Dissertationes Forestales 385

Gamified data collection for participative forest planning

Philip Chambers

School of Forest Sciences
Faculty of Science, Forestry and Technology
University of Eastern Finland

Academic dissertation
To be presented, with the permission of the Faculty of Science, Forestry and Technology of the University of Eastern Finland, for public criticism in the auditorium C2 of the University of Eastern Finland, Yliopistokatu 4, Joensuu, on 8th of May 2026, at 2 o' clock.

Title of dissertation: Gamified data collection for participative forest planning
Author: Philip Chambers

Dissertationes Forestales 385
https://doi.org/10.14214/df.385

Thesis supervisors:
Professor Teppo Hujala
School of Forest Sciences, University of Eastern Finland, Finland

Professor Juho Hamari
Faculty of Information Technology and Communications, Tampere University

Timo Nummenmaa, Senior Research Fellow
Faculty of Information Technology and Communications, Tampere University

Pre-examiners:
Professor Toshiaki Owari
University of Tokyo

Dr. Miika Kajanus, RDI-liaison
Savonia University of Applied Sciences

Opponent:
Professor Marku Holopainen
University of Helsinki

ISSN 1795-7389 (online)
ISBN 978-951-651-860-5 (pdf)

Publishers:
Finnish Society of Forest Science
Faculty of Agriculture and Forestry of the University of Helsinki
School of Forest Sciences of the University of Eastern Finland

Editorial Office: Finnish Society of Forest Science
Viikinkaari 6, FI-00790 Helsinki, Finland
http://www.dissertationesforestales.fi

Chambers P. (2025). Gamified data collection for participative forest planning.
Dissertationes Forestales 385. 55 p. https://doi.org/10.14214/df.385

ABSTRACT

Technological advances and evolving public expectations have created new avenues for participatory forest planning. However, traditional public involvement methods often face challenges, including low participation and limited participant diversity. Contemporary forest planning increasingly functions as a design process that requires tools capable of efficiently gathering stakeholder preferences alongside technical inventory data while ensuring active engagement. This dissertation investigated how gamification approaches can address these challenges by collecting forest data to support participatory processes. A conceptual framework was developed that combines *Technology-Mediated Environmental Engagement*, *Participatory Forest Planning*, and *Cultural Adaptation* to examine how gamification can connect technical data collection with stakeholder participation across diverse contexts.

This research adopted a progressive mixed-methods approach through three studies: utilising geocaching to collect preference data, developing specialised augmented reality applications for forest scanning, and investigating cross-cultural implementation. Article I demonstrated that existing location-based gaming platforms can be leveraged to gather meaningful social data, revealing diverse landscape preferences and human-forest relationships, though spatial accessibility constraints and diminished engagement patterns were evident. Article II found that gamification design significantly affects participant behaviour, movement, and data characteristics, with different game mechanics producing distinct point cloud features suitable for specific forest inventory needs. Article III validated the technical transferability of gamified augmented reality applications between Finnish and Japanese contexts, although significant location effects highlighted that culturally adaptive gamification is essential for optimal implementation.

The findings validate the framework's core principles while highlighting key tensions between purpose and play, where recreational engagement is instrumentalised to collect data for forest design planning. Effective implementation depends on integrating all three conceptual pillars, technological, participatory, and cultural, rather than considering them separately. It also relies on institutional capacity to incorporate citizen-generated data into formal planning. As forest planning evolves towards more inclusive approaches, balancing technical precision with social licence to operate, gamification offers a versatile approach that, when carefully designed and culturally adapted, can enhance participatory forest management while maintaining technical rigour. Future work should focus on sustaining engagement beyond novelty periods and integrating gamified approaches into operational workflows. Additionally, expanding demographic inclusion is essential to promote equitable and inclusive environmental decision-making.

Keywords: participative forestry, location-based games, human-forest relationships, landscape preferences, augmented reality, laser scanning

ACKNOWLEDGEMENTS

Forestry is a deeply human endeavour, and this thesis was no exception. It drew on different fields, took me across countries, and involved numerous false starts. I am grateful for the patience, generosity, and curiosity shown by those around me.

Of all who shaped this work, my deepest gratitude goes to my main supervisor, Professor Teppo Hujala at the School of Forest Sciences. Thank you, Teppo, for agreeing to supervise work that crossed disciplinary boundaries and trusting that the building blocks would eventually fit together. Your patience, your quick and insightful responses, and your willingness to let me explore ideas independently have influenced not only this thesis but how I think about forests, forest technologies, and the people who use them.

Running alongside that support, I am equally grateful to my supervisors at the Research Centre of Gameful Realities, Tampere University: Professor Juho Hamari and Senior Research Fellow Timo Nummenmaa. Juho, thank you for welcoming a forester into the world of gamification research and for the openness that allowed this work to draw on a field you have done so much to build. Timo, thank you for your guidance and for including me in the GamiLiDAR project that brought us to Japan and led to the final study of this thesis.

Equally important to this work were my co-authors, whose collaboration shaped every article. For Study I, I thank Tuulikki Halla, Harri Silvennoinen and Jukka Tikkanen for their partnership and insights. For Studies II and III, I thank Samuli Laato, Tuomas Yrttimaa, Mikko Vastaranta, Oguz Turan Buruk, Kaisa Liimatainen, and Ville-Veikko Uhlgren. Each of you brought something I could not have supplied on my own. I am also grateful to all who participated in these studies in Finland and Japan, especially Lauri Virtanen and all the geocaching community at the Geonautit ry.

Sincere thanks are due to my pre-examiners, Prof. Toshiaki Owari of the University of Tokyo and Dr. Miika Kajanus of Savonia University of Applied Sciences, for their careful and rigorous review of this thesis. I am also honoured that Prof. Markus Holopainen of the University of Helsinki has agreed to serve as my opponent during the public defence.

This research was made possible by the UNITE Flagship, which funded my work and gave me a community to belong to. I am grateful to Prof. Jyrki Kangas, one of my initial supervisors, who helped set the course for this research before his retirement, and to Prof. Heli Peltola, who has since captained the Flagship. Thank you also to my colleagues in Joensuu, Tampere and Helsinki for the conversations and everyday kindnesses.

Journeys like this one begin with small but important nudges. Thank you, Prof. Kyle Eyvindson, for your encouragement, ongoing support and friendship. Thank you, Elina, for your interest and support, as a forester and as a friend, which has meant a great deal to me. And thank you to my dear friend and 'human paperclip' Michelle, for helping me navigate more aspects of this PhD than I can count. Thank you also to my friends Elwyn and Jimmy, who have supported me in more ways than I could list or repay.

Over the years, I have moved and kept on moving, never quite leaving anyone behind but finding others on the way. To all my family and friends in Ireland, Scotland, and Finland: let me tell you that I love you and I think about you all the time. To my father, Gerry, stepmother, Sue, brothers, nephew and niece: although I am so far away today, you are everything I have ever had. Thank you for never letting me become a stranger. To my mother, Carmel, I think about you and feel your love every day. I remember my grandparents, our friend Ingrid Söderblom, and my father-in-law, Christer Storbjörk. I wish you were all still with us.

Yet through all of this, Thomas, you have been by my side. Thank you for the love, the patience, the steady presence through every late night and every doubt, and for being, without contest, my greatest distraction and my greatest joy.

Forests were my first playgrounds, and they became my life's work. They are places where stories are told, where the imagination can run wild, and mine often does. Whenever I find myself sitting before the campfire and listening to the forest choir, my way has always become clear. Forestry is a very human undertaking, and forest planning, at its best, is not only about data and optimisation but also about dialogue, experience, and the sharing of meaning. As we fill our work with ever more capable tools and toys, I hope we remember not to play the humans away from our forest systems, whether digital or ecological. This thesis is offered in that spirit, and I hope it gives something back to the forests of the world, as they have given so much to me.

