



Designing a smart and sustainable research hub: Integrating green and digital solutions in academic libraries

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Abstract

The growing need for a sustainable and digitally connected research environment necessitates that university libraries transform beyond their traditional roles. To date, many libraries have implemented digital services and environmentally friendly initiatives separately, thereby failing to establish a fully integrated research ecosystem. This study aims to explore the development of a Smart and Sustainable Research Hub in university libraries through the integration of green and digital solutions. This study used a qualitative approach and was conducted at the Sebelas Maret University Library. Data was collected through document analysis and interviews with librarians and lecturers. Data analysis was performed to understand the integration between infrastructure, digital research services, innovative technology, and user needs in supporting research activities. The results demonstrate that integrating energy-efficient infrastructure, digital research services, innovative technology, and a user-centered approach can foster a sustainable and productive research ecosystem. Digital services not only improve research efficiency but also contribute to reduced resource use. Furthermore, the use of innovative technology supports more effective space and energy management. This study concludes that the Smart and Sustainable Research Hub concept makes significant conceptual and practical contributions to the development of university libraries as adaptive and sustainable research centers, supporting knowledge creation that aligns with institutional sustainability goals.

Keywords

Smart and sustainable research hub, University library, Digital transformation, Green library, User-centered design

Introduction

The rapid development of digital technology, coupled with growing global attention to environmental sustainability issues, has significantly transformed the landscape of higher education and the academic research ecosystem [1], [14], [15]. Universities today are not only required to produce high-quality research outputs but also to implement

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institutional practices aligned with the principles of sustainable development and environmental responsibility [2], [16]. In this context, university libraries play a strategic role as knowledge infrastructures that support research, learning, innovation, and institutional sustainability agendas [1], [17]. However, the primary challenge facing academic libraries is how to optimally respond to the growing demand for digital research services while maintaining environmental sustainability commitments [2], [18].

Several previous studies have discussed the transformation of academic libraries in the digital era. These studies highlight the shift in services from print-based collections to digital repositories, electronic databases, cloud-based collaboration platforms, and artificial intelligence-supported information retrieval systems [3], [19], [20]. Digital transformation has been shown to enhance research efficiency, improve information accessibility, and facilitate interdisciplinary academic collaboration [4], [21]. Meanwhile, research on green libraries is growing, focusing on energy-efficient buildings, waste reduction strategies, paperless services, and environmental literacy education programs [5], [22], [23]. These studies demonstrate that libraries can contribute directly to institutional sustainability agendas and the achievement of the Sustainable Development Goals (SDGs) [6], [24].

Despite the rapid development of digital services and green initiatives in academic libraries, most existing studies and institutional practices still tend to treat digital transformation and environmental sustainability as separate domains [7], [5], [25]. Digital innovation is often implemented to improve service efficiency and information access, while green initiatives mainly focus on physical infrastructure and environmental awareness programs. This fragmented approach has resulted in a lack of systematic integration between digital systems, environmental strategies, and user-centered research needs [8], [26]. As a consequence, many university libraries have not yet developed comprehensive frameworks that connect technological innovation, sustainability practices, and researchers' work patterns [27]. Digital services are sometimes underutilized, green initiatives are not optimally supported by data-driven management systems, and user needs are insufficiently embedded in service design processes [9], [28]. This situation creates a significant conceptual and practical gap in developing libraries as integrated and sustainable research ecosystems.

Furthermore, limited attention has been given to positioning users as central actors in the design of sustainable and digital library services. Without a strong user-centered approach, the integration of green and digital solutions risks becoming technology-driven rather than research-driven [9], [11], [29]. Previous studies emphasize that user engagement, participatory design, and usability-oriented development are essential for ensuring the long-term effectiveness and sustainability of digital library systems [30], [31]. Therefore, there is a critical need for a holistic model that connects digital transformation, environmental sustainability, and user experience within a unified development framework.

