Applications of metaverse-related technologies in the services of US urban libraries

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Abstract

Purpose – The purpose of this paper is to understand the applications of metaverse-related technologies in US urban libraries, explore excellent cases of US urban libraries' practices in using metaverse-related technologies to serve patrons and try to find the factor that may affect the application of metaverse-related technologies in libraries at this stage.

Design/methodology/approach – To gather information about how and whether libraries use metaverse-related technologies such as three-dimensional (3D) technology, radio frequency identification (RFID), virtual reality augmented reality (AR) and artificial intelligence (AI) in their services. Firstly, the authors visit 150 US urban library websites that are members of the Urban Libraries Council. Secondly, the authors calculate the proportion of services provided by urban libraries that use metaverse-related technologies and introduce outstanding cases. Lastly, the authors discuss the factors that influence the application of metaverse-related technologies in urban libraries in the United States based on data published by the Institute of Museum and Library Services.

Findings – Metaverse-related technologies have been widely used in US urban libraries, but there are differences in the popularity of the applications of different technologies. In all, 84% of libraries use 3D technology, mainly in 3D printing services and 3D model building services; 76% of libraries use virtual and augmented reality technologies in their services, mainly concentrated in head-mounted VR device experiences, AR device experiences, virtual tours and virtual exhibitions; 62% of libraries use Internet of things (IoT) technology, mainly in self-checkout machines and book location services. However, AI technologies are less used in libraries, with 28% of libraries mentioning the applications of AI in their services, mainly focusing on intelligent search, virtual assistants and robot librarians. In addition, this study finds that library operating expenditures and population served do not affect the application of metaverse-related technologies in libraries.

Originality/value – This paper provides updated statistical data on the use of metaverse-related technologies in US urban libraries and aims to help library managers understand the overall applications and best practices. With this as an inspiration, they could formulate corresponding development plans to better serve their communities with metaverse-related technologies.

Keywords Metaverse, Urban libraries, 3D technology, RFID, Virtual reality, Survey, USA

Paper type Research paper

Introduction

In recent years, the topic of the metaverse has been rapidly gaining attention and penetrating all spheres of society. This is evidenced by the Covid-19 pandemic, which saw a significant increase in engagement in online activities. People longed for online experiences that could replicate the real world. To some extent, the online virtual concert of Fortnite and the online academic conference of Animal Crossing Artificial Intelligence reflect the demand for highly simulated online experiences during the pandemic. Additionally, the events, such as the initial public offering (IPO) of Roblox, the first metaverse stock and the rebrand of Facebook as Meta with its development keystone shifting to the metaverse, have amplified people's

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interest in the metaverse. With great potential to shape lives and society, the metaverse will also drastically alter urban libraries.

Urban libraries have made some practical explorations in integrating with the metaverse. In the early 21st century, urban libraries were among the first to explore the metaverse through Second Life. After 20 years of development, metaverse-related technologies have become increasingly mature and are being used in libraries. Urban libraries have begun to experiment with utilizing metaverse-related technologies for immersive services. However, several questions remain to be addressed. For instance, what services are these technologies presently used for? What are the best examples of implementation? Do the library's operating expenditures and the population they serve affect the applications of metaverse-related technologies to their services? To answer these questions, this paper investigates the type, number and nature of services with metaverse-related technologies provided by urban libraries in the United States to understand the applications of key technologies involved so that librarians can better understanding of the integration between the metaverse and libraries.

Literature review

The metaverse concept first appeared in Neal Stephenson's science fiction novel *Snow Crash* in 1992, where it was depicted as a virtual world as opposed to the real one. Users could enter this virtual world with equipment such as head-mounted VR glasses. As the first person who designed the metaverse regarding computer communication, Jaynes *et al.* (2003) propose in "*Proceedings of the workshop on Virtual environments 2003*" that the metaverse is a collection of inexpensive, self-configuring and immersive environments. At the same time, the emergence of Second Life is regarded as an initial form of the metaverse and aroused interest in many scholars. Kumar *et al.* (2008) argue that the operation of Second Life places high demands on servers, clients and the network. As virtual worlds evolve to support more users, types of interactions and realism, these demands will increase by orders of magnitude. In response to increasing hardware requirements, Davis *et al.* (2009) summarize the technological capabilities required for the metaverse, which include communication, rendering, interaction and team process. Regarding the division of metaverse technology capabilities, Ding and He (2021), in his book *Metaverse*, divides metaverse-related technologies into four scopes: construction, mapping, interaction and application. Among them, the construction technologies can form and continuously optimize the digital space in the metaverse, the mapping technologies can connect the virtual world with the real world, the interaction technologies can allow users to travel freely between the real and virtual world and the application technologies can provide users with a realistic human-computer interaction experience. Furthermore, some scholars have investigated applications of metaverse-related technologies of 3D, IoT, VR and AR, and AI in libraries and achieved encouraging initial research results.

Existing studies have given much attention to the application of 3D technology in libraries, but limitations are also apparent. Massis (2013) finds that 3D printing joining the available technology selections in libraries allows patrons to create and further develop their skills, explore and potentially innovate in a welcoming environment of intellectual stimulation and experimentation. Moorefield-Lang (2014) describes the implementation of 3D printing and makerspaces in various library settings and explores commonalities across 3D printing technologies and makerspace learning areas. The research lays the foundation for further exploration of how 3D printing and makerspace could be a part of library services. Radniecki (2017) shares how one academic library provides services and resources to help patrons acquire the necessary 3D modeling skills to design and successfully 3D print new knowledge objects. However, despite extensive research on using new technologies in library

makerspaces, little attention has been paid to the skill and knowledge literacy required to use these emerging technologies. Radniecki's research provides theoretical support for other academic libraries to develop nontraditional library skill-learning programs. Bossart *et al.* (2019) evaluate the sustainability of an academic library 3D printing service, finding that it originally intended to introduce students to emerging technology and expanded to support teaching, learning and research, allowing faculty, staff and students to engage in the maker movement. These studies show the gradual maturation of 3D technology in libraries. However, most studies focus on designing 3D technology in library applications under ideal conditions and neglect to investigate 3D technology in library applications in real-world scenarios.

