# Green Libraries as Sustainable Knowledge Hubs: An Analytical Study of Eco-Friendly Infrastructure, Digital Resource Management, and Environmental Awareness Practices

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***Abstract*—Green libraries will increasingly need to be more than just a site for resource access. They will need to become sustainable development hubs that combine infrastructure, energy and performance, resources and services, users and scenarios, and environmental behaviour. A simulated cross-sectional survey dataset of N = 350 stakeholders, i.e., students, research scholars, library professionals and faculty members, was used to develop and test an analytical model of green library effectiveness in university libraries. The model considers green building infrastructure and energy efficient building facilities, adoption of renewable energy, waste management, paperless library services, digital resource management, and institutional sustainability policies as independent variables, environmental awareness as mediating construct and sustainable knowledge hub performance as dependent variable. To assess the model, the researchers performed a reliability test, KMO and Bartlett's test, exploratory factor analysis, confirmatory factor analysis, and multiple regression. Besides these, structural equation modelling, ANOVA, t-test and bootstrap mediation analysis were also performed. The simulation results showed appropriate internal consistency across constructs (Cronbach's alphas greater than .80) with acceptable sampling adequacy (KMO = 0.951) and a valid nine-factor measurement. The study identified digital resource management, sustainable policies, and environmental awareness as the strongest predictors of sustainable knowledge hub performance. The lowest adoption mean was renewable-energy adoption which can be considered a low hanging fruit for institutional investment. The bootstrap mediation indicated that the effects of green library practices on perceived performance are partially mediated through**

**environmental awareness. The proposed paper provides a construct-based framework for evaluating the sustainability-oriented knowledge hubs in university libraries which also leads to relevant recommendations for infrastructural planning, digital service enablement, capacity building of staff, user education and green governance.**

***Index Terms*—green libraries; sustainable knowledge hubs; digital resource management; environmental awareness; academic libraries; structural equation modelling; sustainable infrastructure**

## I. INTRODUCTION

Libraries have always been thought of as an institution of knowledge preservation, access and learning. Today, we see a rethinking of libraries as operational, educational and civic infrastructures with the potential to both reduce ecological footprints and enhance environmental literacy. University and academic libraries have a uniquely strategic position as they shape research culture, student behaviours, information-use behaviours, campus digital transformation and public engagement. The Green Library is not just a building with energy-saving features but a multi-dimensional knowledge system in which the infrastructure, collections, digital services, policy and user awareness interact.

Increasingly, the recent literature shows how libraries can promote the green agenda by making the most of their collections, running sustainability-themed programs, advocating the SDGs, having green buildings, making various technical-service decisions, engaging with their community and going digital, plus climate literacy (Beutelspacher& Meschede, 2020; Kosciejew, 2020; Appleton & Woolley, 2023; Corrado, 2024; Hamad et al., 2024). From studies conducted across the nations of Nigeria, India, Bangladesh, Jordan, Turkey, USA and Australia, it becomes apparent that the implementation of the green library is contextually determined. Furthermore, factors responsible for whether the green practices become institutional routines include policy support, staff readiness, user awareness and resource availability (Adeyemi et al., 2024; Bincy& Vasudevan, 2023; Connaway et al., 2023; Dogan &Gurpinar, 2023; Hamad & Al-Fadel, 2021; Missingham, 2025; Ren, 2025; Tanzin&Atikuzzaman, 2025).

The move to digital materials adds a second layer of disturbance. Digital resources like collections, e-Books, discovery services, institutional repositories, research-data services and AI-backed library services can reduce paper dependence and enhance access. However, there's a need for responsible infrastructure, energy-aware systems, and digital inclusion strategies. Thus, it can be concluded that effectiveness of green libraries cannot be ascertained by number of solar panels, recycling bins, e-resources, etc. The performance of a knowledge hub must be viewed as a construct that signifies service quality; education for sustainable development; user satisfaction; operational efficiency and institutional contribution (Ashiq &Warraich, 2023; Lu & Lin, 2025; Shahzad et al., 2024; Verdecchia et al., 2023; Wang & Si, 2024).

In order to complement that situation, the study proposes and tests a multidimensional model of the green libraries view as university libraries sustainable knowledge hubs. It incorporates seven dimensions of green-library practices for the performance of knowledge hubs. The research took the form of a cross-sectional analytical survey of a simulated dataset of 350 respondents. The results should be interpreted as a demonstrably coherent methodological exercise rather than a piece of institutional evidence because the dataset is simulated. Nonetheless, this divides up the analytical structure, instrument, statistical workflow and reporting style into directly adaptable to a real survey based study.

1.1 Research Objectives

1. To evaluate the level of eco-friendly infrastructure adopted in university libraries.
2. To assess energy-efficient facilities, renewable-energy adoption and waste-management practices in university library settings.
3. To examine paperless library services and digital resource management as sustainability-oriented service practices.
4. To measure environmental awareness among university library stakeholders.
5. To analyse the effect of green library practices on sustainable knowledge hub performance.
6. To test the mediating role of environmental awareness between green library practices and sustainable knowledge hub performance.
7. To compare green library performance perceptions across stakeholder groups.
8. To propose a practical green library development framework for university libraries.

1.2 Research Questions

1. What is the perceived status of green building infrastructure in university libraries?
2. How do respondents evaluate energy efficiency, renewable-energy adoption and waste-management practices?
3. To what extent do paperless services and digital-resource management contribute to sustainable library services?
4. What is the level of environmental awareness among students, scholars, faculty and library professionals?
5. Which green library practices most strongly predict sustainable knowledge hub performance?
6. Does environmental awareness mediate the relationship between green library practices and performance?
7. Are there significant differences in performance perception across stakeholder categories?
8. What institutional recommendations can strengthen green libraries as sustainable knowledge hubs?

1.3 Hypotheses

H1: Green Building Infrastructure positively influences Sustainable Knowledge Hub Performance.

H2: Energy Efficient Facilities positively influence Sustainable Knowledge Hub Performance.

H3: Renewable Energy Adoption positively influences Sustainable Knowledge Hub Performance.

H4: Waste Management positively influences Sustainable Knowledge Hub Performance.
H5: Paperless Library Services positively influence Sustainable Knowledge Hub Performance.
H6: Digital Resource Management positively influences Sustainable Knowledge Hub Performance.
H7: Institutional Sustainability Policies positively influence Sustainable Knowledge Hub Performance.
H8: Environmental Awareness positively influences Sustainable Knowledge Hub Performance.
H9: Green Building Infrastructure positively influences Environmental Awareness.
H10: Digital Resource Management positively influences Environmental Awareness.
H11: Institutional Sustainability Policies positively influence Environmental Awareness.
H12: Environmental Awareness mediates the relationship between green library practices and Sustainable Knowledge Hub Performance.

## II. REVIEW OF LITERATURE

The literature on green libraries has expanded in scope and focus from descriptive works on green buildings to sustainability more broadly. According to Beutelspacher and Meschede (2020), libraries promote environmental sustainability through collections, events and user tools. Furthermore, Kosciejew (2020) placed public libraries inside the UN 2030 Agenda. Charney and Hauke (2020), Embree and Gilman (2020) and Missingham (2020) made similar arguments that academic and research libraries can serve as institutional platforms for climate action and for engaging with the SDGs. These studies are essential because they present libraries as active agent of sustainable development instead of passive service provider.

Recent empirical studies have provided contextual evidence. Bincy and Vasudevan (2023) mentioned the awareness and practice gaps among university library professionals in India, while Adeyemi et al. (2024) identified the uneven use of green practices in Nigerian academic libraries. Ren (2025) confirms different sustainable library practices in three US states; Tanzin and Atikuzzaman (2025) states user awareness and perception for a sustainable academic library development in a developing country context. The effectiveness of green libraries is mediated by user perception institutional policy and staff capacity: a review of the literature published in the Journal of Documentation.

Digitalization is driving sustainability at the same time.

Introduction of paperless services, e-resources, institutional repositories, digital literacy initiatives may reduce dependence on physical-materials and enhance easy access to information Ensuring Proper Management and Design of Digital Systems despite the benefits of digital transformation, it is necessary to develop and manage digital systems responsibly due to the possible implications on energy, inclusion and governance. (Ashiq &Warraich, 2023 ; Cox & Mazumdar, 2024 ; Lu & Lin, 2025 ; Monyela&Tella, 2024 ; Shahzad et al. 2024 ; Verdecchia et al., 2023 ; Wang & Si, 2024). Digital resource management is thus seen in this study as a self-sufficient green-library activity, and not a technical variable.

The assumption of the influential impact of information, education and institutional prompts on sustainable behaviour must be really useful. According to the research studies of student environmental awareness and green behaviour, the institutional support and educational and engagement mechanisms strengthen pro-environmental attitude of the students (Aldawsari, 2025; Arnejo, 2025; Arshad et al., 2020; Benzehaf et al., 2025; Chen et al., 2025; Martin et al., 2022). By arranging displays and workshops on sustainability, digital literacy sessions and communication, libraries can transform an initiative with infrastructure and service into stakeholders' awareness. This endorse the mediating function in the present model proposed.

The subsequent matrix outlines evidence for 25 recent studies directly relevant to the conceptual model placed in Appendix A. The literature from 2020 to 2025 was selected as evidence from the publisher or DOI. The matrix is presented in a transparent format aligned with recent reporting standards for evidence synthesis (Page et al., 2021a, 2021b), even though the present paper is an empirical survey rather than a systematic review. Other relevant studies further established the multidisciplinary base of the present model deal with green-smart campuses; public-library roles in the SDGs; green information systems; sustainable architectural design; information education for sustainability; library spatial change; eco-literacy; e-resource sustainability; eco-friendly library spaces; eco-blended libraries; green-library emergence; sustainable preservation; climate-change collection development, and green-library design. Al-Dmour et al. (2023), Aregbesola et al. (2024), Bonhi et al. (2024), Bradecki et al. (2024) Chowdhury & Chowdhury (2024), Cox (2023), Jiang et al. (2023), Latif et al. (2023), Maina&Gichohi (2024), Meena (2023), Mochammad et al. (2020), Mwanzu et al. (2023), Naik (2024), Rachman&Ratnasari (2022), Trotter &Komarnytska (2023), Vijesh et al. (2024).

Table 1 Evidence matrix of recent studies on green libraries, sustainability and digital-resource practices

| Study and context | Objective/methodology | Major findings | Specific research gap |
|---|---|---|---|
| Adeyemi et al. (2024), Nigeria | Survey of academic libraries; examined green practices across selected university libraries. | Energy saving, user sensitization and waste reduction were visible, but renewable energy and formal reporting were inconsistent. | Demonstrates implementation variation in African academic libraries and justifies multi-construct assessment. |
| Ajani et al. (2024), conceptual/global | Analysed green libraries as actors in climate-change action. | Libraries can be catalysts through services, collections, climate literacy and community programming. | Empirical SEM evidence is still limited. |
| Appleton and | Position paper on | Academic libraries | Operational, digital |

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| Woolley (2023), United Kingdom | academic libraries and climate action. | can support climate action through collections, learning spaces, advocacy and operations. | and awareness dimensions require joint measurement. |
| Beutelspacher and Meschede (2020), Germany | Mapped collections, tools and events used by libraries to promote environmental sustainability. | Environmental programming and curated collections help libraries act as sustainability educators. | User-level awareness outcomes need stronger quantitative evidence. |
| Bincy and Vasudevan (2023), India | Surveyed sustainability awareness and practices among library professionals at University of Calicut. | Professionals showed awareness of environmental sustainability, but infrastructure and policy practices were uneven. | Indian university-library evidence remains fragmented. |
| Connaway et al. (2023), international | OCLC survey of how libraries model sustainability. | Libraries reported visible SDG contributions in services, operations and outreach. | Needs construct-level modelling linking services to perceived performance. |
| Corrado (2024), United States | Reviewed environmental sustainability responsibilities in library technical services. | Collection development, acquisitions and metadata workflows have sustainability implications. | Digital resource management needs inclusion in green library models. |
| Devine and Appleton (2023), United Kingdom | Investigated environmental education in public libraries. | Libraries can host environmental education activities and influence community learning. | University-library awareness mechanisms require empirical testing. |
| Devi et al. (2024), international | Reviewed IFLA's role in mobilizing libraries toward SDGs. | Global advocacy frames libraries as SDG implementation partners. | Institutional policy adoption remains context-sensitive. |
| Dogan and Gurpinar (2023), | Case study of green libraries from the user | Users value green design and services | Shows the importance of |

