



RESEARCH ARTICLE

Digital Participatory Tree Governance: Implementation of DIGI TREE for Sustainable Tree Management at Brawijaya University

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Funding information

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Abstract

University tree management increasingly requires a technological shift beyond passive inventory systems toward approaches that connect ecological data with actionable governance. This study proposes DIGI TREE as a Digital Participatory Tree Governance model to support sustainable tree management at Brawijaya University. Using a conceptual-qualitative approach, the study synthesizes literature on smart urban forestry, examines governance and technological gaps, and maps collaborative actors, digital features, and operational mechanisms. The study establishes DIGI TREE's circular workflow, which consists of the stages scan–learn–observe–report–verify–respond–feedback. Through this workflow, each tree's digital identity, accessed via QR codes and physical signage, links ecological characteristics and educational content with academic community participation through citizen science, expert verification, managerial decision-making, maintenance actions, and status updates. The main novelty of DIGI TREE lies in integrating citizen participation and digital technology into a closed-loop governance ecosystem, transforming public observations into verified and accountable management actions. Brawijaya University serves as a living laboratory for the development and empirical testing of this framework. Further implementation is needed to evaluate data accuracy, user engagement, and institutional response speed before the model is replicated across other higher education campuses.

Keywords

Digital Participatory Tree Governance; Smart Urban Forests; Digital Participatory Affordances; Citizen Science; Living Laboratory.

1 | INTRODUCTION

Environmental sustainability in higher education is increasingly linked to a university's ability to maintain the quality of its green spaces amid the expansion of academic activities and physical development. Trees play a vital role in this context because they contribute to environmental comfort, carbon sequestration, and biodiversity, while also shaping the character of the campus landscape. However, the current state of vegetation does not always reflect the sustainability of the campus ecosystem. Darmawati *et al.* (2024) found that tree vegetation diversity at the University of Riau was classified as moderate, while vegetation at the sapling, young tree, and seedling levels was classified as low. Tree management therefore requires information capable of describing vegetation conditions in greater detail. A tree census recording species, coordinates, diameter, and height can be used to describe vegetation structure while also estimating carbon potential (Arini *et al.*, 2024). The need for more structured information becomes increasingly important when tree management is directed not only toward maintaining vegetation presence, but also toward preserving its condition and sustainability.

In practice, tree management on university campuses still relies heavily on inspections and maintenance carried out by technical units. This approach has limitations when changes in tree conditions occur between inspection periods. The Ancient Tree Inventory in the UK demonstrates that community involvement can support the large-scale, long-term documentation of trees of conservation value (Nolan *et al.*, 2020). Developments in citizen science have expanded these possibilities through the use of technology to collect observations from the public (Potgieter *et al.*, 2024). Mobilising these observations can broaden understanding of urban biodiversity (Palma *et al.*, 2024). These developments create opportunities to expand campus tree monitoring by involving communities that spend their daily lives in that environment.

Digitalisation through the use of GIS, remote sensing, sensors, and various data processing technologies has expanded the capacity for more integrated tree monitoring and management. The concept of smart urban forests has emerged from the need to link digital technology with the monitoring and management of urban forests (Prebble *et al.*, 2021). Through this approach, trees can be represented as digital objects containing information on location, characteristics, condition, and changes over time. These developments create opportunities for more data-driven tree management, but have not yet fully shifted the role of technology from information provision toward governance. Fry *et al.* (2026), in a scoping review of 73 publications, found that digital technology in urban forestry is most commonly used for inventory and assessment. This indicates that digital developments in urban forestry are still predominantly used to determine tree conditions rather than to track how those conditions change and how management is carried out.

The university context offers a unique setting because environmental management technologies can be integrated with educational functions and the involvement of the academic community. The use of citizen science applications by students has shown potential to increase awareness of plant biodiversity (Forti & Szabo, 2024). The use of plant biodiversity can also be integrated into learning to strengthen conservation awareness (Mumpuni *et al.*, 2022). The campus's dual role as both a learning space and an ecological space allows information about trees to support management and form part of the learning experience and environmental engagement. However, such participation must have a clear link to the institution so that user contributions do not stop at observation. Public participation in environmental management requires institutional support so that the contributions made can be incorporated into planning and implementation processes (Wamsler *et al.*, 2020). Cappa *et al.* (2022) emphasise that citizen science can generate value when data collected by citizens can be processed and utilised by organisations.