To figure out how VR and AR technologies work in libraries, Liarokapis and Conradi (2007) design a mobile navigation patron interface that uses VR and computer graphics to present 3D maps and textual information. This is an early attempt to provide patrons with a VR scenario experience. Siriborvornratanakul (2016) examines the critical triggers and trends related to VR headsets from 2014 to 2016. The study proposes to combine the recently popular heart rate monitoring wearables with VR headsets to open up new communication channels and application scenarios between headsets and wearers. Choi and Kim (2017) suggest a plan to provide a virtual viewing experience for museum visitors by combining beacons and HMDs (head-mounted displays). Pouke *et al.* (2018) design an immersive VR interface for a public library in which a mirror-world-like virtual copy of the physical library is blended with imaginary virtual fantasy layers into a hybrid space for library content. Siriborvornratanakul (2018) designs a software computing paradigm based on a mobile projector AR system, and the study puts forward an AR solution to help patrons improve their experience. Siriborvornratanakul (2019) summarizes the modern AR world from the early 2000s. Based on AR research and community experience, the modern AR world has been summarized and divided into five waves of trends. Lu (2021) designs a new library literature promotion system using mobile virtual reality technologies, which could timely understand the patrons' current information orientation and establish a personal information database. O'Dwyer *et al.* (2021) point out the application of augmented reality in providing cultural heritage and examine the use of augmented reality technology in the context of cultural heritage to enhance the attractiveness, interest and ease of use of AR storytelling strategies. These studies focus on designing virtual and augmented reality technologies for library applications. Some scholars also investigate the application status of virtual reality and augmented reality in libraries. Greene and Groenendyk (2021) survey the websites of the Association of Research Libraries (ARL) members and find that a significant number of ARL-member libraries do offer VR technology, while AR technology is much less widespread. Although scholars have investigated and designed the use of virtual and augmented reality in libraries, little research has focused on the factors that influence the application of these technologies in libraries.

The application of IoT in libraries has also attracted the attention of scholars. Pujar and Satyanarayana (2015) claim that the future of IoT in libraries seems to be robust looking into the developments in this sector. IoT, once fully evolved, may bring dramatic changes to the way how libraries function and provide services to their patrons. Engard (2015) cites several cases of IoT used in libraries, including using RFID technology for self-checkout, using sensors to collect floor pressure information to monitor patrons' movements and provide them with contextual information, and the use of wristbands as library cards. Liang and Chen (2018) report on the current state of research on IoT applications in libraries, describe the challenges that IoT applications face in libraries and discuss the future directions for libraries to adopt IoT. Libraries could provide services to patrons anytime and anywhere via a large number of sensors and integrate a decision support system with a data analysis function. Bayani *et al.* (2017) propose an implementation

framework for renovating conventional library systems into smart online library schemes using IoT. These studies explore the prospects of IoT technology in libraries and show typical cases of IoT applications in libraries. However, there is a lack of macro-level surveys of library IoT application data.

Several studies explore the evolution of artificial intelligence in library applications. Resnick and Clark (2009) describe the further evolution of electronic resources access support in the Texas A&M University Libraries, with recommendations for incorporating electronic resources support into virtual reference services. This gives some clues for later AI-assisted librarians in virtual reference services. Yao *et al.* (2015) introduce a participatory library service based on AI. According to their hypothesis, AI technologies and various technologies that facilitate the use of library resources are combined in the new mobile and social networking environments to provide innovative real-time virtual reference services. Yoon *et al.* (2021) use an online survey questionnaire to understand how AI and related technologies are currently being utilized in public and academic libraries, and how librarians perceive the adoption of new technologies in their relative libraries. They believe that the field of library science is still working to integrate new technologies into practice, but not at the rate needed to keep up with new advancements. These studies seem to show that the application of AI in library services is still in its infancy. However, the existing research lacks the investigation of AI applications in libraries, and further research is needed for specific application data.

From the above review, the authors find a certain basis and sufficient studies on the use of metaverse-related technologies in libraries. However, these studies are generally focused on the applications of a single technology. Moreover, most of the studies focus on theoretical research, exploring the prospect, feasibility and implementation framework of a particular technology in libraries, lacking the investigation of data on the application of metaverse-related technologies in libraries. This paper summarizes the research done so far and also takes the next step of providing a larger picture of how widespread the adoption of metaverse-related technologies is being used in urban libraries, as well as discussing the factors that influence the application of metaverse-related technologies in libraries. Through a series of surveys, the paper presents the current situation of the applications of technologies of 3D, VR, IoT and AI in members of the Urban Libraries Council, introduces typical cases and conceives the service form of metaverse libraries on this basis, to provide a certain theoretical reference for the deep integration between libraries and metaverse.

Research design

The authors select 150 libraries located in the United States from the members of the Urban Libraries Council released in 2022 (Urban Libraries Council, 2022) as survey objects. 3D, RFID, VR, AR and AI, which are relatively easy to be reflected in library services among metaverse-related technologies, are selected as the survey content. The survey was conducted from May 10 to August 19, 2022, and the relevant data were collected via website visiting, content analysis, social media interviews and so on.

