and functional zones can adopt an interconnected information architecture, enabling users to move from digital retrieval to information about resource locations,

spatial routes, access methods, and related services, thereby reducing the information-transition costs between digital and physical environments. Signage systems, electronic displays, mobile applications, and self-service facilities should also maintain consistent modes of information presentation, including typography, graphic symbols, colour coding, and layout conventions, to strengthen continuity across different information channels. Previous wayfinding research suggests that clear information organisation and spatial cues can reduce search effort and improve the efficiency of spatial orientation [106]. Accordingly, ergonomic and accessibility principles can inform the design of text size, visual contrast, information density, and symbol legibility, helping to ensure clear information support for children, older adults, and users with diverse abilities (Figure 5).

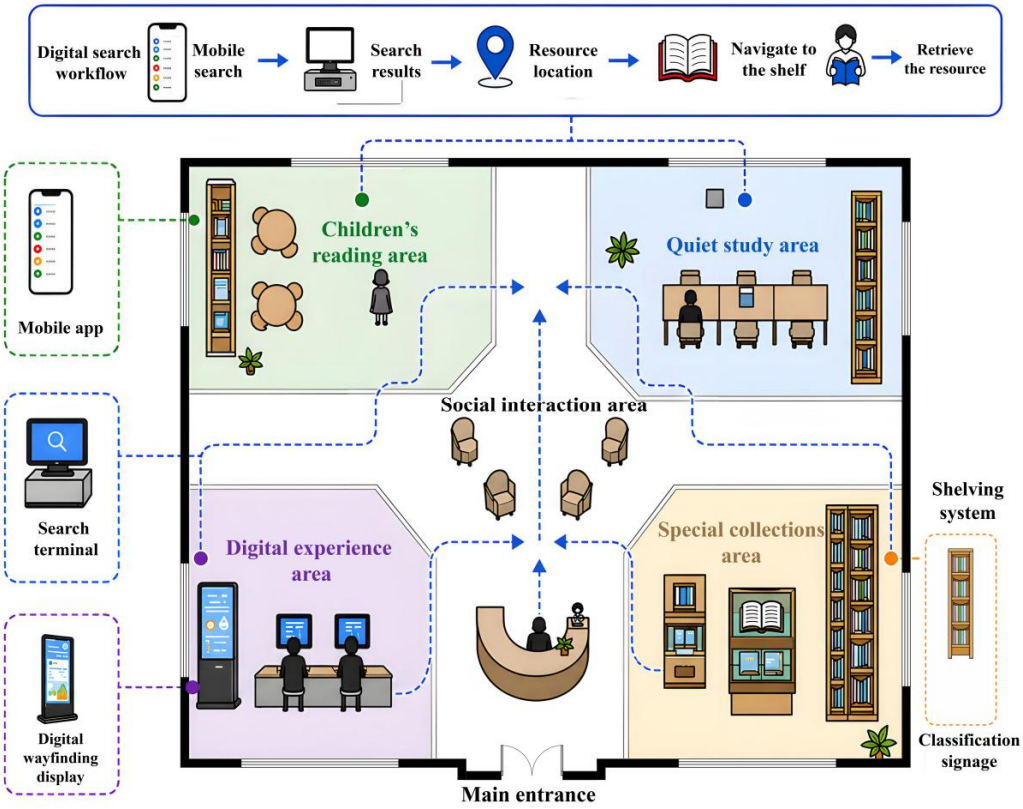


Figure 5. Conceptual illustration of information organisation and wayfinding.

5.3. Service-Node Layout and Digital Service-Scenario Design

The results show that SEQ had significant positive effects on PU and US, suggesting that effective service support can strengthen users' evaluations of the overall value, operational reliability, and perceived security of smart libraries.

Service systems can be organised through tiered service touchpoints according to the complexity and intensity of user needs. Routine tasks, such as information enquiries, borrowing and returning, and reservations and renewals, can be handled through self-service terminals and mobile platforms, whereas complex enquiries, equipment failures, and services for users with specific needs may require staff assistance. Different service touchpoints can be organised in relation to user activity sequences and spatial circulation to improve their visibility and accessibility. Servicescape theory suggests that spatial layout, environmental cues, and facility configuration jointly shape users' evaluations of service quality [107]. Accordingly, the design of service nodes in smart libraries should consider not only functional provision but also interactions among users, space, and facilities. In larger smart libraries, service nodes may be positioned near entrances, digital-experience zones, and major functional areas, while consistent signage and spatial information cues can

establish a continuous system of information recognition. Digital-experience, immersive-reading, and virtual-display settings should also account for viewing distance, patterns of occupancy, and lighting and acoustic conditions to support a coherent experience across digital services and physical space (Figure 6).

