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Measuring the smartness of a library

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ABSTRACT

Traditional libraries around the world are integrating cutting-edge technologies, such as data mining, artificial intelligence, Internet of Things, and voice-based search, to transform themselves into smart libraries. However, what elements make a library smart? How does one estimate the smartness of a library? To address these fundamental questions five elements and fifteen subelements that make a library smart were identified from a comprehensive review of the literature. A fuzzy-based model for use computing a library's smartness index was developed around these elements/subelements. Ease of use of this model was demonstrated by applying it to measure the smartness of a large academic library in South Asia.

1. Introduction

Education and creativity are increasingly being looked upon as the new drivers of economic development and prosperity of a city (Dirks, Keeling, & Dencik, 2009; Zhuhadar, Thrasher, Marklin, & de Pablos, 2017). The growth and economic development of a city in the future will be derived from its people that possess the skills, knowledge, and creativity needed to compete on the world stage (Zhuhadar et al., 2017). Local governments are, therefore, creating *smart cities* to attract and retain such smart people. In this context, *smartness* refers to the initiatives of the local government that use information and communication technologies to increase the quality of life of its people while contributing to sustainable development (Capdevila & Zarlenga, 2015).

People living in smart cities will require increased access to information and knowledge. This need, combined with rapid changes in technology and the massive growth of data and information, is creating new challenges for librarians globally (Cao, Liang, & Li, 2018). Information scientists have strongly recommended that librarians leverage emergent technologies and transition towards making their libraries smart. In general, as shown in Fig. 1, a smart city will need smart people who will need smart libraries to learn, work, and lead a high-quality life.

While there is no unique or generally accepted definition of a smart library, a few researchers have attempted to define it. Aittola, Ryhänen, and Ojala (2003), for instance, defined a smart library as "a location-aware mobile library service, which helps users find books and other material from the library" (p. 411). A multidimensional definition is provided by Schöpfel (2016), who defined a smart library as one that is "social, open, digital, connected, mobile, networking, a virtual space and at the same time, a good place to live and to learn and to work" (p. 127). A more recent definition provided by Cao et al. (2018) states that a smart library is one that is "capable of automatically capturing the needs of users and provides the resources and services to meet those needs" (p. 812). In terms of their offerings, Pan (2010) envisions a smart library to provide personalized services, hypertext services, computer-aided design (CAD) services, translation services, knowledge mining services, and cross-media services to its users. Wei and Yang (2017) described a smart library as one that users have complete control over and that can be accessed via the users' handheld devices.

2. Problem statement & motivation

Library and information scientists have been increasingly using the term "smart library." However, there is still no clarity regarding how one would measure smartness. Measuring the smartness of a library would mean assigning a number or a qualitative natural language label to that library so that it can be used for comparison with other libraries.

To measure the smartness of a library, one would need to study and measure all the elements and subelements that contribute to its smartness. Specifically, this research attempts to address the following questions:

RQ1. What elements and subelements make a library smart?

RQ2. How can the smartness of a library be consistently measured?

The above questions were addressed by developing a framework for a qualitative scale that can be used to determine how smart a library is. This scale is referred to as the library smartness index (LSI). In addition, a mathematical model to consistently measure the LSI was developed. The model also helps identify the relative strengths and weaknesses of

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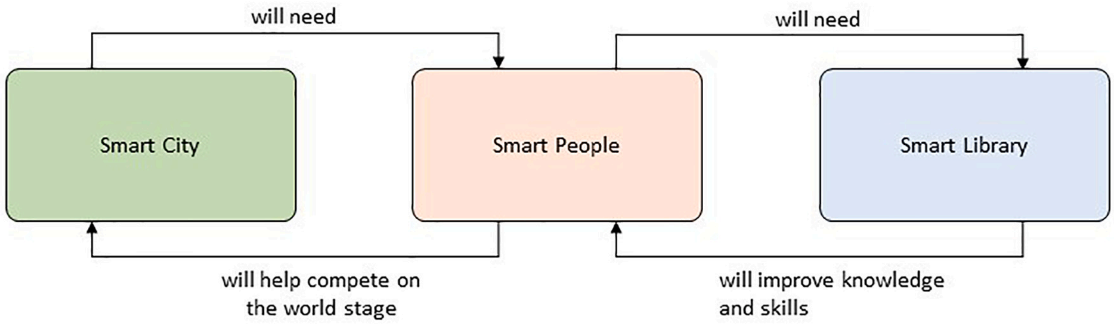

Fig. 1. Relationship between a smart city and a smart library.

the elements and subelements. Librarians can use this model to sustain the strength of the strong elements and subelements and enhance the weak elements and subelements in their library, thus making it smarter.

Several reasons have motivated the development of a smartness scale for libraries. First, while the literature in the domain of developing a smart library is rich and diverse, no attempt has been made to estimate the smartness of a library. Second, investors wanting to transform an existing, traditional library to a smart one will need to understand its current status before they make an informed decision. Third, progressive librarians would need a technique to measure and benchmark their library with the best in class. While researchers in the past have used techniques such as data envelopment analysis (DEA) and free-disposal hull (FDH) (Stroobants & Bouckaert, 2014), a smartness scale, such as the one developed in this paper, will provide an intuitive alternative.

3. Literature review

Governments around the world have declared their intention to transform existing cities into smart cities by harnessing the power of new information and communication technologies. The primary purpose of such smart cities is to empower their diverse stakeholders to collaborate and cocreate smart solutions to pressing problems faced by their city (Capdevila & Zarlenga, 2015). Giffinger, Fertner, Kramar, and Meijers (2007) performed an exercise to rank 70 mid-sized European cities. They identified six characteristics that define a smart city, namely, smart economy, smart people, smart governance, smart mobility, smart environment, and smart living. Further, they identified 31 factors that describe those six characteristics. While their work was from the perspective of a smart city, the current paper adapts their approach to identifying the elements and subelements of a smart library.

Johnson (2012) studied the same six elements presented in Giffinger et al. (2007) from the perspective of a smart library. Because of the diverse roles and needs of a smart library, he further divided the smart people into smart users (people) and smart librarians. His research emphasized that a smart librarian must not only possess the skills but must also have the insight and commitment to continually focus on what information is needed in the city. Schöpfel (2018) described four elements of a smart library, namely, smart services, smart people, smart place, and smart governance. The smart services element includes technological innovations, information search and retrieval, and collaborative efforts to build library assets, as well as interoperability and interconnection with other information services. The smart people element includes the library users as well as the staff, with the expectation that a library user will be a cocreator of knowledge, either individually or with other library users and/or with the library staff. The smart place element consists of the buildings and the ecology/environment, including building monitoring systems, which can transform traditional libraries into "a smart place that contributes as much to the sustainable development as to the smartness of the city" (p. 8). The final element, smart governance, includes aspects such as creating a transparent library administration system, involving users in decision-making and focusing on activities that increase social coherence. It is interesting to note that Schöpfel (2018) considers technology as a hard domain and a mechanism for service delivery, and, therefore this element is not explicitly mentioned in his model for a smart library. Alternately, Cao et al. (2018) identified three elements of a smart library, namely, smart technology (such asInternet-of-Things, data mining, artificial intelligence and the like), smart services (providing user-centric services) and smart people (library users, staff and administrators). The survey on smart libraries carried out by Kulkarni and Dhanamjaya (2017) had questions related to infrastructure and physical space (smart building), services, and financial aspects (smart governance) of a smart library.

