Smart Academic Libraries

Possibilities Through the Application of the Internet of Things

Lorette Jacobs

UNISA

Abstract

Internet of Things (IoT) technologies provide the opportunity for hybrid and digital academic libraries to move towards offering smart library services and access to resources. Within the context of higher education, smart academic libraries are new generation libraries that utilise smart technologies to offer library services and access to resources that are innovative, creative, and infused in technological advancements. Within the context of the Covid-19 pandemic, many higher education institutions revised their modes of teaching and learning towards a hybrid, blended, or even online approach. This forced academic libraries to consider alternative ways of offering information services and resource support. One of these alternatives relates to the use of IoT technologies to create smart academic libraries that can offer varied services and resources, using radio-frequency identification technology, sensors, cloud computing, and artificial intelligence. By following a bricolage design within the constructs of interpretivism, views from different authors were considered to propose an IoT architecture and possibilities towards promoting smart academic libraries. The conceptual relatives theory was used to propose ways in which IoT technologies can be utilised to apply smart technologies, develop smart users, offer smart services, and promote smart governance in an endeavour to reconstruct academic library services that are intelligent, flexible, autonomous, and adaptive. It is envisaged that smart academic libraries will support the creation of a teaching and learning environment where students, academics, and researchers can acquire competencies towards personal and professional growth and development.

Keywords: Internet of Things; smart academic libraries; accessibility; interoperability; architecture

Introduction

The Covid-19 pandemic has blindsided academic libraries (Cox 2020). Because of the speed of transition which was required to remotely offer library services and to ensure access to printed and digital/digitised resources, many academic libraries found themselves unprepared for the urgency with which they had to adapt their services to support higher education endeavours. Within the context of the Covid-19 pandemic and changes to the scope and context of higher education academic offerings, tools and methods used by traditional academic libraries to provide library services were unable to offer access and support to students, academics, and researchers (Chen 2019). Aligned to the fifth law of library science, as stated by Ranganathan in 1931, that libraries as growing organisms should grow and expand, Makori (2017) proposes a transformation through the utilisation of IoT technologies to develop smart academic libraries. This view is reiterated by Moyane, Dube, Nkomo, and Ngulube (2020), who explain that academic libraries must transform to the point where they are able to drive and support strategic changes that influence teaching, learning, and research within their institution. However, embarking on this transition may be easier said than done, considering the globalisation of information supply by the internet, inadequate budgets, increased open access resources, and the need to justify the value of academic libraries in a constantly changing higher education environment (Makori 2017). Towards searching for opportunities to become more flexible and robust, Raju, Claassen, Adam, Dangelo, Keraan, Mostert, and Vonk (2018) propose that academic libraries should consider alternative ways in which to offer services within the South African higher education context. Technological advancements offer opportunities to reshape the focus of academic libraries and its context within higher education organisations and offer a new layer in supporting changes related to the higher education landscape. Yusuf, Ifijeh, and Owolabi (2019) argue that the application of the IoT provides opportunities for academic libraries to improve access to library resources, collection management, information literacy, location-based services, and recommendation services. The views of Yusuf *et al.* (2019) align to that of Wójcik (2016), who explains that the IoT as an emerging technology can be used to support and expand a variety of academic library services, including ease of use, constant contextual assistance, access, and authentication, as well as personalised library services. Linked to the IoT, smart academic libraries refer to libraries that are ‘intelligent, self-renewing, flexible, functional resilient, autonomous and adaptive’ (Gul & Bano 2019).

Within the above context, the aim of this research is to examine how the IoT can be used to compose smart academic libraries that are able to cater for user needs and expectations, particularly given the changing teaching, learning, and research environment brought about by the Covid-19 pandemic. As smart libraries are becoming increasingly important channels for accessing information, the importance of such libraries cannot be underestimated (IFLA 2020). Smart academic libraries offer their users seamless services through the application of various technologies in personalised and innovative ways (Simović 2018). As part of the Fourth Industrial Revolution (4IR), the IoT is one of the technologies that offers the broadest opportunity for academic libraries to supply information resources to students, academics, and researchers by following a smart approach.

Contextualising the Problem

The importance of academic libraries in higher education cannot be denied. As explained by Das (2017), quality education is impossible without quality library services and resources. This view supports the notion by Mahesh (2016) that the purpose of academic libraries to organise, preserve, and make information accessible, places prominence on the supporting role of academic libraries to achieve the core mission of research and education associated with higher education. As per the Committee of Higher Education Libraries of South Africa (CHELSA) (CHELSA 2019), academic libraries must be respected as a partner in teaching, learning, and research. Support must be offered to all role players to discover, access, and use information and knowledge resources towards academic prowess, research, and lifelong learning. Such access, according to CHELSA (2019), should encompass the retrieval of physical and virtual resources to ensure the optimal discoverability of information resources. However, CHELSA maintains that the relevance of academic libraries may be questioned within the Covid-19 era. Changes made to the delivery of teaching and learning practices create tension with regards to the way in which academic libraries offer support to promote higher education endeavours (Chisita & Ukwoma 2021).

Limitations to physical access to library resources and services because of Covid-19 lockdowns and distancing requirements, triggered a need for academic libraries to rethink and consider innovative ways to continue to provide services to users. Innovation in the offering of library services and resources require, according to Raju and Claassen (2017), a proactive collaborative transition where library services and access to resources are dynamic and agile, to support the transition towards online, blended, or a hybrid provision of educational activities. Blended educational activities refer to the combination between offline and online academic engagements, whilst the concept of hybrid educational activities focusses on utilising a variety of teaching and learning modes of engagement to support the needs of individual users. The need for the urgent precipitation of academic library services to offer virtual resources and services in support of academic activities is emphasised by CHELSA. According to the findings of the 2020 CHELSA research, access to the entire scope of academic library services should be moved to a virtual environment. The importance to offer library services through technological advancements that cater for user needs and promote the importance of academic libraries as a key support service towards academic prowess, was not only mentioned in the CHELSA report (CHELSA 2020), but also by authors such as Cox (2020), Farzand and Saleem (2020), Chisita and Ukwoma (2021), and Martzoukou (2021).

Nicholson (2020) explains that events related to the Covid-19 pandemic forced information professionals to speed up the transition to offer services via technology platforms as a matter of urgency. However, Cao, Liang, and Li (2017) state that the utilisation of technologies in and of itself is not sufficient to cater for embedded changes to the academic library environment. Technologies such as the IoT should be used to create smart academic libraries that are capable of automatically capturing the needs of users and provide resources and services to meet those needs. As an advanced version of a hybrid or digital library, a smart academic library should rely on intelligent equipment to support the offering of intelligent services to users (Wu 2012).