The specific operation steps of the survey process are as follows: First, the authors visit the websites of the libraries under the survey one by one and enter keywords such as 3D, VR, AR, AI, RFID, virtual reality and artificial intelligence in the search box to search. For libraries without a search box on the website, the authors use the method of "keyword + site: a library website" to search on the Google search engine, and then check and record the search results. Secondly, the authors search for relevant information posted on the Facebook of the surveyed library as a supplement. Finally, the findings are verified and statistically analyzed. The survey form is shown in Table 1.

Name	3D technology 1.3D Printing 2.3D Model 3.Neither	RFID 1.RFID Book Positing 2.RFID Self-service Checkout 3.Neither	VR/AR 1.Virtual Tour 2. Virtual Exhibition 3.AR Facilities 4.VR Facilities 5.None	AI 1.Robot Librarian 2.Artificial Intelligence Reference 3. Smart Search 4. Others 5. None
Anchorage Public Library	1	2	5	1,4
Pima County Public Library	1,2	2	4	3
Scottsdale Public Library	1	3	4	5
Central Arkansas Library System	1	2	4	5
Alameda County Library	2	3	5	5
Berkeley Public Library	1	2	4	5
Carlsbad City Library	1,2	3	1	5
Contra Costa County Library	1,2	2	4	5
LA County Library	1	2	4	3
Los Angeles Public Library	1,2	2	1,3	2,3,4
Marin County Free Library	1,2	2	1,4	5
Oakland Public Library	1	2	5	5
Palo Alto City Library	1,2	3	1,4	1
Pasadena Public Library	1	3	2	5
San Diego County Library	1	2	5	5
San Diego Public Library	1,2	1,2	1,4	5
San Francisco Public Library	1,2	2	4	3
San José Public Library	1	2	1,4	1
San Mateo County Libraries	1	1	4	5
Santa Clara County Library District	1,2	2	1	3
Santa Clarita Public Library	1	3	4	5
Sonoma County Library	1	2	1,4	1,3
Sunnyvale Public Library	1,2	3	6	5
Anythink	1,2	2	1,4	1
Douglas County Libraries	3	2	4	3
Jefferson County Public Library	1	2	4	5
Poudre River Public Library District	1,2	1,2	3	5
Ferguson Library	1	2	4	5
Hartford Public Library	1,2	2	1,4	1
New Haven Free Public Library	1,2	3	1,4	5
DC Public Library	1	2	1	5
Broward County Library	1	3	4	5
Jacksonville Public Library	1	3	1,4	5
Mandel Public Library of West Palm Beach	1,2	3	4	5
Miami-Dade Public Library System	1	3	4	5
Palm Beach County Library System	2	2	4	3
Sarasota County Public Libraries	1,2	3	3	5
Tampa–Hillsborough County Public Library	1,2	2	3	5

(*continued*)

Table 1.
The list of the 150 urban libraries in the United States that were surveyed

	3D technology	RFID	VR/AR	AI
Athens Regional Library System	3	1,2	3,4	5
Fulton County Library System	1	2	1,4	5
Chattahoochee Valley Libraries	1,2	2	5	5
DeKalb County Public Library	1	2	5	5
Boise Public Library	1	2	4	3
Chicago Public Library	1,2	2	4	1
Skokie Public Library	1,2	2	3,4	3
Schaumburg Township District Library	1	2	4	5
Allen County Public Library	1	2	1	5
Carmel Clay Public Library	1	3	1,4	5
Evansville Vanderburgh Public Library	1	2	5	5
Hamilton East Public Library	1	2	4	5
The Indianapolis Public Library	1	3	5	5
Johnson County Public Library System	1	3	4	4
Lake County Public Library	1	2	5	3
La Porte County Public Library	1	2	1,3	1
Cedar Rapids Public Library	1	2	4	5
Johnson County Library	1	2	1	5
Olathe Public Library	1	2	4	5
Topeka and Shawnee County Public Library	1	2	4	4
Wichita Public Library	1	2	1,4	5
Lexington Public Library	1	3	1,3,4	5
Louisville Free Public Library	1	2	4	1
East Baton Rouge Parish Library	1	2	1	5
New Orleans Public Library	3	3	4	5
Shreve Memorial Library	1	1,2	1,3,4	5
Portland Public Library	1	3	2	5
Anne Arundel County Public Library	1	1,2	5	5
Baltimore County Public Library	3	3	5	5
Enoch Pratt Free Library	1	3	4	5
Howard County Library System	1	3	4	5
Montgomery County Public Libraries	1	2	3	5
Prince George's County Memorial Library System	1	3	1,4	5
Boston Public Library	1	3	5	5
Cambridge Public Library	1	3	3,4	5
Springfield City Library	1	3	1	5
Detroit Public Library	1	3	4	5
Grand Rapids Public Library	3	3	5	5
Kalamazoo Public Library	1,2	1	1,3	5
Kent District Library	3	3	1	5
Dakota County Library	1	3	4	5
Hennepin County Library	3	3	4	5
Saint Paul Public Library	1	3	3,4	4

Table 1. (*continued*)