Ylästö, Vantaa
12th April 2026
Philip Chambers

LIST OF ORIGINAL ARTICLES

This thesis is based on data presented in the following articles, referred to by the Roman Numerals I-IV.

I **Chambers P**, Halla T, Silvennoinen H, Hujala T, Tikkanen J (2024). Using a location-based game to collect preference information for urban and rural forest planning. Landscape and Urban Planning 252, article id 105195. https://doi.org/10.1016/j.landurbplan.2024.105195

II Nummenmaa T, Laato S, **Chambers P**, Yrttimaa T, Vastaranta M, Buruk OT, Hamari J (2024). Employing Gamified Crowdsourced Close-Range Sensing in the Pursuit of a Digital Twin of the Earth. International Journal of Human–Computer Interaction 41(8): 4668–4684. https://doi.org/10.1080/10447318.2024.2352922

III **Chambers P**, Laato S, Yoshida H, Yrttimaa T, Liimatainen K, Uhlgren V, Hamari J, Hujala T, Vastaranta M, Nummenmaa T (2025). Gamified Augmented Reality for Data Collection in Urban Forests. Urban Forestry and Urban Greening 113, article id 129036. https://doi.org/10.1016/j.ufug.2025.129036

Philip Chambers is entirely responsible for the summary of this doctoral thesis. His contribution to the papers included in this thesis is as follows:

I. Philip Chambers (PC) was the main author. The study was conceptualised and planned by PC, Jukka Tikkanen (JM), Harri Silvennoinen (HS) and Tuulikki Halla (THa). PC, HS and THa carried out the study design, collected and analysed data, and interpreted the results. PC wrote the article with co-authors Teppo Hujala (THb), JT, HS and THa.
II. PC was a co-author and collected most of the data. The study was planned and designed by Timo Nummenmaa (TN), Samuli Laato (SL), PC, and Mikko Vastaranta (MV). PC, TN, and SL collected the data and, together with Tuomas Yrttimaa (TY), analysed the data. The aforementioned authors, alongside Oguz Turan Buruk (OB) and Juho Hamari (JH), interpreted the results. TN, SL and PC wrote the article with the co-authors.
III. PC was the main author. The study was planned and designed in collaboration with TN, SL, and HY. PC collected and analysed data and interpreted the results in collaboration with TN, SL, HY, Kaisa Liimatainen (KL), and Ville-Veikko Uhlgren (VU). PC wrote the article with the co-authors TN, VU, KL, TH, and JH.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Forest planning challenges in the digital age

The emergence of systematic forest management in the 18th and 19th-century German states represented a contested transformation toward quantitative approaches to timber production, yield prediction, and state revenue optimisation (Hölzl, 2010). Throughout the 19th and early 20th centuries, this approach, characterised by hierarchical, expert-led methods, was widely adopted in Europe and North America. These systems established clear decision-making hierarchies, with forest policies carried out through strategic, tactical, and operational plans that focused on technical efficiency and economic optimisation (Puettmann et al., 2008; Bettinger & Boston, 2017).

However, from the mid-20th century onwards, this expert-led model faced growing challenges as societal expectations shifted, and conflicts arose over the exclusion of stakeholders from forest decision-making processes (J. Kangas, 1994; Nousiainen & Mola-Yudego, 2022). The diversity of forest systems, stakeholder values, and management contexts across regions created growing tensions between technical and standardised approaches and local adaptation needs, generating conflicts that required new approaches to securing social acceptance of forest management activities. (McDermott et al., 2010). Consequently, forest management increasingly required what has been termed a 'social license to operate' - ongoing approval and acceptance from local communities and society at large for forest management activities (Dare et al., 2014; Moffat et al., 2016). This led to a gradual movement from purely technical optimisation toward approaches that integrate stakeholder engagement and conflict prevention alongside conventional forest management objectives (Menzel et al., 2012).

Contemporary forest planning increasingly functions as a design process that integrates multiple objectives beyond timber production optimisation (Von Gadow & Pukkala, 2008; Eyvindson et al., 2023; Afsar et al., 2026), particularly evident in Nordic countries such as Finland and also in the United Kingdom, where forest planning explicitly results in "forest design plans" (Tahvanainen et al., 2001; Bell et al., 2005; Bell, 2013). This design-oriented approach recognises forest planning as requiring both quantitative analysis and adaptive problem-solving to balance multiple objectives while remaining responsive to diverse stakeholder needs, including non-human (such as wildlife) and more-than-human perspectives (the interconnected relationships between humans, species, and environments) within forest ecosystems (Başkent, 2018; Jhagroe, 2024). These developments in forest planning practice have occurred alongside the emergence of participatory forest planning approaches and collaborative governance strategies that seek to address these complex social and ecological challenges (Friedman et al., 2020).

The spectrum of public engagement approaches utilised in forest planning ranges from intensive co-creation through citizen science and living labs (Bonney et al., 2009; Schlieder & Matyas, 2009) to low-barrier forms of data collection through existing recreational activities. While intensive engagement approaches require participants to become co-creators of knowledge and contribute directly to forest planning processes, low-barrier embedded approaches leverage existing behaviours and motivations to gather environmental observations and stakeholder perspectives without requiring an explicit commitment to forest management objectives (Baldessari et al., 2024; Lawrence et al., 2021). This continuum of engagement reflects that different communities have varying levels of interest and capacity for involvement in forest planning processes.

The ubiquitous nature of mobile device ownership has democratised access to data collection technologies while simultaneously creating public expectations for greater involvement in environmental decision-making (Bonney et al., 2009; Haklay, 2013). This convergence of advanced digital technologies and changing social expectations has created new opportunities for forest planning approaches that can bridge technical data needs with stakeholder engagement requirements. Consequently, forest planners now have access to unprecedented volumes of data through remote sensing, Internet of Things (IoT) sensors, and citizen-generated content. However, this abundance has created new challenges in determining what data is actually needed for effective decision-making (Lindenmayer & Likens, 2018). Gamification approaches offer potential solutions for bridging these technical capabilities with meaningful stakeholder engagement (Vastaranta et al., 2022).

1.2 Games, gamification in environmental citizen engagement

Gamification, the application of game design elements and mechanics in non-game contexts, has emerged as a promising approach for environmental engagement and data collection (Deterding et al., 2011). As a form of motivational information systems engineering, gamification recognises that individuals have diverse intrinsic and extrinsic motivations. Gamified applications can be designed to elicit specific behaviours in context-specific ways (Morschheuser et al., 2018; Ryan & Deci, 2000a). This principle is evident in the success of location-based games, such as Pokémon GO and geocaching, which have demonstrated the potential for games to motivate spatial exploration and environmental interaction on a massive scale (Althoff et al., 2016; Laato et al., 2022).

Gamification offers a promising pathway for the forest sector to earn the social license to operate by transforming traditionally opaque technical processes into transparent and engaging experiences that build trust through meaningful participation (Falk et al., 2023). Unlike conventional consultation methods, where public debate often occurs after key decisions have been made and stakeholder input may have limited influence, gamified approaches can enable continuous, low-barrier engagement throughout the planning process (Speelman et al., 2018).

In environmental contexts, gamification serves a dual purpose: collecting valuable data for forest planning and management decisions while simultaneously helping participants understand ecological systems and human-environment relationships (Palacin-Silva et al., 2018). This approach can contribute to forest managers earning and maintaining social license to operate by providing accessible and engaging ways for people to interact with and understand forest planning processes. The widespread adoption of mobile technologies, applications and online platforms creates new possibilities for motivating behaviours that support both data collection needs and broader forest planning objectives.

However, gamified approaches face implementation challenges, including designing appropriate gamification for specific purposes (Morschheuser et al., 2018), ensuring representative participation (Bowser et al., 2014), sustaining engagement beyond the initial novelty (Hamari et al., 2014), and effectively integrating citizen-generated data into professional forest planning workflows (Boissière et al., 2014; Lindenmayer & Likens, 2018).