Participation linked to institutions therefore requires mechanisms that allow information from users to be incorporated into tree management. Princz-Jakovics and Szemenyei (2024) emphasise the importance of integrating information into environmental governance so that data can be used in decision-making processes. In campus tree management, information regarding tree conditions must be received by managers, verified, and acted upon when users identify issues in the field. This need formed the basis for the development of DIGI TREE at Brawijaya University as a Digital Participatory Tree Governance model. DIGI TREE links information on each tree with the participation of the academic community through observation and reporting, which can then be followed by verification, management, and feedback. This process positions digital technology as an integral part of tree management rather than merely a medium for providing information. Brawijaya University is thus positioned as a living laboratory for developing a tree management model that integrates technology, academic community participation, and institutional response.

2 | BACKGROUND THEORY

The literature on the digitalisation of urban forestry indicates a shift from conventional inventories toward systems capable of integrating spatial data, tree condition, monitoring, and decision-making. The concept of smart urban forests positions digital technology as an integral part of an increasingly data-driven approach to urban forest

management (Prebble *et al.*, 2021), while developments in remote sensing, citizen-led applications, and decision support systems are expanding capabilities from tree identification to monitoring tree condition (Velasquez-Camacho *et al.*, 2024; Rebholz *et al.*, 2026). However, Fry *et al.* (2026) indicate that the use of technology remains concentrated on inventory and assessment. This literature shows that the technical capacity to generate tree data is developing more rapidly than its application within governance processes. The social-ecological-technological systems perspective then positions technology as part of the relationship between ecological systems, social actors, and institutional structures in environmental management (Branny *et al.*, 2022).

Citizen science broadens the public's role from mere recipients of information to producers of environmental data. Community-based tree documentation has generated long-term databases for conservation purposes (Nolan *et al.*, 2020), while app-based observations can be used to detect threats to trees and determine monitoring priorities (Potgieter *et al.*, 2024). In the context of urban biodiversity, the City Nature Challenge demonstrates the capacity of citizen science to expand ecological knowledge through public participation (Palma *et al.*, 2024). Campus environments present unique opportunities because such activities can intersect with education and research. Tiago *et al.* (2024) show that citizen science on campus can enhance community engagement with biodiversity, while Forti and Szabo (2024) found that the use of citizen science apps helps increase students' interest in plants. However, Wamsler *et al.* (2020) suggest that participation may lose its impact when it is not linked to institutional capacity and implementation. Consequently, Cappa *et al.* (2022) position citizen-sourcing as a valuable process when citizens' contributions can be translated into knowledge that organisations can use.

Developments in digital participation and environmental governance provide a basis for bringing these two trends together. Princz-Jakovics and Szemenyei (2024) emphasise the importance of integrating citizens' information and needs into environmental e-governance systems so that participation can be linked to decision-making. Merhi and Ahluwalia (2025) also identified a relationship between the quality of digital services, e-participation, and environmental performance in a cross-national analysis of 179 countries. From the perspective of more-than-human smart urban governance, Sheikh *et al.* (2023) broaden the discussion of digital governance by incorporating non-human entities into technological design and decision-making. This literature provides a foundation for the development of Digital Participatory Tree Governance, but has not yet specifically addressed how the identity of individual trees can serve as a point of convergence between ecological data, citizen participation, verification, decision-making, and management actions within a university setting. DIGI TREE addresses this gap by integrating digital tree information, citizen science, digital participatory affordances, and institutional mechanisms into a single tree management cycle.

3 | METHOD

This study employs a conceptual-qualitative approach to formulate DIGI TREE as a model of Digital Participatory Tree Governance for sustainable tree management at Brawijaya University. The analysis was conducted through a literature review on the digitalisation of urban forestry, smart urban forests, citizen science, digital participation, co-production, and collaborative governance. This literature was used to examine developments in the use of technology in tree management while identifying the limitations of approaches that remain focused on inventory and assessment (Prebble *et al.*, 2021; Fry *et al.*, 2026). A review of citizen participation and citizen science was used to examine how community contributions can support biodiversity monitoring and environmental management (Nolan *et al.*, 2020; Potgieter *et al.*, 2024; Palma *et al.*, 2024).

The subsequent analysis focused on mapping gaps in technology and governance. Each approach examined was compared based on available digital functions, forms of user engagement, the role of data in management, and the relationship between information and action. Literature on citizen science and participation was used to clarify the need for mechanisms that link public contributions to institutional processes (Wamsler *et al.*, 2020; Cappa *et al.*, 2022). Literature on environmental e-governance was also used to examine the importance of information integration in supporting decision-making (Princz-Jakovics & Szemenyei, 2024). The results of this mapping were then synthesised within the context of tree management in a university setting to determine the components required for the DIGI TREE model.