To address this gap, this study proposes the concept of a Smart and Sustainable Research Hub (SSRH) within the context of university libraries. The SSRH concept combines environmentally friendly infrastructure, digital research support systems, and User-Centered Design (UCD) principles to build an adaptive and sustainable research ecosystem [32], [33]. By integrating the Green Digital Framework, which emphasizes the synergy between digital transformation and sustainability, this study views libraries not merely as service providers but as collaborative spaces that actively support the creation and dissemination of sustainable knowledge [34]. This approach positions technology and sustainability as mutually reinforcing elements, rather than mutually exclusive objectives.

This study aims to explore the development of a Smart and Sustainable Research Hub at the Sebelas Maret University Library Unit. Specifically, it seeks to: (1) identify green and digital practices already implemented in the library, (2) analyze the integration of these practices in supporting research productivity and environmental sustainability, and (3) formulate a conceptual model for developing a library as an innovative and sustainable research center based on user needs.

Previous studies have introduced various concepts such as digital libraries, smart libraries, and green libraries to respond to technological and environmental challenges [19], [22], [35]. Digital libraries primarily focus on information access and electronic resources, smart libraries emphasize automation and intelligent systems, while green libraries concentrate on environmentally friendly infrastructure and sustainability programs. However, these concepts are often developed independently and lack an integrative perspective that connects technology, sustainability, and user-centered research support [25], [27], [36].

This study proposes the Smart and Sustainable Research Hub (SSRH) as an integrative concept that synthesizes digital transformation, green infrastructure, and user-centered design into a unified research ecosystem. Unlike existing models, SSRH positions the library not only as a service provider but also as a collaborative and adaptive research platform that systematically links technological innovation with sustainability goals and researchers' work patterns [32], [37].

Method

This study employs a qualitative approach, combining document analysis with interviews of librarians and lecturers, and is expected to make conceptual and practical contributions to the development of academic libraries in the era of digital transformation and sustainability. This research was designed to answer the question of how the integration of green and digital solutions can be effectively implemented in the development of a Smart and Sustainable Research Hub in a university library. To ensure systematic implementation, this study followed a structured research flow consisting of four main stages. First, baseline conditions were identified through document analysis and preliminary observations to map existing green and digital

practices. Second, in-depth data were collected through semi-structured interviews with librarians and lecturers to explore user experiences and institutional readiness. Third, the collected data were analyzed using thematic analysis based on the Green Digital Framework and User-Centered Design principles. Finally, the findings were synthesized into a conceptual model of the Smart and Sustainable Research Hub. Therefore, the research method focused on a deep understanding of the institutional context, existing practices, and user experiences and needs within the library research ecosystem.

This research employed a qualitative approach with a descriptive-exploratory design. This qualitative approach was chosen because it allows researchers to delve deeply into the processes, policies, and practices related to digital transformation and environmental sustainability in academic libraries. This design is suitable for examining complex and contextual phenomena, such as the integration of digital technology, green infrastructure, and user-centered research services.

As a foundation for analysis, this research integrates two conceptual frameworks: the Green Digital Framework and User-Centered Design (UCD). The Green Digital Framework is used to analyze the integration between sustainability practices and digital transformation. In contrast, UCD is used to ensure that the development of the SSRH concept is oriented towards user needs, experiences, and work patterns. The use of these two frameworks enables systematic and replicable analysis within the context of a university library.

The research was conducted at the Sebelas Maret University (UNS) Library Unit (UPT) in Surakarta, which serves as the university's central library and a key supporter of academic research activities. Subjects were selected using purposive sampling, a technique for selecting informants based on their direct involvement in research services, digital system management, and sustainability programs.

Subjects included librarians responsible for digital services and library development, as well as lecturers from various disciplines who actively utilize library facilities for research activities. This subject selection aimed to obtain a balanced perspective between service managers and research service users.

The data in this study consisted of primary and secondary data. Primary data were obtained through semi-structured interviews with librarians and lecturers. The interviews focused on experiences using digital services, perceptions of sustainability practices, and needs and expectations regarding the development of SSRH.

Secondary data were obtained through analysis of institutional documents, including library strategic planning documents, digital service development reports, sustainability policies, and supporting documents related to UNS' participation in UI GreenMetric. This document analysis was used to understand the policy framework and practices that have been formally implemented.

Data collection was conducted using two main techniques: document analysis and semi-structured interviews. Document analysis was conducted first to map baseline conditions and relevant policies, thus providing a basis for developing an interview guide.