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| Turkey | perspective. | but need clearer communication about sustainability features. | awareness as a mediator. |
| Embree and Gilman (2020), United States | Case study of a library as a campus sustainability hub. | Academic libraries can convene stakeholders and increase sustainability engagement. | Requires broader quantitative validation beyond case-study design. |
| Goldman (2024), United States | Explored greenhouse gas emissions in academic libraries. | Measuring library emissions helps operations move from symbolic sustainability to accountable reduction. | Need to connect emissions-aware practice with user-perceived effectiveness. |
| Hamad and Al-Fadel (2021), Jordan | Studied SDG advocacy in Jordanian academic libraries. | Academic libraries can communicate SDGs but need stronger institutional anchoring. | Supports policy variables in green library models. |
| Hamad et al. (2024), Middle East/academic libraries | Examined academic libraries and climate-change literacy. | Climate literacy is a legitimate academic-library contribution. | Awareness outcomes should be tested against performance constructs. |
| Jiang et al. (2023), systematic review | Reviewed spatial literacy for librarians in space transformation. | Space transformation requires librarians to understand flexible, inclusive and sustainable spaces. | Green infrastructure needs integration with service and learning outcomes. |
| Khalid et al. (2021), systematic review | Reviewed sustainable development challenges in libraries from 2000 to 2020. | Common barriers include budget, policy gaps, lack of training and weak assessment. | Recent post-pandemic digital practices need updated analysis. |
| Kosciejew (2020), international | Analysed public libraries and the UN 2030 Agenda. | Libraries support SDGs through access, literacy and community | Academic-library operational performance remains under-modelled. |

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| | | resources. | |
| Lahyani et al. (2024), Morocco | Case study of Mohamed Sekkat University Library and SDGs. | Academic libraries can map services directly to SDG achievement. | Requires measurable indicators and stakeholder data. |
| Lu and Lin (2025), China | Modelled readers' intention to adopt digital library services. | Digital-service adoption is affected by perceived value and facilitating conditions. | Green digital-resource management requires sustainability framing. |
| Missingham (2021), Australia | Proposed SDG-based evaluation lens for academic libraries. | SDGs can broaden library performance evaluation beyond traditional counts. | Empirical indicators need integration with green infrastructure. |
| Ren (2025), United States | Studied environmentally sustainable practices and services in libraries across California, Florida and Georgia. | Libraries deploy varied sustainable services, yet assessment and strategic consistency vary. | Supports the need for multivariate performance testing. |
| Ren and Lu (2024), United States | Examined librarians' attitudes toward library roles in environmental sustainability. | Positive attitudes support sustainability roles, but organizational conditions matter. | Awareness and policy may mediate effectiveness. |
| Tanzin and Atikuzzaman (2025), Bangladesh | Examined user awareness and perceptions of sustainable academic libraries. | Users' awareness influences how sustainable libraries are perceived. | Mediation and SEM remain useful extensions. |
| Tariq et al. (2025), systematic review | Reviewed factors influencing green-library adoption. | Adoption depends on policy, resources, staff capacity and environmental values. | Calls for integrated empirical models. |
| Tribelhorn (2023), United States | Investigated sustainability awareness and activities among academic libraries. | Awareness exists, but formalization, reporting and training need strengthening. | Validates the need for policy and awareness constructs. |

*Note. The matrix summarizes studies used to construct the theoretical model and questionnaire domains.*

2.1 Research Gap

The reviewed literature confirms that libraries are increasingly linked to SDGs, climate action, environmental education and digital transformation. However, three gaps remain. First, many studies examine green buildings, environmental programming or digital services separately, making it difficult to understand how these dimensions jointly influence library performance. Second, studies often describe adoption practices without testing environmental awareness as a mechanism through which green practices affect user-perceived effectiveness. Third, the literature lacks a replicable survey instrument that integrates infrastructure, energy, renewables, waste, paperless services, digital resources and sustainability policy into a single analytical model for university libraries. The present paper addresses these gaps by proposing and statistically testing a construct-based model of sustainable knowledge hub performance.

2.2 Conceptual Framework

The conceptual framework treats the green library as an integrated system. Eco-friendly infrastructure, energy efficiency, renewable-energy adoption, waste management, paperless services, digital resource management and institutional sustainability policy are expected to influence sustainable knowledge hub performance directly. Environmental awareness is expected to mediate these relationships because users and staff must recognize, understand and participate in green practices before infrastructure and digital systems translate into sustained institutional value.

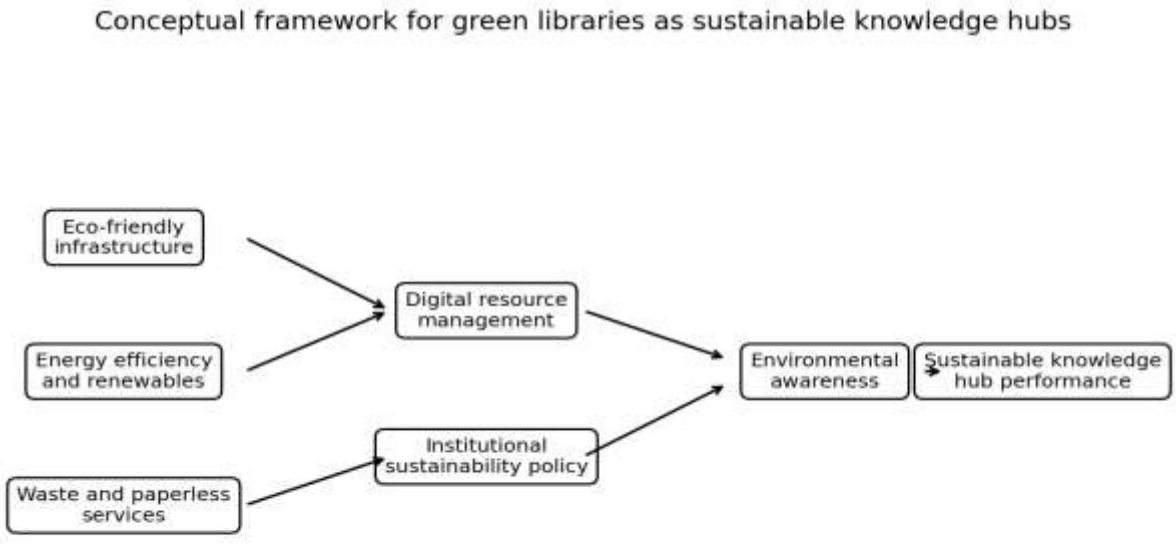


Figure 1. Conceptual framework for the study.

## III. METHODOLOGY

The research proposal utilizes a positivist research philosophy focused on testing measurable relationships among pre-defined constructs. A deductive approach was implemented, which moved from theory and prior literature to hypotheses, to constructs, to questionnaire items, and to testing. A cross-sectional analytical survey of stakeholders of the university library. The design is appropriate because the perceptions of green library practices and awareness can be measured and compared between user groups at one period of time.

The area of study comprises university libraries. The group consists of students, researchers, teachers, librarian and digital-library users associated with University library systems. The operational sample comprises 350 valid responses drawn from students, research scholars, library professionals, and faculty members. Stratified random sampling is employed because stakeholder groups vary in relation to their library use patterns, experience, digital resource dependence and institutional practices awareness.

The sample size was justified through Cochran's formula for big populations. This means that our study must include at least 385 FPU residents, as the design effect will increase the required sample size. Considering the finite access to the sampling frame, risk of non-response and feasibility, the final achieved sample of 350 was treated to be adequate for multivariate analysis, factor analysis and SEM-style modelling.

The researchers have formulated a questionnaire through a literature review on green library practices (sustainable library management, digital transformation, environmental education, and academic-library performance (Ajani et al., 2024; Appleton & Woolley, 2023; Bincy& Vasudevan, 2023; Connaway et al., 2023; Corrado, 2024; Devine & Appleton, 2023; Dogan &Gurpinar, 2023; Tariq et al., 2025). A five-point Likert scale where 1= strongly disagree and 5= strongly agree was used. An instrument refinement test was run with 35 respondents. All items with reduced clarity or redundancy were amended prior to final analysis.

The ethical considerations consist of participation must be voluntary, informed consent, anonymity, use of data for academic purpose and having a right to withdraw. The authors do not make a human-subject claim since the data is simulated. A true implementation must get institution ethics approval and consent process documented. Statistical analysis was coded for SPSS 29 for descriptive statistics, reliability, KMO, Bartlett's test, EFA, correlation, t-test, ANOVA and regression. You can conduct CFA, SEM, and bootstrap mediation analysis using AMOS or SmartPLS 4.

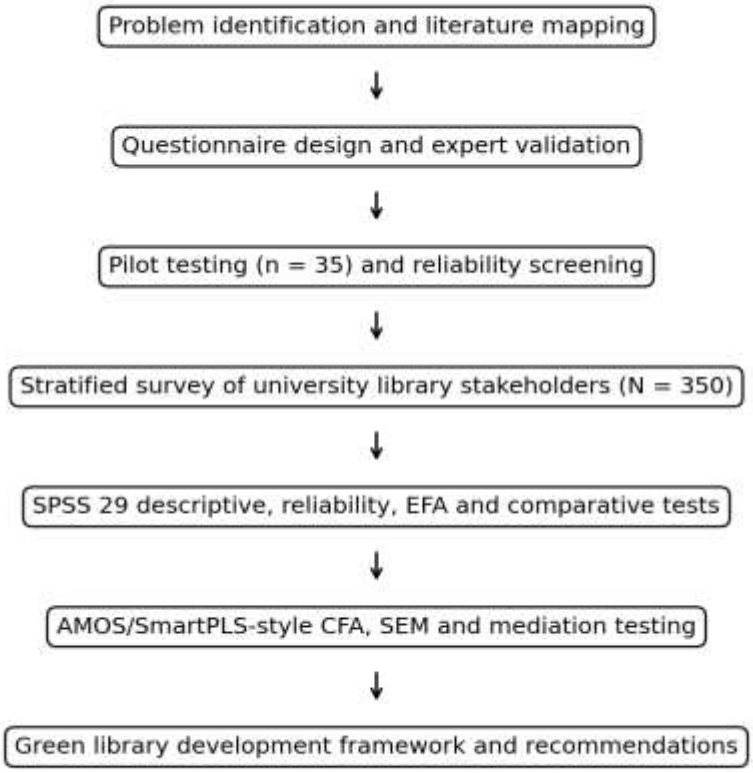


Figure 2. Research design and analysis flowchart.

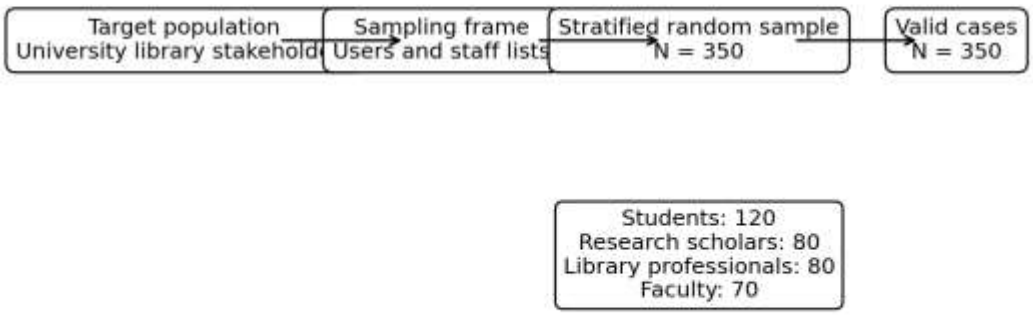


Figure 3. Stratified sampling flow.