Other researchers have not explicitly identified the elements of a smart library. However, such elements have been extracted from the working definitions utilized in their research. Wang (2011), for instance, has stated that a smart library helps to realize the associations between books and people, anywhere and at any time. Further, such a library must be people-oriented and must focus on conservation (green development) and users' convenience. This indicates an emphasis on smart places, smart people, smart services, and smart technology. Aithal (2016) has argued that libraries of the future will not need large buildings but will need the ability to serve its users electronically, placing emphasis on smart technology and smart services rather than on smart buildings. Li and Dong (2016) refer to a smart library as an integration of the library building with technology. Other information and library science researchers have focused on providing smart services to its users (Aittola et al., 2003; Pan, 2010; Tenopir, Sandusky, Allard, & Birch, 2014; Wei & Yang, 2017) and/or physical space and infrastructure (Barniskis, 2016; Cun, Abramovich, & Smith, 2019).

Technology is the foundation of a smart library. Current technologies relevant to a library include data mining, big data/analytics, artificial intelligence, radio frequency identification (RFID), augmented and virtual technologies, 3D printing, and the Internet of Things (IoT) (Cao et al., 2018; A.M. Cox, Pinfield, & Rutter, 2019; Gul & Bano, 2019; Wójcik, 2016). Technologies such as data mining and big data/analytics have been used to deliver personalized recommendations and push solutions (Simović, 2018). Bayani, Segura, Alvarado, and Loaiza (2017) suggest that smart libraries must integrate IoT and RFID with objects (such as books) to track library assets in real-time. The same technologies can be used to provide contextual information to users, as well as support back-office processes (Wójcik, 2016). Artificial intelligence (AI), if integrated successfully with current library systems, has the potential to greatly improve and influence services provided to students and researchers (Massis, 2018; Yang et al., 2017; Yao, Zhang, & Chen, 2015).

3D printing services have started making their way into libraries, with librarians providing support on the subject by organizing workshops, facilitating availability of course materials and offering personal consultations. Letnikova and Xu (2017) have demonstrated the use of

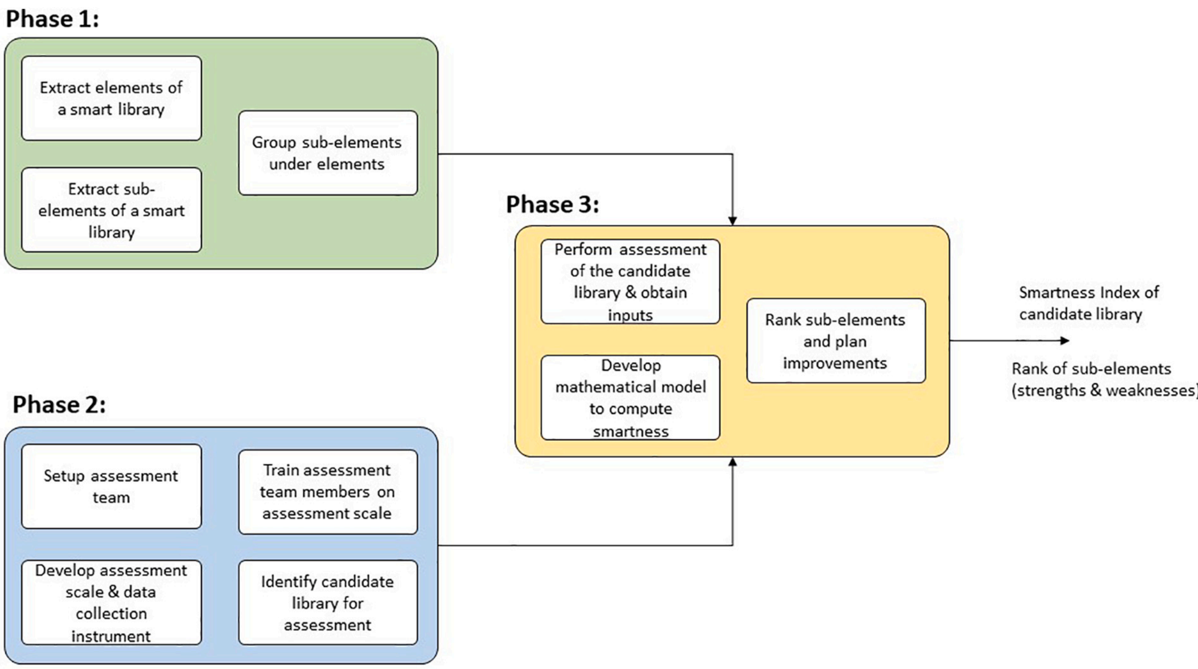

Fig. 2. Methodology for computing library smartness.

3D printing services in a classroom and have proved the effectiveness of an academic library's involvement in enhancing student learning, more so in STEM subjects.

Aithal (2016) has argued that libraries will not need physical spaces in the future. Instead, they will be virtual repositories of content that users may access from anywhere. Librarians will be required to source and store electronic or digital objects (Schöpfel, 2016) that can be accessed by ubiquitous users from anywhere in the world, at any time (Wei & Yang, 2017). Libraries of the future will also need to provide easy access to differently abled users (Bae, Jeong, Shim, & Kwak, 2007). Schöpfel (2018) has argued that a smart library should be able to combine the qualities of an environmentally conscious green building with a physical space. The place must conserve energy and must focus on reducing waste. Such a place also has the potential to attract more users. A new concept, referred to as *making*, has been introduced by Sheridan et al. (2014). Making and makerspaces provide users with "opportunities to learn and create through exploration, creation, and play" (Cun et al., 2019 p. 39). Providing makerspaces in libraries will enable community development, a key objective of smart libraries. Letnikova and Xu (2017) has suggested that makerspaces should be an essential part of a 21st-century academic library.

A smart library must provide location-aware services to users, preferably on their mobile devices (Aittola et al., 2003). Smart services must include high-level personalized services, computer-aided design (CAD) services, translation services, knowledge-mining services, and cross-media services (Pan, 2010). A smart library must create a comfortable environment and encourage user participation in cultural and recreational activities. Services that promote community knowledge exchanges, such as workshops and book festivals, improve relationships within communities (Cao et al., 2018).

Researchers have suggested that libraries will be required to expand their range of services from the current set. Liu, Zamir, Li, and Hastings (2018) found that students relied on Internet sources rather than on materials in their library, even for their course-related work, thereby suggesting a gap between student needs and library offerings. Academic libraries must be better equipped to satisfy the needs of their users. Specifically, a smart library must provide personalized knowledge discovery tools (Nicholson & Bennett, 2016; Schöpfel, 2018). Practitioners have reported successful implementations of smart libraries. Baryshev, Verkhovets, and Babina (2018) analyzed user activities to design features of a smart library at a Russian university. They integrated technology to assist users with an advanced inquiry system, provided users with an automated list of literature selections, and added anti-plagiarism services as their implementation of the smart library project progressed. With this data-driven approach, they were able to achieve an enhanced level of interaction with library users. Simović (2018) has reported another successful implementation of a big-data-based personalized recommender service to library users. Another successful implementation reported by Wei and Yang (2017) has user-centric features, including a listing of borrowed items, resource discovery, and announcements. Wu, Cai, Jin, and Dong (2018) have suggested that libraries must expand their scope of services to include interdisciplinary and scientific funding. Academic libraries may also partner with service providers to offer a research data service (RDS) to their research staff (Tenopir et al., 2014).

Johnson (2012) has advocated the need for smart librarians to cater to the needs of smart people. He states that a smart librarian would need to have the insight to continually construct new sources of information as well as techniques for disseminating it. Cao et al. (2018) suggest that users must not only be consumers of available information but also try to create new knowledge. A smart library must, therefore, actively support users in cocreation and dissemination of new knowledge. Academic libraries are moving up the value chain (Schöpfel, 2016). From being an issuer of books, the function of a library is moving towards cocreation of knowledge. This will change the role of librarians as well, who will now need to be aware of, and answer questions related to, intellectual property rights (Schöpfel, 2016).