Furthermore, the effectiveness of gamified approaches may vary significantly across cultural contexts (Arm et al., 2022; Farinha & Pina, 2025). Human-forest relationships, recreational patterns, and technology adoption behaviours differ markedly between societies (Häggström, 2019). Cultural differences in forest relationships require careful consideration for gamification design. For instance, Finnish forest recreation emphasises individual access rights through 'everyone's rights' (jokaisenoikeus), while Japanese approaches emphasise community stewardship through 'satoyama' traditions of collective landscape management (Fukamachi et al., 2011; Muttilainen et al., 2023). These different cultural frameworks for human-forest interaction suggest that successful gamification approaches for forest monitoring must adapt to local values and practices.

Recent advances in consumer-grade technologies, particularly LiDAR-equipped smartphones and augmented reality capabilities, have opened up new possibilities for crowdsourced environmental data collection (Gollob et al., 2021; Tatsumi et al., 2023). These technologies enable the collection of technically sophisticated data through accessible interfaces, making them particularly suitable for gamified applications that can bridge the gap between professional forest inventory requirements and public engagement.

The diversity of gamification approaches raises important questions about how different game mechanics (design elements like points, rewards, challenges, and feedback systems) influence not only user engagement but also the type and quality of data collected (Cechanowicz et al., 2013; Hamari et al., 2014). Understanding these relationships is crucial for designing effective gamified systems that balance recreational appeal with scientific rigour.

1.3 Objectives of the dissertation

This dissertation examines the application of gamification approaches for forest data collection to support participatory forest planning processes. The research addresses three progressive questions:

RQ1 How effectively can location-based games collect preference data needed for participatory forest planning?
RQ2 How do different gamification strategies affect both user experience and data quality in technical environmental scanning applications?
RQ3 How do cultural factors influence the effectiveness of gamified forest monitoring approaches across different contexts?

Article I investigates whether existing location-based gaming platforms, such as geocaching, can collect meaningful forest preference data from recreational forest visitors. Article II examines how different gamification design choices in tailored augmented reality apps affect user experience and the technical quality of collected point cloud data. Article III investigates the role of cultural contexts in the effectiveness of gamified forest monitoring by comparing implementations in Finland and Japan.

Beyond empirical findings, this research aims to advance methodological innovation in forest planning practice by exploring the application of game design principles to environmental data collection challenges. The research seeks to identify trade-offs between user engagement and data quality, develop design principles for purpose-specific applications, and establish frameworks for the cultural adaptation of gamified approaches.

Collectively, these studies aim to demonstrate how game-based approaches can support the evolution of forest planning from hierarchical, expert-driven processes toward more inclusive, design-oriented practices that maintain scientific rigour while earning social license through meaningful engagement.

2 CONCEPTUAL FRAMEWORK

Contemporary forest planning operates within a complex socio-technical system, where timber volume and economic optimisation models that focus on maximising net present value through timber prices, harvesting costs, and rotation periods are being expanded to integrate social, environmental, and cultural considerations alongside financial objectives (Kangas & Kangas, 2005; Pukkala, 2008; Baskent et al., 2024). This research positions gamified data collection as a bridge between technical forest inventory requirements and participatory processes in forest planning.

The conceptual framework (Figure 1) rests on three interconnected pillars that converge through gamified data collection approaches. These pillars address the technological, social and cultural dimensions necessary for effective environmental monitoring in forest planning contexts.

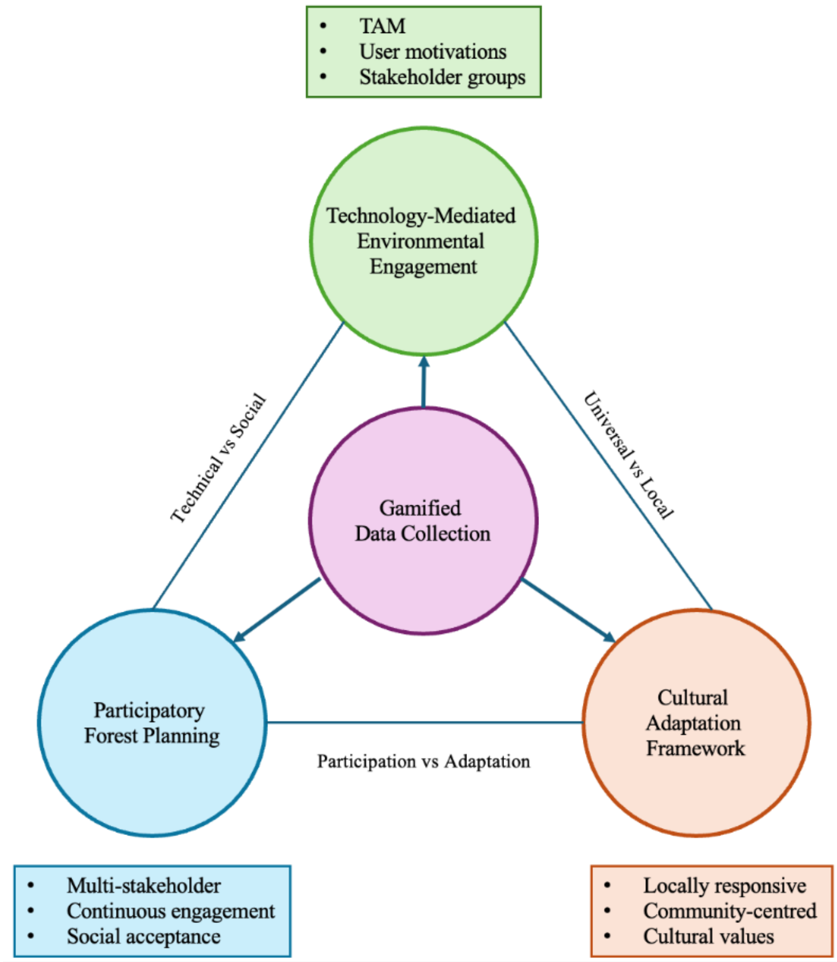

Figure 1. Conceptual framework for gamified data collection for forest planning.

Technology-Mediated Environmental Engagement

This pillar examines how digital technologies can facilitate meaningful human-environment interactions through purposeful design. Building on the Technology Acceptance Model (TAM), which posits that perceived usefulness and ease of use determine technology adoption (Kalana & Junaini, 2025), this framework extends beyond simple acceptance to examine how environmental technologies can be designed to match specific user motivations rather than solely optimising for technical requirements (Papagiannidis & Marikyan, 2022).

Gamification serves as a form of motivational information systems engineering (Vastaranta et al., 2022), providing a design layer that can align technical data collection needs with diverse user motivations. This approach recognises that forest planning stakeholders - from recreational forest visitors to professional foresters – possess varying intrinsic motivations, technical capabilities, and time availabilities (Laato et al., 2022). By tailoring game mechanics and interaction designs to specific stakeholder groups within forest planning processes, gamified systems can accommodate this diversity while maintaining data quality (Bakhanova et al., 2023).

This pillar directly addresses the first research objective by exploring whether location-based game infrastructure can effectively collect forest-preference data. It also addresses the second research objective by examining how various gamification design choices affect both user engagement and data quality.

Participatory Forest Planning

Forest planning has evolved from data-driven optimisation toward multi-objective, multi-stakeholder approaches that require social acceptance (Reed, 2008; Tikkanen et al., 2010; A. Kangas et al., 2015). This evolution reflects growing recognition that technical optimisation alone cannot address the complex social-ecological challenges facing contemporary forest planning. Effective participatory planning requires both accessible engagement mechanisms and processes that enable genuine stakeholder influence on decisions - continuous engagement rather than episodic consultation (Boissière et al., 2014).