Within the above context, the aim of this chapter is to explore key considerations to create smart academic libraries through the IoT. More specifically, the chapter intends to focus on the IoT as it relates to smart libraries, provides foundation information on the architecture of the IoT to consider within academic libraries, and based on the conceptual relatives theory, offers possibilities related to the application of the IoT to create smart academic library services and resources.

Methodological Approach

Sound methodological principles are required to explore possibilities for academic libraries to transform their services and resources to become smart, i.e., innovative, enriching, interactive, and exciting. Exploring the use of the technologies related to the 4IR, such as the IoT, influenced my preoccupation with possibilities that academic libraries can consider towards creating smart library services. By following an interpretivist paradigm, the topic was explored through subjective meaning-making, aligned to the experiences and viewpoints of national and international authors. Because reality is socially constructed through interpretivism, individuals involved in research develop and put forth subjective meanings of their experiences, through their own contextual understanding and as it relates to the viewpoints of others (Creswell & Creswell 2018). Linked to the ontological perspectives of interpretivism, the bricolage design provides the lens through which an epistemological approach can be constructed to explore the topic of the IoT to compose smart academic libraries. As per the view of Yee and Bremner (2001), the bricolage design allows for the collection of rich data from existing literature to be used towards suggesting new knowledge. Kincheloe (2004) explains that the bricolage design neither searches for new tools, nor does it follow a linear plan to conduct research. Existing content is rather utilised to propose innovative insights and new understanding.

Contextualising existing content to come to insightful conclusions require, within the context of interpretivism, and utilising the bricolage design, that a theory or model be used to provide the academic foundation to allow the transformation of information into knowledge (Du Plooy-Cilliers 2014). Loosely founded on the *conceptual relatives* theory towards smart libraries, proposed by Cao *et al.* (2017), the dimensions of the theory relate closely to key components namely technology, people, and service. A similar theory by Schöpfel (2018) proposes that in the development of smart libraries, consideration should be given to dimensions such as technology, people, and services, along with a fourth dimension, which is smart governance. Diagrammatically, the key dimensions of the conceptual relatives theory as it applies to this research, is presented in figure 1:

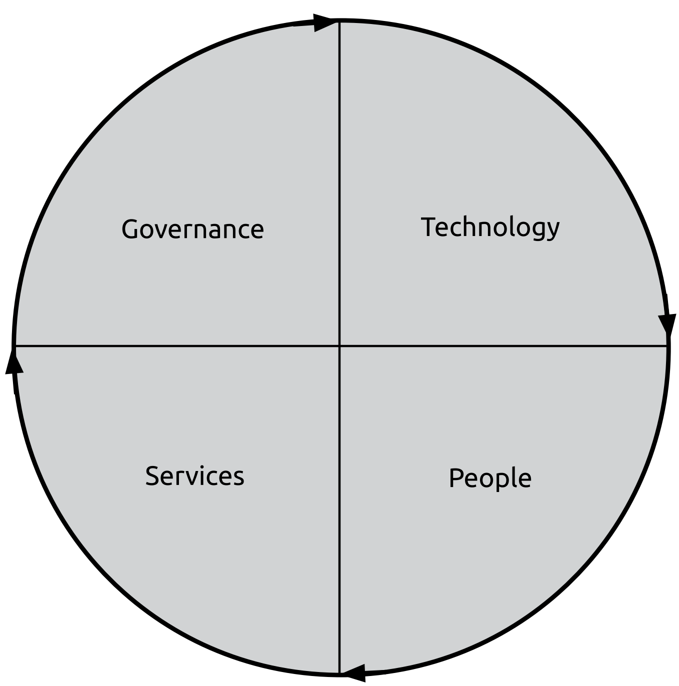

Figure 1: Conceptual relatives theory towards smart libraries (Personal archive; based on the views of Cao et al. 2017).

The *technology dimension* requires of a smart library to encompass an information service system based on electronic communication and computer processing technology (Cao *et al.* 2017). The technology dimension aims to build intelligence by utilising machines and programmes to respond to user queries and accessing resources through word matching. The *service dimension* relates to creating a library space and service model that offers support and interactivity between users and library services. Characteristics of the service dimension of smart libraries include fusion, interaction, visualisation, and ubiquity, specifically relating to offering open, multi-format, and multi-language services (Schöpfel 2018). In terms of the third dimension, smart libraries should offer opportunities for the development of *smart users* who are able to access resources and services through a variety of technological tools such as smartphones, iPADs, really simple syndication, android platforms, international organisation for standardisation platforms, or any integration of various technologies (Cao *et al.* 2017). Smart governance, according to Schöffel (2018), relates to increased transparency and the engagement of users and library staff in shared decision-making. This often requires a real-time analysis of library services usage to improve strategies based on collective intelligence. As the establishment of smart academic libraries require attention to these four dimensions, interoperability among these dimensions is necessary to ensure that smart academic libraries support higher education endeavours related to teaching, learning, and research.

The IoT Related to Smart Libraries

Nag and Nikam (2016) explain that a new era of technology may provide answers to offering academic library services in an innovative and smart way. According to the authors, the IoT, which forms a network of connections to share information through the sensing of objects linked to the 4IR, offers academic libraries the opportunity to mirror the virtual environment with users' knowledge of a physical academic library, to support and expand the extent of services that can be offered. The IoT was first coined by Kelvin Ashton, a British technology pioneer who used sensors and actuators to connect objects using radio-frequency identification (RFID) technology (Jiang, Xu, Zhao, & Chen 2019). According to Hoy (2015), the IoT comprises of three pillars which are required to ensure interconnectivity between objects: Objects must be identifiable, able to communicate, and interact with one another. The principles of the IoT are based on the view that physical and virtual things have identities and that these identities can be used as intelligent interfaces to generate and integrate information into a network where data and information between and among objects can be shared (Makori 2017). Gul and Bano (2019) add that through interconnectivity, autonomous and secure connections between objects can be achieved to promote the exchange of data. Linked to academic libraries, the IoT focuses on using technologies that can enable identification, communication, and interaction over networks without human interventions, to offer improved services and access to information resources (Hou, Yang, Chen, & Yu 2019).