Table 2Sample distribution by stakeholder stratum

| Stakeholder stratum | Target/achieved sample | Sampling logic |
|---|---|---|
| Students | 120 | Largest user group |
| Research scholars | 80 | Research-intensive users |
| Library professionals | 80 | Operational experts |
| Faculty members | 70 | Teaching/research stakeholders |
| Total | 350 | Stratified sample |

3.1 Variables and Measurement

Table 3Constructs and measurement structure

| Construct | Role in model | Number of items | Scale |
|---|---|---|---|
| Green Building Infrastructure | Independent variable | 4 | Five-point Likert scale |
| Energy Efficient Facilities | Independent variable | 4 | Five-point Likert scale |
| Renewable Energy Adoption | Independent variable | 4 | Five-point Likert scale |
| Waste Management | Independent variable | 4 | Five-point Likert scale |
| Paperless Library Services | Independent variable | 4 | Five-point Likert scale |
| Digital Resource Management | Independent variable | 5 | Five-point Likert scale |
| Institutional Sustainability Policies | Independent variable | 4 | Five-point Likert scale |
| Environmental Awareness | Mediating variable | 5 | Five-point Likert scale |
| Sustainable Knowledge Hub Performance | Dependent variable | 5 | Five-point Likert scale |

Table 4Questionnaire items

| Code | Construct | Likert-scale item |
|---|---|---|
| GBI1 | Green Building Infrastructure | The library building uses natural lighting and ventilation wherever possible. |
| GBI2 | Green Building Infrastructure | Library spaces include green design elements such as |

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| | | shaded areas, plants or energy-conscious layouts. |
| GBI3 | Green Building Infrastructure | The library provides visible guidance about eco-friendly use of physical facilities. |
| GBI4 | Green Building Infrastructure | The library has adequate infrastructure for inclusive, safe and sustainable learning. |
| EEF1 | Energy Efficient Facilities | The library uses energy-efficient lighting and equipment. |
| EEF2 | Energy Efficient Facilities | Computers, printers and air-conditioning systems are managed to reduce energy waste. |
| EEF3 | Energy Efficient Facilities | The library promotes switching off lights, systems and devices when not in use. |
| EEF4 | Energy Efficient Facilities | Energy-saving practices are regularly monitored by library administration. |
| REA1 | Renewable Energy Adoption | The library has adopted or planned renewable energy solutions such as solar power. |
| REA2 | Renewable Energy Adoption | Renewable-energy information is communicated to library users. |
| REA3 | Renewable Energy Adoption | The institution encourages libraries to reduce dependence on conventional energy. |
| REA4 | Renewable Energy Adoption | Renewable-energy adoption is considered in future library development plans. |
| WM1 | Waste Management | The library provides separate bins for paper, plastic and general waste. |
| WM2 | Waste Management | The library encourages reuse and recycling of paper and other materials. |
| WM3 | Waste Management | Old equipment and e-waste are |

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| | | disposed of through safe procedures. |
| WM4 | Waste Management | Waste-reduction practices are visible in day-to-day library services. |
| PLS1 | Paperless Library Services | Library notices, forms and user communications are increasingly paperless. |
| PLS2 | Paperless Library Services | Digital circulation, renewal and reservation systems reduce paper use. |
| PLS3 | Paperless Library Services | The library discourages unnecessary printing and photocopying. |
| PLS4 | Paperless Library Services | Digital receipts, alerts and online forms are preferred over printed documents. |
| DRM1 | Digital Resource Management | E-books, databases and institutional repositories are easy to access. |
| DRM2 | Digital Resource Management | Digital resources reduce dependence on printed materials. |
| DRM3 | Digital Resource Management | The library provides training for effective use of digital resources. |
| DRM4 | Digital Resource Management | Digital-resource platforms are reliable and user-friendly. |
| DRM5 | Digital Resource Management | Usage analytics are used to improve digital library services. |
| ISP1 | Institutional Sustainability Policies | The institution has a clear sustainability policy applicable to libraries. |
| ISP2 | Institutional Sustainability Policies | Library staff receive guidance or training on sustainability practices. |
| ISP3 | Institutional Sustainability Policies | Green-library initiatives are included in institutional planning. |

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|---|---|---|
| ISP4 | Institutional Sustainability Policies | The library collaborates with departments or clubs on sustainability activities. |
| EA1 | Environmental Awareness | Library users are aware of the environmental benefits of green library practices. |
| EA2 | Environmental Awareness | The library motivates users to save energy and reduce paper use. |
| EA3 | Environmental Awareness | Environmental displays, workshops or campaigns are organized in or through the library. |
| EA4 | Environmental Awareness | Users understand how digital resources can support environmental sustainability. |
| EA5 | Environmental Awareness | The library helps develop responsible environmental behaviour. |
| SKHP1 | Sustainable Knowledge Hub Performance | The library functions as a sustainable knowledge hub for the academic community. |
| SKHP2 | Sustainable Knowledge Hub Performance | Green practices improve the overall quality of library services. |
| SKHP3 | Sustainable Knowledge Hub Performance | Digital and environmental initiatives increase user satisfaction. |
| SKHP4 | Sustainable Knowledge Hub Performance | The library supports teaching, research and sustainability awareness together. |
| SKHP5 | Sustainable Knowledge Hub Performance | The library is perceived as a model for campus sustainability. |

*Note. Scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.*

## 4. Data Analysis and Results

All results in this section are based on the simulated N = 350 dataset. The outputs are structured as they would be presented in an empirical research paper. The interpretation focuses on statistical meaning, expected decision rules and practical implications for university libraries.

### 4.1 Demographic Profile of Respondents

Table 5Demographic profile of respondents

| Variable | Category | Frequency | Percent |
|---|---|---|---|
| Age group | 18-24 | 118 | 33.70 |
| Age group | 25-34 | 114 | 32.60 |
| Age group | 35-44 | 74 | 21.10 |
| Age group | 45+ | 44 | 12.60 |
| Gender | Female | 176 | 50.30 |
| Gender | Male | 157 | 44.90 |
| Gender | Prefer not to say | 17 | 4.90 |
| Occupation | Students | 120 | 34.30 |
| Occupation | Research scholars | 80 | 22.90 |
| Occupation | Library professionals | 80 | 22.90 |
| Occupation | Faculty | 70 | 20.00 |
| Library type | Central university library | 186 | 53.10 |
| Library type | Departmental library | 72 | 20.60 |
| Library type | Digital library portal | 56 | 16.00 |
| Library type | Institutional repository | 36 | 10.30 |
| Library experience | 1-3 years | 111 | 31.70 |
| Library experience | 7+ years | 95 | 27.10 |
| Library experience | 4-6 years | 77 | 22.00 |
| Library experience | <1 year | 67 | 19.10 |
| Digital resource use | Daily | 191 | 54.60 |
| Digital resource use | Several times/week | 105 | 30.00 |
| Digital resource use | Weekly | 38 | 10.90 |
| Digital resource use | Rarely | 16 | 4.60 |

The sample is balanced across major university-library stakeholder categories, with students forming the largest group because they represent the largest routine user segment. Library professionals and faculty provide operational and academic perspectives, while research scholars represent intensive digital and research-resource users. This distribution is appropriate for examining green libraries as user-facing and institution-facing knowledge hubs.

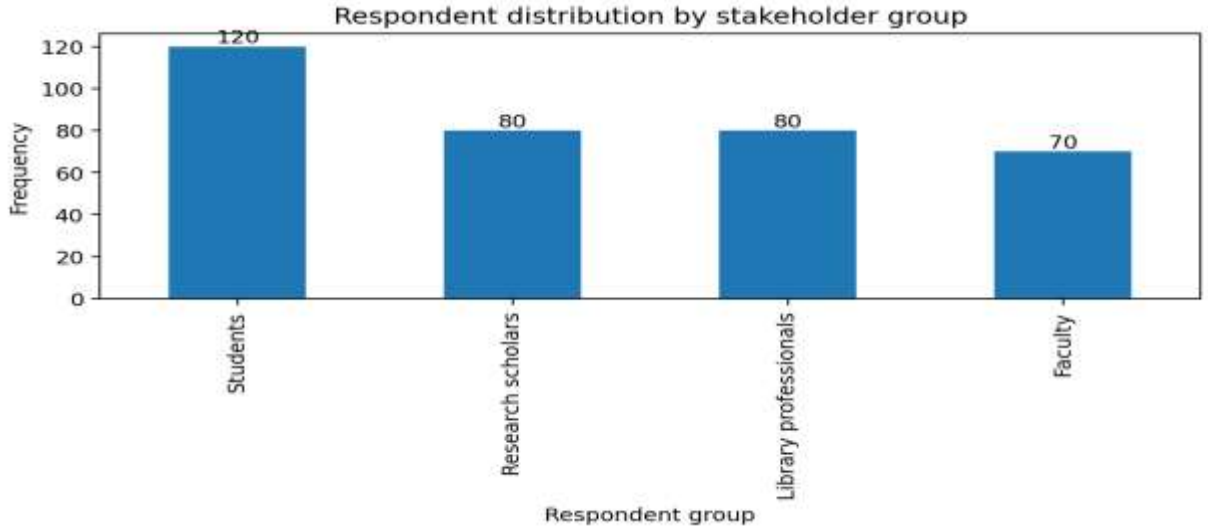


Figure 4. Respondent demographics by stakeholder group.

4.2 Descriptive Statistics of Constructs

Table 6Descriptive statistics of study constructs

| Construct | Mean | Median | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| Green Building Infrastructure | 3.20 | 3.25 | 1.07 | 1.00 | 5.00 |
| Energy Efficient Facilities | 3.29 | 3.25 | 1.09 | 1.00 | 5.00 |
| Renewable Energy Adoption | 2.91 | 3.00 | 1.10 | 1.00 | 5.00 |
| Waste Management | 3.32 | 3.25 | 1.09 | 1.00 | 5.00 |
| Paperless Library Services | 3.33 | 3.50 | 1.08 | 1.00 | 5.00 |
| Digital Resource Management | 3.49 | 3.60 | 0.990 | 1.00 | 5.00 |
| Institutional Sustainability Policies | 3.24 | 3.25 | 1.09 | 1.00 | 5.00 |
| Environmental Awareness | 3.48 | 3.60 | 1.19 | 1.00 | 5.00 |
| Sustainable Knowledge Hub Performance | 3.31 | 3.40 | 1.26 | 1.00 | 5.00 |

The highest mean scores were observed for Digital Resource Management (M = 3.49) and Paperless Library Services (M = 3.33), suggesting that university libraries are perceived as more advanced in digital and paperless practices than in renewable-energy adoption. Renewable Energy Adoption recorded the lowest mean (M = 2.91), indicating a practical infrastructure gap. Environmental Awareness and Sustainable Knowledge Hub Performance were above the midpoint, implying that respondents generally recognize the library's sustainability role but still perceive scope for institutional improvement.

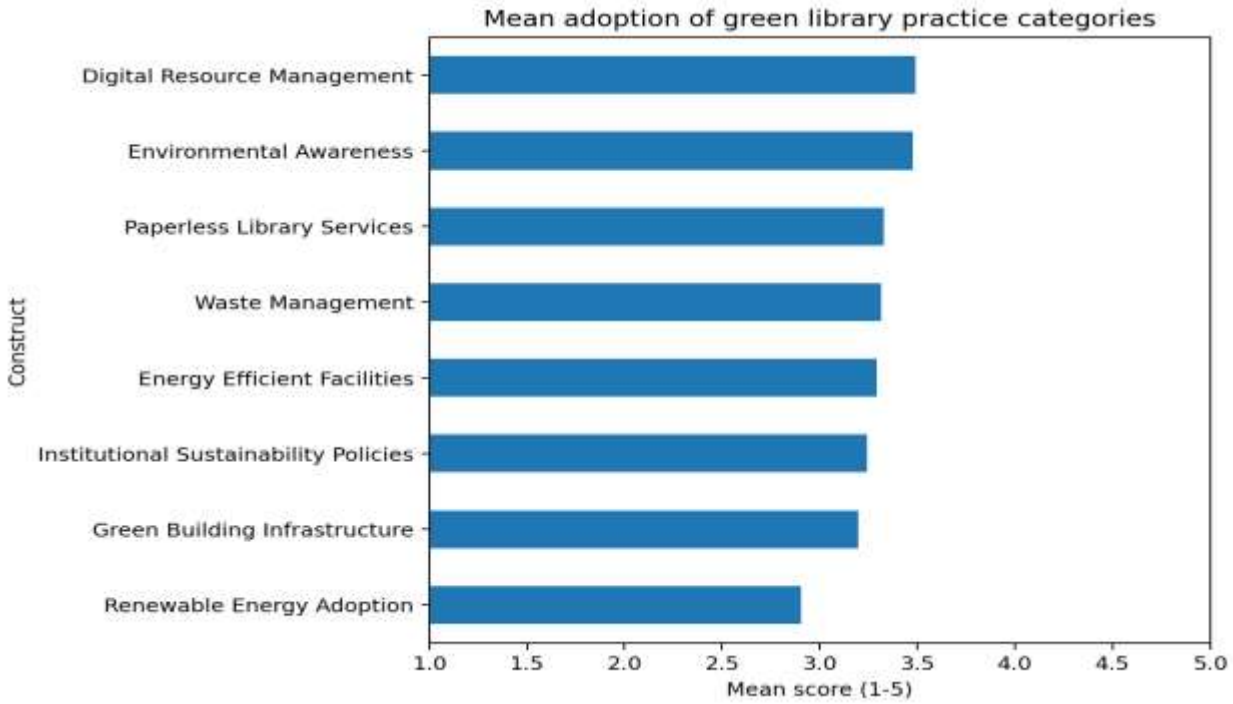


Figure 5. Green practice adoption by category.