	3D technology	RFID	VR/AR	AI
Kansas City Public Library	1,2	2	4	5
Mid-Continent Public Library	3	2	1	5
St. Charles City-County Library	3	2	1	3
St. Louis County Library	1	3	4	5
St. Louis Public Library	1	3	4	5
Do Space	1	3	4	5
Lincoln City Libraries	1	3	5	5
Las Vegas–Clark County Library District	1	2	4	3
Hoboken Public Library	1,2	1,2	1,4	5
Jersey City Free Public Library	3	3	1	3
Newark Public Library	3	3	1	5
Paterson Free Public Library	3	3	5	5
Albuquerque/Bernalillo County Library System	3	3	5	5
Brooklyn Public Library	3	1,2	1	5
New York Public Library	1	1,2	1,4	5
Queens Public Library	1	1,2	4	5
Rochester Public Library	1	2	2	4
Suffolk Cooperative Library System	3	1,2	5	5
Charlotte Mecklenburg Library	1	2	1,4	5
Durham County Library	1	2	4	5
Forsyth County Public Library	1	2	1,4	5
Greensboro Public Library	1	2	1	5
Cincinnati and Hamilton County Public Library	1	3	5	5
Cleveland Public Library	1	2	2	5
Columbus Metropolitan Library	1	2	5	3
Cuyahoga County Public Library	1	2	5	5
Dayton Metro Library	1	2	4	5
The Public Library of Youngstown and Mahoning County	1	2	5	1
Stark Library	1	2	1,3	3
Toledo Lucas County Public Library	1	3	1,2	3
Pioneer Library System	1	3	5	5
Tulsa City-County Library	1	2	5	5
Milton Public Library	1	2	1	5
Multnomah County Library	1	1	1	5
Carnegie Library of Pittsburgh	3	3	4	5
Free Library of Philadelphia	2	2	5	5
Richland Library	1	1,2	3	5
Chattanooga Public Library	1	1,2	4	5
Memphis Public Libraries	1	3	4	4
Nashville Public Library	1,2	2	2	3
Austin Public Library	3	3	4	3
Dallas Public Library	1	3	2	5
El Paso Public Library	1	2	5	5
Frisco Public Library	1	2	3	3
Harris County Public Library	3	1	4	3

(*continued*)

Table 1.

	3D technology	RFID	VR/AR	AI
Houston Public Library	1,2	3	1,4	5
San Antonio Public Library	1	1,2	4	2,3
Salt Lake City Public Library	1	2	4	5
Salt Lake County Library	1	2	3,4	5
Alexandria Library	1	1	5	5
Arlington Public Library	1,2	3	2	1
Chesterfield County Public Library	3	3	5	5
Fairfax County Public Library	1	1,2	1	2,3
Loudoun County Public Library	1	3	5	5
Newport News Public Library System	1	3	5	5
Prince William Public Libraries	3	3	5	5
Richmond Public Library	1	3	5	5
Roanoke County Public Library	1	3	5	5
Virginia Beach Public Library	3	3	5	1
Fort Vancouver Regional Library District	1	2	4	5
Seattle Public Library	1	1,2	2,3,4	4
Spokane Public Library	1	1	4	5
Tacoma Public Library	3	2	2	5
Madison Public Library	1,2	2	5	5
Milwaukee Public Library	3	2	4	5
Metropolitan Library System	1	1,2	4	5
Santa Clara City Library	1,2	3	5	5
Sacramento Public Library	1	1	4	3
Glendale Library, Arts and Culture	3	1	4	3

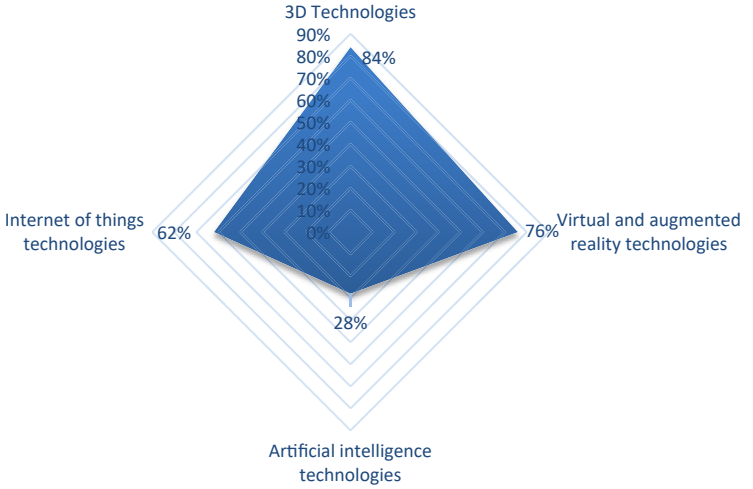
Table 1. **Source(s):** Table by authors

Results

After surveying 150 US urban libraries, this study shows that 84% of the surveyed libraries apply 3D technology, mainly reflected in 3D printing, 3D modeling and display. In all, 76% apply VR and AR technologies, mainly in VR and AR device experience, virtual tours and virtual exhibitions; 62% apply IoT technology, focusing on self-checkout machines with RFID; And 28% mention the applications of AI technology, mainly in intelligent search, robot librarians and virtual reference services. The proportion is shown in Figure 1.

3D technology

3D technology belongs to the mapping category of metaverse-related technologies, which can connect the metaverse with the virtual world and enable the exchange of substances between the real and virtual worlds. Libraries mainly use 3D technology for services such as 3D printing, 3D modeling and display. 3D printing refers to the use of a computer to design a three-dimensional model, through the layering software system and digital control, and the method of superimposing materials with physical layers using laser lights to form a three-dimensional solid. 3D modeling represents, controls, analyzes and outputs geometric and topological information to describe 3D objects via computer. In contrast, 3D modeling constructs a virtual model of a physical resource, while 3D printing manufactures corresponding physical entities through 3D printing equipment based on a virtual model.



