Digital Libraries: Key Concepts in Their Evolution

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Abstract

Digital libraries (DLs) have become popular and unique information resources for diverse users. This entry introduces and highlights the key concepts related to DLs and their evolution: digitization, collection development, metadata, interface design, user types, and DL evaluation. These concepts represent the critical components of DL development. Moreover, new developments in DLs are also presented: social media and AI applications. Most importantly, this entry identifies future directions of DL research and practice on DL design environments, DL universal design, AI applications in DL development, and DL research methodologies.

Key Points

- This entry introduces and emphasizes the fundamental ideas concerning digital libraries (DLs) and their progression, covering digitization, collection development, metadata, interface design, user types, and DL evaluation.
- It presents recent advancements in DLs, such as their integration with social media and applications of artificial intelligence (AI).
- It identifies future directions of DL research and practice, including DL design environments, universal design for DLs, the utilization of AI in DL advancement, and methodologies for DL research.

Glossary

Digital libraries Digital collections of born-digital or digitized information resources of a wide range of materials (e.g., scanned documents, images, and multimedia files) to satisfy the various information needs of user communities to achieve the goal of universal access.

Digitization A process encompassing the conversion of different formats of traditional or physical information resources (e.g., books, manuscripts, and photographs) into digital formats.

Collection development A process that involves systematically constructing library collections to meet the requirements of library users for learning, teaching, leisure, and other purposes and encompasses various tasks, such as selecting and removing materials, devising coherent plans for ongoing acquisitions, and assessing collections to determine their effectiveness in meeting user demands.

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Metadata Structured and encoded data that are utilized to delineate the attributes of information-bearing entities to facilitate their identification, discovery, evaluation, management, and preservation.
User tagging A personalized process through which users create new tags (e.g., keywords) using their own words and assign them to digital resources on different online platforms.
Linked data Structured data that are interconnected, openly published on the web, and searchable through semantic queries.
Digital library evaluation The systematic process of assessing various aspects (e.g., accessibility and usability) of digital libraries to improve user experiences.

Introduction

The development of innovative information technologies has changed how information resources and services are provided and accessed, contributing to the emergence of new types of information retrieval (IR) systems. Digital libraries (DLs) first emerged in the 1990s in the U.S., fueled by federally funded DL projects, such as the Digital Library Initiative from 1994 to 1998; other DL projects followed across the world (Xie and Matusiak, 2016). DLs are defined as digital collections of born-digital or digitized information resources of a wide range of materials (e.g., scanned documents, images, and multimedia files) to satisfy the various information needs of user communities to achieve the goal of universal access (Sheikhshoaei *et al.*, 2021; Xie and Matusiak, 2016).

The development and evolution of DLs can be divided into four major stages: (1) During the formative years from the early 1990s to the early 2000s, there emerged experimental DL initiatives projects and pioneering DLs; (2) In the 2000s, a growing number of digitization projects and open-access repositories were developed; (3) In the 2010s, large-scale DLs began to develop, including the Digital Public Library of America, HathiTrust, and Europeana; and (4) more recently, advanced technologies, such as big data, machine learning, cloud computing, and artificial intelligence (AI) have been incorporated into DLs (Xie and Matusiak, 2016; Yamson, 2023). This entry aims to introduce key concepts and their evolution in the research and practice of DLs.

Digitization and Collection Development

Technology advancements have enabled libraries to digitize individual items and collections, setting the foundation for the development of DLs. In addition, collection development is another crucial aspect of DL development that has been discussed.

Digitization

Digitization is a process encompassing the conversion of different formats of traditional or physical information resources (e.g., books, manuscripts, and photographs) in libraries into digital formats (Xie and Matusiak, 2016). There are two essential types of digitization in DLs based on formats, i.e., digitization of text and still images and digitization of time-based multi-media materials.

Mass digitization refers to the digitization of information resources on a large scale, revolutionizing the landscape of libraries and DLs. One of the most well-known mass digitization projects is the Google Books Library Project. Many DLs have participated in mass digitization projects because of its benefits. For example, the mass digitization of library collections at the University of California has preserved and protected library collections, provided broader ranges of resources to the public, enabled cross-institutional sharing of digital collections, and enhanced student and faculty discovery and access to digital collections (Ewing, 2022).

Much attention has been paid to the benefits and challenges of digitization. DLs can benefit from digitization in various ways. Digitization of library resources helps with the preservation of information resources (especially valuable but fragile and deteriorating items) and facilitates access to library resources (Pandey and Misra, 2014). Multiple users from different locations may access the same item of a digital collection simultaneously, and the digitization prevents items from being damaged by frequent usage (Kim and Maltceva, 2022).