The final stage produced the DIGI TREE conceptual framework through the integration of three key elements: digital technology, academic community participation, and governance mechanisms. These components were formulated into a scan-learn-observe-report-verify-respond-feedback workflow that links a tree's digital identity with ecological information, user contributions, verification, decisions, actions, and feedback. This framework is then mapped onto digital participatory affordances, collaborative actors, and management outputs to clarify the position of DIGI TREE in relation to existing digital tree approaches. Based on this design, the research does not claim to have empirically tested the effectiveness of DIGI TREE. The output of the study is a conceptual model constructed from a literature review and gap analysis, intended to serve as a basis for further development and empirical testing in the next phase.

4 | RESULTS AND DISCUSSION

4.1 Results

The results of the synthesis indicate that the use of digital technology in tree management remains concentrated on inventorying, mapping, identification, and assessment. Fry *et al.* (2026) found that approximately 84 per cent of the publications reviewed focused on inventorying and 70 per cent on assessment. Prebble *et al.* (2021) also situate smart urban forests within technological developments that primarily support monitoring and management efficiency. On the other hand, research on citizen science demonstrates that the public has been able to generate biodiversity data on a large scale (Nolan *et al.*, 2020; Potgieter *et al.*, 2024; Palma *et al.*, 2024). The issue lies in the relationship between this data and institutional management. Participation requires institutional support to be linked to implementation (Wamsler *et al.*, 2020), while citizen-generated data yields value only when it can be utilised by organisations (Cappa *et al.*, 2022). Consequently, DIGI TREE was designed to link tree data with participation, verification, decision-making, and management actions.

These requirements are reflected in the five main components of DIGI TREE: tree objects, data, participation, decision-making, and learning. Each tree has a digital identity linked to ecological information and its management history. The data is then updated through inventories and user contributions. Participation is facilitated through observation and reporting, while incoming information can be verified before forming the basis for prioritisation and action. Management outcomes are subsequently fed back to users through information on tree condition, management status, and learning materials. This structure aligns with the requirements of digital environmental governance, which links databases with participation and decision-making processes (Princz-Jakovics & Szemenyei, 2024). With this structure, DIGI TREE positions trees not merely as objects of inventory, but as a meeting point between ecological information and the university's institutional activities.

Table 1. DIGI TREE's Position in the Environmental Digital Technology Landscape

Technology/Platform	Focus and Key Mechanisms	Forms of Participation	Relationship to Decision-Making	Limitations for Campus Tree Governance	DIGI TREE's Role and Added Value	Empirical References
Remote sensing, GIS, LiDAR, and aerial imagery	Mapping of canopy cover, location, structure, and vegetation condition at the regional scale	Low; users are generally experts or managers	Data serves as input for planning but is not always linked to public reporting	Strong in spatial coverage, but weak in citizen engagement, action history, and accountability on a per-tree basis	Links maps to individual tree identities, citizen reports, inspections, actions, and feedback	Fry <i>et al.</i> (2026); Prebble <i>et al.</i> (2021)
Digital tree inventory and ecosystem services calculator	Records species, size, location, carbon, and ecological benefits	Limited to enumerators or field staff	Supports valuation and planning	Tends to be a static database or updated periodically	Transforms the inventory into dynamic data updated through user activity and maintenance history	Arini <i>et al.</i> (2024); Fry <i>et al.</i> (2026)
Plant.id, Pl@ntNet, and Seek/iNaturalist	Species identification via images and artificial intelligence	Users upload or scan photos	Relatively indirect link to management decisions	Lacks an institutional mandate to manage campus trees	Integrates identification with asset profiles, education, condition reports, and management actions	Velasquez-Camacho <i>et al.</i> (2024)