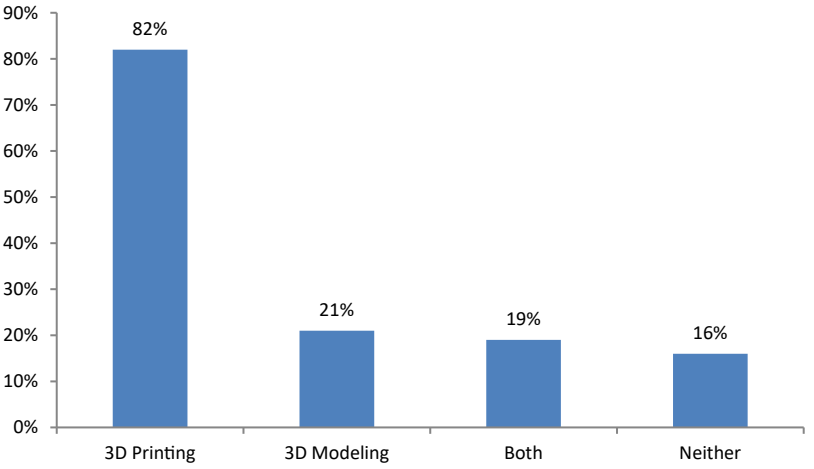
Source(s): Figure by authors

Figure 1.
Percentage of 150 urban libraries in the United States using metaverse-related technologies

Generally, 3D modeling and 3D printing services are offered in the library makerspace, where patrons can create according to their interests.

In all, 82% of surveyed libraries offer 3D printing services to their patrons as daily services in makerspaces; 21% offer 3D modeling services to patrons, mainly in the form of 3D modeling courses and modeling references and equipment; 19% offer both 3D printing and 3D modeling services; and 16% do not mention the use of 3D technology in their services. The findings are shown in Figure 2.

In metaverse construction technology, 3D technology has become an essential part of daily library services and is highly valued by libraries as a new attempt to provide library services. For example, Hartford Public Library (2022) proposes to take 3D scanning and



Source(s): Figure by authors

Figure 2.
Percentage of 150 urban libraries in the United States with 3D printing and 3D modeling

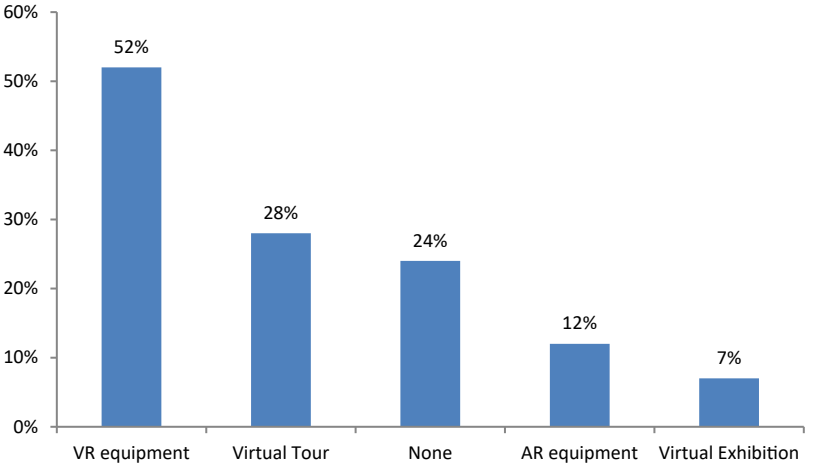
automated 3D modeling as an important part of its future Digital Library Lab development. Marin County Free Library (2022) offers free 3D printing for all library card holders, which allows patrons to obtain digital models online, or print objects made of biodegradable plastic by creating their digital models. The Sunnyvale Public Library (2022) provides patrons with 3D printing design software in the makerspace for 3D model design and poly lactic acid (PLA) plastic filaments to print. The Mandel Public Library of West Palm Beach (2021) prints Christmas tree models for patrons in the run-up to Christmas by 3D printers.

VR and AR technologies

VR and AR technologies belong to the interactive technologies in metaverse-related technologies. Among them, VR technology allows patrons to enter a virtual 3D world for interaction through head-mounted displays, computers or other mobile terminals. AR technology is the usage of computer technology to project virtual information to a natural environment in real time so that patrons can access both information simultaneously. Applications of VR and AR technologies in the library focus on virtual tours, virtual exhibitions and AR/VR experiences. A virtual tour means patrons visit a virtual simulation scene of a certain location through head-mounted displays or computers. Similar to a virtual tour, a virtual exhibition can provide patrons with a virtual space to view virtual exhibits.

Among the surveyed libraries, 52% mention that they provide VR devices for patrons, 28% provide virtual tours, 12% provide AR devices, 7% provide virtual exhibition services and 24% do not mention related applications. The proportion is shown in Figure 3.

VR and AR technologies have been widely used in US urban libraries, mainly in providing devices in makerspaces. Anythink Libraries (2020) provide patrons entertainment and games in makerspaces via head-mounted displays. In the games, patrons are sent to a virtual tourist attraction where they describe the attraction to let friends around them guess where it is. Sarasota County Public Libraries (2021) provide AR devices for children to view virtual butterflies in the makerspace. Allen County Public Library (2022) provides virtual tours on its library website where patrons can browse the library by clicking and dragging panoramas or enter the library with Oculus Quest 2, the head-mounted display.



Source(s): Figure by authors

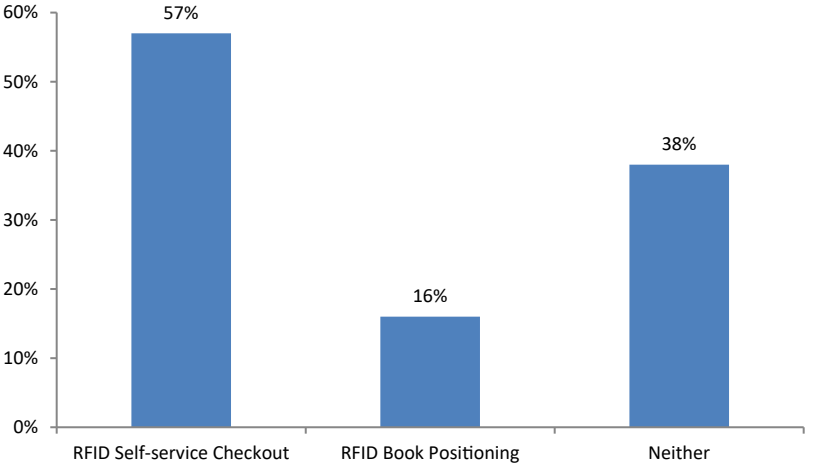
Figure 3.
Percentage of 150 urban libraries in the United States with virtual and augmented reality services