This framework positions gamified data collection as a mechanism for operationalising participatory planning principles. By embedding data collection within recreational or professional activities, gamification can generate ongoing stakeholder input without requiring explicit commitment to lengthy planning processes (A. Kangas et al., 2015). This continuous engagement model supports adaptive management approaches while building social license through transparent, accessible participation opportunities (Falk et al., 2023).

This pillar connects to all three research objectives by examining how gamification can facilitate different forms of stakeholder engagement - from preference expression (1) to technical data contribution (2) across cultural contexts (3).

Cultural Adaptation

Human-forest relationships are culturally constructed, reflecting diverse values, practices, and governance across societies. This pillar emphasises that effective forest planning technologies must be responsive to local cultural contexts rather than imposing universal solutions (Mustalahti, 2009). Research with indigenous and local communities indicates that this adaptation is essential, as studies highlight that technologies not aligned with local values or socio-ecological contexts can be ineffective or harmful (Sarkar & Chapman, 2021). Additionally, studies on participatory forest management show that cultural biases and differing worldviews can greatly hinder collaborative efforts (Hoogstra-Klein et al., 2012).

Cultural adaptation of participatory technologies should extend beyond interface translation to encompass alignment with local forest use patterns, cultural values regarding nature and technology interaction, and established local governance practices (Sarkki et al., 2019). Gamification research has shown that cultural dimensions can significantly affect engagement, where individualistic cultures respond more positively to competitive leaderboards and personal achievement, whereas collectivist cultures favour team-based activities and group rewards (Hsu & Chen, 2021). These differences are particularly relevant for forest contexts, where communities often hold deep, culturally specific relationships to forest spaces (Cocks, 2006; Parrotta & Trosper, 2012).

This framework advocates for community-centred design processes that adapt technological interfaces and engagement mechanics to local contexts, values, and practices. This includes consideration of cultural norms around technology use, recreational patterns in forests, expectations for participation in environmental decision-making, and preferred modes of human-nature interaction. Successful gamification design must balance technological standardisation (necessary for data quality and system efficiency) with cultural responsiveness (necessary for meaningful engagement and social acceptance).

This pillar is central to the third research objective, which explicitly examines how cultural factors influence gamification effectiveness across Finnish and Japanese contexts, but also informs the design considerations explored in the second and third research objectives.

Framework Integration

These three pillars are integrated through gamified data collection, serving as the central integrating mechanism (shown in the centre of Figure 1). Successful gamified forest monitoring requires all pillars to be reflected upon:

- Technical-social integration: Technology design must address both data quality requirements and user engagement needs, balancing rigour with accessibility
- Universal-local adaptation: Systems need to balance standardisation for data comparability while adapting to cultural contexts
- Participation-adaptation balance: Engagement strategies should be both inclusive, allowing stakeholder influence, and culturally sensitive, respecting local values and practices.

The arrows linking the pillars in Figure 1 represent these integration challenges. The framework suggests that gamification acts as a design approach capable of addressing these conflicting demands by allowing adaptable, context-specific implementation of game mechanics, which can be customised for different stakeholder groups, data requirements, and cultural contexts.

This integrated framework underpins the progressive research approach of this dissertation. Article I investigates the basic link between technology and participation using existing gaming infrastructure. Article II analyses how technology design decisions impact the challenge of integrating technical and social aspects. Article III explores cultural adaptation by comparing implementations in different cultural settings. Collectively, these studies examine how the three pillars of the framework interact in practice to promote participatory forest planning through gamified methods.

3 MATERIALS AND METHODS

3.1 Research Philosophy and Epistemological Approach

This dissertation addresses forest planning that spans technical, social, and cultural dimensions, requiring an integrated methodological approach (J. Kangas & Kangas, 2005; Pappila & Pölönen, 2012). The research recognises that forest planning is a complex discipline that demands multiple types of knowledge: technical information on forest resources and production, along with stakeholder views on values, preferences, and priorities. Effective forest planning must integrate both dimensions, using quantitative data to guide management options while also considering diverse perspectives to achieve socially acceptable results that balance economic, ecological, and community objectives (Buchy & Hoverman, 2000).

This research adopts a pragmatic, post-positivist stance in which different types of reality and knowledge claims depend on the phenomenon being studied (Nightingale, 2003; Cresswell & Clarke, 2025). For technical forest data, such as point cloud measurements, spatial coordinates, and tree characteristics, this research acknowledges that while physical forest structures exist independently of observation, our representations of them are inherently approximations (Bhaskar, 1975; Phillips & Burbules, 2000). Digital twins of forests, whether captured through consumer-grade mobile device sensors or professional-grade equipment, are temporal snapshots subject to measurement errors and technological limitations (Döllner et al., 2023). These representations approach but cannot perfectly replicate reality. The value of technical data is therefore assessed by its usefulness (Habermas, 1971): whether meaningful insights into forest characteristics (such as tree dimensions, standing volume, phenology, or structural patterns) can be derived, and whether it can inform better surveying methodologies, tool design, or enhance human-forest-machine interactions.

For preference and perception data, this research acknowledges both the reality of subjective experiences and their socio-cultural construction (Berger & Luckmann, 1966; Greider & Garkovich, 1994). Forest preferences captured through surveys and participant observations represent genuine individual experiences occurring at specific moments in particular places. However, these preferences are not formed in isolation; they emerge through familial, societal, and cultural influences that shape how individuals perceive and value forest environments (Atran & Medin, 2008; Hokajärvi et al., 2009; O'Brien et al., 2024). This dual recognition, that preferences are both real subjective experiences and culturally constructed phenomena, requires methods capable of capturing local specificity and temporal variation while acknowledging broader cultural patterns (Edwards et al., 2012).

The integration of technical measurements with human perceptions reflects the practical reality of forest planning, that both objective forest characteristics and subjective human values matter for effective decision-making (A. Kangas et al., 2006; Upton et al., 2012). Data collection methods should meet human needs, preferences, and capacities for engagement. This dissertation positions gamification as a design layer capable of bridging these domains (Deterding et al., 2011; Hamari et al., 2014), motivating human involvement in gathering technical data and making complex planning processes more accessible and transparent (Bowser et al., 2014; Gómez-Barrón et al., 2019).

This research aims to collect objective data through rigorous experimental design and systematic analysis. However, it recognises that the researcher's interdisciplinary background, covering forestry, gamification, and human-computer interaction, influences research questions, design choices, and interpretation of findings (Rose, 1997). This positioning aids recognition of opportunities at disciplinary intersections while also necessitating reflexivity on potential biases (Finlay, 2002).

Validity and reliability are ensured through targeted, approach-specific strategies. Technical data quality is ensured through established remote sensing metrics (point density, spatial coverage, and measurement accuracy) (Liang et al., 2016), and adapted for consumer-grade sensors. Preference data validity relies on rigorous survey design with questions developed through literature review (Dillman et al., 2014; Silvennoinen et al., 2002), and active engagement with location-based gaming communities. Gamification effectiveness is evaluated through both user experience feedback and objective data quality metrics, acknowledging doctoral research limitations while providing insights into specific contexts and applications (Maxwell, 2010).

This research is fundamentally oriented toward practical application (Goldkuhl, 2012). The goal is not purely theoretical understanding but actionable knowledge that can improve forest planning practice, inform data collection tool design, and advance gamification as a design approach for environmental engagement (Kelly & Cordeiro, 2020; Morgan, 2014). Successful gamification requires a systematic review of all system actors to identify who to involve, how, and for what purpose (Reed et al., 2009; Palmquist, 2024). Similarly, this dissertation uses systemic thinking in forest planning by analysing various stakeholder groups and the methods and technologies that allow their active and meaningful participation as interconnected contributions to a larger planning system in which decisions, data flows, and values interact.

The knowledge produced is therefore pragmatic and context-specific rather than universally applicable (Haraway, 1988). In accordance with pragmatism, the ultimate aim of this research is to generate knowledge that is actionable within real forest planning contexts. Findings from geocaching trails, augmented reality studies with specific participant groups, and cross-cultural comparisons between Finland and Japan provide insights into possibilities and limitations rather than definitive solutions. This modest epistemological stance reflects both the exploratory nature of applying gamification in forest planning and recognition that local adaptation is necessary for broader implementation (Flyvbjerg, 2006).