The IoT is continuously emerging to connect our physical world with the virtual environment. Lueth (2021) states that the most recent developments within the 2021 annum relates to the expansions of IoT technologies to include 5G and the artificial intelligence of things (AIoT). The AIoT is seen as a radical transformation on how we interact with devices and objects around us. As explained by Ghosh (2020), the AIoT is based on programmable intelligence that will enable devices to learn, reason, and process information like humans. Linked to the 5G, connectivity devices will be able to communicate at a near-zero latency rate in real time, so that volumes of data from numerous sources can be shared. Though more research is required on the way in which AIoT may be utilised towards expanding academic library services, its impact on such library services will be immense, according to Bunz and Janciute (2018). AIoT objects will be able to perform services which were not possible before, by seeking, tracking, and processing gathered information through the ability to process language and images to make autonomous decisions. Changes may relate to keyword searching and the semantic analysis of web content; integrated speech recognition; machine translation to support real-time multi-language translation; and cloud services for the identification of diverse and complex web content.

As a key resource to support the transformation of higher education from face-to-face to blended, hybrid, and eventually artificial intelligence (AI), Yu, Gong, Sun, and Jiang (2019) explain that within the context of using modern technologies such as big data, the IoT, cloud computing, RFID, and virtual realities, academic libraries may be transformed to create smart libraries that are able to provide users with more efficient and high-quality services. Within the context of using IoT technologies, Schöpfel (2018) elaborates that the term ‘smart’ refers to efficient, sustainable, equitable, and interconnected. Technologies such as the IoT may thus be used to create an academic library infrastructure of components and services that are intelligent, interconnected, and efficient. However, Zhuang (2021) warns that irrespective of technology evolution and usage, library principles must always be considered in terms of people oriented, reading-centred, and service-oriented focus. For Yu *et al.* (2019) it is therefore important that academic libraries use technologies related to RFID, the IoT, image and speech recognition, and other AI technologies to offer a holistic composition of services. Similarly, Gul and Bano (2019) argue for the use of technology tools to offer services in an intelligent and personalised manner through the exchange of data-sharing. The aim of a smart library must therefore be to ensure that all elements and activities of the library become 'smart,' in order for technologies, services, and user-oriented dimensions to be intelligent and self-renewing to offer a wide range of opportunities for searching, retrieval, and engagement, using complex hardware and software capabilities (Cao *et al*. 2018). As purported by Pujar and Satyanarayana (2015), the creation of smart academic libraries through the application of the IoT can enrich the experiences of library users to connect with information in ways that were hitherto not possible.

Internet of Things Architecture within the Context of Academic Libraries

As described by Jiang *et al*. (2019), the IoT is not a single technology but an accumulation of various technologies that function in unison to support communication and the exchange of information among objects, the environment, and humans. The basic set of technologies that is needed for the IoT to function effectively refer to RFID, wireless communication devices, sensors, cloud computing, and advanced Internet Protocol (IP) (Chen 2019). In addition, Xie, Liu, Zhu, Chong, Shi, and Chen (2019) suggest that other technologies should be incorporated as part of the IoT to expand its functionality and relevance. These may include near-field communication (NFC), low-rated wireless personal area networks, Bluetooth, wireless fidelity (Wi-Fi), worldwide interpretability for microwave access (WiMAX), mobile communications, and wireless sensor networks (WSNs). Gul and Bano (2019) state that for academic libraries to become smart, technologies related to electronic resource management, digital asset management, and institutional repositories should also form part of the technologies to be linked to the IoT. Cao *et al*. (2018), Gul and Bano (2019), and Xie *et al*. (2019) propose that IoT technologies used within a smart library context be divided into three layers to ensure that all technology is in place to convert a hybrid or digital academic library to a smart academic library through the application of the IoT. These three layers are the perception layer, the device and network/computing layer, and the access/discovery layer. Diagrammatically the three layers and technological tools applicable to each can be presented as per figure 2.

In terms of the perception layer, there are key technologies that should form the foundation of the IoT architecture. Of these, the RFID is probably the most important (Yusuf *et al*. 2019). The RFID encompasses tags with built-in integrated circuits that can store information and includes an antenna to receive and transmit signals. RFID tags are miniaturised to a few millimetres in length and width, which enable it to be linked to everyday objects (Cooper & James 2009). The RFID tags are activated by radio waves which communicate wirelessly with the tags. These radio waves are used to transfer data from

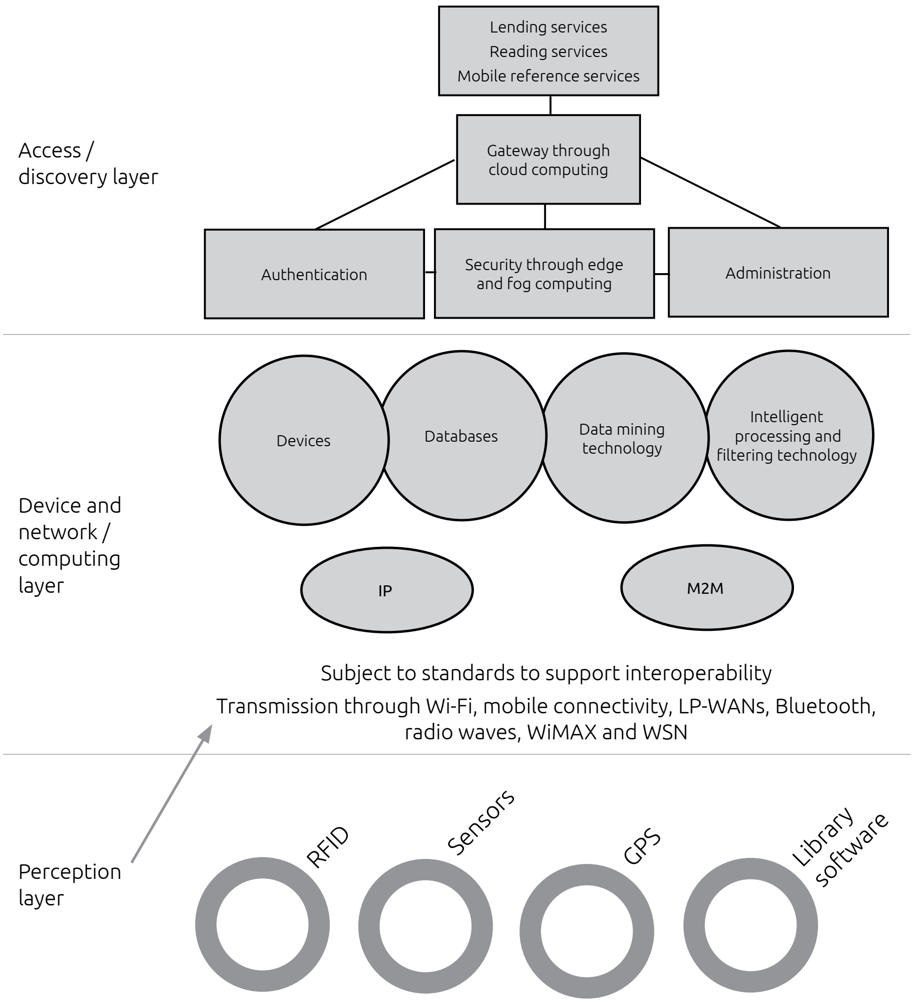

Figure 2: Graphical representation of architecture of the IoT related to smart academic libraries (Personal Archive).