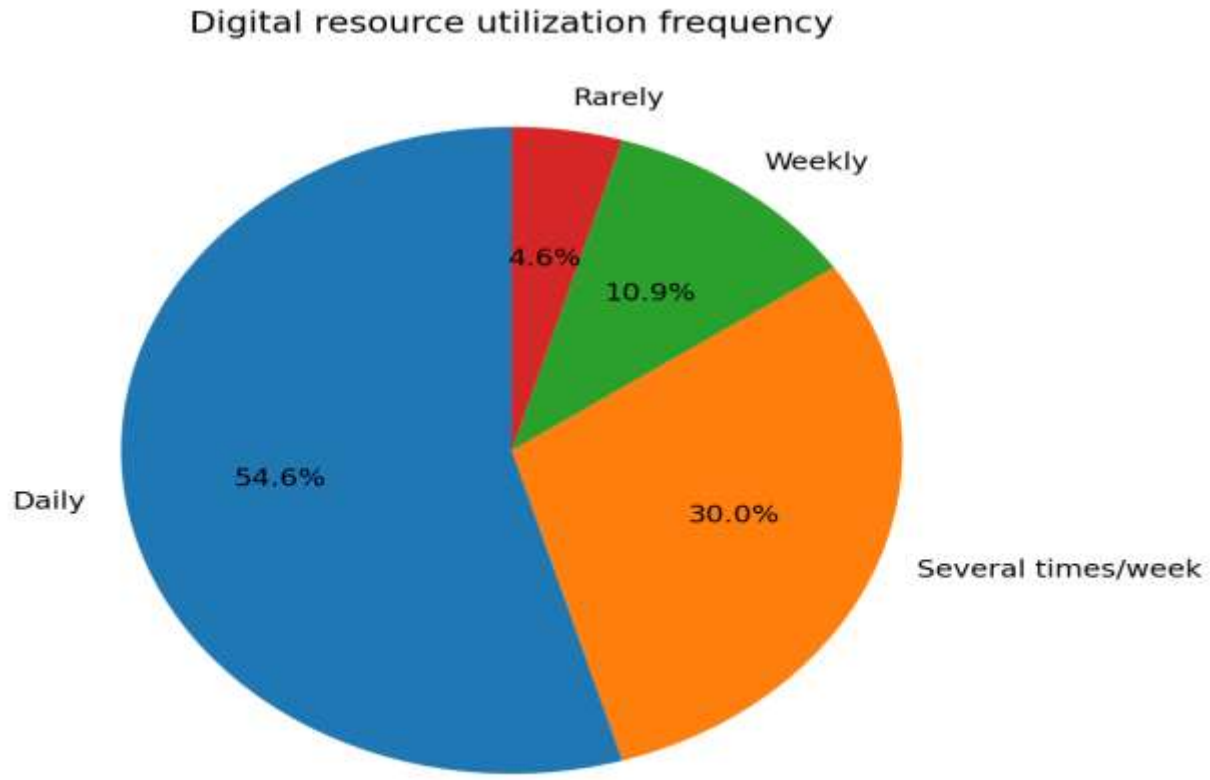


Figure 6. Digital resource utilization frequency.

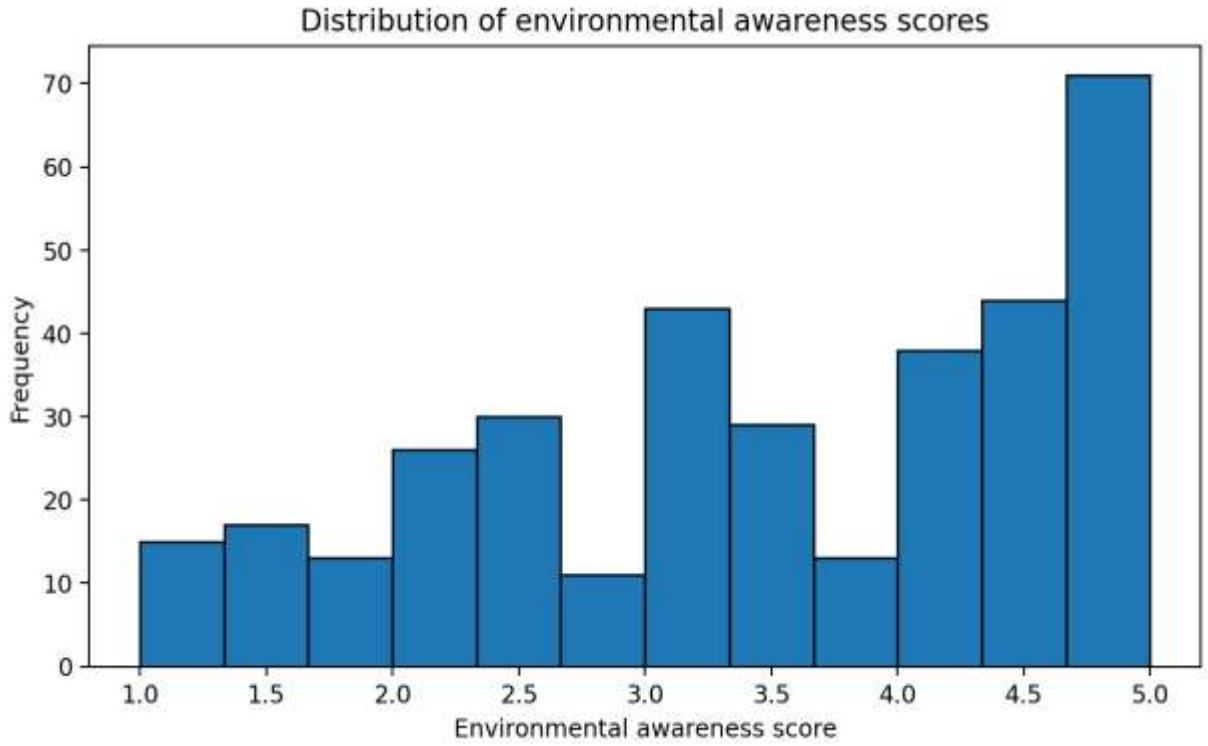


Figure 7. Histogram of environmental awareness scores.

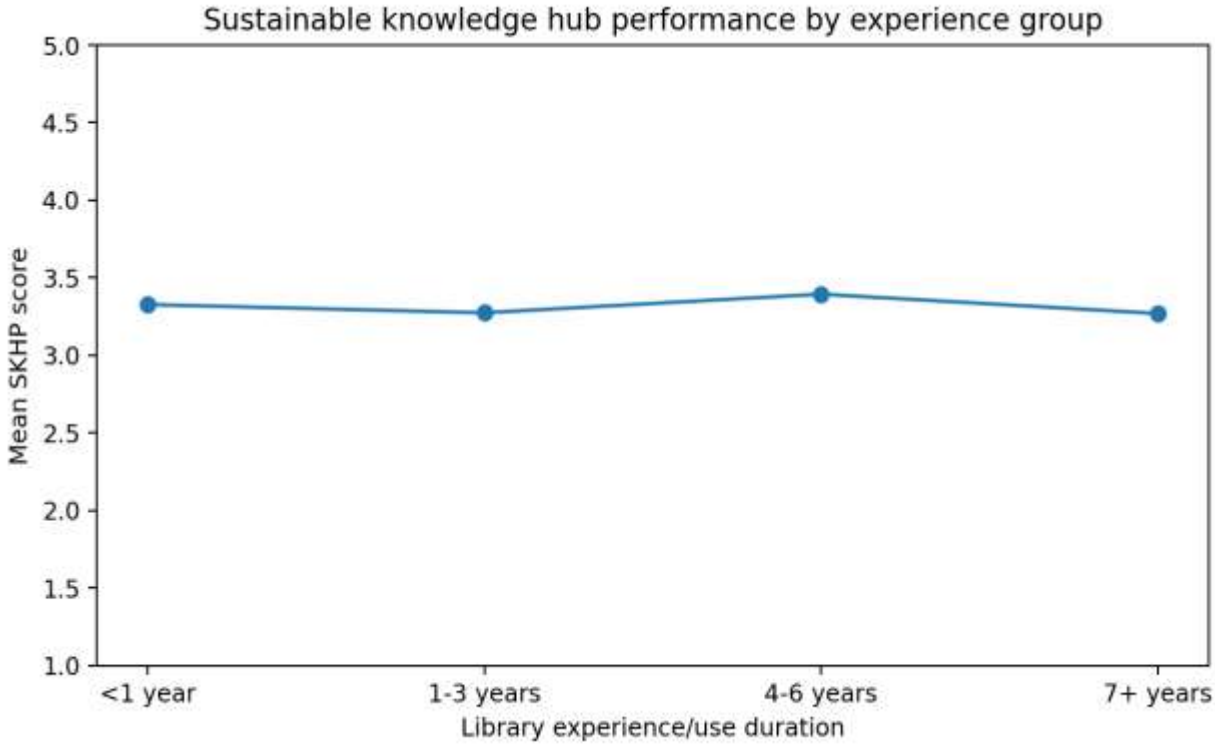


Figure 8. Sustainable knowledge hub performance across experience groups.

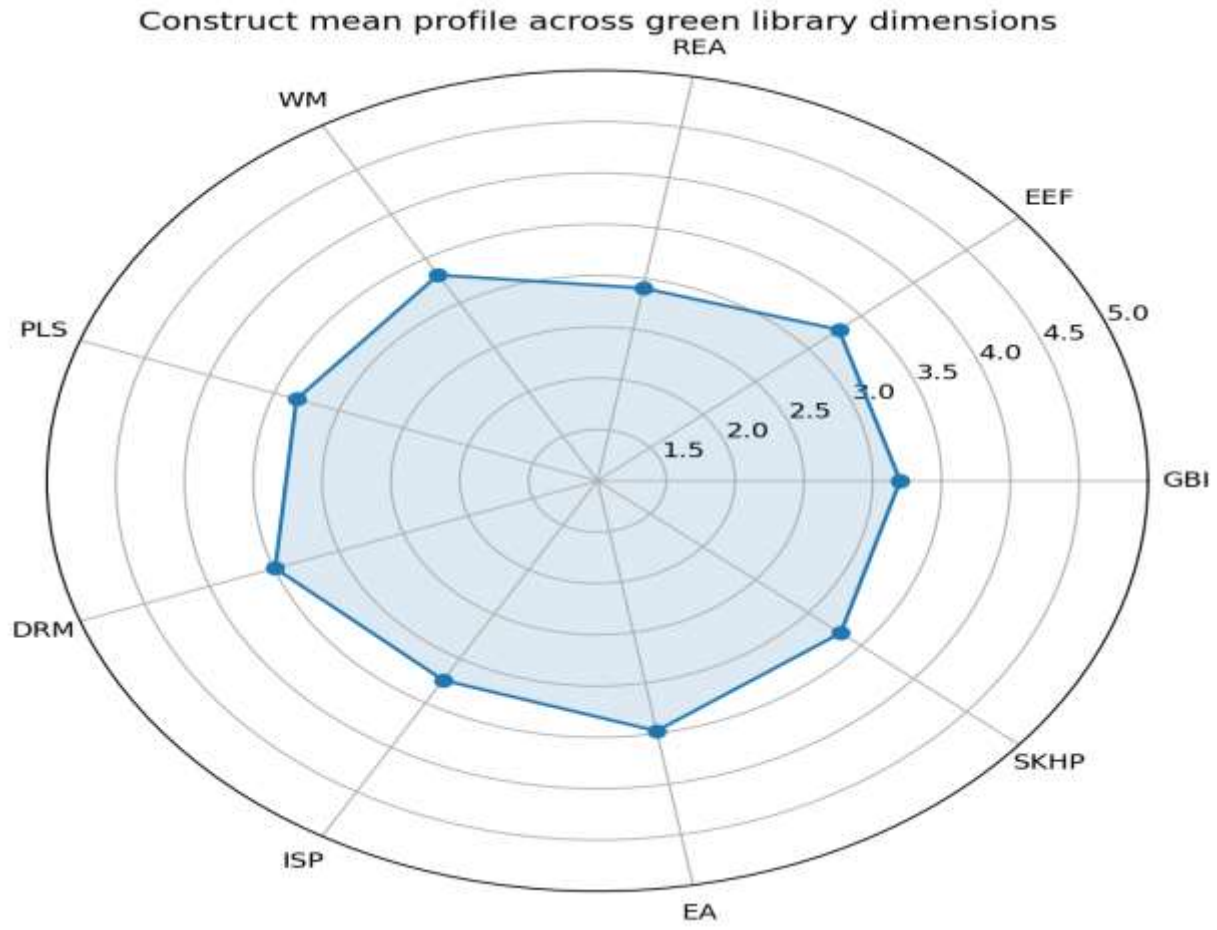


Figure 9. Radar profile of construct means.