The challenges of digitization should be acknowledged. Digitization requires specialized software, hardware, and other technological infrastructures, and changes in these technologies present a challenge to librarians (Pandey and Misra, 2014). According to Rafiq *et al.* (2018), university libraries face multiple barriers to digitization, such as a lack of professional training, a lack of funding, inadequate technological infrastructures, and low recognition of libraries and librarians. Ethical issues associated with digitization are also notable as, for example, Ma (2020) viewed digitization as a translational vehicle and focused on how to digitize culturally sensitive materials in cross-cultural digitization practices by considering cross-cultural ethical issues (e.g., privacy and authenticity). Finally, DLs must comply with policies and laws related to intellectual property regulations (e.g., copyright) (Pandey and Misra, 2014).

Collection Development

Collection development involves systematically constructing library collections to meet the requirements of library users for learning, teaching, leisure, and other purposes. This process encompasses various tasks, such as selecting and removing materials, devising coherent plans for ongoing acquisitions, and assessing collections to determine their effectiveness in meeting user demands (Gabriel, 1995).

New technologies influence DL collection development. Corrall and Roberts (2012) outlined four phases of collection development based on the evolution of digital technology since the 1960s. During the late 1960s and 1970s, automation and computer-based operations increased the efficiency of the collection process. In the 1980s and early 1990s, computer-based services enabled users to access local and consortia collections. During the late 1980s and 1990s, digitized collections led to the emergence of DLs. Since the 2000s, collaborative and network-driven efforts have contributed to the emergence of DL management systems, institutional repositories, and advancements in data curation. Focusing on digital collection development, Bullis and Smith (2011) identified research themes from relevant literature from 2004 to 2008, including the changing nature of local collections, redefining collection management responsibilities and practices, cooperation and collaboration, and collection assessment.

A collection development policy is a formal document or statement that expresses a dedication to the systematic building and development of collections. DL collection development policies play an essential role in collection development and involve multiple aspects, such as purposes, scope and types of content, and selection criteria (Mwilongo *et al.*, 2020). Collection development criteria are the central component of collection development policies, with basic criteria consisting of quality, relevance, timeliness of materials, diversity, and aesthetic and technical aspects (Holleman, 2000; Jahnke *et al.*, 2022; Papadakos *et al.*, 2014). Some common digital collection selection criteria include value and demand, copyrights, technical feasibility, infrastructure, added value, cost, and collaboration with other institutions (Levenson and Hess, 2020).

Legal issues may emerge in collection development, especially concerns over copyright protection. During the collection development process, it may be challenging to determine whether a digital item can be included in a digital collection based on the availability of permission to use copyrighted items; thus, libraries prefer to digitize items that they own the copyright or in the public domain (Xie and Matusiak, 2016). It is recommended to have librarians or staff with expertise in copyright to help comply with copyright laws in libraries (Kawooya *et al.*, 2015). In addition, clear copyright statements (e.g., ownership right to digitized materials, permission obtained from copyright holders, and the fair use defense against infringement claims), and clear material submission policies for authors and copyright owners should be provided by DLs (Singeh *et al.*, 2020).

Metadata

Metadata constitutes a key dimension of DLs. Widely known as "data about data," metadata can be defined as "structured, encoded data that describe characteristics of information-bearing entities to aid in the identification, discovery, assessment, management, and preservation of the described entities" (Zeng and Qin, 2020, p. 14). In the context of DLs, metadata can contribute to efficient information organization, compatible interoperability, and improved information search and access. Traditionally, diverse metadata schemas (e.g., the Dublin Core) have been implemented in DLs. In response to evolving technologies, user tagging and linked data have emerged as methods that supplement traditional schema-based metadata.

Metadata Types and Implementation

Different types of metadata exist with varying functions. Researchers have proposed diverse classifications of metadata types. According to Miller (2022), there are three metadata categories: administrative, structural, and descriptive. Baca (2016) identified five types of metadata based on metadata functions, including administrative, descriptive, preservation, technical, and use metadata. **Table 1** summarizes metadata types, definitions, associated functions, and examples based on relevant literature (Baca, 2016; Xie and Matusiak, 2016; Zeng and Qin, 2020). Metadata schemas can accommodate various metadata types. For example, Dublin Core includes both administrative and descriptive metadata elements. In addition, there are schemas exclusively dedicated to one particular metadata type, such as AudioMD and VideoMD, to capture technical specifications of audio and video files.

Metadata schemas are predefined structured sets of metadata elements that can guide practices concerning data structures, data content, data values, and data exchange (Zeng and Qin, 2020). Some primary principles for designing and applying metadata schemas include modularity, extensibility, refinement, multilingualism, and interoperability (Zeng and Qin, 2020). Multiple metadata schemas have been developed, varying in terms of underlying data models (e.g., flat or hierarchical structure), numbers of data elements, granularity of description, and use of mandatory fields (Xie and Matusiak, 2016). Some of the most frequently used schemas in DLs include the Dublin Core, Metadata Object Description Schema (MODS), Metadata Encoding and Transmission Standard (METS), Text Encoding Initiative (TEI), Encoded Archival Description (EAD), Visual Resources Association (VRA) Core, and Categories for the Description of Works of Art (CDWA). Dublin Core is one of the most widely adopted metadata schemas for describing information resources in various contexts, including libraries, museums, archives, governments, and others.