3.2 Progressive research design

This dissertation adopts a progressive mixed-methods approach, beginning with the use of existing digital infrastructure, followed by the development of new applications, and culminating in tests of their cross-cultural applicability. The research design intentionally increases complexity and control over gamification elements.

Article I utilised the established geocaching platform to test the core hypothesis that location-based games can collect meaningful data for forest planning. This approach provided access to a motivated, pre-existing user community while minimising development costs and technical barriers. Building on these findings, Article II involved the creation of custom augmented reality applications to examine how specific gamification design choices influence both data collection outcomes and user experiences. This transition from existing to customised platforms allowed for systematic exploration of how specific design choices, such as goal structure, feedback mechanisms, and interaction patterns, influence both the quantity and quality of the collected point cloud data. Article III incorporated a comparative component to determine whether the principles and approaches identified remained effective across different cultural and environmental contexts, specifically between Finland and Japan.

The methodological progression also reflects increasing sophistication in data collection capabilities. While Article I relied on traditional survey methods embedded within the geocaching framework, Article II incorporated real-time environmental laser scanning using LiDAR technology, marking a considerable advancement in the technical complexity of forest data that can be citizen-generated. This shift from subjective preference data to objective environmental measurements illustrates the growing potential of gamification methods to address various forest planning requirements. The comparative implementation in Article III provides preliminary insights into the applicability of gamified environmental data collection across different cultural and environmental contexts.

3.3 Study sites and participants

The selection of study sites followed a systematic approach designed to capture variation in both forest characteristics and user populations. In Article I, four sites were established across Finland, including two urban forests (Lehmo Recreation Forest in Joensuu and Hervanta Recreation Forest in Tampere) and two rural forests (Ruunaa National Hiking Area and Seitseminen National Park) (see Figure 2). This urban-rural contrast was essential for understanding how population density and accessibility influence participation patterns in gamified data collection. The urban sites were chosen for their proximity to population centres and established recreational use, whereas the rural sites were located in more remote forest areas with distinct visitor patterns and management objectives.

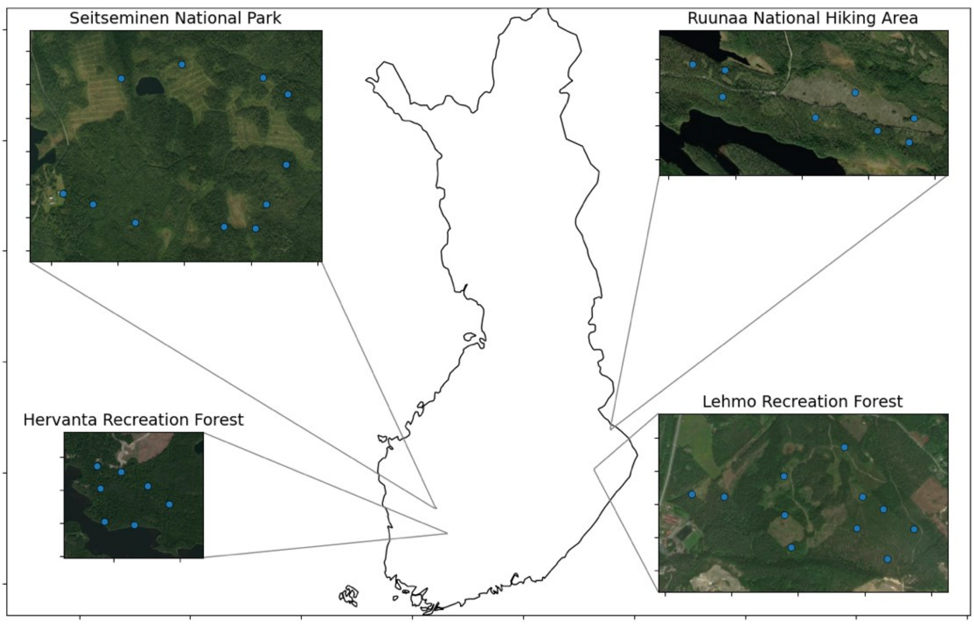

Figure 2. Map of geocaching trail locations in Eastern and Western Finland (Adapted from Article I, Figure 1, p. 3). Map data sources: National Land Survey of Finland; aerial photography - ESRI.

Article II adopted a more flexible site-selection approach, utilising various forest locations across Finland that met the technical requirements for AR testing. These sites needed to offer diverse forest structures to evaluate the scanning capabilities of different gamification designs while remaining accessible to research participants. The specific locations varied by participant to facilitate convenience sampling, while ensuring that all sites contained sufficient forest complexity to test the full range of AR interactions thoroughly.

For Article III, the site selection process involved identifying comparable urban forest settings in Finland and Japan (Figure 3). This required controlling for factors such as forest type, accessibility, and urban environment, while allowing cultural differences in forest use patterns to become apparent. Japan was selected as a comparison country due to its technological advancement and distinctive forest use practices, providing a meaningful test of whether the gamified approaches could perform similarly in a different socio-cultural and environmental context.

Participant recruitment strategies varied across the three studies to match their specific objectives. Article I relied solely on voluntary participation from the existing geocaching community, resulting in 966 survey responses from 3,021 cache visits (Article I, Table 3, p. 5). This self-selected sample provided valuable insights into motivated users but also revealed demographic limitations, with 89% of respondents holding a college education or higher and 71% residing in urban areas (Article I, Table 4, p. 6). Article II used convenience sampling to recruit 16 participants with diverse backgrounds in gaming, AR technology, and forest use (Article II, Table 3, p. 11). This smaller sample size was appropriate for the intensive data collection methods used, including think-aloud protocols and post-experience interviews. Article III required participant samples in both countries (N=31; Finland n=16, Japan n=15), necessitating recruitment strategies that accounted for the different gaming cultures and forest visitation patterns, while maintaining methodological consistency (Article III, Table 2, p. 6).

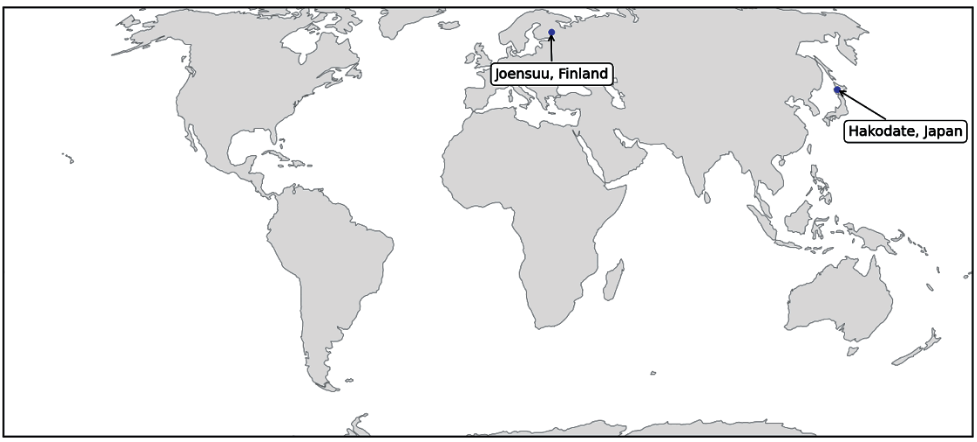

Figure 3. Article III workshop sites: Urban forests in Joensuu, Finland, and Hakodate, Japan. Map data source: Natural Earth Data.

3.4 Data collection methods

The data collection methods used across the three studies demonstrate a shift from traditional survey techniques to multi-modal data collection systems. All studies adhered to key methodological principles, including collecting data at the location of the experience, combining quantitative and qualitative methods, and capturing real-time experiences rather than relying on retrospective recall. This focus on contemporaneous data collection addresses a common limitation in traditional forest planning-related research, where participants often recall past experiences rather than describing their immediate ones.