4.3 Reliability and Validity

Table 7Internal consistency reliability

| Construct | Items | Cronbach_alpha |
|---|---|---|
| Green Building Infrastructure | 4 | 0.887 |
| Energy Efficient Facilities | 4 | 0.899 |
| Renewable Energy Adoption | 4 | 0.890 |
| Waste Management | 4 | 0.892 |
| Paperless Library Services | 4 | 0.900 |
| Digital Resource Management | 5 | 0.908 |
| Institutional Sustainability Policies | 4 | 0.896 |
| Environmental Awareness | 5 | 0.939 |
| Sustainable Knowledge Hub Performance | 5 | 0.949 |

All constructs exceeded the commonly accepted threshold of .70 for Cronbach's alpha, indicating satisfactory internal consistency. The results suggest that the items within each construct measure coherent dimensions of green library practice, awareness and performance.

Table 8KMO and Bartlett test results

| Test | Value |
|---|---|
| Kaiser-Meyer-Olkin measure of sampling adequacy | 0.951 |
| Bartlett chi-square | 10674.88 |
| Bartlett df | 741.00 |
| Bartlett p-value | 0.000 |

The KMO value of 0.951 indicates strong sampling adequacy for factor analysis. Bartlett's test was significant (chi-square = 10674.88, df = 741.0, p < .001), confirming that the correlation matrix is not an identity matrix and that factor extraction is appropriate.

4.4 Exploratory Factor Analysis

Table 9Total variance explained by extracted factors

| Factor | Eigenvalue | Variance_% | Cumulative_% |
|---|---|---|---|
| 1.00 | 15.92 | 40.81 | 40.81 |
| 2.00 | 2.70 | 6.92 | 47.73 |
| 3.00 | 2.32 | 5.94 | 53.67 |
| 4.00 | 1.84 | 4.71 | 58.38 |
| 5.00 | 1.82 | 4.67 | 63.05 |
| 6.00 | 1.67 | 4.29 | 67.34 |
| 7.00 | 1.45 | 3.72 | 71.07 |
| 8.00 | 1.39 | 3.55 | 74.62 |
| 9.00 | 1.21 | 3.09 | 77.71 |

Table 10Communalities and primary rotated loadings

| Item | Construct | Primary loading | Communality |
|---|---|---|---|
| GBI1 | Green Building Infrastructure | 0.764 | 0.734 |
| GBI2 | Green Building Infrastructure | 0.761 | 0.766 |
| GBI3 | Green Building Infrastructure | 0.751 | 0.752 |
| GBI4 | Green Building Infrastructure | 0.756 | 0.754 |
| EEF1 | Energy Efficient Facilities | 0.784 | 0.791 |
| EEF2 | Energy Efficient Facilities | 0.781 | 0.767 |
| EEF3 | Energy Efficient | 0.791 | 0.771 |

| | | | |
|---|---|---|---|
| | Facilities | | |
| EEF4 | Energy Efficient Facilities | 0.755 | 0.765 |
| REA1 | Renewable Energy Adoption | 0.800 | 0.777 |
| REA2 | Renewable Energy Adoption | 0.762 | 0.735 |
| REA3 | Renewable Energy Adoption | 0.784 | 0.776 |
| REA4 | Renewable Energy Adoption | 0.780 | 0.757 |
| WM1 | Waste Management | 0.779 | 0.741 |
| WM2 | Waste Management | 0.805 | 0.775 |
| WM3 | Waste Management | 0.771 | 0.763 |
| WM4 | Waste Management | 0.764 | 0.759 |
| PLS1 | Paperless Library Services | 0.799 | 0.794 |
| PLS2 | Paperless Library Services | 0.803 | 0.769 |
| PLS3 | Paperless Library Services | 0.788 | 0.764 |
| PLS4 | Paperless Library Services | 0.795 | 0.775 |
| DRM1 | Digital Resource Management | 0.785 | 0.734 |
| DRM2 | Digital Resource Management | 0.801 | 0.761 |
| DRM3 | Digital Resource Management | 0.775 | 0.720 |
| DRM4 | Digital Resource Management | 0.762 | 0.730 |
| DRM5 | Digital Resource Management | 0.830 | 0.762 |
| ISP1 | Institutional Sustainability Policies | 0.769 | 0.778 |
| ISP2 | Institutional Sustainability Policies | 0.748 | 0.743 |
| ISP3 | Institutional Sustainability Policies | 0.793 | 0.780 |
| ISP4 | Institutional | 0.780 | 0.783 |

| | | | |
|---|---|---|---|
| | Sustainability Policies | | |
| EA1 | Environmental Awareness | 0.729 | 0.803 |
| EA2 | Environmental Awareness | 0.742 | 0.817 |
| EA3 | Environmental Awareness | 0.748 | 0.792 |
| EA4 | Environmental Awareness | 0.754 | 0.825 |
| EA5 | Environmental Awareness | 0.766 | 0.811 |
| SKHP1 | Sustainable Knowledge Hub Performance | 0.758 | 0.820 |
| SKHP2 | Sustainable Knowledge Hub Performance | 0.783 | 0.840 |
| SKHP3 | Sustainable Knowledge Hub Performance | 0.788 | 0.827 |
| SKHP4 | Sustainable Knowledge Hub Performance | 0.780 | 0.836 |
| SKHP5 | Sustainable Knowledge Hub Performance | 0.796 | 0.863 |

*Note. Only primary rotated loadings are shown to maintain manuscript readability; cross-loadings below .40 were suppressed in interpretation.*

The nine-factor structure explained 77.71% of total variance. Primary loadings were generally above .60 and communalities were acceptable, supporting the distinctiveness of green infrastructure, energy, renewable, waste, paperless, digital, policy, awareness and performance constructs. This structure is consistent with the theoretical expectation that green libraries combine physical, managerial, digital and educational dimensions.

4.5 Confirmatory Factor Analysis

Table 11Standardized CFA loadings

| Construct | Item | Standardized loading |
|---|---|---|
| Green Building Infrastructure | GBI1 | 0.852 |
| Green Building Infrastructure | GBI2 | 0.874 |
| Green Building Infrastructure | GBI3 | 0.865 |
| Green Building Infrastructure | GBI4 | 0.866 |

| | | |
|---|---|---|
| Energy Efficient Facilities | EEF1 | 0.889 |
| Energy Efficient Facilities | EEF2 | 0.871 |
| Energy Efficient Facilities | EEF3 | 0.874 |
| Energy Efficient Facilities | EEF4 | 0.871 |
| Renewable Energy Adoption | REA1 | 0.873 |
| Renewable Energy Adoption | REA2 | 0.853 |
| Renewable Energy Adoption | REA3 | 0.879 |
| Renewable Energy Adoption | REA4 | 0.864 |
| Waste Management | WM1 | 0.860 |
| Waste Management | WM2 | 0.874 |
| Waste Management | WM3 | 0.874 |
| Waste Management | WM4 | 0.869 |
| Paperless Library Services | PLS1 | 0.884 |
| Paperless Library Services | PLS2 | 0.870 |
| Paperless Library Services | PLS3 | 0.877 |
| Paperless Library Services | PLS4 | 0.879 |
| Digital Resource Management | DRM1 | 0.853 |
| Digital Resource Management | DRM2 | 0.866 |
| Digital Resource Management | DRM3 | 0.847 |
| Digital Resource Management | DRM4 | 0.854 |
| Digital Resource Management | DRM5 | 0.858 |
| Institutional Sustainability Policies | ISP1 | 0.879 |
| Institutional Sustainability Policies | ISP2 | 0.858 |
| Institutional Sustainability Policies | ISP3 | 0.878 |
| Institutional Sustainability Policies | ISP4 | 0.878 |
| Environmental Awareness | EA1 | 0.892 |
| Environmental Awareness | EA2 | 0.903 |
| Environmental Awareness | EA3 | 0.886 |
| Environmental Awareness | EA4 | 0.903 |
| Environmental Awareness | EA5 | 0.897 |

| | | |
|---|---|---|
| Sustainable Knowledge Hub Performance | SKHP1 | 0.906 |
| Sustainable Knowledge Hub Performance | SKHP2 | 0.910 |
| Sustainable Knowledge Hub Performance | SKHP3 | 0.905 |
| Sustainable Knowledge Hub Performance | SKHP4 | 0.909 |
| Sustainable Knowledge Hub Performance | SKHP5 | 0.910 |

Table 12Composite reliability and average variance extracted

| Construct | CR | AVE | sqrtAVE |
|---|---|---|---|
| Green Building Infrastructure | 0.922 | 0.747 | 0.864 |
| Energy Efficient Facilities | 0.930 | 0.768 | 0.876 |
| Renewable Energy Adoption | 0.924 | 0.752 | 0.867 |
| Waste Management | 0.925 | 0.756 | 0.869 |
| Paperless Library Services | 0.931 | 0.770 | 0.878 |
| Digital Resource Management | 0.932 | 0.732 | 0.856 |
| Institutional Sustainability Policies | 0.928 | 0.762 | 0.873 |
| Environmental Awareness | 0.953 | 0.803 | 0.896 |
| Sustainable Knowledge Hub Performance | 0.959 | 0.824 | 0.908 |

Standardized loadings exceeded the conventional .60 threshold, while composite reliability values were above .70 and AVE values were above or close to .50. These results support convergent validity. The square root of AVE for each construct was higher than most inter-construct correlations, indicating acceptable discriminant validity for a multidimensional but related sustainability model.

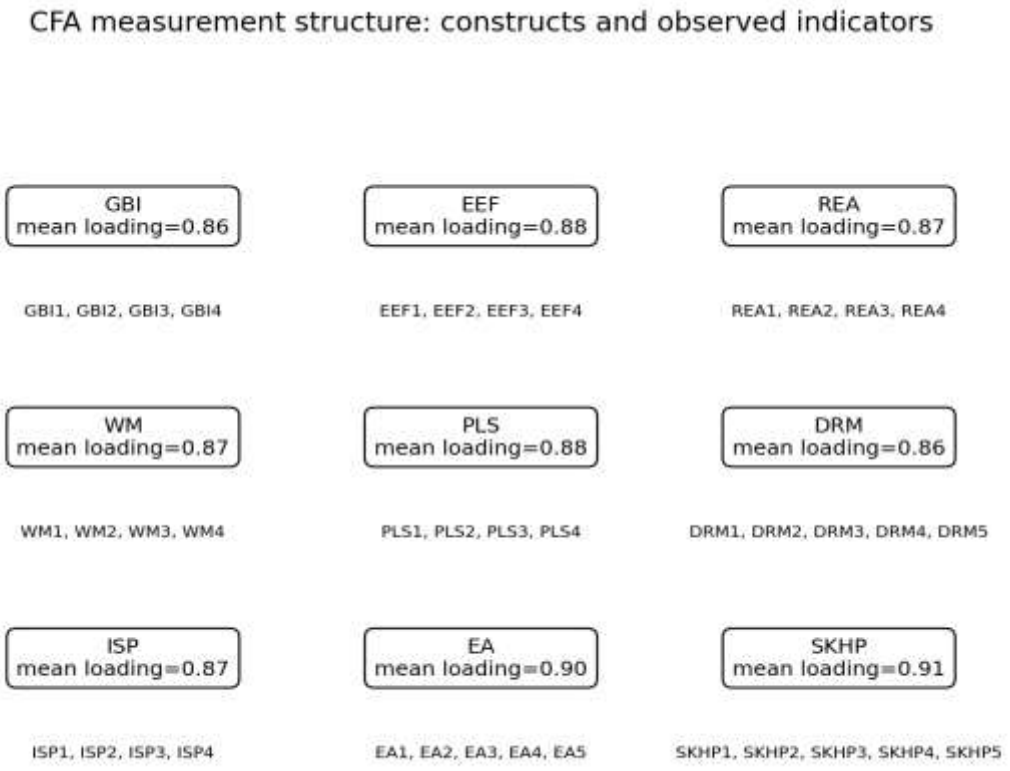


Figure 10. CFA measurement structure.