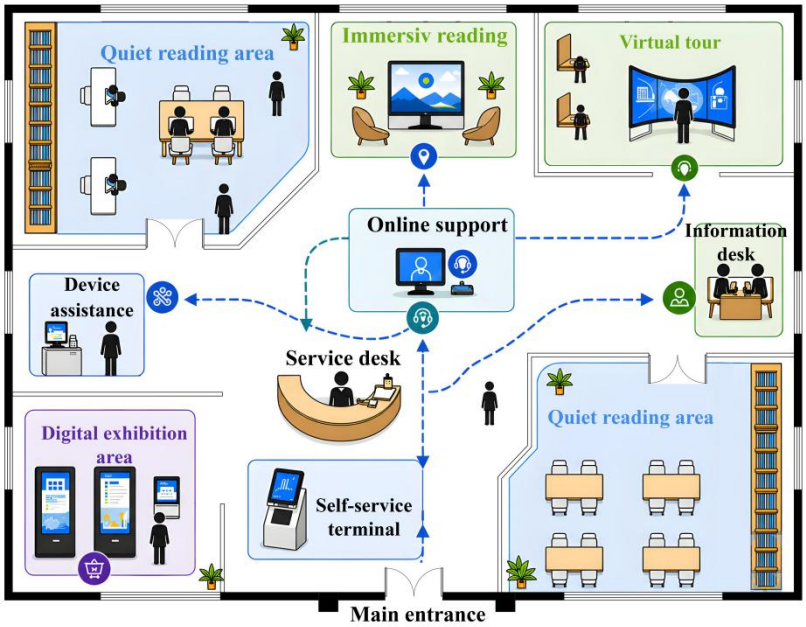


Figure 6. Conceptual illustration of service-node layout.

5.4. Functional Zoning and Indoor Environmental Optimisation

EQ had significant positive effects on PU and US. This finding indicates that the physical environment is an important component shaping users' evaluations of reading, learning, knowledge acquisition, and overall smart-library use. Appropriate lighting, acoustic conditions, indoor air quality, and spatial organisation can strengthen users' perceptions of the functional value of smart libraries while improving affective experience and overall satisfaction.

Smart libraries accommodate a range of activities, including reading, learning, social interaction, and digital experiences, each of which imposes different requirements for spatial openness, environmental control and privacy. Spatial organisation can therefore be adapted to different behavioural needs through functional zoning, circulation planning, and spatial-scale control, providing environmental conditions that correspond to different types of activity. Previous research on library architecture likewise emphasises the importance of organising spatial relationships according to functional requirements. Spatial environmental quality should also be considered comprehensively in relation to lighting, acoustics, and human-scale requirements. In reading areas, appropriate lighting design can help reduce visual fatigue, with attention to illuminance uniformity and glare control in accordance with the Standard for Lighting Design of Buildings (GB 50034) [108]. Discussion, social-interaction, and digital-experience areas can incorporate architectural-acoustic principles, using spatial arrangement and sound-absorbing measures to reduce mutual disturbance. The design of furniture, equipment, and circulation spaces should also accommodate the needs of different user groups, with reference to the Code for Accessibility Design (GB 50763) [109] to improve spatial accessibility and inclusiveness. Accordingly, environmental design in smart libraries should extend beyond visual enhancement to integrate spatial organisation, environmental performance, and usability around users' behavioural needs, allowing the physical environment to function as an effective setting for digital services and improved user experience (Figure 7).