the RFID tags for automatic identification and tracking of objects. In this way RFID tags act as 'smart' signatures that transmit information to radio-frequency readers (Shepard 2018). Using RFID technology, objects can be 'sensed' through low-power, ultra-high frequency sensors used for gathering data from objects (Mulloni & Donelli 2020). These sensors can be managed through cameras, GPS, and other smart sensors to identify and locate objects. Sensors are used within the IoT construct as an inexpensive way to turn objects in academic libraries into 'smart' objects (Rajapaksha 2020). Within the environment of academic libraries, Sheeja and Mathew (2019) explain that

RFID technology linked to sensors can be used as a tracking device for books on shelves. In this way the misplacement of books can be eliminated as the use of RFID tags linked to a positioning system and NFC through Wi-Fi or mobile connectivity can ensure the quick and easy tracking of books.

Connected to the perception layer, Chen (2019) as well as Costa, Genovesi, Borgese, Michel, Dicandia, and Manara (2021) explain that a variety of methods can be used to transmit RFID information related to objects, inclusive of low-power wide-area networks (LP-WANs), Bluetooth, Zigbee, WiMAX, and WSNs. Data that were stored and made accessible via these networks require the use of protocols to enhance transmission. Such protocols can include interoperable communication protocols, security protocols, interface protocols, and internet protocols (Liu & Chou 2018). Hoy (2015) states that protocol standards are imperative to ensure full interoperability between objects linked to the internet. The Zigbee Alliance has for example produced a set of standards for the creation of WSNs (Cooper & James 2009), whilst standardisation of machine-to-machine communications (M2M) has secured the establishment of technical standards for interoperability related to architecture, security, and machine-to-machine reading (Mehmood, Ahmad, Yaqoob, Adnane, Imran, & Guizani 2017; Zhuang 2021). Of particular importance to offer smart library services and resources, is the IP. Objects connected to the internet require a unique identifier to ensure interoperability. Currently the IPv6 is applied to provide each object with its own unique IP address. IPv6 uses a 128-bit address (Liang & Chen 2018) to provide a unique identifier to each object linked to the internet. Through RFID technology, the unique IPv6 address of each object can be identified and by using sensors, data related to the physical or virtual states of objects can be traced. Such data is stored via cloud computing to enhance interoperability (Yan, Huang, Luo, Gong, & Yu 2018). Coupled with blockchain technology (also linked to the 4IR), data can be time-stamped to provide the validity and reliability of information available via the cloud (Gul & Bano 2019). Blockchain creates unique, verifiable records that can be tied to digital material and used to show provenance of records and data (Bhatia & Wright de Hernandez 2019).

A well-constructed IoT architecture will, according to Xie *et al.* (2019), ensure that various objects within an automated system are able to communicate and exchange real-time data and information among people and people, people and objects, and objects and objects. Data mining is required to enhance such communication by analysing and processing large data/information repositories to discover potentially useful information (Chen 2019). Data mining can be used in smart academic libraries to collect data from library collections and users to create patron-driven acquisition and recommendation resources within library holdings to users. Gul and Bano (2019) are of the opinion that data mining is imperative in providing individualised intelligent smart library services based on knowledge of user needs and interests.

Contextualised within the access and discovery layer, Yan *et al.* (2018) propose that privacy issues be considered and built into the administration and authentication of library services and resources. The authors propose three layers of privacy, namely edge computing, fog computing, and cloud computing. Edge computing is required to link all objects with RFID tags with spyware to protect devices from security attacks. Fog computing comprises software defined networking controlling clusters, stored on application servers, where data is processed (Zhuang 2021). This level of security provides a low latency, high-quality service, to detect and limit attempts to access objects that are not available via the internet. It is only once objects are made accessible via the cloud computing space, that such data and information become detectable and discoverable. Security measures through, for example honeypots, should be programmed into the cloud computing space to prevent unauthorised access. It is also from this cloud computing space, where users or objects can discover data and information which are related to other objects available via the IoT. In this way the cloud computing space becomes the gateway to ensure access to library resources and services. According to Martin (2020), cloud computing is the best option for smart libraries in the digital environment to become sources of collaboration, to expound research, teaching, and learning opportunities. The aim of this final layer is to enhance discovery, to ensure that data and information transmitted via objects, and saved on networks become accessible to cater for individual user needs (Gul & Bano 2019).

Creating Smart Academic Libraries through the Internet of Things: Interactive Possibilities

Schöpfel (2018) proposes that smart academic libraries can be categorised as libraries that are well-performing in a forward way as information hubs that aim to provide access to information, so that individuals can explore and identify intelligent solutions to improve their academic and lifelong learning progression. Once libraries adopt IoT technologies and the interoperability of data exchange and service, the offering of alternative access to services and resources will improve (Jiang *et al.* 2019). This requires the realisation of full data exchange through an integrated combination of the four dimensions proposed by the conceptual relatives theory, namely smart technologies, smart people, smart services, and smart governance. As explained by Min (2014), the importance of these dimensions to expound the theoretical model offers a holistic approach to consider possibilities towards ensuring that academic libraries offer opportunities to support teaching, learning, and research within vastly changing higher education environments.

Related to the first dimension of *smart technologies*, Gul and Bano (2019) explain that emerging technologies are a core component of a smart library. Technology tools should support web access, the personalisation of the library environment, smart searching in natural language (what users mean rather than what they say), and smart detection of knowledge through journal metrics and impact factors. Advanced technology founded on the premise of advanced internet functionalities, intelligent processing technology, cloud computing, and virtual universal technology linked to the IoT, form the foundation of converting libraries to smart academic libraries (Mohammadi 2019). As an example of achieving intelligence within the smart academic library, Yusuf, *et al.* (2019) propose the use of BluuBeam technology, which sends location-triggered information to mobile devices to assist users in searching for resources and expand their interests with contextual hints. The utilisation of BluuBeam technology offers vast opportunities for smart academic libraries to create structures where users can engage more actively with information resources. Linked to RFID interoperability, BluuBeam allows individuals and organisations to create, engage, and share new or existing content.