In Article I, embedded surveys were integrated into the existing geocaching infrastructure through carefully designed cache descriptions. Each cache page contained a voluntary participation statement, a brief introduction to the research, and a link to a mobile-optimised survey that collected data from participants at each location (Figure 4). The surveys combined quantitative measures using established landscape preference scales with qualitative open-ended questions about forest relationships and experiences. Additionally, an autophotographic component asked participants to capture images representing their most and least favourite aspects of each location. This mixed-methods approach produced rich data, with an 89% completion rate for qualitative questions and meaningful photographic submissions that revealed consistent patterns in environmental preferences.

Article II expanded the data collection toolkit by combining multiple concurrent data streams. Screen recordings captured all user interactions with the AR applications (Figure 5), while voice recordings documented think-aloud protocols as participants engaged with different gamification designs. The applications themselves collected point cloud data and mesh information using the devices' LiDAR sensors, producing objective environmental scans in parallel with subjective user experiences. Post-experience interviews provided

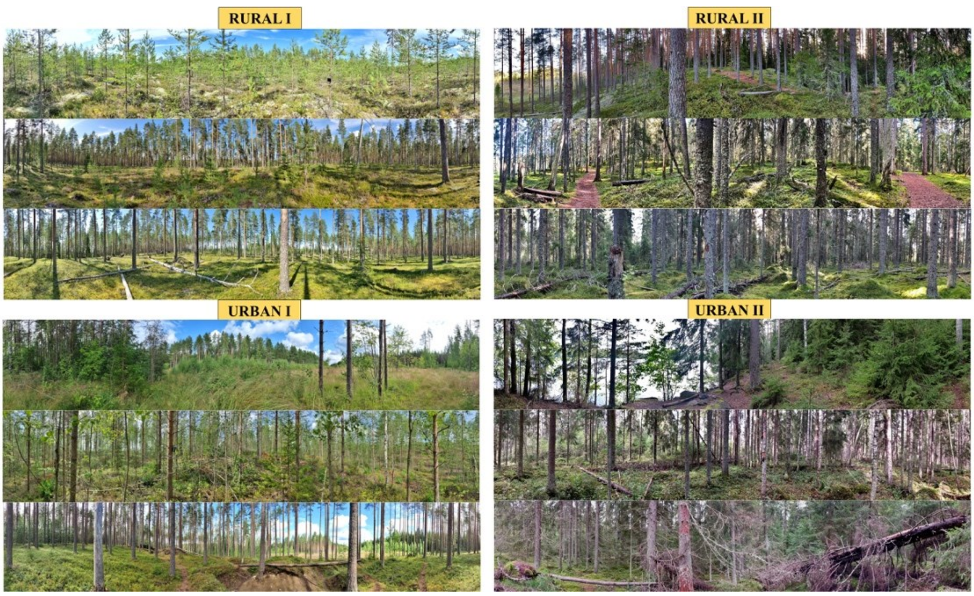

Figure 4. Panoramic images from geocaching trail sites showing landscape diversity across urban and rural locations (Article I, Figure 2, p. 3).

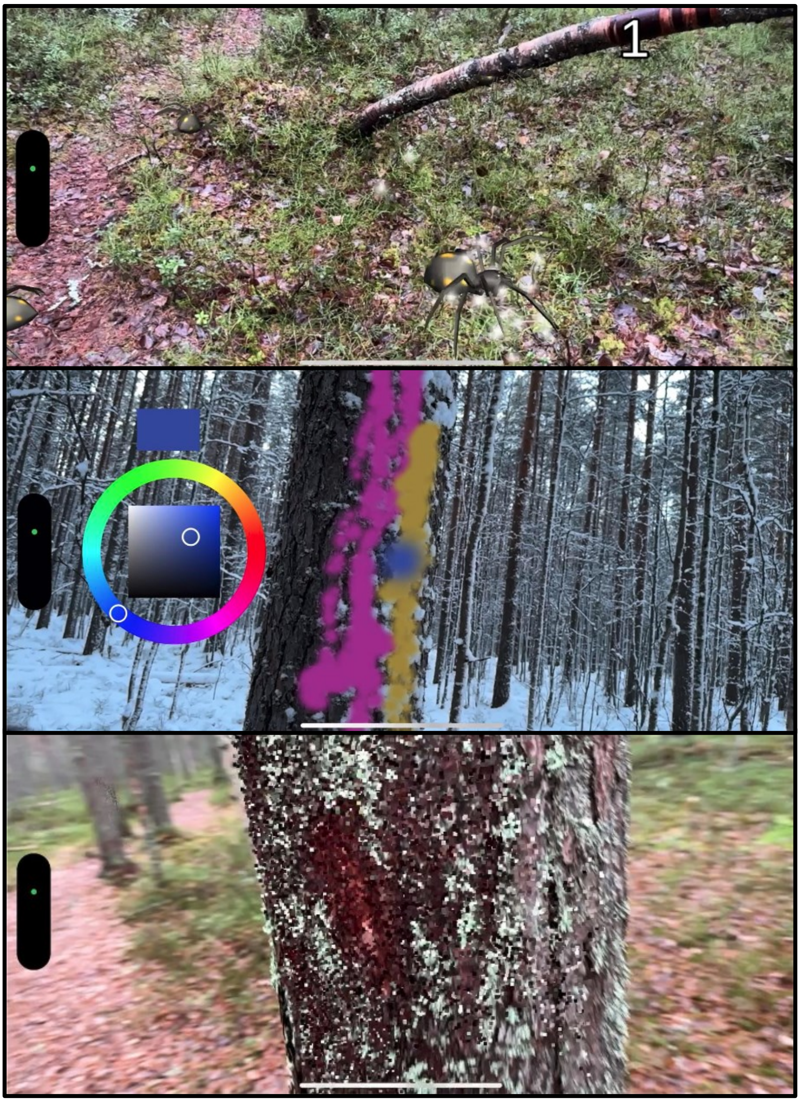

Figure 5. Screenshots of the three augmented reality scenarios used in Study II: (top to bottom) Spider Vacuuming, Spray Painting, Space Probe Retrieval, Environment Scanning. The control condition (Nothing) displayed only the camera viewfinder without AR elements (adapted from Article II, Figures 1-3, pp. 4-5).

reflective insights that complemented the real-time data capture. This multimodal approach enabled triangulation between what users said, did, and the data they generated.

The implementation of Article III in both Finnish and Japanese contexts required adapting data collection tools to ensure linguistic and contextual clarity while maintaining methodological comparability (Figure 6). A native Japanese speaker translated surveys to ensure conceptual consistency, and minor adjustments were made to question framing based on informal cultural consultation. The gamified elements remained unchanged, and the

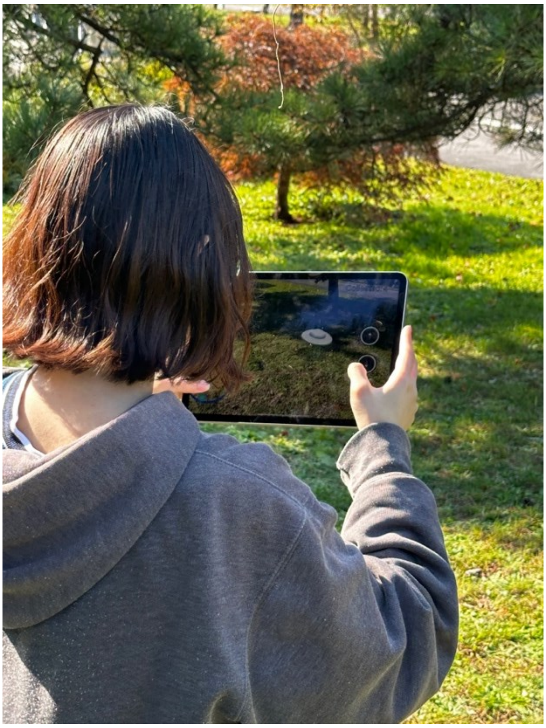

Figure 6. Participant collecting point cloud data during cross-cultural field study (Article III, Figure 2, p. 5).

methods for collecting technical data stayed consistent across all contexts. This consistency enabled an initial investigation into how cultural and environmental factors might influence user behaviour and data quality.