Governance is a critical success factor in any initiative. Key stakeholders that are involved in the governance of a library include individuals and groups that have high interest and high power. From the perspective of creating a smart library, these will include the funding agencies, such as the government, community representatives, academic donors, heads of libraries, and the like. Jantz (2017) found that the vision statement of a library positively and significantly impacts its innovativeness. The key stakeholders will need a clear vision of the smart library they are funding, as well as its linkages to the development of their community. The remaining stakeholders, such as the users, service providers, etc., will need to be aligned with this vision and must share responsibilities for the success of setting up a smart library. Together, they will be accountable for the successful governance of the smart library (Schöpfel, 2018).

4. Methodology

The methodology is structured into 3 phases, as shown in Fig. 2.

Phase 1: Extraction of elements and subelements

The expected outcome of this phase is the identification and tabulation of all elements and subelements of a smart library. While an element is a label (e.g., smart technology), the subelement must be a statement that can be assessed. The key issues addressed during this phase include extraction of the elements and subelements, and the creation of element-subelement grouping.

Phase 2: Preparation for assessment

During this phase, an assessment team is put together. The team assesses the candidate library against the elements and subelements identified in Phase 1 and provides their inputs. A data collection instrument will be developed to ensure a consistent process. The key issues addressed during this phase include the criteria for the selection of assessment team members, the design of data collection instruments, and the training of the assessment team.

Phase 3: Computation of the smartness index

The inputs provided by the assessors will be translated into the smartness index. A mathematical model that can process these inputs and generate a smartness index is required. The model must be able to help identify the strong and weak elements of the candidate library.

4.1. Phase1: extraction of elements and subelements

The literature review was used to identify possible elements of a smart library. A top-down approach was employed, as shown in Fig. 3, to identify these elements and subelements of a smart library.

Four elements of a smart library were extracted: (1) smart technology, (2) smart services, (3) smart building, and (4) smart governance. The patterns displayed by smart people (users) and smart people (librarians) are almost the same, and, therefore, it was decided to merge them into one. This fifth element is referred to as smart people without differentiating between users and library staff.

A similar exercise was carried out to extract the subelements of a smart library. Several techniques exist in the literature to extract characteristics of an object of interest. The popular ones include Delphi, cross-case analysis, and historical (literature) reviews (Bokrantz, Skoogh, Berlin, & Stahre, 2017; Brookes & Locatelli, 2015). Historical (literature) reviews are suitable for smaller studies such as this one. It was therefore decided to use the historical review technique to extract subelements of a smart library. One of the challenges with this technique is the possibility of a subelement being categorized under more than one group. For example, would makerspace be grouped under smart space, or would it be appropriate to group it under smart services? In this case, the assessment team members went back to the definition of a makerspace to decide on grouping. Because a makerspace is defined as "a physical location where people of all ages can use digital and physical technologies (…) and create new products" (Cun et al., 2019 p. 40), it was decided to group this subelement under smart building. The assessment team members should discuss the basis for grouping subelements so that all members have the same understanding. In some cases, a statement will need to be broken down further such that it is placed under only one group.

Based on the review of the literature, fifteen subelements were extracted and grouped under the five elements identified earlier.

Table 1 shows a complete list of the fifteen subelements and five elements.

4.2. Phase 2: preparation for assessment

4.2.1. Assessment team composition

Estimation of the LSI requires that an assessment be carried out by a team of trained assessors. While there are no guidelines for the composition of the assessment team, stakeholders from all strata should be involved in such studies. It would be best to compose an assessment team of five members consisting of the following:

- Two experienced librarians (with one of them being an expert in information technology and services)
- Two users (one a senior academician and another a research scholar), and
- One senior library staff

4.2.2. Data collection

Measurement of the LSI is based on the rolling-up philosophy, where the measurements of lower-level attributes are combined to obtain the measurement of a higher-level attribute. Given a candidate library, the team of assessors will need to gauge the following for each of the elements and subelements:

a) What is the *level of presence* of the element (subelement)?
b) What is the *level of importance* of the element (subelement)?

If the classical set theory were employed, then the assessors would use Boolean values to represent the levels of presence and importance of each element/subelement. However, this would give inaccurate results. In the past, researchers have used fuzzy set theory, introduced by (Zadeh, 1965), to model vagueness and uncertainty in decision-making.

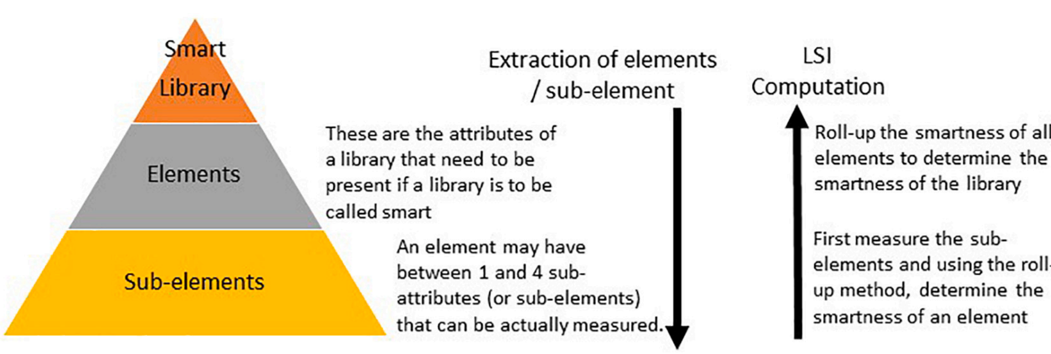

Fig. 3. Approach to identifying elements and subelements.

Table 1
Elements and subelements of a smart library.

No.	Element/subelement	Reference
E 1	Smart technology	
E 1.1	The library uses cutting-edge technology to integrate and track all library assets and labeled objects, including books, computers, and equipment	(Bayani et al., 2017)
E 1.2	The library uses technology to collect and preserve new digital objects	(Schöpfel, 2016)
E 1.3	The library provides access to required electronic content to users, including print-disabled users, anytime and anywhere in the world	(Aithal, 2016) (Bae et al., 2007) (Wei & Yang, 2017)
E 2	Smart buildings	
E 2.1	The library building is energy-efficient, focuses on waste reduction, and uses clean technology and equipment.	(Schöpfel, 2018)
E 2.2	The library building offers makerspaces to users to explore, learn and use cutting-edge tools for personal benefits	(Cun et al., 2019)
E 3	Smart services	
E 3.1	The library provides location-aware services, i.e., the ability of users to locate a book on the shelf, preferably on their mobile devices	(Aittola et al., 2003) (Yang et al., 2017)
E 3.2	The library provides services that promote community knowledge exchanges and improve community relations	(Cao et al., 2018)
E 3.3	The library provides knowledge discovery tools and has a facility to recommend personalized content to users by analyzing their interests	(Simović, 2018) (Schöpfel, 2016) (Nicholson & Bennett, 2016) (Baryshev et al., 2018)
E 3.4	The library provides services to help researchers in scientific funding applications and research data services	(Wu et al., 2018) (Tenopir et al., 2014)
E 4	Smart people	
E 4.1	The library has regular programs that strengthen user education concerning library use	(Cao et al., 2018)
E 4.2	Users of the library are not only consumers of information but also encouraged to actively coproduce knowledge	(Cao et al., 2018)
E 4.3	The library staff are trained resources with the ability to manage and answer questions related to intellectual property rights	(Schöpfel, 2016)
E 5	Smart governance	
E 5.1	Key stakeholders have a clear vision of the library of the future linked to the sustainable development of the community	(Schöpfel, 2016) (Jantz, 2017)
E 5.2	The library is managed based on collective intelligence and on shared responsibilities between the library staff, the library community, and other institutions	(Schöpfel, 2018)
E 5.3	The library administrators can identify funding sources and sponsors for new digitization projects	(Schöpfel, 2016)

Table 2
Fuzzy numbers for the level of presence and level of importance.