Similarly, social media can be used to further expand the engagement with smart library resources. Through platforms such as Facebook and Twitter, users can become creators of information, which is key within the context of the IoT, to expand the communication between objects and objects, objects and people, and people and people (Makori & Mauti 2016). Information available via existing social media can also be used to build and create connections with academic communities, by sharing information related to new resources and upcoming training endeavours.

In addition, innovative technologies can bring forth a vast array of new services. Mohammadi (2019) explains that innovative technologies can include the utilisation of a bookBot (robotic book delivery system) or virtual library simulation that assists the user to navigate virtually through the library via their mobile device. The use of AI technologies can expand opportunities related to user handling, networking, and communication (Gul & Bano 2019). As AI technology can think and act like a human without the manpower, AI tools such as robots can be used to offer virtual assistance to users, explore and connect content on behalf of users, and monitor the quality of material available in a smart academic library collection. Cao *et al.* (2017) refer, for example, to the library robot Map Treasure, which is used to inform readers of the precise shelf location of a book, updated in real time. Utilising AI for tasks such as accessing sources on behalf of users is not only cost effective in terms of time, but also spares human and material resources.

In instances where users visit library buildings, pressure pad sensors and wireless sensor networks can be used to obtain relevant information on the interests of users. Such information can be used to build a profile for each user. Pressure pad sensors are thin pad sensors enabled with Wi-Fi technology to record the movement of users in particular aisles (Mohammadi 2019). Linked to the pressure pads, wireless sensor network devices can track the movement of users through the library. Combining this information within the sensor network to obtain information on collection interests can provide much needed information towards collection development (Nag & Nikam 2016). Knowledge about the profile of individual users can, according to Makori (2017), also be used to supply users with instant update alerts on information products and services. Linked to IoT, smartphones can be used to provide users with instant alerts on new arrivals, the reservation of material, and the location of resources on shelves.

As the second dimension, *smart people* (information professionals and users) are required to ensure the effective utilisation of technology tools to execute and engage in smart library activities. As the development of smart libraries are reliant on people, well-trained, professional, and technologically savvy staff are at the core of smart library realisation (Cao *et al.* 2017). Similarly, users who can utilise technology optimally, are imperative to ensure that smart library services and resources are used towards promoting academic endeavours (Fernandez 2015).

In terms of smart library staff, Yusuf *et al.* (2019) explain that enhanced awareness and increased professional training in the technologies related to the IoT, are imperative to provide information professionals with the attributes required to offer enhanced services that cater for the needs of users within higher education institutions. Makori and Mauti (2016) elaborate that IoT technologies have transformed the role of information professionals, who are now required to be proficient in the use of technology tools such as website development, the use of educational games, simulations, video conferencing, the mobile exchange of information and webometrics, aimed at integrating information from the public web as part of the resources offered by academic libraries (Cao *et al.* 2017). Jadhav and Shenoy (2020) argue that smart information professionals must not only possess the skills to apply the IoT technology effectively, but also show insight and commitment to continually focus on technology advancements that may be needed to offer improved smart library services and access to resources.

Smart library users are needed to ensure that the library services and resources based on IoT technologies are fully used. Cao *et al.* (2017) state that library users can be divided into three categories: Novice users, urgent-need-of-information users, and senior users. Especially in the case of novice and urgent-need-of-information users, extensive training is required to not only introduce library services and resources to these users, but also the extent to which technology can be used to assist them in engaging with smart library services and resources. For these users, bots can be made available to provide quick answers to frequently asked questions. Users can be trained through the use of animation games with further support offered through microblogging. Alagumalai and Natarajan (2020) emphasise the importance of library users to engage in information literacy and digital information literacy training. Through video displays, virtual library tours, social media engagements, video conferencing, and interactive library website information, basic and advanced information and digital literacy programmes can be offered to expand the knowledge and understanding of users on the use of smart library services (Makori 2017).

The third dimension relates to *smart services* that are highly personalised, computer-aided, and focused on knowledge sharing across media resources (Schöpfel 2018). Jadhav and Shenoy (2020) indicate that smart services are influenced by technological innovations aimed at building and exchanging smart library assets, as well as the offering of smart interoperable and interconnected library services. Alagumalai and Natarajan (2020) propose that academic libraries can utilise IoT technologies to offer a variety of smart library services. Gupta and Singh (2018), as well as Sheeja and Mathew (2019) suggest that smart services may include virtual tours and shelve guides from users' favourite lists and alerting services. Smart services relate to personalised services, library orientation and information literacy services, smart circulation control, and inventory control services.

Related to smart collection management and inventory control, RFID tags linked to enterprise resource management software, can be used to enable information professionals to assess the extent of a collection available to users (Gul & Bano 2019). The library collection processes and activities can be executed by notifying users of available new resources or resources that might link to their interests. The RFID tags can also be used to ensure the easy access of resources for inventory control. Android mobile readers can be used to read the RFID tags to offer a detailed list of resources available on library shelves. In this way the IoT can be used to improve the process of stock verification (Sheeja & Mathew 2019).

In terms of conducting searches for information linked to library resources and beyond (open web and resources available via other institutions), cloud-based access apps can be made available to users. Apps such as Deepknowledge, VitalSource, and the Bookshelf-mobile can be made available to users via the website of an academic library to promote remote-based access to information resources (Jadhav & Shenoy 2020). The use of such apps is important to provide users with access to advanced inquiry systems, automated lists of literature selection, and anti-plagiarism services. To promote real-time access to information resources, smart academic libraries may also increase their access to electronic textbooks instead of printed copies. Textbooks are being procured through publishers such as McGraw Hill, Pearson, and VitalSource. Such electronic textbooks are accessed through the internet, using metadata to promote ease of identification and access, being ready to use anywhere and anytime (Cao *et al*. 2017).

As explained by Wójcik (2016), personalised services through the virtualisation of information resources can be offered with the help of the IoT. The virtualisation of information resources linked to interests and needs obtained about users via BluuBeam, can for example assist information professionals to rate preferred resources and to determine the best approach to promote and market underutilised resources. The IoT can be used to deliver contextual hints and information resources to support the extended use of varied information resources. The IoT can communicate detail about new additions in their area of interest to users and send them notifications about searches completed through catalogues. Data visualisation provides information on the use of information resources, which can be used as planning aids and decision-making on services and resources to offer to users (Makori 2017).

