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Interactive Digital Botanical Keys: A Scalable QR Code Based Platform for Plant Identification and Experiential Taxonomy Pedagogy in Academic Campus Ecosystems

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Abstract
Academic campuses offer ideal environments for biodiversity literacy, yet traditional methods often underutilize on-site plant diversity. This study details the design, deployment, and evaluation of a QR code-based botanical information system at college campus. Using object-oriented analysis and design (OOAD), we conducted semi-structured interviews and a systematic tree inventory to document taxonomy, provenance, and ecological roles. Each plant received a peer-reviewed, mobile-optimized profile, validated via authoritative digital repositories. QR codes were algorithmically generated with high-density matrices and medium error correction, customized with institutional branding, and printed on ultra-durable vinyl panels (7×7 cm), affixed at standard heights. Mixed-methods field testing showed high scan reliability (>95%), content accuracy, and strong user satisfaction (Likert ≥ 4.2). Participants reported increased engagement with flora and real-time access to scientific data, turning passive observation into active learning. As digital botanical keys, the platform complements resources like Plants of the World Online, IPNI, and Pl@ntNet, enhancing accessibility for non-specialists and promoting inclusive, informal pedagogy. Aligned with Sustainable Development Goals and national education policies, this low-cost, scalable model transforms campus greenery into a dynamic educational asset. Future directions include assessing long-term knowledge retention and integrating augmented reality and citizen-science tools.
Keywords: *Academic campus ecosystems; QR code technology; digital botanical keys; experiential learning; biodiversity education; sustainability pedagogy*

INTRODUCTION

Academic campus ecosystems play a pivotal role in advancing both biodiversity conservation and environmental education, aligning with global and national sustainability agendas. At the global level, the United Nations' 2030 Agenda for Sustainable Development emphasizes Quality Education (Sustainable Development Goal [SDG] 4) and Life on Land (Sustainable Development Goal [SDG] 15) as core goals, calling for innovative pedagogies that foster ecological literacy (United Nations 2015). Nationally, India's National Education Policy (NEP) 2020 mandates the integration of environmental awareness and sustainability into curricula, drawing on traditional conservation practices to cultivate "pro-planet people" (Government of India 2020). Under Mission Lifestyle for Environment (LiFE) a global initiative launched in Glasgow in 2021 and adopted at the school and collegiate levels via Eco Clubs, institutions are encouraged to undertake activities such as Earth Day "QR Codes for Flora" campaigns to marry digital skills with environmental stewardship (Ministry of Education, Government of India 2025).

Despite these mandates and the well-documented ecosystem services of campus trees improving air quality, moderating microclimates, managing stormwater, and enhancing mental well-being (United States Department of Agriculture Forest Service 2018; Ruddell, Greenwood & Kendal 2020; Rupard et al. 2019; Moran et al. 2020; Sifferlin 2016) students and visitors often remain unaware of the identities and ecological roles of the plants around them (Pratiwi et al. 2024). Traditional teaching methods (lectures, textbooks, occasional field trips) lack in situ interactivity and fail to leverage campuses as living laboratories for experiential learning.

Quick Response (QR) codes offer a scalable solution by linking specimens to rich online content taxonomic data, ecological functions, conservation messages accessible via smartphone scan (Onyekwelu et al. 2023; Kurabayashi et al. 2018). Empirical studies demonstrate their effectiveness: a scavenger-hunt activity improved nonmajors' engagement and application skills (Smith et al. 2018); QR codes in a

Brazilian sensory garden boosted botanical knowledge and curiosity among adolescents (Prestes et al. 2020); and a Thai botanical garden deployment achieved a 4.55 / 5 visitor satisfaction score (Nuansoi & Makon 2024). However, implementations to date tend to be isolated pilots targeting single species or garden patches with limited evaluation of system architecture, user interface design, or integration with broader sustainability frameworks (Sarkar et al. 2024).