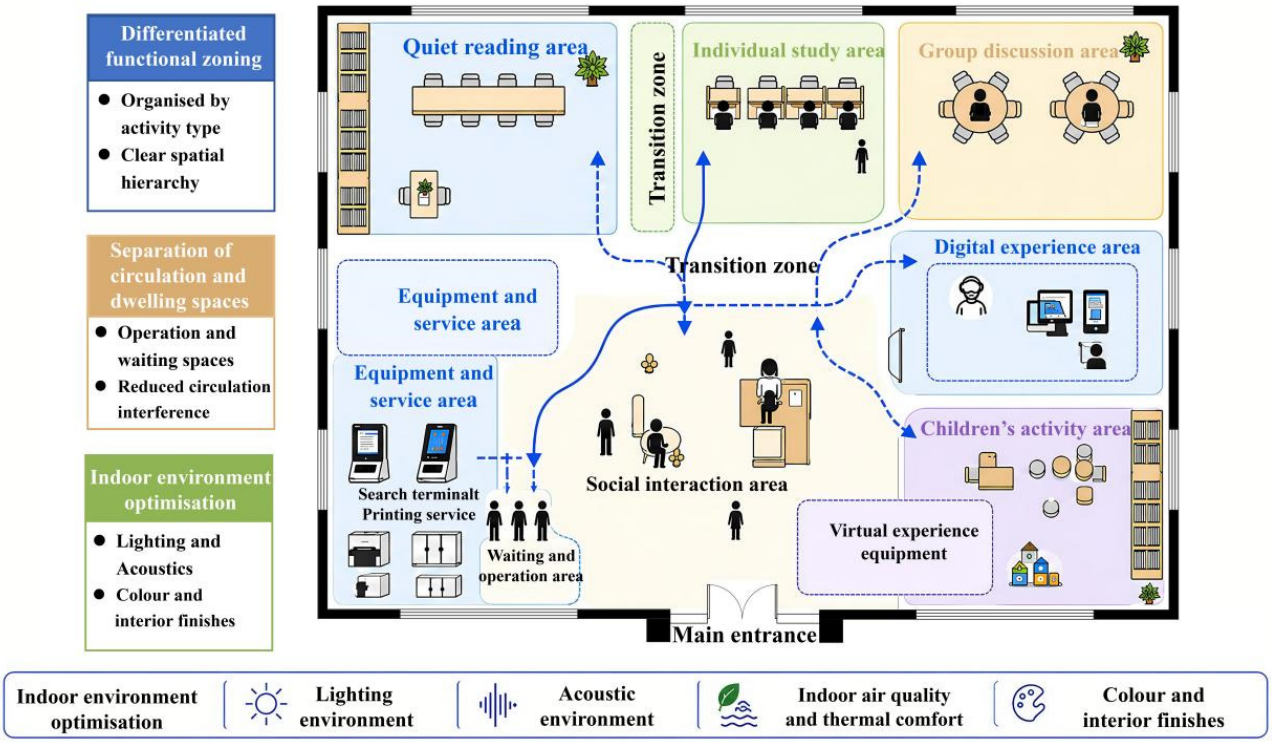


Figure 7. Conceptual illustration of indoor environmental optimisation.

6. Discussion

6.1. Key Findings

This study integrates the ISSM and TAM to examine how SYQ, IQ, SEQ, and EQ shape users' evaluations and UI in smart libraries. The findings not only demonstrate the differential effects of these quality dimensions on PEOU, PU, and US, but also extend the explanatory scope of conventional technology-acceptance models to hybrid digital–physical environments. In contrast to conventional ISSM–TAM research, which focuses primarily on digital-system attributes, this study shows that smart libraries are not merely information-service systems but hybrid built environments comprising digital technologies, smart facilities, service touchpoints, and indoor environmental conditions. Within this setting, SYQ, IQ, and SEQ are embedded in the physical environment through smart facilities, information interfaces, and service nodes, whereas EQ shapes users' evaluations of smart-service value and overall experience by supporting activities such as reading, learning, knowledge acquisition, and social interaction.

SYQ was positively associated with PEOU, PU, and US, indicating that stable, intuitive and responsive systems can simultaneously improve users' operational experience, perceptions of functional value, and overall evaluations of smart libraries. These findings are consistent with those of previous studies [48,70]. Alyoussef [20] reported a similar result, showing that higher system quality enhanced users' perceptions of the ease of use and usefulness of e-learning systems in educational institutions. Unlike purely online platforms, smart libraries allow users to perceive system quality directly through physical facilities, including self-service borrowing and return kiosks, search terminals, interactive displays, and identity-authentication devices. Its influence therefore depends not only on back-end performance but also on the visibility and accessibility of these devices and the extent to which digital interfaces are integrated with the physical environment.