User information services can also be improved by using IoT technologies. Online help desks, where bots are used to supply generic information, can be created by using IoT technologies to solve users' queries remotely. For more advanced queries, AI tools can be used that are able to analyse and interpret the queries of users and to provide help through remote engagement (Sheeja & Mathew 2019). Similarly, virtual reference information services can be offered through platforms such as e-mails, instant messaging, and chat discussions. Makori (2017) refers to the Chatbot, which is a 24-hour virtual reference service that responds to users' queries without any human intervention. Users can ask questions in a web-based environment and the robot answers the questions in both voice and text. The use of data mining in libraries is of particular importance in the context of offering quality reference services (Gul & Bano 2019). Through data mining, large repositories of information are analysed, and potentially useful information discovered. Data mining is necessary because of the growing volumes of information and limitations of human analysis. Data mining therefore becomes an important service in providing individualised intelligent information, based on user needs within an academic context.

Smart circulation control can be achieved by utilising IoT technologies to alert users about their current holdings, overdue dates, and fines. Through smart circulation control where android-based mobile readers are used, users can borrow, return, and renew library materials from anywhere and at any time. The android-based system provides each user with an authenticated ID and password to log into the system. This enables privacy and security, as only the user with the specific ID and password can access details related to their borrowing history (Sheeja & Mathew 2019). Self-check-in, self-check-out, overdue reminders, online fine payments, and minimising the misplacement of books can all be executed using IoT technologies. In addition, Gul and Bano (2019) propose that book delivery drones can be used in future to deliver information resources to users. Especially within the context of the Covid-19 pandemic, book delivery drones could be used to supply users with access to printed resources, where electronic versions are not available. Drone technology links mobile devices to users and their bibliographic information, to determine where books should be delivered. The value of book delivery drones is that they can be used to deliver books to disabled users who may not be able to visit a library building. In this way, varied technologies can be used to enhance the way in which smart libraries offer services and access to resources to users.

As the final dimension, *smart governance* relates to aspects such as utilising the IoT to create transparent library administrative systems, according to Jadhav and Shenoy (2020), by involving users in decision-making and focusing on increased social coherence. Schöpfel (2018) explains that smart governance includes components such as collaboration, cooperation, partnerships, engagement, and participation. At the heart of smart governance is the community and the use of technology to encourage active and engaged communities within the activities of smart academic libraries. IoT technologies are to be used to encourage user participation in decision-making, optimising administration procedures, real-time analysis of big data on library usage, and embeddedness of smart academic libraries in the social and cultural environment of the organisation with which it is associated. As explained by Okwu (2021), systems designed to facilitate collaboration, engagement, and improved access to information and service delivery, are imperative to support smart governance. Governance is a critical factor in any endeavour to introduce and expand academic library services through the application of the IoT. Key stakeholders must buy in on the endeavour to create smart academic libraries through IoT technologies, as these stakeholders have a high interest in the success of such endeavours. The emphasis of smart governance is therefore on collective intelligence, where shared responsibilities between staff, users, and other stakeholders promote transparency and accountability. Galve-Montore (2019) states that such shared responsibilities can be achieved through social media, automation of omnichannel marketing, screen experience evaluations, and the sharing of management dashboard platforms through library web interfaces. Okwu (2021) adds that smart governance is necessary to provide better and faster academic library services through digital technology, embedded systems, AI, and the IoT. Thus, the governance of smart academic libraries is built around smart people, smart systems, and smart technologies to provide transparent and interactive academic library services.

Conclusion

Makori and Mauti (2016) emphasise the need for advanced information and technological infrastructures to support education and training needs within higher education institutions. To manage the digital environment, information professionals must obtain knowledge, skills, and competencies in electronic resource planning systems, social computing, business entrepreneurship practices, proactive marketing, collaboration and partnership, leadership skills, and digital literacy skills. Higher education institutions and university libraries need effective planning strategies for the implementation of IoT technologies, to promote smart academic libraries that render interactive and innovative services. As the centre of information sharing, the important role of smart academic libraries is to disseminate information and mediate the access to information. To facilitate this role, the IoT can support the facilitation of improved and innovative smart academic library services related to information access, information sharing, circulation, security, and self-serving. The IoT has unlimited potential for libraries, but it requires proper planning and effective implementation of technologies to bring true value to communities.

The information provided in this chapter aimed to clarify the architecture related to the IoT that should be considered when moving academic libraries from hybrid to digital to smart libraries. The chapter also provided a theoretical model as a foundation to explore possibilities wherein IoT technologies could be utilised to support the development and expansion of smart academic library services. It is now time for information professionals to further explore ways in which the IoT can be used to promote change, innovation, and advanced access to library services and resources. More research into the utilisation of new technology tools associated with the IoT is required, as well as ways in which the IoT can be applied to create smart academic libraries within the South African and African context. Research related to funding, training of smart people, and the utilisation of mobile technology to extend smart library services, is also required. To conclude:

> *The twenty-first century has demonstrated to be an era of digital revolution which has paved the way for smarter opportunities in the world including smart libraries. Now one can visualise libraries not as places, but as platforms that have redesigned the technologies, services and the humans adherent to them (Gul & Bano 2019).*

References

Alagumalai, E. & Natarajan, R. 2020. Internet of things and libraries: An empirical study of selected educational institutions in United Arab Emirates. *Library Philosophy and Practice* (e-journal). 3912. Available at: https://digitalcommons.unl.edu/libphilprac/3912/. (Accessed on 26 August 2021.)

Bhatia, S. & Wright de Hernandez, AD. 2019. Blockchain is already here: What does that mean for records management and archives? *Journal of Archival Organisation* 16(1):75-84. https://doi.org/10.1080/15332748.2019.1655614

Bunz, M. & Janciute, L. 2018. *Artificial intelligence and the Internet of Things*. Available at: https://library.oapen.org/bitstream/handle/20.500.12657/29709/UWP-025-bunz.pdf?sequence=1&isAllowed=y. (Accessed on 26 August 2021.)