Table 1 Types of metadata.

Metadata type	*Definition*	*Functions*	*Examples of metadata elements*
Administrative	Metadata that presents information related to the management of collections and information items	Indicating information concerning ownership or digital provenance Providing management and rights information	Acquisition information Right and reproduction tracking Local information
Descriptive	Metadata that provides information to identify and describe collections and information items	Describing a collection or an object Providing access points to facilitate resource discovery Indicating relationships	Cataloging records Finding aids Curatorial information
Preservation	Metadata that offers information regarding the preservation management of collections and information items	Describing properties of archived digital objects Recording preservation activities	Documentation of physical conditions of resources Documentation of actions taken to preserve resources Documentation of changes during digitization or preservation
Structural	Metadata that depicts the relationships of a digital object to other associated ones or describes the structural characteristics of compound objects	Expressing the relationships of an object (or aggregation of objects) to other objects Describing structural characteristics of compound objects	Structural maps
Technical	Metadata that details the technical specifications of information systems or digital objects	Identifying technical specifications of information systems and digital objects	Hardware and software documentation Technical digitization (e.g., formats, compression ratios) Authentication and security data (e.g., encryption keys, passwords)
Use	Metadata that shows the level of and the types of use of collections and information items	Presenting the levels and types of use of collections and items	Circulation records Use and user tracking Search logs

Ethical issues associated with metadata or knowledge organization in general should be considered (Wang, 2019). Metadata practitioners have an ethical duty to authentically represent items and consider the possible harm to people whose information might be revealed by the metadata used in DLs (Seeman, 2012). Moreover, creating metadata schemas based on ethics (e.g., fair representation, accessibility, and control) is essential for protecting individuals' rights and ensuring the good of society (McQueen, 2015).

User Tagging

User tagging, also known as social tagging or collaborative tagging, among others, emerges due to Web 2.0 technologies, indicating a shift from a static online environment to a dynamic and interactive digital state (Ding *et al.*, 2009). Web 2.0 offers new opportunities for user engagement in describing and organizing DL materials. User tagging represents a personalized process through which users create new tags (e.g., keywords) using their own words and assign them to digital resources on different online platforms (Michael and Han, 2020; Shi *et al.*, 2024).

There are multiple benefits of applying user tags in DLs. User tagging introduces users' language and perspectives to offer additional access points, which may help enhance metadata created by librarians and other professionals and contribute to the effectiveness of IR (Lin *et al.*, 2019). Moreover, user tags are building blocks of folksonomies that can help develop semantic DLs (Shahzad and Khan, 2023).

Meanwhile, the challenges and disadvantages of user tagging are worth noting. User tags may be uncontrolled, imprecise, and inaccurate due to users' limited background knowledge and skills (Rafferty, 2018; Xie and Matusiak, 2016). The effectiveness of social tagging depends on active user participation, and an extensive number of user tags can help reveal the evolution of knowledge sharing among users (Huang and Chuang, 2009; Shi *et al.*, 2024). However, users may hesitate to contribute tags because of privacy concerns, and thus, it is important to balance social sharing and privacy protection in tagging systems (Lee *et al.*, 2014).

Linked Data

Linked data refers to "all types of structured data that can be interlinked, published openly on the web, and searched through semantic queries" (Xie and Matusiak, 2016, p. 157). Linked data is associated with the semantic web or Web 3.0. The semantic web aims to enable computers to understand online resources and their interlinked relationships and create a global network of data connected through semantic relationships to enhance the discovery of inter-related information and the use and reuse of data (Candela *et al.*, 2022). The semantic web also encourages DLs to exchange and disseminate their data on the web (Gaitanou *et al.*, 2024; Hallo *et al.*, 2016).

Regarding linked data models and technologies, Resource Description Framework (RDF) functions as a conceptual model for establishing relationships and representing linked data (Zeng and Qin, 2020). RDF can enable the merging of data, even in cases where the underlying schemas are different. It is designed to support the evolution of schemas over time without necessitating modifications for all users. Librarians hold positive attitudes regarding the adoption of linked data, believing that linked data can improve users' navigation of and access to library resources and serve as the standard for creating metadata (Chen, 2023; Warraich and Rorissa, 2018).

Despite the promising application of linked data, the quality of linked data in DLs has been considered a challenge, according to information professionals. Based on a survey study, Debattista *et al.* (2018) identified various quality issues of linked data in DLs encountered by information professionals, including problems related to semantic accuracy, completeness, interoperability, conciseness, data formatting, language versatility, availability, trustworthiness, interpretability licensing, timeliness, provenance, interlinking, and documentation. In addition, librarians often lack knowledge of linked data concepts, and there are limited linked data best practices for them to reference (Warraich and Rorissa, 2018). Moreover, the lack of relevant policies and standards in libraries hinders interoperability of linked data (Gaitanou *et al.*, 2024).

Interface Design

DL interfaces are the places where iterative interactions between users and DLs occur. The iterative design of DLs and associated accessibility and usability testing deserve special attention in the DL interface design process.