3.5 Gamification approaches

The evolution of gamification methods across the three studies demonstrates a systematic exploration of the design space for environmental data collection games. Article I's use of geocaching represented a minimal-intervention approach, as it integrated research data collection into an existing recreational activity without changing the core game experience. Geocaching trails, caches arranged along a route, ranged from 1.8 to 5.7 kilometres and each featured 7 to 11 caches, designed to provide thorough coverage of different forest types while minimising participant fatigue. Cache placement followed established geocaching guidelines, including a minimum distance of 161 metres between caches and terrain difficulty ratings of 1.5 or lower on geocaching's 5-point scale (where 1 is wheelchair accessible and 5 requires specialised equipment). This threshold ensured both physical accessibility and compatibility with the free version of the geocaching application, enabling broad participation. This approach demonstrated that meaningful data collection could be achieved without the need to develop new technologies or make significant modifications to existing recreational activities.

Article II marked a shift from using existing games to designing purpose-built experiences. The AR applications were specifically designed to motivate participants to systematically scan forest structures with their mobile device's LiDAR sensors, generating point cloud data of above-ground vegetation. By integrating this technical data collection into engaging, game-like interactions, the design aimed to capture detailed three-dimensional forest information, including tree positions, lower trunk and branch structure, and understory features, which could be useful for forest inventory and planning.

Four distinct AR designs were created to test different interaction paradigms and their effects on data collection (see Figure 5). The 'Nothing' scenario served as a control condition, displaying only the camera view without gamification features. This baseline helped isolate the effects of gamification from simply viewing forest environments on a mobile device. The 'Spider Vacuuming' scenario introduced clear goals and immediate feedback, with animated spiders appearing on forest surfaces that users needed to vacuum by tapping the screen. This target-driven approach was designed to encourage ground-level scanning and horizontal movement through the forest, collecting data suitable for understory assessment and tree positioning. The 'Spray Painting' scenario offered creative expression, allowing users to paint virtual colours onto forest surfaces. This design prompted participants to focus attention on individual trees and vertical surfaces, resulting in detailed scans of tree trunks and the lower canopy structures while balancing guided activity with user agency. The 'Environment Scanning' scenario visualised point cloud formation in real-time as small pixels appearing on scanned surfaces, making the data collection process transparent. This real-time feedback encouraged participants to identify and fill gaps in their scans, promoting systematic coverage of forest structures suitable for comprehensive structural analysis.

Each design represented different positions along key design dimensions: goal clarity (specific tasks versus open exploration), feedback immediacy (real-time versus post-hoc), user agency (directed versus creative), and data collection transparency (hidden versus visible). The 90-second duration for each scenario was determined through pilot testing to balance data collection needs with participant attention spans and technical constraints. The applications were developed using Unity game engine with AR Foundation framework, which ensured consistent technical performance across different scenarios while allowing for rapid prototyping and modification.

Article III focused on implementing the most promising approaches from Article II within a cross-cultural setting (Figure 7). In addition to the core AR experiences from Article II, a ‘Space Probe Retrieval’ game was introduced, where participants controlled a virtual UFO to collect robotic space probes. This design required precise 3D navigation and spatial awareness, promoting thorough scanning across multiple height layers and encouraging systematic exploration of the forest.

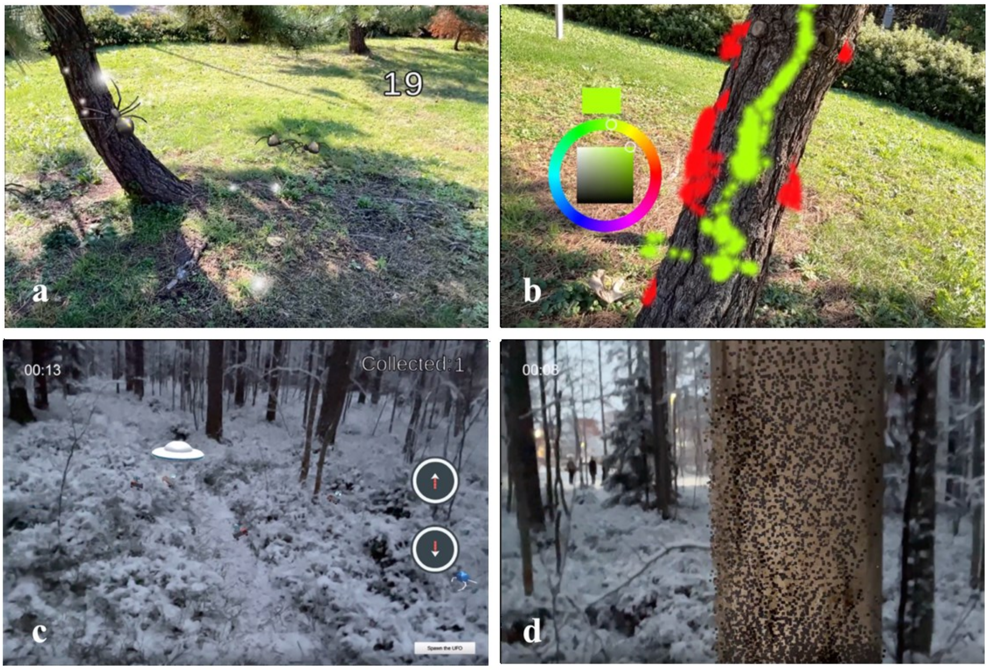

Figure 7. Screen captures of each gamified AR experience include: (a) Spider Vacuuming, where players vacuum spiders as they spawn; (b) Spray Painting, participants could freely paint objects in AR; (c) Space Probe Retrieval, requiring players to hover UFOS over probes; (d) Environmental Scanner, with point clouds visualised in AR.

3.6 Framework and methods of analyses

The analytical approaches used across the three studies combined established methods from multiple disciplines, including forest sciences, human-computer interaction, and cultural studies (Table 1). Quantitative analyses focused on measurable outcomes that could be compared across studies and contexts. Response rates were calculated as the proportion of cache visitors who completed surveys, providing a key metric for engagement effectiveness. Spatial analyses examined how distance from parking, trail characteristics, and cache sequence influenced participation patterns.

For the technical data of Article II, point cloud quality metrics commonly employed in close-range forest sensing were adapted (Gollob et al., 2021; Tatsumi et al., 2023). Key measures included point density (points per square metre), spatial coverage (convex hull area), height distribution (proportion of ground versus non-ground points), and completeness (gap analysis) (Liang et al., 2016). These metrics allowed for an objective comparison of data quality across different gamification designs, revealing that design choices had a significant influence on data characteristics. For statistical comparisons, suitable tests were used based on the data types and research questions, including chi-square tests for categorical comparisons and t-tests for continuous variables.

Table 1. Summary of research design and methods across studies (adapted from Articles I, II, and III).