iNaturalist for monitoring threats to trees	Open collection of observations of species and pests	High during the observation collection phase	Data helps determine locations and priority threats	Does not specifically manage <i>service requests</i> and campus maintenance tasks	Converts findings into handling tickets, risk verification, unit assignments, and completion reports	Potgieter <i>et al.</i> (2024)
Ancient Inventory	Tree Community-led inventory of old and conservation-valued trees	Residents contribute as recorders	Supporting conservation knowledge and priorities	Focus on conservation inventory, not the entire asset maintenance cycle	Combines conservation, health, safety, education, and maintenance history	Nolan <i>et al.</i> (2020)
City Nature Challenge	Activity-based or community-driven biodiversity data collection	High, but often periodic or event-based	Results can inform local government decision-making	Continuity of participation and follow-up per site are not yet core functions	Making participation a routine process with case status updates and feedback	Palma <i>et al.</i> (2024)
Tree-Quest	Measuring tree diameter, height, and species using AR, curation, and gamification	Volunteers collect tree measurements	Generating tree data for analysis	Focused on data acquisition, not yet on institutional governance	Adding actor structures, verification rules, decision-making, handling, and accountability	Milenković <i>et al.</i> (2026)
Sensor systems and <i>smart irrigation decision support</i>	Soil and weather sensors are used to determine irrigation needs	Primarily involves operators and managers	Strong in operational technical decisions	Citizen participation and public deliberation are relatively limited	Will integrate future sensor data with citizen reports and collaborative decision-making	Rebholz <i>et al.</i> (2026)

The comparison in Table 1 highlights that the innovation of DIGI TREE lies in the integration of functions rather than in the creation of entirely new technology. GIS, sensors, AI, QR codes, identification apps, and citizen science have already been utilised in various forms. However, the integration of technology with institutional mechanisms that link tree information to concrete action has not yet been widely implemented. In DIGI TREE, a tree's identity serves as the link between ecological data and user activities. Reports do not end as mere observations, but feed into processes of verification, prioritisation, task allocation, and feedback. This approach expands the function of the digital tree platform from an information provider to a governance infrastructure. Findings regarding the importance of the relationship between participation and implementation (Wamsler *et al.*, 2020) and between citizen contributions and their utilisation by organisations (Cappa *et al.*, 2022) form the basis for this configuration.

DIGI TREE's participatory dimension also differs from citizen science, which is primarily oriented toward data production. Users can act as observers and reporters, while experts and managers play a role in verification and follow-up. This division allows users' local knowledge to be combined with professional expertise within a single management workflow. This approach is consistent with the use of citizen science for monitoring biodiversity and threats to trees (Potgieter *et al.*, 2024; Palma *et al.*, 2024), but extends the function of data to the level of campus asset management. DIGI TREE also maintains an educational function through species information, ecological benefits, and digital storytelling, ensuring that participation not only generates reports but also strengthens users' connection with the campus environment (Forti & Szabo, 2024; Mumpuni *et al.*, 2022).

The core workflow of DIGI TREE is structured around the stages scan–learn–observe–report–verify–respond–feedback. Scan connects users with tree identification, while learn provides ecological and educational information. Observe allows users to monitor the condition of trees, and report transforms users' findings into reports. Verify ensures reports are checked before being used in management. The verification results then enter the respond stage through management actions, while feedback returns the status of the actions to the user. This sequence forms a cycle of tree-data-participation-verification-decision-action-learning, which lies at the heart of Digital Participatory Tree Governance. The model's key contribution lies in the integration of digital technology with tree governance processes within a single, interconnected workflow.

DIGI TREE offers a conceptual model; it does not provide evidence that the effectiveness of tree management has improved following implementation. The model's value lies in its ability to unify the functions of information, participation, verification, decision-making, and action within a single framework. Brawijaya University is positioned as a living laboratory for the subsequent development and testing phases. Empirical implementation is required to assess whether the model is truly capable of improving data quality, user engagement, response speed, managerial accountability, and the sustainability of tree management. Therefore, the results of this study provide a conceptual basis for the development of a more integrated campus tree management system that can be tested in the context of other higher education institutions.



Figure 1. Conceptual Framework for Digital Participatory Tree Governance (DIGI TREE)

4.2 Discussion

The findings indicate that DIGI TREE moves beyond the usual pattern of digital tree management, which still leans heavily on inventory, mapping, and assessment. Several studies show that digital tools in urban forestry are still used mainly to collect and classify data rather than to guide action (Prebble *et al.*, 2021; Fry *et al.*, 2026). DIGI TREE takes a different direction by linking tree identity, ecological data, user reports, expert review, and managerial response in one workflow. This shift matters because technology in environmental management should do more than store information; it should help institutions act on what the data show. The social–ecological–technological systems view also supports this approach by placing technology alongside social actors and ecological conditions in a shared management process (Branny *et al.*, 2022). The participatory side of DIGI TREE is also well aligned with citizen science studies. On campuses, citizen science has been shown to raise attention to biodiversity and support learning around living environments (Forti & Szabo, 2024; Tiago *et al.*, 2024; Mumpuni *et al.*, 2022). In urban tree studies, community observations have helped build long-term records and improve monitoring of biodiversity and tree threats (Nolan *et al.*, 2020; Palma *et al.*, 2024; Potgieter *et al.*, 2024). Still, participation only becomes useful when institutions are ready to process the reports and respond to them. Without that step, public input stops at the stage of data entry and has little effect on management outcomes (Wamsler *et al.*, 2020; Cappa *et al.*, 2022). DIGI TREE addresses this gap by placing users in the roles of observer and reporter, while experts and managers handle verification and action.