DL Designs

Some general interface design principles can be applied in the DL context, such as Nielsen's (2024) usability heuristics for user interface design and Norman's (2013) guidelines for interface design. Researchers have also proposed some specific principles focusing on DL design. For example, McCray and Gallagher (2001) provided a list of basic principles for DL development, including expecting change, knowing your content, involving the right people, designing usable systems, ensuring open access, being aware of data rights, automating whenever possible, adapting and adhering to standards, ensuring quality, and being concerned about persistence. Focusing on video DLs, Albertson (2015) noted that user requirements are closely associated with DL interface design, and he considered both user factors (e.g., experience, knowledge) and situational factors (e.g., system support or barriers) in the conceptual framework of the interface design.

Iterative design means that DL interface design requires multiple rounds of user-centered design processes instead of being done in one step, highlighting the importance of ongoing interactions between designers and representative users throughout the interface design process. According to Xie and Matusiak (2016), designing and implementing a DL interface involves the following main steps: identifying users' unique needs, designing prototypes, configuring interfaces, customizing interfaces, and testing accessibility and usability (**Fig. 1**).

For each of these main steps, associated activities can be taken. User studies should be conducted using different methods (e.g., interviews, focus groups, and log analysis) to reveal users' unique needs. Designing prototypes is a flexible method for developers to gather feedback from various types of stakeholders (especially users). DL content management systems (e.g., CONTENTdm, DSpace, and Omeka) offer configuration options for DL interface design. For example, CONTENTdm is one of the most popular systems DLs use, providing multiple configuration options, such as appearance, searching and browsing, UI widgets, image viewer, navigation, items, paper types, tools, and custom. The uniqueness of each DL and its unique user groups should be considered, highlighting the need for customizing DL interfaces.

Accessibility and Usability Testing

Accessibility and usability testing are critical in user-centered design to improve user interfaces and user experiences. Accessibility testing assesses whether a DL is accessible by its users, especially those with disabilities, and usability testing examines whether a DL is usable and enables its users to use it effectively and efficiently. Researchers have been employing diverse methods to assess the accessibility and usability of different DLs in recent decades. In practice, some design guidelines have been developed, such as the Digital Library Accessibility and Usability Guidelines (DLAUG) to support blind and visually impaired (BVI) users (Xie *et al.*, 2021a).

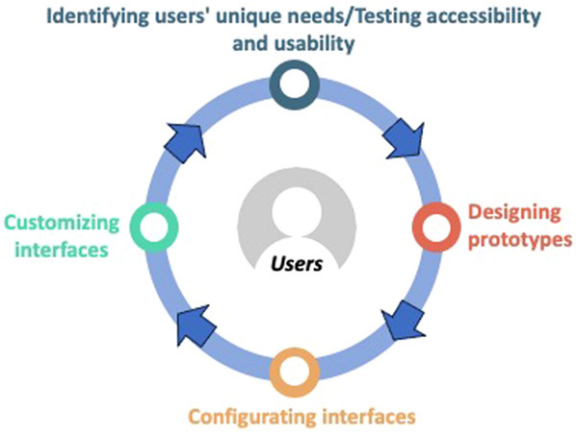

Fig. 1 Key iterative stages involved in designing DL interfaces.

Ensuring DL accessibility helps support universal access for all potential users, especially people with disabilities. Accessibility is the most frequently discussed topic in library and information science literature focusing on BVI users (Xie *et al.*, 2021d). Researchers have concentrated on identifying accessibility issues of DLs, thus helping make DLs accessible to people with disabilities. For example, Babu and Xie (2017) identified five categories of design problems, including a lack of meaningful text description for multimedia content and format, a lack of meaningful labels or instructions for features, a lack of meaningful labels for hyperlinks, a lack of descriptive headings, and a lack of explanations for jargon. From a more holistic perspective, when investigating the accessibility of the mobile application and the mobile website of a DL, Xie *et al.* (2023a) focused on four accessibility variables, including accessing a DL, accessing a navigation component, accessing a feature, and accessing information/objects.

Conducting DL usability studies is essential to enhance all types of user experience (Barifah and Landoni, 2020). Usability is associated with multiple evaluation criteria, such as learnability, efficiency, ease of use, memorability, errors, and satisfaction (Jamal *et al.*, 2021; Nguyen *et al.*, 2023; Xie *et al.*, 2023a). Scholars have conducted usability studies using different methods. For example, Kous *et al.* (2020) investigated how different types of users (i.e., pupils, seniors, students, researchers, and working populations) perceived a system's usability based on think-aloud protocols, log data, and questionnaires. Jamal *et al.* (2021) examined the usability of one DL by using a web-based questionnaire to measure users' perceptions. Scholars have recently begun to pay attention to DL usability on mobile devices. For example, Nguyen *et al.* (2023) investigated the impact of a mobile DL application on learning, finding that student participants were highly satisfied with the application, stating that it was user-friendly and helped them to improve their search skills. Xie *et al.* (2023b) applied multiple data collection methods (i.e., think-aloud, transaction logs, questionnaires, and interviews) to understand BVI users' assessment of usability (i.e., ease of use, efficiency, and satisfaction) of the Library of Congress Digital Collections on the mobile app and mobile website. BVI users showed significant differences in perceived levels of all the variables between the two platforms, with a preference for the mobile app.