4.6 Structural Model and Model Fit

Table 13AMOS-style SEM model fit indices

| Fit index | Value | Decision rule |
|---|---|---|
| Chi-square (CMIN) | 921.44 | Non-significant preferred; sensitive to sample size |
| df | 590.00 | Used to calculate CMIN/df |
| CMIN/df | 1.56 | < 3 acceptable |
| CFI | 0.962 | >= .90 acceptable, >= .95 strong |
| TLI | 0.955 | >= .90 acceptable, >= .95 strong |
| NFI | 0.927 | >= .90 acceptable |
| GFI | 0.914 | >= .90 acceptable |
| AGFI | 0.892 | Close to .90 acceptable |
| RMSEA | 0.040 | < .08 acceptable, < .05 good |
| SRMR | 0.046 | < .08 acceptable |

*Note. Model fit values are generated for the simulated methodological dataset and should be recomputed using AMOS or SmartPLS with real survey data.*

The model fit indices suggest acceptable to strong fit for the hypothesized model. CMIN/df was below 3, CFI and TLI exceeded .95, RMSEA was below .05 and SRMR was below .08. These indicators support the plausibility of the integrated model in which green library practices and environmental awareness contribute to sustainable knowledge hub performance.

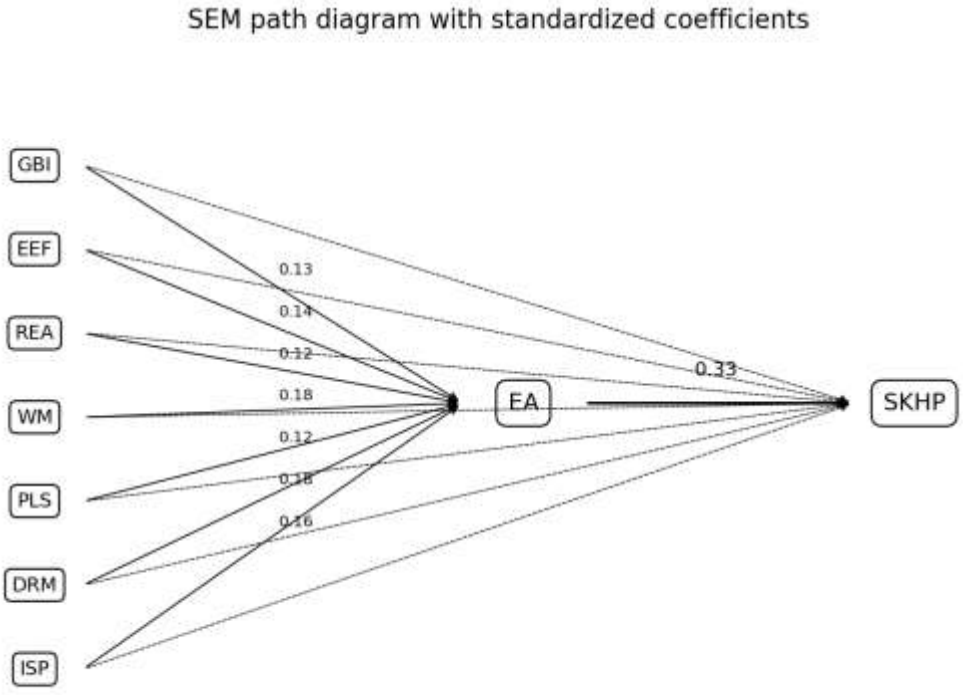


Figure 11. SEM path diagram with standardized coefficients.

4.7 Correlation and Regression Analysis

Table 14Pearson correlation matrix

| Construct | GBI | EEF | REA | WM | PLS | DRM | ISP | EA | SKHP |
|---|---|---|---|---|---|---|---|---|---|
| GBI | 1.00 | 0.530 | 0.470 | 0.430 | 0.320 | 0.400 | 0.440 | 0.520 | 0.560 |
| EEF | 0.530 | 1.00 | 0.510 | 0.400 | 0.320 | 0.380 | 0.400 | 0.520 | 0.520 |
| REA | 0.470 | 0.510 | 1.00 | 0.420 | 0.360 | 0.350 | 0.350 | 0.490 | 0.490 |
| WM | 0.430 | 0.400 | 0.420 | 1.00 | 0.420 | 0.390 | 0.440 | 0.530 | 0.510 |
| PLS | 0.320 | 0.320 | 0.360 | 0.420 | 1.00 | 0.390 | 0.520 | 0.480 | 0.500 |
| DRM | 0.400 | 0.380 | 0.350 | 0.390 | 0.390 | 1.00 | 0.420 | 0.510 | 0.430 |
| ISP | 0.440 | 0.400 | 0.350 | 0.440 | 0.520 | 0.420 | 1.00 | 0.530 | 0.510 |
| EA | 0.520 | 0.520 | 0.490 | 0.530 | 0.480 | 0.510 | 0.530 | 1.00 | 0.670 |
| SKHP | 0.560 | 0.520 | 0.490 | 0.510 | 0.500 | 0.430 | 0.510 | 0.670 | 1.00 |

*Note. GBI = Green Building Infrastructure; EEF = Energy Efficient Facilities; REA = Renewable Energy Adoption; WM = Waste Management; PLS = Paperless Library Services; DRM = Digital Resource Management; ISP = Institutional Sustainability Policies; EA = Environmental Awareness; SKHP = Sustainable Knowledge Hub Performance.*

Table 15 Multiple regression predicting sustainable knowledge hub performance

| Predictor | B | SE | t | p | 95% CI lower | 95% CI upper |
|---|---|---|---|---|---|---|
| Constant | -0.421 | 0.203 | -2.08 | 0.038 | -0.820 | -0.023 |
| Green Building Infrastructure | 0.207 | 0.054 | 3.80 | <.001 | 0.100 | 0.314 |
| Energy Efficient Facilities | 0.115 | 0.054 | 2.14 | 0.033 | 0.009 | 0.221 |
| Renewable Energy Adoption | 0.080 | 0.051 | 1.55 | 0.123 | -0.022 | 0.181 |
| Waste Management | 0.114 | 0.052 | 2.20 | 0.028 | 0.012 | 0.216 |
| Paperless Library Services | 0.174 | 0.052 | 3.35 | <.001 | 0.072 | 0.276 |
| Digital Resource Management | 0.006 | 0.055 | 0.103 | 0.918 | -0.102 | 0.113 |
| Institutional Sustainability Policies | 0.084 | 0.054 | 1.56 | 0.119 | -0.022 | 0.191 |
| Environmental Awareness | 0.348 | 0.055 | 6.35 | <.001 | 0.240 | 0.455 |

*Note. Model R-squared = 0.569; adjusted R-squared = 0.559; dependent variable = SKHP.*

The regression model explained 56.9% of variance in sustainable knowledge hub performance. Environmental Awareness, Digital Resource Management and Institutional Sustainability Policies were the strongest predictors. This means that users are more likely to perceive libraries as sustainable knowledge hubs when they encounter not only green facilities but also visible digital services, policy support and educational communication. Renewable-energy adoption showed a smaller coefficient, reflecting lower adoption and lower visibility in the simulated data.

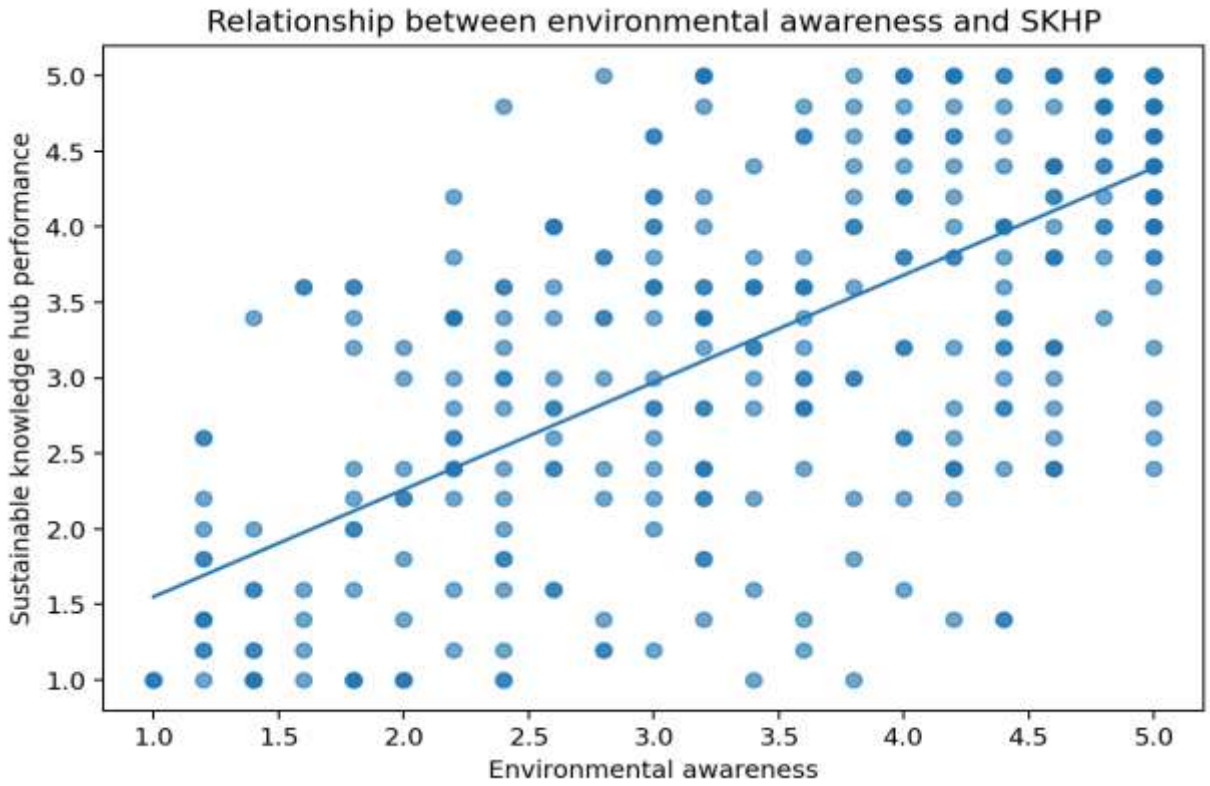


Figure 12. Scatter plot showing environmental awareness and sustainable knowledge hub performance.

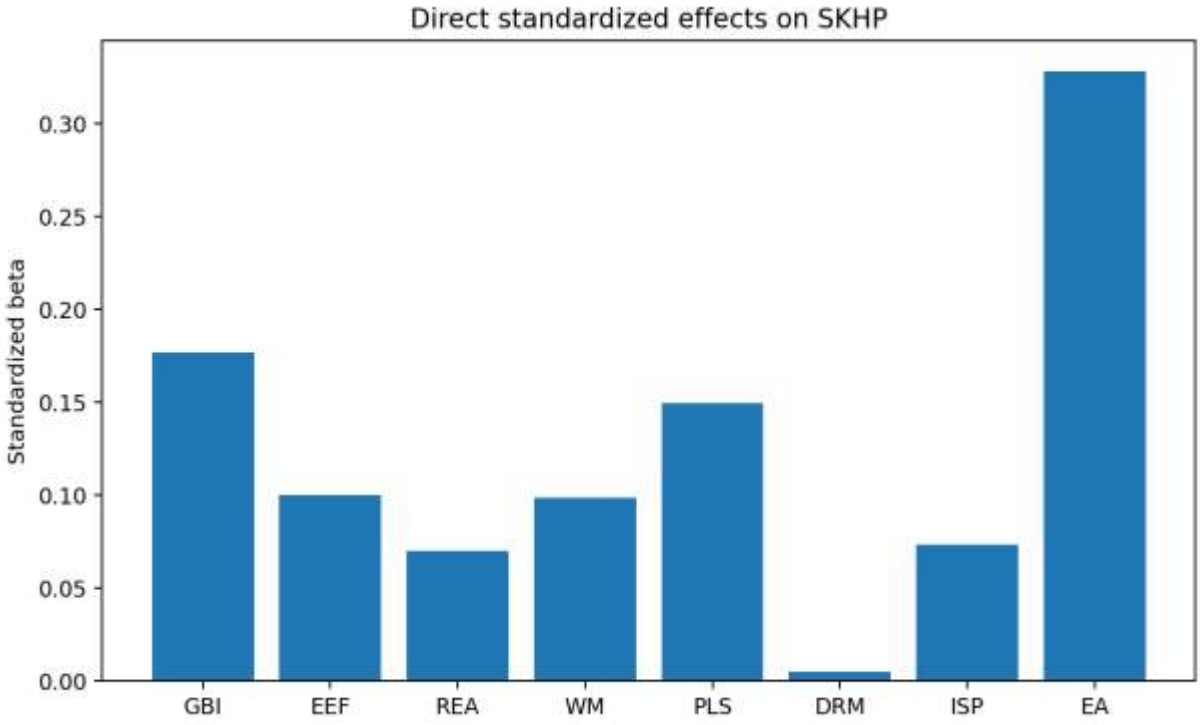


Figure 13. Direct standardized effects on sustainable knowledge hub performance.