Interviews were conducted both in person and online, with an average duration of 60–90 minutes per informant. The entire interview process was performed with the informant's consent and recorded for transcription and analysis purposes. This technique enabled consistent data collection and could be replicated by other researchers in different institutional contexts.

The data was analyzed using thematic analysis, which involved several stages: (1) reading and understanding the entire data set, (2) conducting an initial coding process, (3) grouping codes into central themes, and (4) interpreting the themes within the Green Digital Framework and UCD.

The main themes analyzed included green infrastructure practices, digital research services, intelligent system integration, and the role of users in the development of SSRH. This sequence of analysis aligns with the presentation of the research findings in the Results section, ensuring a systematic understanding of the relationship between the methods and conclusions.

To ensure data validity, this study employed a source triangulation strategy, comparing interview results with findings from institutional documents. Furthermore, limited member checking was conducted by confirming interview summaries with informants to ensure that the researcher's interpretations aligned with their intended meanings.

This approach ensured that the research process was transparent and accountable, allowing for the replication or adaptation of the method in future research.

Results and Discussion

This section presents the main research findings related to the development of the Smart and Sustainable Research Hub (SSRH) at the Sebelas Maret University Library. The research results were obtained through an analysis of institutional documents and interviews with librarians and lecturers who use library research services. The results are presented systematically, following the research methodology, which begins with green infrastructure practices, digital research services, smart system integration, and institutional and user readiness. The findings presented are representative and relevant to explaining how the integration of green and digital solutions contributes to the formation of a sustainable research ecosystem.

Results

The research findings indicate that the Sebelas Maret University Library has implemented various environmentally friendly infrastructure practices. These practices include the use of light-emitting diodes (LEDs) in most service spaces, the

implementation of an inverter air conditioning system, the utilization of natural lighting, and the regulation of air circulation in certain areas. Furthermore, the presence of indoor plants in several reading rooms contributes to user comfort and the quality of the space's environment.

These findings suggest that energy efficiency efforts have become an integral part of the library's operational policy. However, their implementation has not yet been fully integrated with a data-driven monitoring system. These green infrastructure practices form the initial foundation for the development of SSRH, particularly in supporting reduced energy consumption and improving the comfort of research spaces.

The research also reveals that the library has significantly developed its digital research services. These services include an institutional repository for academics' scientific works, access to electronic databases, an online library-free service system, and the implementation of radio frequency identification (RFID) technology for collection circulation. The digitization of these services has had a direct impact on reducing paper usage and enhancing the efficiency of administrative processes.

From the user perspective, digital services are considered to facilitate access to information sources and support research activities without dependence on the library's physical space. These findings demonstrate that digital research services play a crucial role in establishing a more flexible and sustainable research ecosystem.

This study found that libraries have begun utilizing innovative technology to support research activities, particularly through the use of academic writing support software, plagiarism detection systems, and cloud-based collaboration platforms. This technology helps researchers enhance the quality of their writing, improve the efficiency of reference management, and facilitate cross-disciplinary research collaboration.

Furthermore, there are early initiatives in implementing Internet of Things (IoT)-based monitoring systems, particularly for energy and space management. Although still limited and not yet fully integrated, these findings demonstrate the significant potential of innovative technology in optimizing resource utilization and improving user experience.

Interviews indicate that librarians have a high level of awareness of the importance of integrating sustainability and digitalization into library services. Capacity-building efforts, including training and internal discussions, have been undertaken; however, further development of technical competency in innovative system management and data analysis remains necessary.

From the perspective of lecturers as users, libraries are viewed not only as information providers but also as potential spaces for research collaboration. Users believe that the development of the Smart and Sustainable Research Hub (SSRH) should focus on providing more integrated digital services, along with a space design that promotes comfort, collaboration, and work efficiency. These findings confirm that organizational

readiness and user engagement are key factors in the successful development of the Smart and Sustainable Research Hub.

Based on the research findings, the relationship between green infrastructure, digital research services, innovative technology, and user-centered approaches can be summarized in a conceptual model of the Smart and Sustainable Research Hub, as shown in Figure 1.