Moreover, QR codes function as digital botanical keys, complementing established online databases such as Plants of the World Online (Royal Botanic Gardens, Kew 2025) and the International Plant Names Index (International Plant Names Index 2025), as well as mobile identification apps like Pl@ntNet (Pl@ntNet n.d.). This ecosystem of digital keys fosters informal, passive pedagogy that piques student interest in taxonomy, broadens access for non-botanical audiences, and serves as a simple yet powerful innovation in taxonomic education.

Responding to this gap, and to support institutional adoption under Eco Clubs and similar bodies, this study pursues two interrelated objectives:

1. To architect and implement a robust, scalable, end-to-end QR code–based botanical information platform for academic campus ecosystems.
2. To assess the system's operational reliability and pedagogical effectiveness through in situ testing of scan performance, information accuracy, and end-user satisfaction.

By aligning with SDG targets, Mission LiFE goals, and NEP 2020 directives, our approach transforms campus flora into interactive, educational assets.

MATERIAL AND METHODS

Study Area

The project was conducted at a Post graduate college campus with an approximately 35-acre campus hosting a diverse tree flora under the purview of Mission LiFE (Ministry of Education, Government of India 2025). The study focused on cataloguing and digitally augmenting the tree flora through QR code implementation, thereby converting the campus into a living laboratory for sustainability education.

Methodology

This study adapts and refines protocols from Smith et al. (2018), Pratiwi et al. (2024), Syaikhu et al. (2023) and Apriyanto & Anggraeni (2024) to implement a six-phase workflow (Figure 1) for generating, deploying, and validating QR codes on campus trees.

Requirements Analysis and Tree Identification

An OOAD-driven requirements process (Syaikhu et al. 2023) ran parallel to a comprehensive tree inventory. Semi-structured interviews with campus botanists, facility managers, and Eco Club coordinators defined data attributes (taxonomy, provenance, ecological role), user-interface needs (mobile readability), tag durability criteria, and digital integration requirements. Simultaneously, systematic transect walks catalogued each tree: specimens were identified in situ using dichotomous keys and herbarium references, geolocated with GPS units, and photographed to capture diagnostic features and canopy structure. Detailed records botanical/common names, family, provenance, key traits, and ecological functions were stored in a centralized database to support code generation.

Content Compilation and Verification

Raw records were distilled into concise, mobile-optimized profiles (≤ 150 words) covering taxonomy, diagnostic features, ecological significance, and ethnobotanical notes. Drafts underwent peer review by two campus botanists and were cross-validated against Plants of the World Online and Pl@ntNet to ensure nomenclatural consistency and trait accuracy (Royal Botanic Gardens, Kew 2025; Pl@ntNet n.d.).

System Design and QR Code Generation

Use-case, class, and sequence diagrams specified workflows for data management, profile publication, and code encoding. Verified profiles were published as mobile-optimized web pages; their URLs were encoded into high-density, medium-error-correction QR matrices and exported in vector format to preserve resolution across varied print dimensions.

Design Optimization and Code Customization

Institutional logos and color accents were embedded within code patterns without compromising scan performance. Pilot tests at panel sizes (5 × 5 cm, 7 × 7 cm, 10 × 10 cm) identified 7 × 7 cm as optimal.

Mounting height (1.2–1.5 m) and orientation adhered to ISO/IEC 18004:2015 standards to minimize glare and damage.

Printing and Installation

Codes were printed on matte, UV-resistant vinyl panels (200 × 200 mm) using outdoor-grade inks, then affixed at 1.3 m on trunks or adjacent posts with stainless-steel hardware. Installations were coordinated post-monsoon during low-traffic periods to ensure visibility and minimal disruption.

Functional Testing and Evaluation

In situ mixed-methods testing assessed technical performance and user experience: scans across multiple smartphone and tablet models recorded decoding times and success rates; retrieved pages were inspected for accuracy and link integrity; a pilot cohort rated ease of scanning and information clarity on a five-point scale. Codes meeting ≥ 95 % decoding reliability and mean satisfaction ≥ 4.0 were finalized.