Level of presence and its corresponding fuzzy numbers					Level of importance and its corresponding fuzzy numbers				
Completely absent	CA	1	2	3	Not important	NI	0	0.05	0.15
Very low presence	VL	2	3	4	Least important	LI	0.1	0.2	0.3
Fairly low presence	FL	3	4	5	Somewhat important	SI	0.2	0.35	0.5
Minimal presence	MP	4	5	6	Important	IT	0.3	0.5	0.7
Fairly high presence	FH	5	6	7	Extremely important	EI	0.5	0.65	0.8
Very high presence	VH	6	7	8	Critical	AC	0.7	0.8	0.9
Fully present	FP	7	8	9	Mandatory	MY	0.85	0.95	1.0

With the fuzzy set theory, it is possible to represent not just extreme values but also partial terms such as *fully present*, *very high presence*, or *completely absent*. Fuzzy set theory was, therefore, used in this study to measure the LSI.

This study uses a triangular fuzzy number to represent a linguistic term. A triangular fuzzy number is one with three parameters (a,b,c) in domain x. The value a represents a pessimistic value, b represents a more probable value, and c corresponds to an optimistic value. The reader may refer to (Zadeh, 1965) to learn basic fuzzy operations.

An important aspect of the assessment is the design of a scale to obtain assessor inputs. Researchers in the past have used questionnaires that employ a Likert scale (Narayanamurthy, Gurumurthy, Subramanian, & Moser, 2018). A key design factor of the scale is the number of points, or the linguistic terms used in the assessment. Krosnick and Presser (2010) found that a 7-point scale was optimal in most instances. Another design factor is the appropriate mapping of a linguistic term to a fuzzy number. The assessment team performed a pilot study using four randomly identified subelements. Based on the linguistic terms used, the level of uncertainty involved, and the cognitive needs of the team members during the pilot study, the assessment team decided to use 7-point fuzzy scales as shown in Table 2. The scales used for the assessment of levels of presence and importance are similar to those used in Lin, Chiu, and Chu (2006) and Narayanamurthy et al. (2018) with minor changes to the linguistic terms. As shown in Table 2, each linguistic term is mapped to a triangular fuzzy number. Using these scales, the assessment team members will be able to provide their estimates for the levels of presence and importance for each of the elements/subelements in a candidate library. Estimates thus obtained can be fed into a mathematical model to compute the LSI.

4.3. Phase 3: Mathematical model for computation of the smartness index

Consider a team of l experienced assessors ($i = 1$ to l) that is used to estimate the smartness of a candidate library. There are m elements ($j = 1$ to m), and each element has up to n subelements ($k = 1$ to n). For a candidate library, each of the l assessors is asked to estimate the levels of presence and importance of the subelements.

Let $R_{ik} = (x_{ik}, y_{ik}, z_{ik})$ be the fuzzy number that represents the estimate of the level of presence of subelement k given by assessor i. The average fuzzy number for the k^{th} subelement is as follows:

Table 3
Assessor ratings for the academic library under study.

	Ratings for the level of presence					Ratings for the level of importance				
	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5
E 1						MY	AC	MY	MY	AC
E 1.1	VH	FH	FH	VH	FH	AC	EI	EI	AC	AC
E 1.2	MP	FL	FL	MP	FL	MY	AC	AC	EI	MY
E 1.3	FH	FH	MP	FH	FH	AC	EI	IT	AC	MY
E 2						EI	AC	MY	MY	AC
E 2.1	MP	FL	VL	MP	MP	EI	MY	EI	AC	AC
E 2.2	CA	CA	CA	CA	VL	MY	AC	AC	MY	MY
E 3						MY	AC	MY	MY	AC
E 3.1	MP	MP	VL	VL	MP	IT	EI	EI	IT	IT
E 3.2	MP	MP	VH	MP	VH	EI	AC	AC	MY	MY
E 3.3	FL	FL	VL	VL	MP	MY	AC	EI	EI	IT
E 3.4	CA	CA	CA	CA	CA	EI	EI	MY	AC	AC
E 4						EI	AC	EI	EI	AC
E 4.1	FH	FL	VL	VL	MP	IT	EI	EI	IT	IT
E 4.2	MP	MP	FH	MP	FH	EI	AC	AC	MY	MY
E 4.3	MP	CA	CA	CA	VL	MY	AC	EI	EI	IT
E 5						EI	AC	MY	AC	AC
E 5.1	FH	FH	MP	VL	MP	IT	EI	EI	IT	IT
E 5.2	MP	MP	VH	MP	VH	EI	AC	AC	MY	MY
E 5.3	FL	FL	VL	VL	MP	MY	AC	EI	EI	IT

$$R_k = \left(\frac{\sum_{i=1}^{l} x_{ik}}{l}, \frac{\sum_{i=1}^{l} y_{ik}}{l}, \frac{\sum_{i=1}^{l} z_{ik}}{l}\right) \tag{1}$$

Let $W_{ik} = (a_{ik}, b_{ik}, c_{ik})$ be the fuzzy number that represents the estimate of the level of importance of subelement k rated by assessor i. The average fuzzy number for the k^{th} subelement is as follows:

$$W_k = \left(\frac{\sum_{i=1}^{l} a_{ik}}{l}, \frac{\sum_{i=1}^{l} b_{ik}}{l}, \frac{\sum_{i=1}^{l} c_{ik}}{l}\right) \tag{2}$$

The fuzzy number for the k^{th} subelement, L_k, is the product of the fuzzy average number for its level of presence and the fuzzy average number for its level of importance, given by the following:

$$L_k = R_k(.)W_k \tag{3}$$

The fuzzy values for an element can be computed by rolling up the fuzzy values of its subelements. Specifically, the level of the j^{th} element, F_j, can be computed by the following:

$$F_j = \frac{\sum_{k=1}^{n} R_k(.)W_k}{\sum_{k=1}^{n} W_k} \tag{4}$$

Eq. (5) can be used to compute the LSI by aggregating the fuzzy average numbers for its level of presence and the importance of all its elements as follows:

$$LSI = \frac{\sum_{j=1}^{m} R_j(.)W_j}{\sum_{j=1}^{m} W_j} \tag{5}$$

At this stage, the LSI is still a fuzzy number. This fuzzy number needs to be expressed in a natural language term that is consistent with its stakeholders. In the past, researchers have used Euclidean distance to measure the gap between a fuzzy number and a natural language label. If the natural language labels for the smartness of a library (NLS) are as follows:

$$\{\text{Fully Smart}[FS], \text{Almost Smart } [AS], \text{Fairly Smart } [RS], \text{Low Smart } [LS], \text{Not Smart } [NS]\}$$

then the Euclidean distance between the calculated LSI and one of the natural language labels can be calculated using the following Eq. (6); (see Lin et al., 2006):

$$d[LSI, NLS] = \left\{\sum_{x\in p} (U_{SL}(x) - U_{NLS}(x))^2\right\}^{1/2} \tag{6}$$

where $p = \{x_0, x_1, \cdots, x_m\} \subset [0, 1]$.

The natural language label with the least difference corresponds to the smartness level of the candidate library.

The next step in the process is to rank each of the subelements based on their fuzzy scores. Ranking of triangular fuzzy numbers can be performed by computing their centroids (Sreedharan, Raju, Sunder, & Antony, 2019), given by the following:

$$\rho = \frac{(a + 4b + c)}{6} \tag{7}$$

where a, b and c are the three components of a triangular fuzzy number. Eq. (7) will generate a crisp score, ρ, that can be used to rank the relative strengths of the elements/subelements.