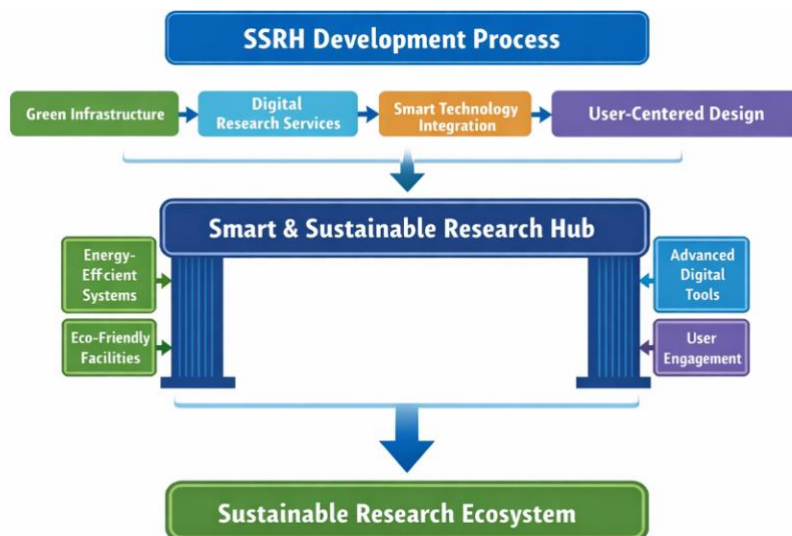


Figure 1. Conceptual model of the smart and sustainable research hub

Figure 1 illustrates the research process and conceptual development of the Smart and Sustainable Research Hub (SSRH). The model begins with the identification of existing green infrastructure and digital research services through document analysis and interviews. These elements are then integrated with smart technology initiatives and user-centered design principles. The integration process is followed by institutional and user readiness assessment, which determines the feasibility of implementation. Finally, the combined components form an adaptive and sustainable research ecosystem that supports research productivity and environmental sustainability. The directional arrows in the model represent the sequential and interrelated nature of each development stage.

To further clarify the research findings, a summary of the Smart and Sustainable Research Hub implementation is presented in Table 1.

Table 1. Summary of the smart and sustainable research hub implementation

Aspect	Implementation	Observed Outcome
Green infrastructure	LED lighting, inverter AC, natural lighting	Improved energy efficiency and user comfort
Digital research services	Institutional repository, e-databases, paperless services	Increased accessibility and research productivity
Smart technology support	AI-assisted tools and early IoT initiatives	Optimized resource use and research workflow
User-centered approach	Alignment of services with research needs	Improved relevance and usability of services
Sustainability impact	Reduced paper usage and efficient energy management	Contribution to institutional sustainability and SDGs

Discussion

This discussion aims to interpret the research findings related to the development of the Smart and Sustainable Research Hub (SSRH) and place them within the context of previous theory and research. Overall, the research findings demonstrate that the integration of green infrastructure, digital research services, innovative technology, and a user-centered approach forms an adaptive and sustainable research ecosystem. These findings not only strengthen the concept of academic library transformation but also provide a conceptual contribution to the development of a sustainability- and digitalization-based library model.

First, the findings regarding the integration of green infrastructure and digital services can be explained through the Green Digital Framework, which emphasizes that digital transformation and environmental sustainability are mutually reinforcing agendas. This research demonstrates that the implementation of energy-efficient facilities such as LED lighting, inverter air conditioning, and the use of natural light does not stand alone but gains strategic value when linked to the digitalization of research services. Digital repositories, online services, and paperless systems not only improve academic work efficiency but also directly contribute to reducing the use of physical resources. Thus, these findings clarify that digitalization does not necessarily imply increased energy consumption, as feared in some previous studies, but can instead be directed to support sustainability goals if designed within a green-digital integration framework [10].

Second, from a User-Centered Design (UCD) perspective, the research results indicate that the alignment between technology, space, and user needs has a strong influence on the success of SSRH development. The UCD approach emphasizes that an effective system is determined not only by technological sophistication but also by its ability to support users' actual activities. The finding that lecturers view libraries as potential spaces for research collaboration reinforces the argument that digital services and space design should be developed based on research workflows, not just technical standards. In this context, this research extends the application of UCD from the realm of information systems design to the development of a library research ecosystem that encompasses physical, digital, and social aspects in an integrated manner.