IoT technology

IoT technology connects objects and communication networks through various information collection and identification technologies. It is responsible for connecting objects to objects and objects to people in metaverse-related technologies. The main application of IoT technology in the library is to upload the real-time status of books to the library management information system through RFID electronic tags. Specific services supported by IoT include RFID self-checkout services and RFID book positioning services. RFID self-checkout systems have three parts: an electronic tag attached to the book, a reader and an information management system. The electronic tag of a book stores the basic information about the book. By reading the information on the electronic tag, the reader uploads the information of patrons' borrowing and returning operation of the book to the information management system to complete the work of book borrowing and returning. The libraries provide machines loaded with an RFID reader for patrons to use self-checkout services. RFID book positioning means that the librarian puts the book on the designated shelf according to the library's shelving rules, and uses the RFID inventory cart to complete the correspondence between the book and the RFID shelf tag so that the book can be quickly shelved after returning and the reader can quickly locate the book.

In all, 57% of the surveyed libraries use RFID readers to provide self-checkout services, and 16% provide RFID book positioning services; however, 38% do not mention the applications of RFID in their services. The findings are shown in Figure 4.

RFID technology applications in US urban libraries are common, mainly for self-checkout services. Notably, the surveyed data on RFID book positioning in libraries may be less than anticipated due to an error in the web survey. However, the existing survey data still show that US urban libraries attach great importance to RFID technology applications. The applications of RFID technology have improved the efficiency of library lending services and the ability of library book management. Multnomah County Library (2011) mentions that it is easier to read numbers by RFID reader than by the previous barcode scanner because the former makes check-in and checkout faster. In addition, the library indicates that using RFID inventory devices to locate things that are on hold or lost allows for better and more efficient collection management.



Source(s): Figure by authors

Figure 4.
Percentage of 150 urban libraries in the United States with RFID self-service checkout and RFID book positioning

AI technology

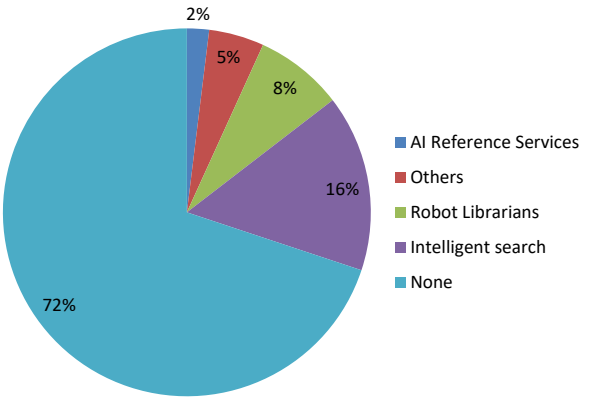
AI technology can provide intelligent service to patrons in libraries. Its working principle is to analyze the laws of human intelligence activities and collect data, then give the data to intelligent artificial systems and learn them, so that the computer can learn the logic of human thinking, and finally enable the computer to complete some tasks that could only be done by human intelligence. The main applications of AI technology in libraries are intelligent search, robot librarians and AI reference services. Intelligent search is a search provided by the library after learning and analyzing the patrons' information search behavior by using AI technology. Before presenting search results to patrons, AI technology filters unwanted content or recommends content that patrons may be interested in based on their search behavior. Robotic librarians are machines with AI technology that can provide patrons with the same interactive experience as a real librarian. AI reference services are 24-h reference services provided by AI assistants on library websites.

AI technology is rarely used in US urban libraries. A total of 24 of the surveyed libraries mention that they use AI technology to help patrons search for information in search engines, 12 libraries mention that they use robot librarians to provide services to patrons and 3 libraries provide AI reference services, accounting for 16%, 8% and 2%, respectively, of the total surveyed. It is worth noting that the 147 libraries that do not mention AI reference services all provide patrons with online or offline reference services by human librarians during office hours. Moreover, 5% of the libraries mention that they use AI for other services, such as AI audio and AI report analysis. The proportion is shown in Figure 5.

In the surveyed libraries, Anchorage Public Library (2018) mentions that they use AI technology for automated business processing to enhance patrons' library experience, as well as to provide a safer workplace, reduce repetitive task movement and limit heavy lifting from recycling bins. Fairfax County Public Library (2022) provides an AI assistant to provide consulting services to patrons in the lower right corner of the home page of its website. Palo Alto City Library (2022) has robotic librarians, Dewey and Elsie, who can chat with and dance for patrons.

Discussion

Some metaverse-related technologies have been commonly used in libraries. For example, 3D technology has been used in most US urban libraries, where 3D printers have become almost



Source(s): Figure by authors

Figure 5.
Percentage of 150 urban libraries in the United States with artificial intelligence services

indispensable to makerspaces. Letnikova and Xu (2017) believe that library 3D printing services significantly promote students' motivation to learn, and the proper planning and management of this innovative service allow academic librarians to enhance the class curriculum by providing the means of transforming theory into physical reality. However, only 28 US urban libraries offer both 3D printing and 3D modeling services, accounting only for 23% of libraries offering 3D printing. Patrons without 3D modeling skills seem to have difficulty in 3D printing, so setting up 3D modeling courses in libraries will be widely welcomed.