The final step is to test the model's robustness by applying it to a candidate library. The LSI and other results produced by this model may be compared with those generated by an existing model. However, in the absence of an existing model, an alternative validation method would be for the assessment team and the management of the candidate library to jointly discuss the results (Rathore, Thakkar, & Jha, 2017). The outcome of the discussion can then be used to calibrate and modify the model parameters if required. Sensitivity analysis can also be performed to gauge the robustness of the model.

5. Results of case application to an academic university library

An academic library of a university was identified as a candidate for the application of the fuzzy-based model. This 70-year-old state-funded university offers undergraduate, postgraduate, and doctoral studies across 40 major and interdisciplinary domains. The university library caters to approximately 200,000 users, including students and faculty. It houses more than half a million books, journals, theses, and other published material. A large proportion of the library users are research scholars and faculty members that are actively engaged in research and curriculum enrichment. With a committed annual grant from central and state governments, this library has been able to successfully integrate technology such as data mining, RFID, and IoT to improve their user services. It has an electronic repository to store digital objects and

Table 4
Conversion of assessor ratings to fuzzy numbers.

ID	Fuzzy numbers for the level of presence provided by assessors (A1 through A5)															Fuzzy numbers for the level of importance provided by assessors (A1 through A5)														
	A1			A2			A3			A4			A5			A1			A2			A3			A4			A5		
E 1																0.85	0.95	1.00	0.70	0.80	0.90	0.85	0.95	1.00	0.85	0.95	1.00	0.70	0.80	0.90
E 1.1	6	7	8	5	6	7	5	6	7	6	7	8	5	6	7	0.70	0.80	0.90	0.50	0.65	0.80	0.50	0.65	0.80	0.70	0.80	0.90	0.70	0.80	0.90
E 1.2	4	5	6	3	4	5	3	4	5	4	5	6	3	4	5	0.85	0.95	1.00	0.70	0.80	0.90	0.70	0.80	0.90	0.50	0.65	0.80	0.85	0.95	1.00
E 1.3	5	6	7	5	6	7	4	5	6	5	6	7	5	6	7	0.70	0.80	0.90	0.50	0.65	0.80	0.30	0.50	0.70	0.70	0.80	0.90	0.85	0.95	1.00
E 2																0.50	0.65	0.80	0.70	0.80	0.90	0.85	0.95	1.00	0.85	0.95	1.00	0.70	0.80	0.90
E 2.1	4	5	6	3	4	5	2	3	4	4	5	6	4	5	6	0.50	0.65	0.80	0.85	0.95	1.00	0.50	0.65	0.80	0.70	0.80	0.90	0.70	0.80	0.90
E 2.2	1	2	3	1	2	3	1	2	3	1	2	3	2	3	4	0.85	0.95	1.00	0.70	0.80	0.90	0.70	0.80	0.90	0.85	0.95	1.00	0.85	0.95	1.00
E 3																0.85	0.95	1.00	0.70	0.80	0.90	0.85	0.95	1.00	0.85	0.95	1.00	0.70	0.80	0.90
E 3.1	4	5	6	4	5	6	2	3	4	2	3	4	4	5	6	0.30	0.50	0.70	0.50	0.65	0.80	0.50	0.65	0.80	0.30	0.50	0.70	0.30	0.50	0.70
E 3.2	4	5	6	4	5	6	6	7	8	4	5	6	6	7	8	0.50	0.65	0.80	0.70	0.80	0.90	0.70	0.80	0.90	0.85	0.95	1.00	0.85	0.95	1.00
E 3.3	3	4	5	3	4	5	2	3	4	2	3	4	4	5	6	0.85	0.95	1.00	0.70	0.80	0.90	0.50	0.65	0.80	0.50	0.65	0.80	0.30	0.50	0.70
E 3.4	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	0.50	0.65	0.80	0.50	0.65	0.80	0.85	0.95	1.00	0.70	0.80	0.90	0.70	0.80	0.90
E 4																0.50	0.65	0.80	0.70	0.80	0.90	0.50	0.65	0.80	0.50	0.65	0.80	0.70	0.80	0.90
E 4.1	5	6	7	3	4	5	2	3	4	2	3	4	4	5	6	0.30	0.50	0.70	0.50	0.65	0.80	0.50	0.65	0.80	0.30	0.50	0.70	0.30	0.50	0.70
E 4.2	4	5	6	4	5	6	5	6	7	4	5	6	5	6	7	0.50	0.65	0.80	0.70	0.80	0.90	0.70	0.80	0.90	0.85	0.95	1.00	0.85	0.95	1.00
E 4.3	4	5	6	1	2	3	1	2	3	1	2	3	2	3	4	0.85	0.95	1.00	0.70	0.80	0.90	0.50	0.65	0.80	0.50	0.65	0.80	0.30	0.50	0.70
E 5																0.50	0.65	0.80	0.70	0.80	0.90	0.85	0.95	1.00	0.70	0.80	0.90	0.70	0.80	0.90
E 5.1	5	6	7	5	6	7	4	5	6	2	3	4	4	5	6	0.30	0.50	0.70	0.50	0.65	0.80	0.50	0.65	0.80	0.30	0.50	0.70	0.30	0.50	0.70
E 5.2	4	5	6	4	5	6	6	7	8	4	5	6	6	7	8	0.50	0.65	0.80	0.70	0.80	0.90	0.70	0.80	0.90	0.85	0.95	1.00	0.85	0.95	1.00
E 5.3	3	4	5	3	4	5	2	3	4	2	3	4	4	5	6	0.85	0.95	1.00	0.70	0.80	0.90	0.50	0.65	0.80	0.50	0.65	0.80	0.30	0.50	0.70

Table 5
Computing average fuzzy numbers for subelement E1.1 – a sample.

Assessor	Level of presence				Level of importance			
	Linguistic rating	Fuzzy number			Linguistic rating	Fuzzy number		
A1	VH	6	7	8	AC	0.70	0.80	0.90
A2	FH	5	6	7	EI	0.50	0.65	0.80
A3	FH	5	6	7	EI	0.50	0.65	0.80
A4	VH	6	7	8	AC	0.70	0.80	0.90
A5	FH	5	6	7	AC	0.70	0.80	0.90
	Average	5.4	6.4	7.4		0.62	0.74	0.86

provides its users access to online research databases. It has not started offering makerspace services. Services such as the management of research data have not yet been initiated but are in the works. The building housing the library is old and does not focus much on energy and waste reduction.

An assessment team consisting of 5 members was formed. The team was involved in the development of the fuzzy scales shown in Table 2. Table 3 shows the ratings provided by the assessors for the levels of presence and importance for the elements and subelements.

The first step is to convert these ratings to fuzzy numbers using the rules presented in Table 2. For example, the *Very High* rating for the level of presence assigned by A1 for subelement E1.1 is converted to a fuzzy number (6, 7, 8). Table 4 shows the fuzzy numbers for all the elements and subelements.

The next step is to compute the average fuzzy numbers for all of the subelements. A sample calculation, using Eqs. (1) and (2), for computing average fuzzy numbers for the level of presence and level of importance of subelement E 1.1 is shown in Table 5. The average fuzzy numbers for the levels of presence and importance of all of the subelements are shown in Table 6. The fuzzy numbers shown in the last three columns were obtained using multiplication operations (Eq. (3)).

The next step is to roll up the fuzzy numbers for the subelements to the element level. This is done using Eq. (4). A sample calculation for computing the average fuzzy number for the element *smart technology* is shown in Table 7. As seen in the table, the subelements that are part of the smart technology element are used for the computation of the average fuzzy number for the *smart technology* element. The fuzzy number computed for the *smart technology* element is (4.47, 5.49, 6.51).