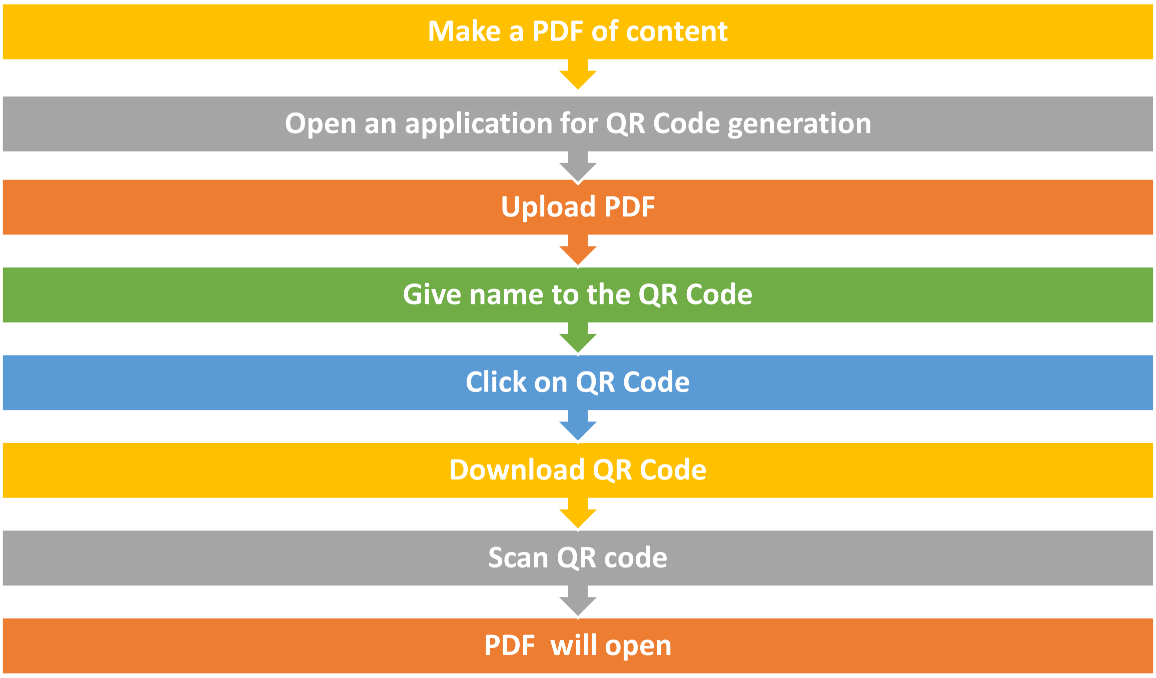

Figure-1. Steps for QR Code generation

RESULTS AND DISCUSSION

A total of 45 plant species including 20 tree taxa were documented across the college campus (Figure 2). Each tree received a unique QR code panel, facilitating immediate access to digital profiles at eye level. This inventory mirrors similar tagging of 30 tree species in an Indian higher-education setting (Nagajyothi et al. 2023) and parallels botanical garden deployments for over 60 species (Apriyanto & Anggraeni 2024). The observed arboreal diversity—comprising both native and introduced taxa—underscores the campus's role as a living laboratory for biodiversity research.

QR code deployment proved operationally feasible: vector exports ensured scan reliability across print sizes, and strategic placement at 1.3 m on north-facing aspects yielded consistent decoding under varied lighting conditions. User feedback from a pilot cohort highlighted high satisfaction with information clarity and accessibility, demonstrating that QR codes transform passive green spaces into interactive, informal learning platforms.

By serving as digital botanical keys, the QR system complements existing online resources such as Plants of the World Online and the International Plant Names Index and mobile apps like Pl@ntNet, thereby broadening engagement among non-specialist audiences and reinforcing taxonomic pedagogy (Royal Botanic Gardens, Kew 2025; International Plant Names Index 2025). Participants reported heightened interest in plant taxonomy, suggesting that this low-cost intervention fosters curiosity and deepens ecological literacy without disrupting routine campus activities.