User Types

DLs are developed for the general public, serving different types of users. To better serve diverse types of users, it is essential to understand their needs, search behaviors, and associated factors.

Types of Users and Associated Information Search Behaviors

Scholars have examined different types of user interactions with DLs, paying much attention to children and college students. It is worth noting that there are DLs specifically designed for children, such as the International Children's Digital Library (ICDL). To characterize children's information-seeking behaviors in DLs, Bilal *et al.* (2008) identified seven modes spanning children's searching processes, including starting, recognizing, browsing, differentiating, reading, exploring, and finishing. Children's unique characteristics (e.g., cognitive and physical developmental restrictions) impact their information search processes (Martens, 2012). For example, Wu (2015) found that children were better at dealing with uncertainty when searching for entertainment-related information than information related to assigned tasks.

College students are important users of DLs, primarily academic DLs. For undergraduate and graduate students, remote access, fast access, and 24-hour access are top factors in considering DL use (Liu and Luo, 2011). Research also shows that information relevance, system accessibility, technical support, perceptions of services, and perceptions of usability affect college students' intention to use or continue using DLs (Iqbal *et al.*, 2022; Joo and Choi, 2016). Notably, the availability of other IR systems

provides college students with alternatives to DLs. The survey study by Alotaibi *et al.* (2023) shows college students preferred Google Scholar to DLs when searching for information because Google Scholar was perceived to provide superior search performance with less effort.

Researchers have been paying more attention to the use of DLs by people with disabilities. It has been acknowledged that the sight-centered design of DLs and design issues concerning accessibility and usability lead to increased and unique help-seeking situations for BVI users. Different types of help-seeking situations have been identified for BVI users in both desktop and mobile DL environments, such as difficulty accessing the content of visual items, difficulty locating metadata, and difficulty assessing the relevance of an item (Xie *et al.*, 2023b). Differences in orientation tactics have also been revealed between blind and sighted users. Xie *et al.* (2021b) found that blind novice users focused on exploring DL structure while sighted users tended to skim DL content. Moreover, adding accessibility metadata in DLs can help people with disabilities locate materials that fit their needs, contributing to the goal of universal access (Beyene, 2017).

Nonetheless, research focusing on the use of DLs by elderly adults and people with disabilities is relatively sparse. As Yusuf *et al.* (2016) noted, demographic factors, such as age, impact people's information-seeking in DLs, and elderly adults do not adapt to new digital environments as positively as their younger counterparts. They suggested that elderly adults acquire the necessary skills to navigate DLs.

Factors Affecting Users' Interaction With DLs

Different types of factors affect how people use DLs, including user, system, task, and interaction outcome factors (Xie and Cool, 2009; Xie, 2008). **Fig. 2** summarizes the main categories of factors and associated typical factors within each category.

User factors highlight how users' personal infrastructure (e.g., domain knowledge, system knowledge, IR knowledge, and previous experience) and other characteristics (e.g., vision conditions) affect their use of DLs (Lykke *et al.*, 2021; Vakkari, 2016). For example, users' domain and system knowledge influence how they accomplish their tasks (Lykke *et al.*, 2021). People's physical and cognitive conditions also influence their interactions with DLs. For example, BVI people must rely on assistive technologies to interact with systems linearly, and they encounter unique help-seeking situations (Vigo and Harper, 2013; Xie *et al.*, 2018).

System factors are mainly associated with various elements within the DL infrastructures (e.g., overall structure, system features, and information objects). System factors may arise from the complexity DL structural elements (e.g., headings, links), complex page components (e.g., browsing categories, featured collections, and individual objects), unique two-level organization (collection-level and item-level), various features (e.g., advanced search features, filters, and help features), and heterogeneous content formats (e.g., scanned documents, images, audios, and videos) (Singeh *et al.*, 2020; Xie *et al.*, 2021b, 2023a). Some studies have