Third, the integration of intelligent technologies, such as AI-assisted tools and early IoT initiatives, can be understood through socio-technical systems theory, which views organizations as dynamic interactions among people, technology, and the environment [11]. The results of this study suggest that intelligent technologies in libraries do not function optimally when they are isolated from organizational policies, librarian competencies, and user behavior. In other words, a smart library is not simply the result of technology adoption, but rather the alignment of technical and social systems. These findings reinforce criticisms of the overly automation-oriented smart library approach, emphasizing that long-term sustainability and effectiveness can only be achieved through balanced socio-technical integration [12].

Furthermore, the SSRH model generated from the research findings (Figure 1) can be understood within the framework of the living laboratory concept, where the library serves as a concrete testbed for green and digital innovations. In this concept, users are positioned not as passive recipients of services, but as actors who interact directly with the system and contribute to shaping sustainable practices [13]. These research findings expand the living laboratory concept by demonstrating that academic libraries have an advantage as sites for sustainable experimentation due to their proximity to research, learning, and knowledge production activities.

However, this study also identifies several limitations that require critical examination. The implementation of innovative technology is still in its early stages and has not been fully integrated into a data-driven management system. Furthermore, this study does not provide quantitative measurements related to energy savings or increased research productivity. These limitations do not weaken the findings, but rather highlight the scope for further research, particularly through a mixed methods approach to more measurably test the long-term impact of the SSRH model.

Compared to existing models such as digital libraries, smart libraries, and green libraries, the Smart and Sustainable Research Hub (SSRH) offers a more integrative and holistic framework. Digital library models mainly emphasize electronic resource management and information accessibility, while smart library concepts focus on automation, artificial intelligence, and service efficiency. In contrast, green library approaches prioritize environmentally friendly buildings and sustainability campaigns.

Although these models contribute significantly to library development, they tend to operate in parallel rather than in synergy. The SSRH model differs by systematically integrating digital systems, green infrastructure, and user-centered research support within a single conceptual framework. This integration enables libraries to function simultaneously as sustainable physical spaces, intelligent digital platforms, and collaborative research environments.

Therefore, the novelty of this study lies in its conceptual synthesis of technological innovation, environmental sustainability, and user experience into a unified research ecosystem. Rather than proposing a new isolated model, this research demonstrates how existing approaches can be strategically connected to enhance research productivity and institutional sustainability.

Conclusion

This study concludes that the development of a Smart and Sustainable Research Hub (SSRH) in academic libraries is a strategic approach to addressing the challenges of digital transformation and environmental sustainability simultaneously. The research findings demonstrate that integrating green infrastructure, digital research services, innovative technology, and a user-centered approach creates an adaptive, efficient, and sustainable research ecosystem. This conclusion aligns with the research objective,

which emphasizes understanding the integration of green and digital solutions in supporting research activities in higher education.

Based on the discussion, this study confirms that the success of library transformation is not determined by the adoption of technology or environmental policies in isolation, but rather by the functional interrelationship between the two within a socio-technical system. Libraries that integrate the principles of the Green Digital Framework and User-Centered Design can expand their role from merely providing information services to becoming collaborative research centers that support academic productivity while maintaining ecological responsibility. Thus, libraries function not only as service spaces but also as strategic spaces for sustainable innovation.

This research's primary contribution to the field of Library and Information Science lies in strengthening the conceptual perspective of libraries as innovative and sustainable research hubs. This research enriches the discourse on smart libraries and green libraries by demonstrating that their integration yields greater added value than their partial implementation. The resulting SSRH model provides a conceptual framework that can be adapted by other university libraries in developing research ecosystems aligned with sustainable development and digital transformation agendas.

However, this study has limitations, particularly the lack of quantitative measurements related to the impact of energy efficiency and increased research productivity. Therefore, future research is recommended to combine qualitative and quantitative approaches to more measurably evaluate the effectiveness of the SSRH model. Furthermore, cross-institutional comparative studies are necessary to assess the relevance and sustainability of this model in various university library contexts.

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