A similar procedure is used to compute the average fuzzy numbers for all of the other elements. This is shown in Table 8. The average fuzzy numbers for the importance of the elements are retrieved from Table 3.

Using Eq. (5) and repeating the procedure, but this time for all of the elements, the fuzzy number for the candidate library can be determined. A sample calculation is shown in Table 8. The last row presents the LSI, represented by a fuzzy number (3.38, 4.37, 5.36).

The final step is to map the fuzzy LSI to a natural language term. The natural language terms for the smartness of a library with corresponding fuzzy numbers are shown in Table 9 (see columns 1 and 2). For example, the natural language term *Not Smart* is represented by a fuzzy number (1,1,3). The Euclidean distance between each of the natural language terms and the fuzzy LSI is now computed (3.38, 4.37, 5.36) using Eq. (6). A sample computation for the Euclidean distance between the natural language term *Not Smart* and the fuzzy LSI is as shown in Table 10.

The calculation needs to be repeated to determine the Euclidean distances between each natural language term and the fuzzy LSI. The results are shown in Table 9 and represented graphically in Fig. 4.

The natural language label with the least difference corresponds to the smartness level of the candidate library. The minimum Euclidean distance of 1.79 corresponds to the natural language smartness label *Fairly Smart*. In natural language terms, therefore, the academic library

Table 6
Average fuzzy numbers for all subelements.

Subelement ID	Average fuzzy numbers - presence			Average fuzzy numbers - importance			Subelement fuzzy number		
E 1.1	5.4	6.4	7.4	0.62	0.74	0.86	3.35	4.74	6.36
E 1.2	3.4	4.4	5.4	0.72	0.83	0.92	2.45	3.65	4.97
E 1.3	4.8	5.8	6.8	0.61	0.74	0.86	2.93	4.29	5.85
E 2.1	3.4	4.4	5.4	0.65	0.77	0.88	2.21	3.39	4.75
E 2.2	1.2	2.2	3.2	0.79	0.89	0.96	0.95	1.96	3.07
E 3.1	3.2	4.2	5.2	0.38	0.56	0.74	1.22	2.35	3.85
E 3.2	4.8	5.8	6.8	0.72	0.83	0.92	3.46	4.81	6.26
E 3.3	2.8	3.8	4.8	0.57	0.71	0.84	1.60	2.70	4.03
E 3.4	1.0	2.0	3.0	0.65	0.77	0.88	0.65	1.54	2.64
E 4.1	3.2	4.2	5.2	0.38	0.56	0.74	1.22	2.35	3.85
E 4.2	4.4	5.4	6.4	0.72	0.83	0.92	3.17	4.48	5.89
E 4.3	1.8	2.8	3.8	0.57	0.71	0.84	1.03	1.99	3.19
E 5.1	4.0	5.0	6.0	0.38	0.56	0.74	1.52	2.80	4.44
E 5.2	4.8	5.8	6.8	0.72	0.83	0.92	3.46	4.81	6.26
E 5.3	2.8	3.8	4.8	0.57	0.71	0.84	1.60	2.70	4.03

Table 7
Sample calculation of the fuzzy number for element E1: Smart Technology.

Subelement ID	Average fuzzy numbers - presence			Average fuzzy numbers - importance			Subelement fuzzy numbers		
E 1.1	5.4	6.4	7.4	0.62	0.74	0.86	3.35	4.74	6.36
E 1.2	3.4	4.4	5.4	0.72	0.83	0.92	2.45	3.65	4.97
E 1.3	4.8	5.8	6.8	0.61	0.74	0.86	2.93	4.29	5.85
Total				1.95	2.31	2.64	8.72	12.68	17.18
Element E1: Smart Technology Average Fuzzy Number							$\frac{8.72}{1.95} = 4.47$	$\frac{12.68}{2.31} = 5.49$	$\frac{17.18}{2.64} = 6.51$

Table 8
Fuzzy numbers for elements and the library smartness index of the academic library.

Category	Average fuzzy numbers - presence			Average fuzzy numbers - importance			Element fuzzy numbers		
Smart Technology	4.47	5.49	6.51	0.79	0.89	0.96	3.53	4.89	6.25
Smart Buildings	2.19	3.22	4.25	0.72	0.83	0.92	1.58	2.67	3.91
Smart Services	2.98	3.97	4.96	0.79	0.89	0.96	2.36	3.54	4.76
Smart People	3.24	4.20	5.17	0.58	0.71	0.84	1.88	2.98	4.34
Smart Governance	3.94	4.91	5.89	0.69	0.80	0.90	2.72	3.93	5.30
			Total	3.57	4.12	4.58	12.06	18.01	24.57
Library Smartness Index (LSI)							$\frac{12.06}{3.57} = 3.38$	$\frac{18.01}{4.12} = 4.37$	$\frac{24.57}{4.58} = 5.36$

Table 9
Euclidean distance between LSI (3.38, 4.37, 5.36) and natural language labels for the academic library.

Natural language label	Fuzzy numbers	Euclidean Distance
Not smart	(1, 1, 3)	4.76
Low smart	(1, 3, 5)	2.77
Fairly smart	(3, 5, 7)	**1.79**
Almost smart	(5, 7, 9)	4.77
Fully smart	(7, 9, 9)	6.91

The natural language label with the least difference corresponds to the smartness level of the candidate library. In this case, the least Euclidean distance of 1.79 corresponds to the natural language label "Fairly Smart" and that is why we have the font in bold.

is considered to be *Fairly Smart*. This label is well below the desired label of *Fully Smart*.

6. Discussion

The results of the smartness measurement for the library under study indicate serious gaps between the current and desired levels of smartness. To systematically close the gaps, the ranks of the elements and subelements were computed. Table 11 shows the centroid of each element, computed using Eq. (7), and the ranks, assigned to the elements, based on decreasing centroid values.

As seen from the results presented in Table 11, the elements *smart technology* and *smart governance* seem to be relative strengths of the library under study. This concurs with the observation of the library

Table 10
Sample calculation of Euclidean distance.

$U_{SL}(x)$	$U_{NLS}(x)$	$(U_{SL}(x) - U_{NLS}(x))$	$(U_{SL}(x) - U_{NLS}(x))^2$
LSI fuzzy number	Fuzzy number for the natural language term "Not Smart"	Difference (Col. 1–Col 2)	Square of the difference
3.38	1	2.38	5.66
4.37	1	3.37	11.36
5.36	3	2.36	5.59
	Euclidean distance $d = (\sum (U_{SL}(x) - U_{NLS}(x)))^{\frac{1}{2}}$		4.76