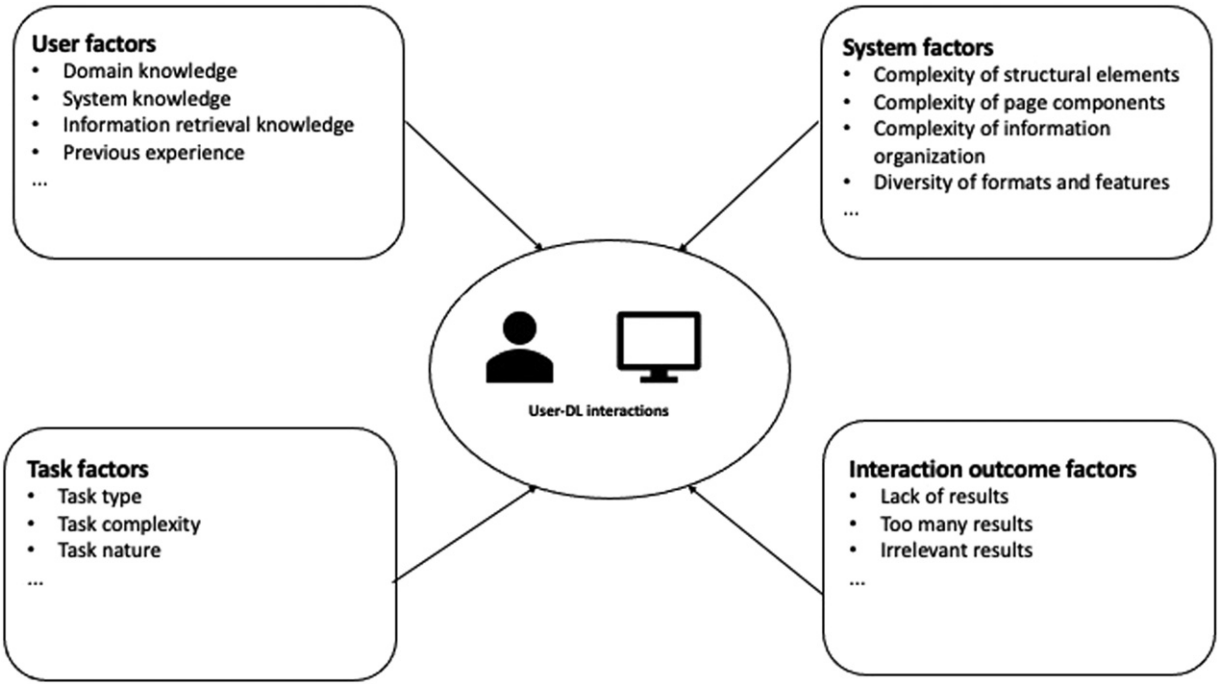

Fig. 2 Types of factors affecting user-DL interactions.

examined the system design issues of DLs. For example, Xie *et al.* (2023a) identified design factors associated with the accessibility and usability of mobile DLs, such as feature location, availability of help information, and adequacy of item metadata and collection descriptions.

Task factors are directly related to the characteristics of tasks that lead to users' information searching and impact their search processes. Research has identified multiple task factors, such as different task types (e.g., known-item search, specific information search, and exploratory search) and task complexity (Li and Liu, 2019; Liu, 2021). Li and Liu (2019) suggested that DLs should provide help features to assist users with complex tasks. User/system interactions are based on search result outcomes, such as too many results, too few results, no results, irrelevant results, or confusing results; As a result, users often modify their search queries (Choi, 2013; Xie and Cool, 2009).

DL Evaluation

Evaluating is vital for DL development and improvement. Without evaluation, assessing a DL's success or identifying its shortcomings is impossible. On a theoretical level, evaluation dimensions, criteria, and measures constitute the critical components of DL evaluation (Xie and Matusiak, 2016), and various evaluation frameworks or models have been proposed to guide DL evaluation. In practice, different approaches can be adopted to evaluate DLs, including criteria-based evaluation, log data analysis, and accessibility and usability tests involving users.

DL Evaluation Frameworks/Models

DL evaluation frameworks or models function as systematic and structured methods that often incorporate constructs of and predefined criteria and measures to evaluate diverse aspects of a DL. Various comprehensive or general evaluation frameworks or models have been proposed, such as Saracevic's (2000, 2004) comprehensive list of evaluation elements, including constructs for evaluation (e.g., digital collections or content, interfaces, and users), contexts of evaluation (e.g., user-centered, system-centered), criteria (e.g., usability criteria), measures reflecting selected criteria, and methods for doing evaluation (e.g., surveys, interviews). Based on Saracevic's framework, Zhang (2010) further developed a holistic DL evaluation model that focuses on six dimensions (i.e., content, user, interface, service, content, and technology) and associated criteria and considers heterogeneous stakeholders (i.e., administrators, developers, librarians, researchers, and users). Notably, some comprehensive frameworks or models are user-centered, such as Xie's (2006) user-centered evaluation framework, involving five dimensions of evaluation criteria (i.e., interface usability, collection quality, service quality, system performance efficiency, and user feedback solicitation) and Matusiak's (2022) multifaceted user-centered evaluation of digital archives based three evaluation dimensions (i.e., interface design, collections, and information organizations) and associated user criteria.

In addition, evaluation models or frameworks emphasize specific aspects of DLs (e.g., quality and maturity levels). For example, Yan *et al.* (2014) developed different measures to assess three aspects of quality: information quality, system quality, and service quality in DLs. Sheikhshoaei *et al.* (2021) proposed a DL maturity model that helps rate the levels of DL development. Nevertheless, existing models or frameworks mainly focus on DLs in the desktop environment, and there is sparse research exploring DL evaluation in the mobile environment.