Though not as widespread as 3D technology, VR and AR technologies are favored by many libraries, and more than half of US urban libraries offer these services to patrons. A large number of libraries have set up makerspaces where VR and AR experiences are offered. During the survey, it was found that most libraries displayed the rules for using VR/AR devices on their websites, including who can apply for use, how to apply and opening hours. However, most libraries do not display specific information about the equipment they offer, how to use it and whether librarians will be on hand to provide support. When libraries use VR/AR devices to engage patrons, it is important not only to make the patrons aware of the new technology but also to provide support services to ensure that patrons learn to use the VR/AR devices and to handle patrons' feedback promptly.

Liang and Chen (2018) suggest that although IoT enables traditional libraries to convert into digital ones, the implementation of the IoT in libraries is slow. As the survey shows, 62% of US urban libraries use RFID technology to provide services to their patrons. IoT technology has the potential to improve library services, and RFID is only one of the paths to IoT technology applications. In this regard, it is necessary to popularize IoT technology in libraries and build a smart service system that connects everything in the library.

AI technology is less used in US urban libraries. Most libraries employ real librarians to provide reference and interactive services to patrons, which makes these services available only during office hours. AI technology can provide 24-h services for patrons, which solves constraints of time and space in services and saves library operating costs. However, the popularization of AI technology in libraries still needs to solve issues regarding patron privacy and capital investment.

To understand whether the application of metaverse-related technologies in US urban libraries is affected by library operating expenditures and the population served, the authors followed the research norms of Carlozzi (2018) for analysis. Based on data published by the IMLS (2022), the authors chose library operating expenditure, and population served as the analysis data for the following reasons. Firstly, the operating expenditure of the library could explain the construction and maintenance costs of the library to a certain extent. And it could truly reflect the actual funds invested by the library to the operating income. Secondly, to meet the needs of patrons, libraries that serve a large number of people tend to introduce more advanced technologies. Finally, the reason why other data are not used is that after common sense analysis. It is found that the other data are not directly related to the application of metaverse-related technologies in libraries.

In this process, some abnormal data in the original data were deleted, such as the astronomical amount much higher than other libraries, and the sample size of the city library was finally determined to be 146. Then the authors analyzed the correlation between library operating expenditures, the population served and the number of types of metaverse-related technologies applied in US urban library services. The scatter plots are shown in Figures 6 and 7. The resulting Pearson correlation coefficients are shown in Table 2.

From Table 2, the correlation coefficient value between the "number of types" and "population" is 0.262, and the significance level is 0.01, thus indicating that there is a significant positive correlation between "number of types" and "population." Besides, the correlation coefficient value between "number of types" and "expenditures" is 0.248, and the

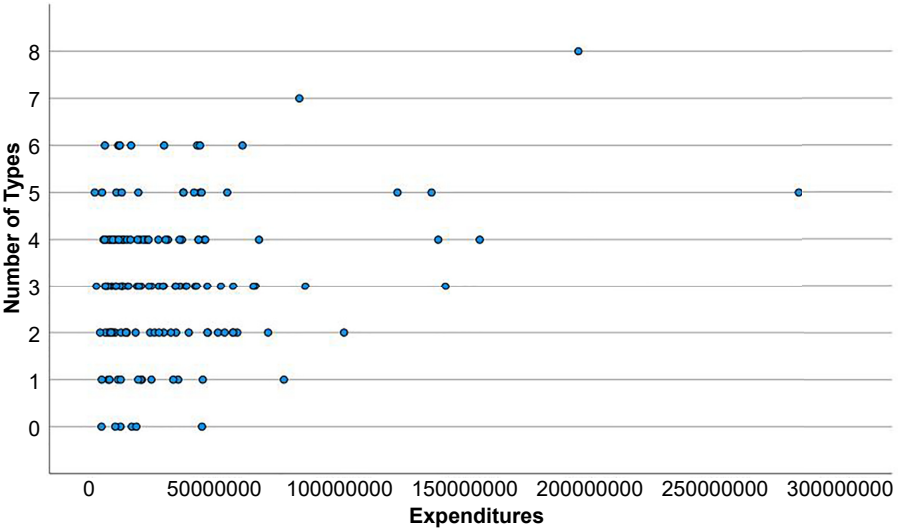


Figure 6.
Scatter plot of operating expenditures versus the number of types of metaverse-related technology applications in US urban library services

Source(s): Figure by authors

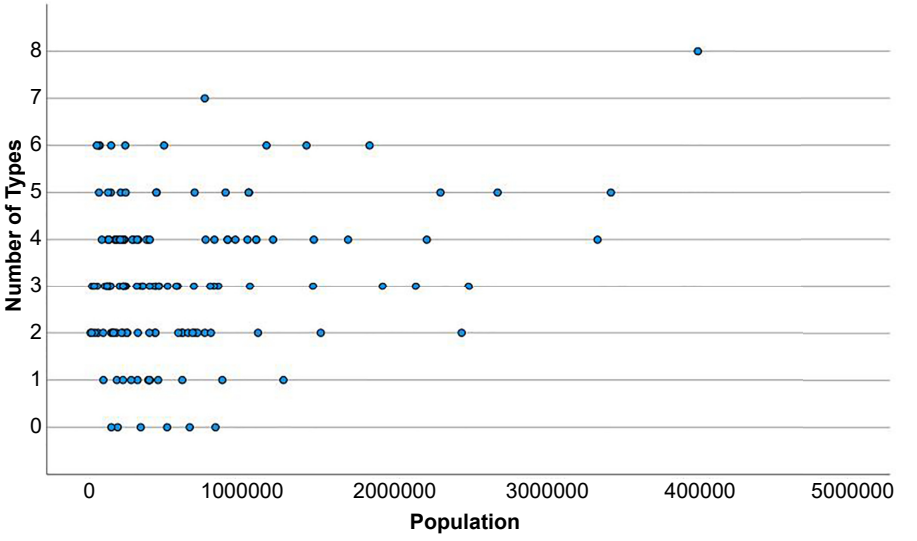


Figure 7.
Scatter plot of the population served versus the number of types of metaverse-related technologies application in US urban library services

Source(s): Figure by authors

significance level is 0.01, thus indicating that "number of types" and "expenditures" are significantly positively correlated. Furthermore, regression analyses are then conducted to confirm whether library operating expenditures and population served to affect the use of metaverse-related technologies in library services. The results of the analysis are shown in Table 3.