IQ had significant positive effects on PEOU, PU, and US, with comparatively larger path coefficients across several IQ-related relationships. This suggests that users' evalua-

tions of smart-library value depend not only on the quantity of available resources, but also on whether information is clearly organised, accurately identified, and efficiently accessed. This finding is consistent with the results reported by Luo et al. [110]. In smart libraries, information resources are distributed across mobile applications, search terminals, digital displays, physical shelves, and functional zones. Such information can be transformed into usable knowledge resources only when it is supported by a consistent classification system, clear visual presentation, and accurate spatial positioning. Information quality therefore encompasses not only the authority and timeliness of content but also the efficiency with which digital information is organised in relation to the physical environment.

SEQ was positively associated with PU and US, a finding that is further supported by previous studies [111,112]. Unexpectedly, SEQ was not significantly associated with PEOU. This result contrasts with previous studies reporting a positive association between service quality and perceived ease of use [113]. One possible explanation is that, as Yu and Huang [114] observed, perceived ease of use primarily reflects the simplicity of the interface and the convenience of system operation rather than the availability of external service support. Although service quality may improve the overall experience of smart-library users, it may not directly alter their judgement of whether the system itself is easy to operate. This distinction may explain the non-significant association between service quality and PEOU.

EQ had significant positive effects on PU and US, whereas its effect on PEOU was not significant. This finding suggests that, whereas conventional TAM primarily explains user acceptance through interactions with digital systems, perceptions of technological value in hybrid digital–physical environments such as smart libraries are also shaped by spatial context. Unlike purely digital systems, in which users evaluate technological performance mainly through interface interaction, smart facilities, digital resources, and service functions in smart libraries are realised within specific physical settings. Spatial layout, environmental comfort, and facility configuration can therefore shape users' evaluations of the functional value and overall experience of smart services. Accordingly, EQ should not be regarded as an external add-on to conventional information-system evaluation frameworks, but as an important contextual condition through which the value of digital services is realised. At the same time, the non-significant effect of EQ on PEOU suggests that the physical environment does not directly alter users' perceptions of operational difficulty, but instead influences the extent to which technology-enabled services effectively support user activities. This finding extends the technology-centred logic of conventional acceptance models by showing that, in public built environments such as smart libraries, user acceptance depends not only on whether a system is easy to use and effective, but also on whether digital technologies and the physical environment jointly support users' information-seeking, learning, and social-interaction needs. We therefore propose that technology acceptance in smart libraries is partly spatially constituted, with the acceptance process jointly shaped by digital systems and the physical environment.

PEOU did not significantly predict ATU. This finding is consistent with Koutromanos et al. [115], who reported that users maintained positive attitudes towards mobile augmented-reality technology regardless of whether they perceived it as easy to use. Foroughi et al. [116] similarly reported a non-significant relationship between PEOU and ATU. This result may reflect the service-oriented nature of smart libraries and the goals that motivate their use. Unlike conventional technology products or frequently used digital applications, smart libraries are not centred on technological interaction itself, but function as public-service environments that support learning, reading, and information access. Users primarily visit smart libraries to access information resources, complete learning tasks, and make use of spatial services, rather than to engage with smart technologies as an

end in itself. PEOU may therefore function more as a basic enabling condition, reducing the effort required to use smart-library services and enhancing PU, rather than independently generating a favourable ATU. In addition, preliminary fieldwork conducted before the formal survey indicated that most participants were already familiar with the main functions of smart libraries and could use them with relative proficiency. Such familiarity may have compressed variation in PEOU, making it less able to differentiate users' ATU. Foroughi et al. [117] likewise suggested that prior experience and familiarity with a system may help explain why PEOU does not significantly shape ATU. This finding further suggests that additional contextual factors may be needed to improve the explanatory and predictive capacity of extended technology-acceptance models.