DL Evaluation Dimension/Criteria/Measures

As various evaluation frameworks and models show, multiple dimensions or aspects of DLs need to be holistically examined to comprehensively assess a DL. In general, some major dimensions include collections, information organization, interface design, system/technology, effects on users, services, preservation, administration, user engagement, and context; There are different types of criteria and corresponding measures under each dimension. **Fig. 3** presents the key dimensions and criteria of DL evaluation (Xie *et al.*, 2018, 2021c). Due to space limitations, only the top three criteria that were perceived most important by different types of stakeholders (i.e., scholars, practitioners, and users) were presented under each dimension.

The specific measures under each evaluation criteria can be classified into two categories: quantitative and qualitative. Quantitative measures are based on numeric data (e.g., discrete and continuous data). Examples of quantitative measures include the cost of building a digital collection, users' perceived usefulness and ease of use based on scales, and recall and precision measures of retrieval effectiveness. In contrast, qualitative measures are reported via non-numeric textual data and categorical data. Examples of qualitative measures include data types in digital collections and commentaries on satisfaction and ease of use.

New Developments on DLs

New developments and emerging directions of DLs are worth noting, particularly the applications of social media and AI in DLs.

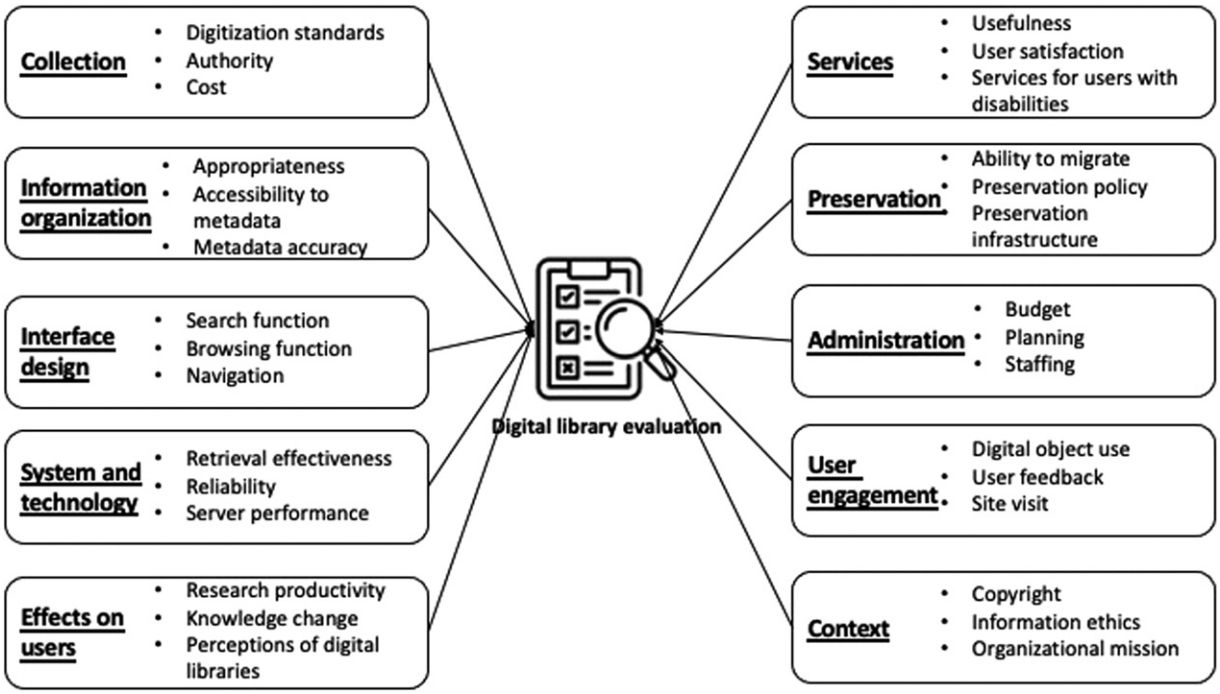

Fig. 3 Dimensions and associated criteria for DL evaluation.

Social Media in DLs

Social media encompasses online applications rooted in the principles of Web 2.0, facilitating informational and social interactions (Kaplan and Haenlein, 2010). There exist different types of social media, mainly including blogs, microblogs, social networking sites, podcasts, online collaborative projects, and online content communities (Kaplan and Haenlein, 2010; Xie and Matusiak, 2016).

The importance of social media strategies for DL development has been recognized by library staff, and many institutions have regarded social media as an important tool for their DLs (Mensah and Onyancha, 2021; Xie and Matusiak, 2016). Among the different social media platforms, Facebook and Twitter appear to be the most popular, followed by Flickr, blogs, and other social media platforms (Xie and Stevenson, 2014).