Cao, G., Liang, M., & Li, X. 2017. How to make the library smart? The conceptualisation of the smart library. *The Electronic Library* 36(5):811-825. https://doi.org/10.1108/EL-11-2017-0248

Chen, Y. 2019. Information integration in libraries. *Library Hi Tech* 38(1):210-219. https://doi.org/10.1108/LHT-11-2017-0232

Chisita, CT. & Ukwoma, SC. 2021. Rethinking academic library spaces amidst the COVID-19 pandemic in South Africa: Preparing for the future. *Information Discovery and Delivery* 49(2). https://doi.org/10.1108/IDD-07-2020-0087

CHELSA (Committee of Higher Education Libraries of South Africa). 2019. Academic library standards framework. Available at: https://chelsa.ac.za/wp-content/uploads/2020/08/academiclibrarystandardsframework.pdf. (Accessed on 26 August 2021.)

CHELSA (Committee of Higher Education Libraries of South Africa). 2020. Report on COVID-19 survey. Available at: https://chelsa.ac.za/wp-content/uploads/2020/08/covid19survey.pdf. (Accessed on 26 August 2021.)

Cooper, J. & James, A. 2009. Challenges for database management on the Internet of Things. *IETE Technical Review* 26(5):320-329. https://doi.org/10.4103/0256-4602.55275

Costa, F., Genovesi, S., Borgese, M., Michel, A., Dicandia, FA., & Manara, G. 2021. A review of RFID sensors, the new frontier of Internet of Things. Available at: https://res.mdpi.com/d_attachment/sensors/sensors-21-03138/article_deploy/sensors-21-03138-v2.pdf. (Accessed on 26 August 2021.) https://doi.org/10.3390/s21093138

Cox, C. 2020. Changed, changed utterly. Available at: https://www.insidehighered.com/views/2020/06/05/academic-libraries-will-change-significant-ways-result-pandemic-opinion. (Accessed on 26 August 2021.)

Creswell JW. & Creswell JD. 2018. *Research design: Qualitative, quantitative and mixed method approaches*. 5th ed. Los Angeles: Sage.

Das, JM. 2017. Role of academic libraries in higher education: An Indian perspective. Available at: https://www.researchgate.net/publication/337060066_Role_of_Academic_Libraries_in_Higher_Education_an_Indian_Perspective. (Accessed on 26 August 2021.)

Du Plooy-Cilliers, F. 2014. Research paradigms and traditions. In Du Plooy-Cilliers, F., Davis, C., & Bezuidenhout, RM. (Eds.): *Research Matters*, 18-36. Cape Town: Juta.

Farzand, AA. & Saleem, QUA. 2020. Open access resources as an opportunity for academic libraries during pandemic: A study. *Library Philosophy and Practice* (e-journal). 4743. URL: https://digitalcommons.unl.edu/libphilprac/4743.

Fernandez, P. 2015. Through the looking glass: Thinking through the Internet of Things. *Library Hi Tech News* 5:4-7. https://doi.org/10.1108/LHTN-05-2015-0035

Galve-Montore, C. 2019. Smart cities: An opportunity for libraries to be part of future urban management. *IFLA WLIC*. Available at: http://library.ifla.org/2479/7/100-galve-en.pdf. (Accessed on 26 August 2021.)

Ghosh, I. 2020. *AIoT:* When artificial intelligence meets the Internet of Things. *Visual Capitalist*. 12 August 2020. Available at: https://www.visualcapitalist.com/aiot-when-ai-meets-iot-technology/. (Accessed on 26 August 2021.)

Gul, S. & Bano, S. 2019. Smart libraries: An emerging and innovative technological habit of the 21st century. *The Electronic Library* 37(5):764-779. https://doi.org/10.1108/EL-02-2019-0052

Gupta, J. & Singh, R. 2018. Internet of things (IoT) and academic libraries: A user friendly facilitator for patrons. 5th International Symposium on Emerging Trends and Technologies in Library and Information Services:71-74. https://doi.org/10.1109/ETTLIS.2018.8485234

Hou, H., Yang, J., Chen, Y., & Yu, M. 2019. A material delivery system built on Internet of Things and the role of libraries. *Library Hi Tech* 38(1). https://doi.org/10.1108/LHT-11-2017-0253

Hoy, MB. 2015. The 'Internet of Things:' What it is and what it means for libraries. *Medical Reference Service Quarterly* 34(3):353-358. https://doi.org/10.1080/02763869.2015.1052699

IFLA (International Federation of Library Associations and Institutions). 2020. Covid-19 and the global library field. *IFLA*. 13 October 2020. Available at: https://www.ifla.org/covid-19-and-libraries#services. (Accessed on 26 August 2021.)

Jadhav, DK. & Shenoy, D. 2020. Measuring the smartness of a library. *Library and Information Science Research* 42(3). https://doi.org/10.1016/j.lisr.2020.101036

Jiang H., Xu, H., Zhao, S., & Chen, Y. 2019. Selection of technology standardization mode for libraries based on game theory. *Library Hi Tech* 38(1):233-250. https://doi.org/10.1108/LHT-11-2017-0248

Kincheloe, JL. 2004. Introduction: The power of the bricolage: Expanding research methods. In Kincheloe, J. & Berry, K. (Eds.): *Rigour and complexity in educational research: Conceptualising the bricolage*, 1-22. New York: Open University Press. URL: http://www.journal.mai.ac.nz/sites/default/files/MAIJrnl_6_2_Cardno_02_Final.pdf.

Liang, X. & Chen, Y. 2018. Libraries in Internet of Things (IoT) era. *Library Hi Tech* 38(1). https://doi.org/10.1108/LHT-11-2017-0233

Liu, Y. & Chou, YJ. 2018. Big data, the Internet of Things and the interconnected society. *Telecommunications Policy* 42:277-281. https://doi.org/10.1016/j.telpol.2018.03.014

Lueth, KL. 2021. IoT 2020 in review: The 10 most relevant IoT developments of the year. *Analytics*. 12 January 2021. Available at: https://iot-analytics.com/iot-2020-in-review/. (Accessed on 26 August 2021.)

Mahesh, GT. 2016. Changing roles of academic libraries in quality higher education. Paper delivered at higher education in India – New paradigms and challenges Conference, 137-142. Available at: https://www.researchgate.net/publication/335320673_Changing_Roles_of_Academic_Libraries_in_Quality_Higher_Education. (Accessed on 26 August 2021.)

Makori, EO. 2017. Promoting innovation and application of the Internet of Things in academic and research information organisations. *Library Review* 66(8/9):655-678. https://doi.org/10.1108/LR-01-2017-0002

Makori, EO. & Mauti, NO. 2016. Digital technology acceptance in transformation of university libraries and higher education institutions in Kenya. *Library Philosophy and Practice* (e-journal). Available at: https://www.semanticscholar.org/paper/Digital-Technology-Acceptance-in-Transformation-of-Makori-Mauti/221089a7f4f34f53d2dff5e442fee1b0f7c82d1e. (Accessed on 26 August 2021.)