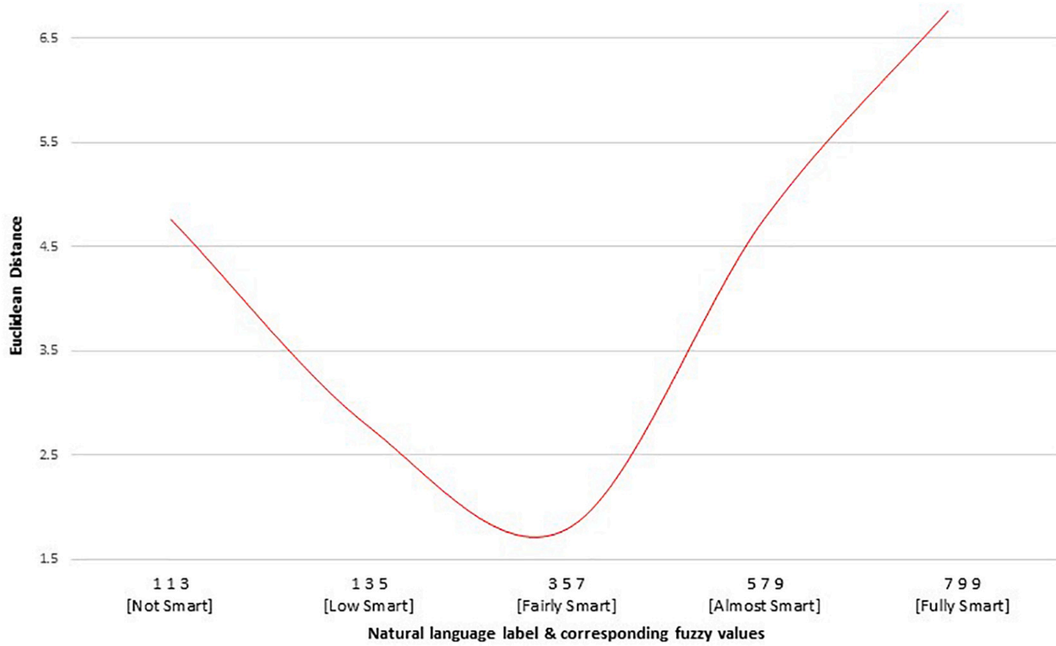

Fig. 4. Euclidean distance plot.

Table 11
Ranking of the elements.

Element ID	Element	Element fuzzy number			ρ	Rank
		a	*b*	*c*		
E1	Smart technology	3.53	4.89	6.25	4.88	1
E2	Smart buildings	1.58	2.67	3.91	2.70	5
E3	Smart services	2.36	3.54	4.76	3.54	3
E4	Smart people	1.88	2.98	4.34	3.03	4
E5	Smart governance	2.72	3.93	5.30	3.96	2

Table 12
Ranking of the subelements for the academic library.

Subelement ID	Subelement fuzzy number			ρ	Rank
	a	*b*	*c*		
E 1.1	3.35	4.74	6.36	4.78	3
E 1.2	2.45	3.65	4.97	3.67	6
E 1.3	2.93	4.29	5.85	4.32	5
E 2.1	2.21	3.39	4.75	3.42	7
E 2.2	0.95	1.96	3.07	1.98	14
E 3.1	1.22	2.35	3.85	2.41	11
E 3.2	3.46	4.81	6.26	4.83	2
E 3.3	1.6	2.7	4.03	2.74	10
E 3.4	0.65	1.54	2.64	1.58	15
E 4.1	1.22	2.35	3.85	2.41	12
E 4.2	3.17	4.48	5.89	4.50	4
E 4.3	1.03	1.99	3.19	2.03	13
E 5.1	1.52	2.8	4.44	2.86	8
E 5.2	3.46	4.81	6.26	4.83	1
E 5.3	1.6	2.7	4.03	2.74	9

having successfully implemented relevant technologies such as mobile computing, IoT, and RFID to serve its users. The elements *smart buildings* and *smart people* in contrast, seem to be areas for improvement. The old buildings that house the library and the lack of investment (e.g., training) in people are possible reasons for the lower ratings for these two elements. A similar procedure was carried out for all of the subelements, and the results are shown in Table 12.

Based on the ranks assigned to subelements, the following are the weaknesses of the library under study, along with suggested changes that need to be made:

- Rank 15, Subelement E 3.4: Funding applications for grants are complex and time-consuming, and every proposal needs to be backed by high-quality data and scenarios. In addition, the probability of a successful grant is very small. Given that a library has the required information, the library staff can take on the additional role of managing such funding applications.
- Rank 14, Subelement E 2.2: Makerspaces are key to improving the skills of people. Providing makerspaces in a library will help users access digital and physical technologies to learn and improve their skills through exploration. This goal is also directly related to the overall objective of a smart city.
- Rank 13, Subelement E 4.3: With libraries being looked upon as places where users can learn, share ideas and cocreate new knowledge and products, library administrators will take on the additional role of managing such innovations. This requires them to be trained on intellectual property rights. This enhanced ability among the library staff will encourage and increase user engagement with the library.

As part of the testing process, the findings were discussed with the library management. There was a general agreement on the results, and the library management felt that they could focus in the right areas, create a plan, and improve the smartness of the library. Two sensitivity tests were also performed, one to check the behavior of the model to extreme values, and another to check its reaction to incorrect inputs. The model behaved as expected during these tests, thereby proving its robustness.

6.1. Application to other libraries

The model is based on elements and subelements extracted from a comprehensive review of the literature and can be generalized to other libraries. While the model has been tested on one academic library, the assessment procedure, the equations required to compute the smartness index, and the fuzzy scales are transferable to any library.

The model provides librarians with a simple and logical structure to transform their existing library into a smart one. With the help of a trained team of assessors, this model can be used to not only estimate the smartness but also identify the strengths and weaknesses of a library, as demonstrated in this section.

A limitation of the model is the granularity of the identified subelements. Further research is required to identify more subelements that can refine the smartness levels. However, the developed model is flexible in that the new elements and subelements identified in the future may be integrated quite easily.

7. Conclusion

Governments around the world are investing time and money to create smart cities that will attract smart people. Smart people will need smart libraries to learn, improve their skills, explore ideas and cocreate new knowledge and products. Librarians thus have a great opportunity to transform their traditional libraries into smart ones. While technology is key, integrating cutting-edge technologies alone will not make a library smart. This study has discovered relationships between the attributes of a library and the smartness level that have not been previously identified.

A key contribution of this study is the development of a model for the measurement of a library smartness index. Librarians can use this model to measure the smartness of their libraries. They can also use this model to identify the strong and weak attributes of their libraries. This information can then be utilized to systematically plan and enhance the overall smartness of their library.

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References

Aithal, P. S. (2016). Smart library model for future generations. *International Journal of Engineering Research and Modern Education, 1*, 693–703.

Aittola, M., Ryhänen, T., & Ojala, T. (2003). SmartLibrary - Location-aware mobile library service. *Lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics)*. *2795*. *Lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics)* (pp. 411–416). . https://doi.org/10.1007/978-3-540-45233-1_38.

Bae, K. J., Jeong, Y. S., Shim, W. S., & Kwak, S. J. (2007). The ubiquitous library for the blind and physically handicapped — A case study of the LG Sangnam Library, Korea. *IFLA Journal, 33*, 210–219. https://doi.org/10.1177/0340035207083302.

Barniskis, S. C. (2016). Access and express: Professional perspectives on public library makerspaces and intellectual freedom. *Public Library Quarterly, 35*, 103–125. https://doi.org/10.1080/01616846.2016.1198644.

Baryshev, R. A., Verkhovets, S. V., & Babina, O. I. (2018). The smart library project: Development of information and library services for educational and scientific activity. *Electronic Library, 36*, 535–549. https://doi.org/10.1108/EL-01-2017-0017.

Bayani, M., Segura, A., Alvarado, M., & Loaiza, M. (2017). IoT-based library automation & monitoring system: Developing an implementation framework. *E-Ciencias de La Información, 8*(1), 1–18. https://doi.org/10.15517/eci.v8i1.30010.

Bokrantz, J., Skoogh, A., Berlin, C., & Stahre, J. (2017). Maintenance in digitalised manufacturing: Delphi-based scenarios for 2030. *International Journal of Production Economics, 191*, 154–169. https://doi.org/10.1016/j.ijpe.2017.06.010.

Brookes, N. J., & Locatelli, G. (2015). Power plants as megaprojects: Using empirics to shape policy, planning, and construction management. *Utilities Policy, 36*, 57–66. https://doi.org/10.1016/j.jup.2015.09.005.

Cao, G., Liang, M., & Li, X. (2018). How to make the library smart? The conceptualization of the smart library. *Electronic Library, 36*, 811–825. https://doi.org/10.1108/EL-11-2017-0248.