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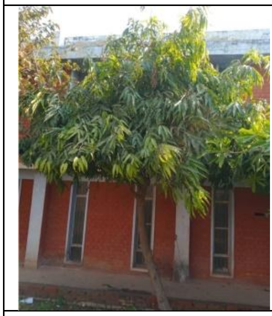
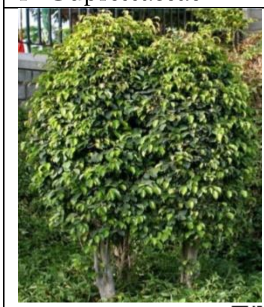
Collectively, these results suggest that two-dimensional code systems can transform static green spaces into dynamic educational platforms, fostering both botanical education and conservation outreach. By bridging traditional dichotomous keys with multimedia-rich, technology-driven approaches, QR codes help integrate field observations with authoritative online content. Future studies should track longitudinal impacts on knowledge retention and conservation behaviors, and assess integration with augmented-reality and citizen-science tools to further enrich user interaction and data collection.

			
C.N.- Gular B.N.- *Ficus racemo* F- Moraceae	C.N- Teak B.N- *Tectona grandis* F- Lamiaceae	C.N- Rosebay B.N-*Nerium olean* F- Apocynaceae	C.N- Weeping bottle b B.N- *Callistemon vimin* F- Myrtaceae
			
C.N- False ashoka B.N- *Monoon longifo* F- Annonaceae	C.N- Jamun B.N- *Syzygium cumini* F- Myrtaceae	C.N- Guava B.N- *Psidium guaj* F- Myrtaceae	C.N- Shisham B.N- *Dalbergia sissoo* F- Fabaceae
			
C.N- Chinese th B.N- *Platycladus orientalis* F- Cupressaceae	C.N- Sago palm B.N.- *Cycas revoluta* F- Cycadaceae	C.N- Bael B.N- *Aegle marmel* F- Rutaceae	C.N- Star pine B.N- *Araucaria heteropl* F- Araucariaceae
			
C.N- Weeping fig B.N- *Ficus benjami*	C.N- Kassod tree B.N- *Senna siamia*	C.N- Neem B.N- *Azadirachta in*	C.N- Curry leaf tree B.N- *Murraya koenigii*

F- Moraceae	F- Fabaceae	F- Meliaceae	F- Rutaceae
			
C.N- Peepal tree B.N- *Ficus religiosa* F- Moraceae	C.N- Toddy palm B.N- *Borassus flabellife* F- Arecaceae	C.N- Lemon B.N- *Citrus limon* F- Rutaceae	C.N- Devil's tree B.N- *Alstonia scholaris* F- Apocynaceae

Figure 2. Pictures of trees with their QR code and classification in college campus of GGDSD, Palwal (Abbreviation used: B.N.- Botanical Name; C.N.- Common Name; F- Family)

CONCLUSIONS

This study demonstrates that QR codes function as digital botanical keys, effectively bridging traditional botanical instruction and experiential, place-based learning in academic campus ecosystems. By encoding peer-validated profiles into mobile-accessible codes and deploying them across College's tree flora, we created a scalable platform that integrates digital taxonomy with field observations. High decoding reliability and positive user feedback confirm that QR tagging enhances immediate access to taxonomic, ecological, and ethnobotanical information, fostering deeper understanding of plant diversity.

Moreover, this approach democratizes plant exploration serving students, faculty, Eco Club members, and lay audiences alike by offering an informal, passive pedagogical tool that aligns with SDG 4 and SDG 15 targets, as well as national sustainability directives. As a replicable, low-cost model, campus QR code systems empower institutions to convert green spaces into living laboratories. Future work will explore longitudinal learning outcomes, expansion to additional taxa, and synergy with advanced interactive technologies to further cultivate ecological literacy and conservation engagement.

Conflict of interest: The authors declare that there are no conflicts of interest.

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