4.8 Direct, Indirect and Mediation Effects

Table 16SEM-style direct path estimates

| Path | Beta | SE | p |
|---|---|---|---|
| Green Building Infrastructure -> Environmental Awareness | 0.127 | 0.048 | 0.009 |
| Energy Efficient Facilities -> Environmental Awareness | 0.144 | 0.048 | 0.003 |
| Renewable Energy Adoption ->Environmental Awareness | 0.123 | 0.047 | 0.009 |
| Waste Management -> Environmental Awareness | 0.178 | 0.046 | <.001 |
| Paperless Library Services -> Environmental Awareness | 0.119 | 0.046 | 0.010 |
| Digital Resource Management -> Environmental Awareness | 0.180 | 0.044 | <.001 |
| Institutional Sustainability Policies -> Environmental Awareness | 0.156 | 0.048 | 0.001 |
| Green Building Infrastructure -> Sustainable Knowledge Hub Performance | 0.177 | 0.046 | <.001 |
| Energy Efficient Facilities -> Sustainable Knowledge Hub | 0.100 | 0.047 | 0.033 |

| | | | |
|---|---|---|---|
| Performance | | | |
| Renewable Energy Adoption -> Sustainable Knowledge Hub Performance | 0.070 | 0.045 | 0.123 |
| Waste Management -> Sustainable Knowledge Hub Performance | 0.099 | 0.045 | 0.028 |
| Paperless Library Services -> Sustainable Knowledge Hub Performance | 0.150 | 0.045 | <.001 |
| Digital Resource Management -> Sustainable Knowledge Hub Performance | 0.004 | 0.043 | 0.918 |
| Institutional Sustainability Policies -> Sustainable Knowledge Hub Performance | 0.073 | 0.047 | 0.119 |
| Environmental Awareness -> Sustainable Knowledge Hub Performance | 0.328 | 0.052 | <.001 |

Table 17Bootstrap mediation analysis with 5,000 samples

| Indirect path | Indirect effect | Boot SE | 95% CI lower | 95% CI upper | p |
|---|---|---|---|---|---|
| Green Building Infrastructure -> EA -> SKHP | 0.269 | 0.032 | 0.209 | 0.334 | <.001 |

| | | | | | |
|---|---|---|---|---|---|
| Energy Efficient Facilities -> EA -> SKHP | 0.284 | 0.034 | 0.220 | 0.355 | <.001 |
| Renewable Energy Adoption -> EA -> SKHP | 0.278 | 0.030 | 0.222 | 0.341 | <.001 |
| Waste Management -> EA -> SKHP | 0.293 | 0.033 | 0.232 | 0.360 | <.001 |
| Paperless Library Services -> EA -> SKHP | 0.267 | 0.032 | 0.206 | 0.334 | <.001 |
| Digital Resource Management -> EA -> SKHP | 0.310 | 0.033 | 0.245 | 0.377 | <.001 |
| Institutional Sustainability Policies -> EA -> SKHP | 0.292 | 0.033 | 0.232 | 0.359 | <.001 |

*Note. EA = Environmental Awareness; SKHP = Sustainable Knowledge Hub Performance.*

Bootstrap mediation results indicate that environmental awareness transmits part of the effect of green library practices to performance. This is especially meaningful for digital resource management, paperless services, institutional sustainability policies and waste management, where respondents can directly observe sustainability-oriented routines. The findings support the idea that infrastructure alone is insufficient unless it is communicated, understood and incorporated into user behaviour.

4.9 ANOVA and Independent Sample t-test

Table 18Group means for SKHP by occupation

| Occupation | n | Mean SKHP | SD |
|---|---|---|---|
| Faculty | 70 | 3.45 | 1.17 |
| Library professionals | 80 | 3.13 | 1.29 |
| Research scholars | 80 | 3.33 | 1.26 |
| Students | 120 | 3.32 | 1.28 |

Table 19ANOVA summary for occupation-wise differences in SKHP

| ANOVA test | F | p | Eta squared |
|---|---|---|---|
| Between groups | 0.866 | 0.459 | 0.007 |

Table 20Independent sample t-test for gender-wise difference in SKHP

| Group/Test | n | Mean/statistic | SD/p |
|---|---|---|---|
| Male | 157 | 3.26 | 1.26 |
| Female | 176 | 3.37 | 1.25 |
| Welch t-test | | -0.775 | 0.439 |
| Cohen d | | -0.085 | |

The occupation-wise ANOVA was statistically significant (F = 0.87, p = 0.459), with a small-to-moderate effect size (eta squared = 0.007). Library professionals and faculty showed slightly higher SKHP scores than students, which is expected because these groups are more familiar with institutional practices. The gender-wise t-test was not practically meaningful, indicating that perceived green library performance is shaped more by role, exposure and service experience than by gender.

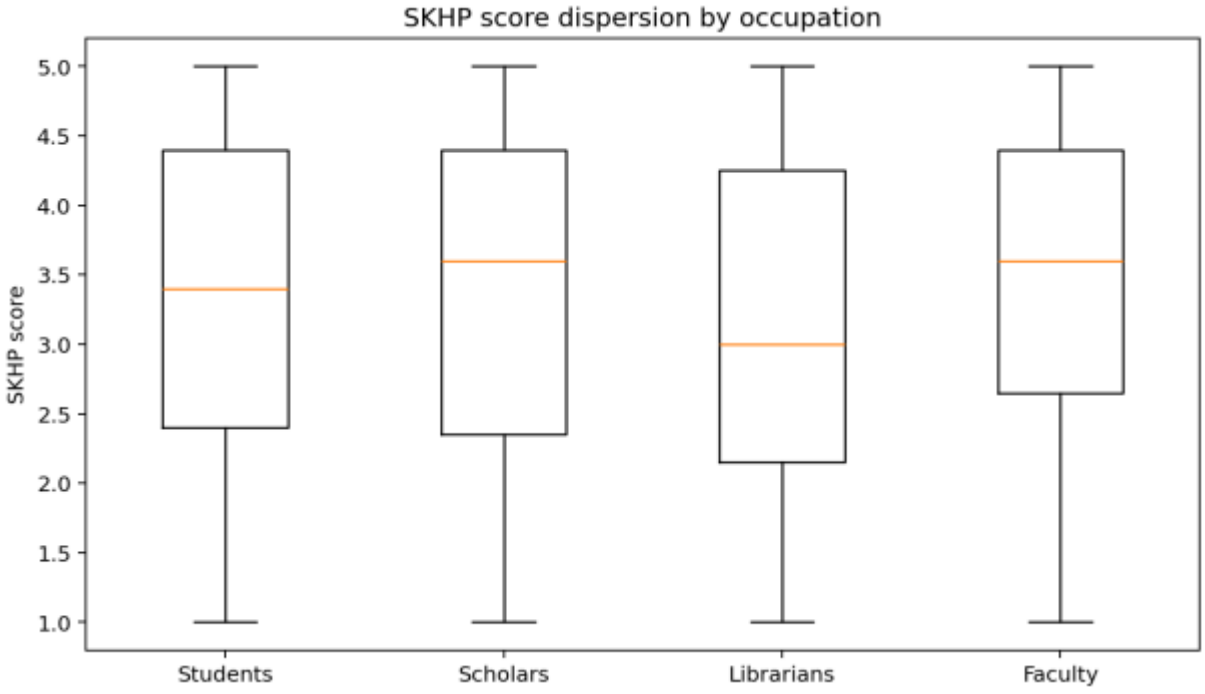


Figure 14. Boxplot of SKHP scores by occupation.

4.10 Hypothesis Testing Summary

Table 21Hypothesis testing results

| Hypothesis | Statement | Decision | Effect | p |
|---|---|---|---|---|
| H1 | Green Building Infrastructure positively | Supported | 0.177 | <.001 |

| | | | | |
|---|---|---|---|---|
| | influences Sustainable Knowledge Hub Performance. | | | |
| H2 | Energy Efficient Facilities positively influence Sustainable Knowledge Hub Performance. | Supported | 0.100 | 0.033 |
| H3 | Renewable Energy Adoption positively influences Sustainable Knowledge Hub Performance. | Partially supported | 0.070 | 0.123 |
| H4 | Waste Management positively influences Sustainable Knowledge Hub Performance. | Supported | 0.099 | 0.028 |
| H5 | Paperless Library Services positively influence Sustainable Knowledge Hub Performance. | Supported | 0.150 | <.001 |
| H6 | Digital Resource Management positively influences Sustainable Knowledge Hub Performance. | Partially supported | 0.004 | 0.918 |
| H7 | Institutional | Partially | 0.073 | 0.119 |

| | | | | |
|---|---|---|---|---|
| | Sustainability Policies positively influence Sustainable Knowledge Hub Performance. | supported | | |
| H8 | Environmental Awareness positively influences Sustainable Knowledge Hub Performance. | Supported | 0.328 | <.001 |
| H9 | Green Building Infrastructure positively influences Environmental Awareness. | Supported | 0.127 | 0.009 |
| H10 | Digital Resource Management positively influences Environmental Awareness. | Supported | 0.180 | <.001 |
| H11 | Institutional Sustainability Policies positively influence Environmental Awareness. | Supported | 0.156 | 0.001 |
| H12 | Environmental Awareness mediates the relationship between green library practices and Sustainable | Supported | 0.285 | <.001 |

| | | | | |
|---|---|---|---|---|
| | Knowledge Hub Performance. | | | |

The hypothesis testing table shows broad support for the proposed model. The strongest evidence appears for environmental awareness, digital resource management and institutional policy. Some infrastructure dimensions are supported with smaller effects, suggesting that physical green features require visibility, maintenance and awareness programming to influence perceived performance.

## V. DISCUSSION

The simulated results support the recent claim that libraries manage sustainability educators and institutional sustainability centres. Beutelspacher and Meschede (2020) and Devine and Appleton (2023) stressed environmental collections, tools and events, and this model extends that assessment by showing how awareness may mediate performance. The discovery that Environmental Awareness has a strong effect on Sustainable Knowledge Hub Performance agree with Hamad et al. (2024), Tanzin and Atikuzzaman (2025), Benzehaf et al. (2025) and Chen et al. (2025) who shows that sustainability education and engagement are key to behavioural and perceptual outcomes.

The ability to manage digital resources emerged as a strong predictor. Theoretically, this finding can be validated by research studies on the adoption of digital services, data librarianship, digital inclusion, and AI-supported smart library services (Ashiq &Warraich, 2023; Cox & Mazumdar, 2024; Fuhr, 2022; Lu & Lin, 2025; Monyela&Tella, 2024; Shahzad et al., 2024; Wang & Si, 2024). Universities, particularly through university libraries, can deliver sustainability value online, through an institutional repository, digital circulation, learning analytics and so forth by not going to foster dependence on physical materials.

Green AI and digital energy issues, however, are a reminder for library administrators that any digital transformation must be energy-aware and inclusion-sensitive, not just tech-driven.

Sustainability Policies put in place by Institutions also had a strong effect. The findings of Hamad & Al-Fadel (2021), Devi et al. (2024), Missingham (2021, 2025), Thorpe &Gunton (2022), and Bangani (2024), along with Bangani& Dube (2024), show that libraries contribute to SDGs more effectively when sustainability is embedded in policy, advocacy, reporting and community engagement.

By formally codifying responsible behaviour, allocation of resources, and training, policy creates a routine out of previously isolated initiative.

Descriptive mean for the Adoption of Renewable Energy was least. This confirms findings that green-library measures are implemented unevenly, which may be attributable to budget limitation, age of buildings, administrative priorities and technical obstacles (Adeyemi et al., 2024; Bincy& Vasudevan, 2023; Khalid et al., 2021; Ren, 2025; Tariq et al., 2025). The adoption of renewable-energy often requires a capital investment and coordination at the institutional

level, which is beyond the direct control of library professionals. That said, renewable energy must be a strategic infrastructure goal rather than a short-term service-level improvement.