Capdevila, I., & Zarlenga, M. I. (2015). Smart city or smart citizens? The Barcelona case. *Journal of Strategy and Management, 8*, 266–282. https://doi.org/10.1108/JSMA-03-2015-0030.

Cox, A. M., Pinfield, S., & Rutter, S. (2019). The intelligent library: Thought leaders' views on the likely impact of artificial intelligence on academic libraries. *Library Hi Tech, 37*, 418–435. https://doi.org/10.1108/LHT-08-2018-0105.

Cun, A., Abramovich, S., & Smith, J. M. (2019). An assessment matrix for library makerspaces. *Library and Information Science Research, 41*, 39–47. https://doi.org/10.1016/j.lisr.2019.02.008.

Dirks, S., Keeling, M., & Dencik, J. (2009). *How smart is your city? Helping cities measure progress.* IBM Global Business Services. Retrieved Oct 15, 2019 from https://www.ibm.com/downloads/cas/KLEYQE6Z.

Giffinger, R., Fertner, C., Kramar, H., & Meijers, E. (2007). *City-ranking of European medium-sized cities.* Vienna UT: Centre of Regional Science. (October). Retrieved 10 Oct 2019 from http://www.smart-cities.eu/download/city_ranking_final.pdf.

Gul, S., & Bano, S. (2019). Smart libraries: An emerging and innovative technological habitat of 21st century. *Electronic Library, 37*, 764–783. https://doi.org/10.1108/EL-02-2019-0052.

Jantz, R. C. (2017). Vision, innovation, and leadership in research libraries. *Library and Information Science Research, 39*, 234–241. https://doi.org/10.1016/j.lisr.2017.07.006.

Johnson, I. M. (2012). Smart cities, smart libraries, and smart librarians. *Smart city and library service. The proceedings of the Sixth Shanghai International Library Forum* (pp. 30–34). . Retrieved Oct 15, 2019 from http://eprints.rclis.org/20429/.

Krosnick, J. A., & Presser, S. (2010). Question and questionnaire design. In J. D. Wright, & P. V. Marsden (Eds.). *Handbook of survey research*(2nd ed.). Bingley, England: Emerald Group Publishing.

Kulkarni, S., & Dhanamjaya, M. (2017). Smart libraries for smart cities: A historic opportunity for quality public libraries in India. *Library Hi Tech News, 34*, 26–30. https://doi.org/10.1108/LHTN-08-2017-0061.

Letnikova, G., & Xu, N. (2017). Academic library innovation through 3D printing services. *Library Management, 38*, 208–218. https://doi.org/10.1108/LM-12-2016-0094.

Li, H., & Dong, F. (2016). Research on the implementation strategy of the smart library services. *Library, 260*(5), 80–84.

Lin, C. T., Chiu, H., & Chu, P. Y. (2006). Agility index in the supply chain. *International Journal of Production Economics, 100*, 285–299. https://doi.org/10.1016/j.ijpe.2004.11.013.

Liu, J., Zamir, H., Li, Y., & Hastings, S. K. (2018). Search systems and their features: What college students use to find and save information. *Library and Information Science Research, 40*, 118–124. https://doi.org/10.1016/j.lisr.2018.06.002.

Massis, B. (2018). Artificial intelligence arrives in the library. *Information and Learning Science, 119*, 456–459. https://doi.org/10.1108/ILS-02-2018-0011.

Narayanamurthy, G., Gurumurthy, A., Subramanian, N., & Moser, R. (2018). Assessing the readiness to implement lean in healthcare institutions – A case study. *International Journal of Production Economics, 197*, 123–142. https://doi.org/10.1016/j.ijpe.2017.12.028.

Nicholson, S. W., & Bennett, T. B. (2016). Dissemination and discovery of diverse data: Do libraries promote their unique research data collections? *International Information and Library Review, 48*(2), 85–93. https://doi.org/10.1080/10572317.2016.1176448.

Pan, Y. H. (2010). Important developments for the digital library: Data Ocean and Smart Library. *Journal of Zhejiang University: Science C, 11*, 835–836. https://doi.org/10.1631/jzus.C1001000.

Rathore, R., Thakkar, J. J., & Jha, J. K. (2017). A quantitative risk assessment methodology & evaluation of food supply chain. *International Journal of Logistics Management, 28*, 1272–1293. https://doi.org/10.1108/IJLM-08-2016-0198.

Schöpfel, J. (2016). Six futures of academic libraries. In D. Baker, & W. Evans (Eds.). *The end of wisdom?: The future of libraries in a digital age* (pp. 123–128). Oxford, England: Elsevier. https://doi.org/10.1016/B978-0-08-100142-4.00013-0.

Schöpfel, J. (2018). Smart libraries. *Infrastructures, 3*(4), 43. https://doi.org/10.3390/infrastructures3040043.

Sheridan, K. M., Halverson, E. R., Litts, B. K., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review, 84*, 505–531. https://doi.org/10.17763/haer.84.4.brr34733723j648u.

Simović, A. (2018). A big data smart library recommender system for an educational institution. *Library Hi Tech, 36*, 498–523. https://doi.org/10.1108/LHT-06-2017-0131.

Sreedharan, V. R., Raju, R., Sunder, M. V., & Antony, J. (2019). Assessment of Lean Six Sigma Readiness (LESIRE) for manufacturing industries using fuzzy logic. *International Journal of Quality and Reliability Management, 36*, 137–161. https://doi.org/10.1108/IJQRM-09-2017-0181.

Stroobants, J., & Bouckaert, G. (2014). Benchmarking local public libraries using non-parametric frontier methods: A case study of Flanders. *Library and Information Science Research, 36*, 211–224. https://doi.org/10.1016/j.lisr.2014.06.002.

Tenopir, C., Sandusky, R. J., Allard, S., & Birch, B. (2014). Research data management services in academic research libraries and perceptions of librarians. *Library and Information Science Research, 36*, 84–90. https://doi.org/10.1016/j.lisr.2013.11.003.

Wang, S. (2011). New pattern of future libraries : The smart library. *Library Development, 2011*(12), 1–5.

Wei, Q., & Yang, Y. (2017). WeChat library: A new mode of mobile library service. *Electronic Library, 35*, 198–208. https://doi.org/10.1108/EL-12-2015-0248.

Wójcik, M. (2016). Internet of Things – Potential for libraries. *Library Hi Tech, 34*, 404–420. https://doi.org/10.1108/LHT-10-2015-0100.

Wu, J., Cai, J., Jin, M., & Dong, K. (2018). Embedding funding consultation in library services: A co-occurrences network analysis of knowledge flow in scientific funding. *Library Hi Tech, 36*, 378–399. https://doi.org/10.1108/LHT-06-2017-0127.

Yang, X., He, D., Huang, W., Ororbia, A., Zhou, Z., Kifer, D., & Giles, C. L. (2017). Smart library: Identifying books on library shelves using supervised deep learning for scene text reading. *Proceedings of the ACM/IEEE joint conference on Digital Libraries. Toronto, ON, 2017* (pp. 1–4). . https://doi.org/10.1109/JCDL.2017.7991581.

Yao, F., Zhang, C., & Chen, W. (2015). Smart talking robot Xiaotu: Participatory library service based on artificial intelligence. *Library Hi Tech, 33*, 245–260. https://doi.org/10.1108/LHT-02-2015-0010.

Zadeh, L. A. (1965). Fuzzy Sets. *Information and control, 8*, 338–353.

Zhuhadar, L., Thrasher, E., Marklin, S., & de Pablos, P. O. (2017). The next wave of innovation—Review of smart cities intelligent operation systems. *Computers in Human Behavior, 66*, 273–281. https://doi.org/10.1016/j.chb.2016.09.030.

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