Social media applications enable DL staff (e.g., digital librarians) to interact with their users using various functions, such as commenting, friending, following, liking, and sharing. Social media platforms play important roles in promoting DLs, including providing information about DLs, facilitating peer-to-peer connections, and marketing and promoting collections and events. For example, Xie and Stevenson (2019) examined the use of Twitter in DLs. They identified 15 roles of Twitter and classified them into five main categories, including information, promotion, related resources, social identity, and social connection.

Survey results show that most student users prefer libraries to provide services through social networking sites (Kumar Bhatt and Kumar, 2014). In addition, Goedert (2023) pointed out that collaborative social media campaigns helped DLs promote collections to their users. Moreover, using social media platforms like Twitter also contributes to enlarging the user base and building online DL communities (Goedert, 2023; Xie and Stevenson, 2019). However, the challenges of using social media in DLs should also be noted. Many libraries lack well-formulated social media strategies, plans, or policies, and users have a low awareness of DLs' social media presence (Mensah and Onyancha, 2021, 2022). Moreover, user engagement level is low on social media pages of libraries (Kushniryk and Orlov, 2021).

AI in DLs

AI refers to developing computer systems or software that can mimic human cognitive functions and perform tasks that typically require human intelligence, such as learning, reasoning, problem-solving, language understanding, and even creative abilities (Harisanty *et al.*, 2023). Common AI technologies include natural language processing, machine learning, and deep learning.

Recently, researchers have been paying attention to ChatGPT and other chatbots in relation to library services. Even though applications of AI in DLs are sparce, their future is promising. Currently, AI can effectively assist with routine library activities (e.g., routine reference inquiries). For example, research shows that using ChatGPT for reference services can provide relevant responses to users' routine inquiries, enabling librarians to focus on more specialized inquiries (Adetayo, 2023; Yamson, 2023). College students recognize the advantages of ChatGPT, such as convenience, accessibility, and user-friendliness (Adetayo, 2023).

AI technologies also have their limitations, and their challenges should be further addressed. AI-based chatbots like ChatGPT cannot entirely replace human interaction and may have difficulty addressing complicated questions or tasks that require more significant and/or more specific expertise (Kaushal and Yadav, 2022; Yamson, 2023). Also, how well AI tools perform is often based on the quality of training data and algorithms; low-quality training data and biased algorithms may adversely impact user experience (Yamson, 2023). Stakeholders also perceive different types of potential risks in adopting chatbots in academic libraries, such as employment risk (e.g., fear of losing jobs among librarians), financial risk (e.g., limited budget for libraries), social risk (e.g., excessive social isolation), privacy risk (e.g., privacy concerns over personal data), and functional risk (e.g., functional limitations of chatbots) (Kaushal and Yadav, 2022).

Conclusion

This entry highlights the key concepts related to DLs and their evolution in DL research and practice. Digitization serves as the foundation for DL development that involves techniques to convert physical resources into digital formats and considerations of policies and legal issues. Collection development has expanded beyond local collections, extending to large-scale DLs through collaborative and network-driven initiatives. Legal aspects, particularly copyright and fair use, are crucial in the collection development process. Diverse metadata schemes and associated metadata types are introduced, and the benefits and challenges of alternative approaches (user tagging and linked data) are discussed. Iterative design and user-centered DL design are emphasized, and accessibility and usability issues are further addressed along with the needs of various user groups. Additionally, factors related to systems, users, tasks, and interaction outcomes are elaborated. DL evaluation focuses on its frameworks, covering considerations from collection development to user engagement, using criteria ranging from standards to site visits, and employing measures encompassing both quantitative and qualitative data. Most importantly, new developments in DLs, especially the application of social media and AI, open new avenues for the enhancement of DLs.

Future research should concentrate on the following key areas:

- DL design environments
  Existing models and frameworks predominantly focus on DLs in the desktop environments, with limited exploration of DL design and evaluation in the mobile environment. Future research should develop universal or integrated design and evaluation models adaptable to different contexts. Additionally, specific attention should be given to the design and evaluation of mobile DLs.
- DL universal design
  Currently, DLs are designed primarily for the general public, overlooking the specific needs of individuals with disabilities, elderly people, and children. Designing multiple interfaces for different user groups may not be practical. Future research should explore the feasibility of one-size-fits-all design and alternative designs capable of adapting to specific user needs without overburdening other user groups.
- AI applications in DL development
  AI can be applied to multiple areas of DL development and management. Creating metadata is the most time and effort-intensive activity in DL development. Future research should investigate the utilization of AI to streamline the creation of metadata for digital items, ensuring credibility and quality. Designing DL interfaces to facilitate use by diverse types of users is the greatest challenge in DL development; further research should work on either developing AI-powered DL interfaces that take into consideration of users' special needs or providing relevant results to users without requiring extensive search processes.
- DL research methodologies

  Surveys are widely used in DL research for usability testing and DL evaluation. While surveys can solicit users' perceptions of DLs, they essentially provide general data. Future research should explore multiple data collection methods, such as think-aloud protocols, log analysis, interviews, focus groups, etc. These alternative methods can yield more specific and in-depth data that sheds light on users' challenges in their interactions with DLs.

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