This model also strengthens the link between participation and governance. Digital participation is often treated as a technical feature, but its real value lies in whether institutions can turn user input into decisions and follow-up actions. Research on e-governance shows that environmental policy works better when citizen information is built into decision systems rather than left outside them (Princz-Jakovics & Szemenyei, 2024). Merhi and Ahluwalia (2025) also found that e-participation and institutional capacity shape environmental performance. In DIGI TREE, this means reports about tree damage, disease, or maintenance needs should move through verification, response, and feedback. That flow helps make participation visible and accountable. The model is also in line with recent digital tools that focus on single-tree data. Tree-Quest shows that app-based participation can collect tree-level information in a structured way, while remote sensing and

AI tools can help identify species and assess urban forest biodiversity (Milenković *et al.*, 2026; Velasquez-Camacho *et al.*, 2024). Yet many of these tools still stop at data collection. DIGI TREE goes further by connecting reports to institutional handling, task assignment, and recorded action. This makes the system more suitable for campus governance, where the issue is not only knowing the condition of trees, but also making sure the condition leads to follow-up.

The campus setting gives this model a strong practical base. Trees on a university campus serve ecological, educational, and symbolic roles at the same time. Research on campus biodiversity and green campus conditions shows that campus vegetation can support environmental learning and strengthen ecological awareness (Darmawati *et al.*, 2024; Arini *et al.*, 2024). DIGI TREE builds on that role by making each tree part of an active learning and management process. Users do not only see trees as landscape features; they can read their ecological identity, follow their condition, and take part in reporting and monitoring. This design fits the university as a living laboratory, where governance can be tested in direct relation to daily campus life. DIGI TREE also responds to the growing interest in smarter tree management. Sensor-based irrigation systems and smart urban forest tools show that digital systems can support more responsive decisions when they are linked to operational needs (Rebholz *et al.*, 2026; Prebble *et al.*, 2021). Even so, technical efficiency alone is not enough if the data never reaches decision-makers in a usable form. DIGI TREE deals with this issue through the scan-learn-observe-report-verify-respond-feedback cycle. Each step has a clear role, but the full value appears only when the cycle is completed and the user receives feedback. That traceability gives the model a stronger footing for accountability.

5 | CONCLUSIONS AND FUTURE WORK

This study aims to formulate DIGI TREE as a Digital Participatory Tree Governance model to support sustainable tree management at Brawijaya University. The results of the synthesis indicate that the use of digital technology in tree management remains concentrated on inventory, identification, mapping, and assessment. DIGI TREE offers expanded functionality through the integration of trees' digital identities, ecological information, academic community participation, expert verification, management decisions, maintenance actions, and feedback. This integration is formulated within a scan-learn-observe-report-verify-respond-feedback workflow, which forms an iterative tree management cycle from data collection to decision-making. The main contribution of this research lies in the formulation of a model that positions digital participatory engagement as an integral part of iterative and sustainable interaction and communication processes in tree management, rather than merely as a source of data. DIGI TREE brings together the academic community as observers and reporters, experts as validators, and managers as decision-makers and implementers of actions. The novelty of the model lies in this configuration, which links digital technology, citizen science, and institutional mechanisms within a single framework for tree governance. This model simultaneously expands the function of trees as ecological objects to become part of campus learning, participation, and governance. Brawijaya University is positioned as a living laboratory to develop, test, and implement DIGI TREE within a real-world institutional environment. The next stage involves testing the model through empirical implementation by examining data quality, user participation, verification accuracy, management response, and the traceability of actions. This testing is crucial for refining the design, establishing operational standards, and assessing the model's readiness for replication. If the results are satisfactory, DIGI TREE can be developed as a broader tree management model across higher education institutions in Indonesia.

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How to cite this article: Susenohaji, S., Dhaniyas, F. R., Kusairi, K., Pratiwi, A. I., Widia, I. D. M., & Bintang, R. M. (2026). Digital Participatory Tree Governance: Implementation of DIGI TREE for Sustainable Tree Management at Brawijaya University. *Indonesian Journal Economic Review (IJER)*, 6(3), 1568–1575. <https://doi.org/10.59431/ijer.v6i3.1008>.