In addition, the mediation results further clarify the mechanisms through which different quality dimensions influence UI. SYQ, IQ, SEQ, and EQ all exerted significant indirect effects on UI through PU and US, indicating that users do not form UI solely in response to external quality conditions; rather, these effects are transmitted through evaluations of the functional value and overall experience of smart libraries. Moreover, SYQ, IQ, SEQ, and EQ exerted significant serial indirect effects through the PU → ATU → UI pathway, suggesting that the influence of external quality factors on behavioural intention is transmitted through a sequential process of value evaluation and attitude formation. These findings further suggest that user acceptance in smart libraries is not driven directly by technological attributes alone. Instead, technological, service and spatial conditions first shape users' value evaluations and satisfaction, which are subsequently translated into favourable attitudes and UI.

6.2. Research Limitations and Future Directions

Although this study provides exploratory insights into user evaluations and UI in smart libraries, several limitations should be acknowledged. First, participants were recruited through on-site intercept sampling, and data collection was conducted mainly at weekends. The resulting sample may therefore be skewed towards younger and more frequent users of smart libraries. The generalisability of the findings to other age groups, infrequent users, and users in other regions therefore requires further examination. Future studies could employ more diverse probability-based sampling strategies and broaden coverage across regions and user groups to improve external validity. Second, because the study involved multiple smart-library sites, some clustering may arise from differences in library environments and user populations. The present analysis focused on overall relationships at the individual-user level and did not further examine between-library differences using multilevel modelling. Future research could apply multilevel structural models to investigate how site-level environmental characteristics across different types of smart libraries shape user evaluations. Third, all variables were measured using self-reported data collected at a single time point. Although procedural controls were incorporated into questionnaire design, anonymous administration, and data screening, the possibility of common method bias and measurement overlap among conceptually related constructs cannot be entirely excluded. Future studies could combine objective behavioural measures, experimental data, or longitudinal observations and further refine construct distinctions to strengthen the robustness of the findings. Finally, the design implications proposed in this study were derived from user-evaluation findings and are intended primarily to illustrate potential relationships between user-related factors and spatial design elements. These conceptual design interpretations were not validated through actual spatial interventions, environmental measurements, or behavioural experiments. Future research could therefore incorporate spatial-performance testing, behavioural observation, and experimental evaluation to assess the effectiveness of specific architectural and spatial interventions.

7. Conclusions

This study integrates the ISSM and TAM to develop and validate a model explaining the formation of UI in smart libraries. The results show that SYQ, IQ, SEQ, and EQ significantly shape users' evaluations and subsequently influence UI. Among these quality dimensions, IQ and EQ showed comparatively greater explanatory contributions across the relevant paths, while PU, ATU, and US emerged as important determinants of UI. The mediation analysis further showed that SYQ, IQ, SEQ, and EQ did not influence UI through direct paths, but instead exerted their effects through specific indirect pathways involving PU, US, and the PU–ATU pathway. These findings indicate that the effects of smart-library quality factors on user acceptance are progressively transmitted through psychological mechanisms involving value evaluation, satisfaction, and attitude formation. The incorporation of EQ extends conventional technology-acceptance research by explicitly accounting for the role of the physical environment, showing that smart libraries are not merely information-service systems but hybrid built environments in which digital technologies, smart facilities, and indoor environments are closely integrated. Accordingly, smart-library development should move beyond technology-centred provision towards the coordinated design of digital systems and indoor environments, with attention to the relationships among smart-facility layout, information wayfinding, service-node organisation, and indoor environmental conditions. These design directions may help improve spatial-use efficiency and overall user experience, while providing practical implications for the planning and design, post-occupancy evaluation, and spatial renewal of smart libraries.

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Abbreviations

The following abbreviations are used in this manuscript:

ISSM	Information Systems Success Model
TAM	Technology Acceptance Model
PLS-SEM	Partial Least Squares Structural Equation Modelling
CB-SEM	Covariance-Based Structural Equation Modelling
SYQ	System Quality
IQ	Information Quality
SEQ	Service Quality
EQ	Environmental Quality
PEOU	Perceived Ease of Use

PU	Perceived Usefulness
US	User Satisfaction
ATU	Attitude Toward Use
UI	Usage Intention
AVE	Average Variance Extracted
HTMT	Heterotrait–Monotrait Ratio
VIF	Variance Inflation Factor
ICC	Intraclass Correlation Coefficient
LM	Linear Model
RMSE	Root Mean Square Error
MAE	Mean Absolute Error

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