From Table 3, multiple regression analysis is conducted with "population" and "expenditures" as independent variables and "number of types" as dependent variables. The regression coefficient value for "population" is 4.017E-9 ($t = 1.248$, $p = 0.214 > 0.05$), implying that "population" does not have an impact relationship on "number of types." The regression coefficient value for "expenditures" is 3.948E-7 ($t = 0.675$, $p = 0.501 > 0.05$), implying that "expenditures" does not have an impact relationship on "number of types." It concludes that the application of metaverse-related technologies in US urban libraries services is not influenced by library operating expenditures or population served.

It is worth mentioning that some factors affecting the application of metaverse-related technologies in libraries attract the attention of scholars. Suen *et al.* (2020) argue that the major limitations of using VR in academic libraries are technical capabilities, space and budget, causing libraries to hesitate in introducing and developing VR services. The successful application of artificial intelligence in libraries is inseparable from the technical support of librarians. Yoon *et al.* (2021) discuss the significance of training for preparing librarians for AI and related technologies. The librarian training can enhance the technological capabilities of libraries and promote the application of metaverse-related technologies in libraries. In addition, librarians' subjective perceptions of new technologies could affect the application of metaverse-related technologies in libraries. Andrews *et al.* (2021) mention that performance expectancy and attitude toward the use of AI and related technologies have a significant impact on librarians' willingness to adopt AI and related technologies.

There is a growing body of research on how various metaverse-related technologies are used in libraries and what advantages they bring, but little research focuses on the existing

Table 2.
Pearson correlation coefficients for operating expenditures, population served and number of types of metaverse-related technologies application in US urban library services

		Population	Expenditures	Number of types
Population	Pearson correlation	1		
	P			
Expenditures	Pearson correlation	0.831**	1	
	P	<0.001		
Number of Types	Pearson correlation	0.262**	0.248**	1
	P	0.001	0.003	

Note(s): **. Correlation is significant at the 0.01 level (2-tailed)
Source(s): Table by authors

Table 3.
Results of multiple regression analysis

	Unstandardized coefficients		Standardized coefficients			
	B	Std. Error	*Beta*	*t*	*p*	VIF
Constant	2.779	0.167	–	16.670	0.000**	–
Expenditures	4.017E-9	0.000	0.181	1.248	0.214	3.231
Population	3.948E-7	0.000	0.098	0.675	0.501	3.231
R^2	0.072					
Adj R^2	0.059					
F	$F(2,143) = 5.517, p = 0.005$					
D-W	1.865					

Note(s): Dependent variable: number of Types
*$p < 0.05$ **$p < 0.01$
Source(s): Table by authors

situation of widespread adoption of metaverse-related technologies in libraries and the possible influencing factors of technology adoption. This paper takes the next step in existing research by investigating the application of various metaverse-related technologies in libraries. It demonstrates that, at this stage, the operating expenditures and population served do not affect the adoption of metaverse-related technologies in libraries. This finding seems to break the common preconceptions. It shows that some libraries do not actively introduce advanced technologies in the process of operation and construction, even though new technologies can bring many benefits to the development of libraries and better attract and serve patrons. The application of metaverse-related technologies requires more investment, not only financial investments, but also more publicity and training for librarians. This will enable librarians to recognize the advantages that libraries could gain by adopting metaverse-related technologies, and have the knowledge to use related technologies and equipment, thereby promoting libraries to spend more funds on the introduction of new technologies. Furthermore, this study finds that libraries serving larger populations are not necessarily adopting more metaverse-related technologies, which is regrettable. Metaverse-related technologies make historical data identifiable to patrons through different media forms. Jerkov and Milnovic (2018) point out that digital objects structured in this way will draw patrons' attention and bring the historical content back into focus. This may lead to a greater number of patrons visiting the library.

This study is the first to directly explore the factors that affect the adoption of Metaverse-related technologies. And the research results are important because it was found that, contrary to expectations, the libraries' operating investment and service population do not affect the library's adoption of metaverse-related technologies, which could provide a reference for libraries to formulate metaverse development policies; that is, the premise of increasing metaverse-related technologies investment is to improve librarians' willingness to accept and technical ability.

This paper mainly conducts research through online surveys. Due to limited conditions, the findings are inevitably biased. The survey was conducted from May 10 to August 19, 2022, and the use of metaverse-related technologies of the survey objects changes in real-time, which may affect the accuracy of the data. Moreover, some libraries may use metaverse-related technologies but do not mention them on their websites or Facebook pages, which is also a factor affecting the findings.

Conclusion

Some metaverse-related technologies are common in US urban libraries, especially 3D and VR/AR technologies, with more than half of the surveyed libraries using these technologies to provide services. However, the number of libraries using IoT and AI technologies to offer services is relatively small. Furthermore, the use of 3D printing and VR/AR technologies in libraries is more experimental, as most of them are set up in makerspaces as part of the emerging technology experience, rather than integrated into library services. Additionally, in the process of library development, it is essential to strengthen the capacity of librarians to apply new technologies in order to serve patrons better. Optimistically, at least presently, the integration between the metaverse and libraries is becoming increasingly visible. The existing applications of metaverse-related technologies in libraries have provided experience for future metaverse libraries. Nevertheless, further research is necessary to develop metaverse libraries using various technologies.

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