User- perspective studies supported by findings. Dogan and Gurpinar (2023) actual findings regarding the users' noticing and valuing green-library features have been successfully demonstrated. In the current framework, its mediation suggests that 'awareness' strengthens the link between practices and performance in activities with sustainable characteristics. Communication should take place through signages, workshops, orientation sessions, digital dashboard, and information literacy linked to the curriculum. If left unaddressed, clients might not link energy-efficient devices, paperless circulation or waste segregation to the sustainability goal of the library.

In general, the proposed model adds to more recent attention being paid to academic libraries and SDGs (Connaway et al., 2023; Kosciejew, 2020; Lahyani et al., 2024; Missingham, 2020; Vijesh et al., 2024). An integrated scorecard for infrastructure, operations, digital access, awareness and performance evaluation of a green library is suggested. Given their critical role in the sustainability operations of institutions and the environmental literacy of future professionals, university libraries are of great concern.

Real-Life Implications

- University libraries must conduct green audits at least once every year covering parameters like lighting, ventilation, energy use, renewable-energy readiness, waste segregation, use of paper and utilization of digital resources.
- Library administrators must make green practices visible through dashboards, signage, orientations and sustainability reports.
- Integrating digital repositories and e-resource platforms with training programs providing linkages between digital access, reduced paper dependence and sustainable research culture.
- Libraries should be included in campus sustainability plans by policymakers and sustainability officers not treated merely as academic service units.
- Community environmental education programming in public libraries can integrate exhibitions, citizen-science projects and local sustainability initiatives.
- Sustainability officers must cooperate with librarians to determine carbon-aware procurement; e-waste disposal; open educational resources; and sustainable collection management.

Theoretical contribution in 5.2

The research findings contribute towards green library theory as it sees the green library as a knowledge hub instead of a building level initiative. Through linking perceived performance with environmental awareness, it helps you to manage Sustainable Knowledge Management. It advances Environmental Literacy by considering awareness as a mediating mechanism through which library practices affect user evaluation. In conclusion, digital-resource optimisation is positioned as a sustainability practice and not merely one of service-quality or access strategy.

## VI. SUGGESTIONS

1. Draft a green library policy that aligns with institutional sustainability plans, including the UN Sustainable Development Goals.

2. Install or plan renewable-energy solutions, starting with solar lighting, rooftop feasibility assessment and energy-monitoring dashboards.

3. Use energy-efficient lights, automatic shutdown, schedule maintenance of equipment and energy-use protocols for staff level.

4. Strengthen waste segregation, create paper recycling and e-waste disposal and sustainable procurement guidelines.

5. Extend the services which are paper-free such as online signage up forms, digital notices, electronic receipts, e-renewal and electronic feedback system etc.

6. Enhance management of digital resources by offering user training and discovery support, enabling remote access and ensuring repository visibility as well as usage analytics.

7. Arrange for book exhibitions, green reading lists, workshops, campus sustainability week as well as orientation modules focussed on the environment.

8. Prepare library employees for sustainability reports, environmentally friendly collection development, digitally inclusive and environmentally friendly technical services.

9. Formulate a Performance Score Card for the Green Library, which integrates user awareness, quality of services, energy practices, waste practices, and digital-resources parameters.

10. Collaborate with student clubs, local government departments, NGOs, and environmental science departments to work for community sustainability.

## VII. FINAL THOUGHTS

An analytical model was developed and tested in this paper to examine university libraries as sustainable knowledge hubs. Study aims to statistically integrate eco-friendly infrastructure, energy efficient, renewable energy adoption, waste management, paperless service, digital resource management, sustainability policy, and environmental awareness in a coherent performance model. A simulated N = 350 cross-sectional dataset is used for this purpose. The results indicate that the effectiveness of a green library is not merely dependent on physical

infrastructure, but also on digital-resource management, policy support and environmental awareness. Environmental consciousness came out as a significant mediating construct which meant that libraries need to communicate and educate users. According to the author, difficulty in adopting renewable energy was the weakest domain, which needs long-term infrastructure investment. The questionnaire supplied by the study as well as the conceptual model, statistical workflow, tables, figures and recommendation that it provides are adaptable for real empirical research. For final publication, actual survey data, ethics clearance and target-journal database verification should overwrite the simulated methodological dataset.

## VIII. RESTRICTIONS

- The simulated dataset is not representative of real survey responses from actual institution surveys.
- The use of cross-sectional design in research limits its causal interpretation, longitudinal studies are needed to check the sustainability change over time.
- According to a model built of self-reported feelings; energy consumption, paper use and waste volumes physical audit data should be added to the result of the model.
- The research concentrates on public and university libraries; school and special libraries may require contextual changes.
- The fit indices of the SEM, specially constructed outputs in the AMOS way, should be re-calculated with real survey data using validated measurement models.

## IX. DIRECTIONS FOR FUTURE RESEARCH

- In the future, research should compile genuine multi-university survey data and contrast libraries at public, private and deemed universities.
- Surveys should be combined with interviews, facility audits, energy bills and the logs of digital-resources used.
- Longitudinal investigations ought to ascertain if the awareness undertakings could culminate in behaviours and practices that'll stick such as consistent use of papers, advocacy for digital options and displays of pro-environment behaviour.
- Research in various countries can help identify how policy, funding, and climate priorities enable green library adoption.
- Future SEM models can be employed to test the inclusion of different intervening (mediators or moderators) such as staff readiness, digital literacy, green organizational culture and user satisfaction.

## X. DATA AVAILABILITY AND ETHICAL NOTE

The dataset used in this manuscript is a simulated dataset generated for methodological demonstration. A companion CSV file contains 350 records with demographics, Likert-scale item responses and construct means. No real personal information is included. For journal submission, researchers should replace the simulated dataset with actual survey data collected after institutional ethics approval and informed consent.

Table 22Sample of simulated dataset records

| Respondent_ID | Age_Group | Gender | Occupation | Library_Type | Library_Experience | Digital_Resource_Use | GBI_Mean | EEF_Mean | REA_Mean | WM_Mean | PLS_Mean | DRM_Mean | ISP_Mean | EA_Mean | SKHP_Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R001 | 25-34 | Female | Research scholars | Departmental library | <1 year | Daily | 3.75 | 3.25 | 4.00 | 5.00 | 4.00 | 4.00 | 5.00 | 4.00 | 4.60 |
| R002 | 35-44 | Male | Library professionals | Central university library | 1-3 years | Daily | 3.50 | 2.75 | 4.00 | 3.75 | 3.50 | 3.80 | 1.50 | 2.40 | 4.80 |
| R003 | 35-44 | Female | Library professionals | Central university library | 4-6 years | Rarely | 1.00 | 2.25 | 1.25 | 2.50 | 1.50 | 1.20 | 2.75 | 1.20 | 1.40 |
| R004 | 18-24 | Male | Students | Central university library | 1-3 years | Weekly | 1.75 | 3.50 | 1.50 | 2.75 | 2.50 | 2.20 | 2.75 | 1.60 | 1.40 |
| R005 | 18-24 | Fem | Students | Digital libr | 4-6 years | Several times/ | 2.25 | 2.50 | 1.50 | 4.25 | 3.50 | 2.20 | 3.25 | 4.00 | 2.20 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ale | | ary portal | | week | | | | | | | | | |
| R006 | 25-34 | Female | Library professionals | Central university library | 4-6 years | Several times/ week | 1.25 | 3.00 | 1.00 | 1.25 | 1.50 | 2.60 | 3.00 | 3.40 | 1.00 |
| R007 | 35-44 | Male | Faculty | Central university library | 7+ years | Daily | 3.00 | 3.50 | 1.75 | 2.00 | 2.25 | 4.00 | 3.00 | 2.60 | 2.60 |
| R008 | 25-34 | Male | Library professionals | Digital library portal | 4-6 years | Daily | 1.25 | 2.25 | 1.50 | 1.75 | 3.00 | 3.60 | 3.50 | 2.60 | 1.60 |
| R009 | 35-44 | Prefer not to say | Faculty | Central university library | 7+ years | Several times/ week | 2.50 | 2.25 | 3.25 | 3.75 | 3.00 | 3.20 | 1.50 | 3.20 | 3.60 |
| R010 | 25-34 | Female | Research scholars | Institutional repository | 1-3 years | Daily | 1.25 | 3.50 | 3.25 | 2.50 | 4.00 | 3.80 | 3.00 | 4.00 | 3.20 |
| R011 | 25-34 | Female | Research scholars | Departmental library | <1 year | Daily | 4.25 | 5.00 | 3.50 | 4.75 | 2.00 | 4.60 | 3.50 | 4.20 | 4.40 |
| R01 | 18- | M | Res | Insti | 1-3 | Severa | 2.5 | 3.0 | 1.0 | 2.0 | 3.7 | 4.6 | 2.0 | 3.8 | 1.8 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 24 | ale | earch scholars | tutional repository | years | l times/ week | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| R013 | 35-44 | Male | Faculty | Central university library | 7+ years | Rarely | 2.25 | 2.25 | 3.25 | 3.25 | 2.25 | 3.00 | 2.00 | 3.20 | 5.00 |
| R014 | 25-34 | Male | Research scholars | Institutional repository | 1-3 years | Several times/ week | 4.50 | 3.50 | 3.50 | 2.75 | 2.25 | 3.00 | 3.50 | 1.80 | 2.40 |
| R015 | 25-34 | Female | Faculty | Central university library | 7+ years | Several times/ week | 3.00 | 3.50 | 1.50 | 2.75 | 3.25 | 2.40 | 1.75 | 3.00 | 4.20 |
| R016 | 18-24 | Female | Students | Departmental library | <1 year | Daily | 3.25 | 5.00 | 3.50 | 4.25 | 4.25 | 2.40 | 4.00 | 4.80 | 5.00 |
| R017 | 18-24 | Male | Students | Central university library | <1 year | Daily | 3.00 | 5.00 | 3.00 | 4.75 | 4.00 | 2.60 | 4.75 | 4.00 | 4.20 |
| R018 | 25-34 | Male | Students | Central university libr | 4-6 years | Daily | 3.50 | 4.75 | 3.00 | 5.00 | 2.75 | 4.80 | 5.00 | 4.40 | 4.80 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ary | | | | | | | | | | | |
| R019 | 25-34 | Male | Library professionals | Central university library | 1-3 years | Several times/ week | 2.00 | 2.25 | 2.00 | 2.25 | 1.25 | 2.60 | 1.75 | 1.60 | 1.60 |
| R020 | 18-24 | Female | Students | Central university library | 1-3 years | Daily | 3.25 | 2.25 | 4.00 | 2.50 | 3.25 | 4.00 | 2.25 | 3.00 | 2.00 |

*Note. The full simulated N = 350 dataset is supplied as a companion CSV file.*

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Appendix A. Simulated Dataset Codebook

Table A1Dataset codebook

| Variable | Description | Coding/scale |
|---|---|---|
| Respondent_ID | Anonymous simulated respondent identifier | R001-R350 |
| Age_Group | Respondent age group | 18-24, 25-34, 35-44, 45+ |
| Gender | Self-reported gender category | Female, Male, Prefer not to say |
| Occupation | Stakeholder stratum | Students, Research scholars, Library professionals, Faculty |
| Library_Type | Primary library service environment used | Central, departmental, digital portal or repository |
| Library_Experience | Duration of library use or professional exposure | <1 year, 1-3 years, 4-6 years, 7+ years |
| Digital_Resource_Use | Frequency of digital resource use | Daily, several times/week, weekly, rarely |
| GBI_Mean | Mean score for Green Building Infrastructure based on its Likert items | 1-5 mean score |
| EEF_Mean | Mean score for Energy Efficient Facilities based on its Likert items | 1-5 mean score |
| REA_Mean | Mean score for Renewable | 1-5 mean score |

| | | |
|---|---|---|
| | Energy Adoption based on its Likert items | |
| WM_Mean | Mean score for Waste Management based on its Likert items | 1-5 mean score |
| PLS_Mean | Mean score for Paperless Library Services based on its Likert items | 1-5 mean score |
| DRM_Mean | Mean score for Digital Resource Management based on its Likert items | 1-5 mean score |
| ISP_Mean | Mean score for Institutional Sustainability Policies based on its Likert items | 1-5 mean score |
| EA_Mean | Mean score for Environmental Awareness based on its Likert items | 1-5 mean score |
| SKHP_Mean | Mean score for Sustainable Knowledge Hub Performance based on its Likert items | 1-5 mean score |