Martin, L. 2020. *Cloud computing, smart technology and library automation*. University of Arkansas: Pine Bluff. URL: https://www.igi-global.com/chapter/cloud-computing-smart-technology-and-library-automation/255387. https://doi.org/10.4018/978-1-7998-4742-7.ch006

Martzoukou, K. 2021. Academic libraries in Covid-19: A renewed mission for digital literacy. *Library Management* 42(4/5):1-16. https://doi.org/10.1108/LM-09-2020-0131

Mehmood, Y., Ahmad, F., Yaqoob, I., Adnane, A., Imran, M., & Guizani, S. 2017. Internet-of-Things-based smart cities: Recent advances and challenges. *IEEE Communications Magazine* 55(9):16-24. https://doi.org/10.1109/MCOM.2017.1600514

Min, S. 2014. The research on the development of smart library. *Applied Mechanisms and Materials* 571-572:1184-1188. https://doi.org/10.4028/www.scientific.net/AMM.571-572.1184

Mohammadi, M. 2019. IoT: Applied new technology in academic libraries. Conference paper. Available at: https://www.researchgate.net/publication/333634140_IOT_Applied_New_Technology_in_Academic_Libraries. (Accessed on 26 August 2021.)

Moyane, SP., Dube, L., Nkomo, N., & Ngulube, P. 2020. Competitive intelligence as a coping strategy for academic libraries in South Africa. *Library Management* 41(6):593-606. https://doi.org/10.1108/LM-05-2020-0083

Mulloni, V. & Donelli, M. 2020. Chipless RFID sensors for the Internet of Things: Challenges and Opportunities. *Sensors* 20(7). 29 pages. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7181130/. https://doi.org/10.3390/s20072135

Nag, A. & Nikam, K. 2016. Internet of Things applications in academic libraries. *International Journal of Information Technology and Library Science* 5(1):1-7.

Nicholson, DR. 2020. Covid and copyright – impact on education and libraries in South Africa. *InfoJustice*. 18 July 2020. Available at: https://infojustice.org/archives/42517. (Accessed on 26 August 2021.)

Okwu, E. 2021. Academic libraries, science and technology development and the Nigerian smart city initiatives (NSCI): Issues, roles, and challenges. *Library Philosophy and Practice I* (e-journal). Available at: https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=9789&context=libphilprac. (Accessed on 26 August 2021.)

Pujar, SM. & Satyanarayana, KV. 2015. Internet of Things and libraries. *Annals of Library and Information Studies* 62(3):186-190. Available at: https://www.researchgate.net/publication/286224381_Internet_of_things_and_libraries. (Accessed on 26 August 2021.)

Rajapaksha, NR. 2020. RFID tags for IOT (Internet of Things). http://dx.doi.org/10.13140/RG.2.2.11307.67362

Raju, R. & Claassen, J. 2017. The changing landscape of academic libraries in South Africa from subject librarianship to functional librarianship. *IFLA*. 19 June 2017. https://blogs.ifla.org/arl/2017/06/19/the-changing-landscape-of-academic-libraries-in-south-africa-from-subject-librarianship-to-functional-librarianship-by-reggie-raju-and-jill-claassen/. (Accessed on 26 August 2021.)

Raju, R., Claassen, J., Adam, A., Dangelo, A., Keraan, S., Mostert, N., & Vonk, S. 2018. Restructuring for relevance: A paradigm shift for academic libraries. *Library Management* 39(6):418-429. https://doi.org/10.1108/LM-06-2017-0062

Schöpfel, J. 2018. Smart libraries. *Infrastructures* 3(43):1-11. https://www.researchgate.net/publication/328037691_Smart_Libraries. (Accessed on 26 August 2021.) https://doi.org/10.3390/infrastructures3040043

Sheeja, NK. & Mathew, SK. 2019. Internet of things (IoT) in academic libraries. Conference paper. Available at: https://bit.ly/370VU7a. (Accessed on 26 August 2021.)

Shepard, P. 2018. Configuring RFID tags to work as low-power sensors. *EE Power*. 22 June 2018. Available at: https://eepower.com/news/configuring-rfid-tags-to-work-as-low-power-sensors/#. (Accessed on 26 August 2021.)

Simović, A. 2018. A big data smart library recommender system for an educational institution. *Library Hi Tech* 36(3):498-523. https://doi.org/10.1108/LHT-06-2017-0131

Wójcik, M. 2016. Internet of Things – potential for libraries. *Library Hi Tech* 34(2):404-420. https://doi.org/10.1108/LHT-10-2015-0100

Wu, E. 2012. Smart library and the construction of its service model. *Information and Documentation Services* 33(5):102-105.

Xie, Y., Liu, J., Zhu, S., Chong, D., Shi, H., & Chen, Y. 2019. An IoT-based risk warning system for smart libraries. *Library Hi Tech* 37(4):918-932. https://doi.org/10.1108/LHT-11-2017-0254

Yan, Q., Huang, W., Luo, X., Gong, Q., & Yu, R. 2018. A multi-level DDoS mitigation framework for the industrial internet of things. *IEEE Communications Magazine* 56(2):30-36. https://doi.org/10.1109/MCOM.2018.1700621

Yee, J. & Bremner, C. 2011. Methodological bricolage: What does it tell us about design? Doctoral Design Education Conference, 23-25 May 2011. Hong Kong: Hong Kong Polytechnic. Available at: https://apps.crossref.org/SimpleTextQuery. (Accessed on 26 August 2021.)

Yu, K., Gong, R., Sun, L., & Jiang, C. 2019. The application of artificial intelligence in smart library. *Atlantis Press*. Available at: https://www.atlantis-press.com/article/125919402.pdf. (Accessed on 26 August 2021.)

Yusuf, F., Ifijeh, G., & Owolabi, S. 2019. Awareness of internet of things and its potential in enhancing academic library service delivery in a developing country. *Library Philosophy and Practice* (e-journal). 12 pages. Available at: https://core.ac.uk/download/pdf/231923034.pdf. (Accessed on 26 August 2021.)

Zhuang, Y. 2021. Optimization of the personalized service system of university library based on Internet of Things technology. *Wireless Communication and Mobile Computing.* 10 pages. https://doi.org/10.1155/2021/5589505

Prof Lorette Jacobs is Associate Professor in the Department of Information Science, College of Human Sciences at the University of South Africa.