	Article I	Article II	Article III
Approach	Location-based game integration	Purpose-built AR application testing	Cross-cultural comparison
Gamification method	Existing geocaching platform with embedded surveys	Four custom AR scenarios: Nothing (control), Spider Vacuuming, Spray Painting, Environment Scanning	AR scenarios from Article II + Space Probe Retrieval game
Study sites	4 locations in Finland: • Urban: Lehmo (Joensuu), Hervanta (Tampere) • Rural: Ruunaa (Lieksa), Seitseminen (Ikaalinen, Ylöjärvi),	Convenience-sampled forested and tree-filled urban and peri-urban environments across Finland	Convenience-sampled forested and tree-filled urban environments in Finland and Japan
Data collection period	June 2022 – September 2023	November – December 2023	November – December 2024
Participants	N = 966 (3,021 cache visits)	N = 16	N = 31 (Finland n=16, Japan n=15)
Data type	*Quantitative*: Survey responses, spatial data, temporal patterns. *Qualitative*: Open-ended responses, participant photographs	*Quantitative*: Point cloud data, spatial coverage metrics, point density. *Qualitative*: Think-aloud protocols, interviews, screen recordings	*Quantitative*: Point cloud data, spatial metrics, survey responses. *Qualitative*: Observations, participant feedback
Analysis methods	*Quantitative*: Descriptive statistics (response rates, spatial and temporal patterns); Chi-squared goodness-of-fit tests *Qualitative*: Inductive content analysis, thematic analysis, photo-coding	*Quantitative*: Descriptive statistics, point cloud quality metrics; paired-sample t-tests. *Qualitative*: Thematic analysis, video analysis, behavioural coding	*Quantitative*: Descriptive statistics; paired-sample t-tests, correlation analysis, Fisher's exact test; two-way ANOVA; comparative analysis across locations *Qualitative*: Thematic analysis, cross-cultural comparative analysis

Qualitative analyses followed established procedures to ensure rigour and trustworthiness (Finfgeld-Connett, 2014; Kleres, 2011). The content analysis of open-ended survey responses in Article I used an inductive approach, allowing themes to emerge from the data rather than imposing predetermined categories. The identification of 15 distinct themes related to human-forest relationships demonstrated the richness of data that could be collected through gamified methods (Halla et al., 2023). The analysis process involved initial familiarisation with all responses, systematic coding, theme development, and validation through researcher triangulation, for both open-ended survey responses and the autophotographic data. For the survey responses, conventional content analysis procedures were followed, with coding and theme development conducted in spreadsheets to ensure transparency and traceability of decisions. Similarly, for the autophotographic data, a two-phase photo-coding methodology was conducted in spreadsheets, first cataloguing visible elements, then conducting thematic analysis to identify patterns in what participants chose to photograph.

Article II's analysis of user experience data combined multiple data streams to develop a comprehensive understanding of how participants interacted with different AR designs. Video analysis facilitated the coding of movement patterns, interaction sequences, and moments of confusion or delight. Think-aloud protocols were transcribed, coded, and analysed thematically using ATLAS.ti for Windows (ATLAS.ti 2024), with particular attention to expressions of enjoyment, frustration, or confusion. The integration of behavioural data (what users did) with experiential data (what users felt) revealed important disconnections between optimal data collection behaviours and enjoyable user experiences.

The cross-cultural comparative analysis in Article III required further analytical considerations. Beyond simply comparing outcomes between countries, the analysis aimed to identify universal principles versus culture-specific differences. The analysis assessed whether certain design elements worked universally or exhibited context-specific effects by comparing point cloud metrics, movement patterns, and participant feedback between Finnish and Japanese participants.

4 RESULTS

4.1 Geocaching for forest preference data (Article I)

To address the first research objective, investigating whether location-based games can effectively collect forest preference data for participatory forest planning, geocaching trails were established across four sites in urban and rural forest areas in Finland. The study achieved response rates ranging from 22.9% to 38.6%, collecting 966 valid survey responses from 3,021 cache visits between June 2022 and September 2023 (Table 2).

The spatial distribution of responses revealed clear differences between urban and rural areas. Urban trails saw significantly higher engagement, with the Tampere trail averaging 117.9 visits per cache compared to 42.9 for the rural trail in Eastern Finland, reflecting variations in population density, accessibility and geocaching community activity levels. Participation decreased with distance from access points in urban locations, with participation decreasing by 50% at distances over 2 kilometres from parking facilities or trailheads (Figure 8).

Table 2. Accumulation of cache logs and survey responses across all four trails (adapted from Article I, Table 3, p. 5).

	Area			
	U I	R I	U II	R II
Total number of cache finds across the whole trail	869	343	825	984
Number of caches in trail	11	8	7	11
Average visitors per cache on the trail	79	42.9	117.9	89.5
Finnish survey respondents across the whole trail	268	97	256	208
English survey respondents across the whole trail	67	8	45	17
Combined no. of respondents	335	105	301	225
Average respondents per cache	30.5	13.1	43	20.5
Average response rate, %	**38.6**	**30.6**	**36.5**	**22.9**

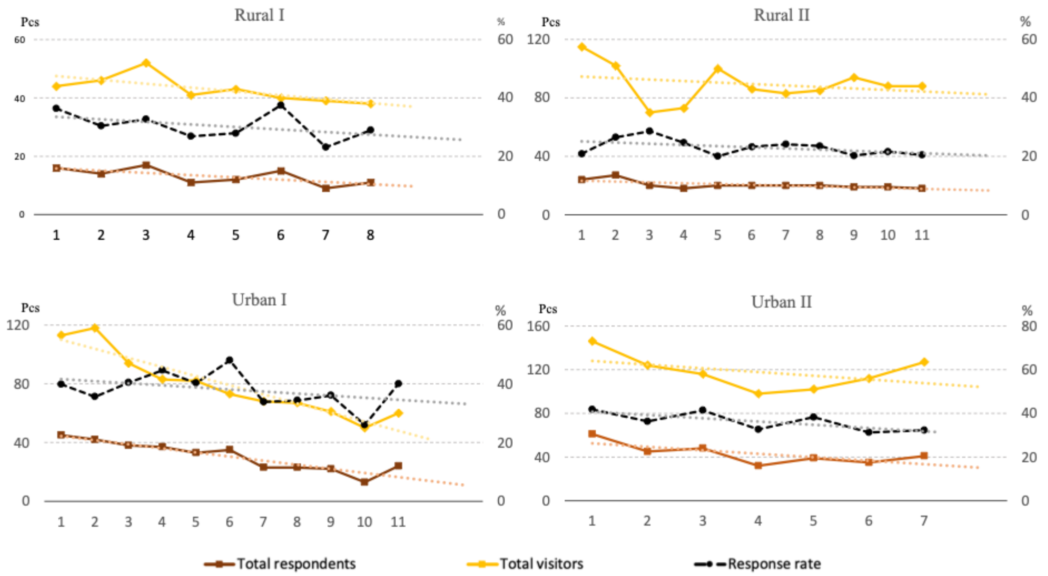

Figure 8. The effect of the distance from the parking place to the geocaches on the cache visits, cache responses and response rate across all four sites (adapted from Article I, Figure 7, p. 8).

Temporal analysis indicated that the first summer following trail establishment was important for data collection, with participation rates decreasing significantly in subsequent seasons. However, this may be specific to Finland, where winters are typically cold and trails are snow-covered. Despite temporal variation, data quality during peak periods was notably high. Participants actively engaged with qualitative questions, achieving an 89% completion rate for open-ended responses. Content analysis of these responses identified 15 distinct themes related to human-forest relationships, including aesthetic appreciation, biodiversity values, forest management concerns, temporal experiences, and wellbeing benefits (Table 3 below and Article I, Table 6, p. 10). This thematic richness suggests that participants were not completing surveys mechanically but were genuinely reflecting on their forest experiences.

Table 3. Qualitative survey response (adapted from Article I, Tables 5, p. 9)

Trail name	No. caches on the trail	No. of caches with qualitative questions	Total survey submissions	No. of responses to qualitative questions	Response rate (%)
Urban Trail 1	11	7	216	213	98.6
Rural Trail 1	8	4	62	58	96.5
Urban Trail 2	7	4	178	141	79.2
Rural Trail 2	11	7	135	116	85.9

Respondents were predominantly highly educated (89% with college or higher) and urban residents (71%). The age distribution showed good coverage across adult age groups, with the 41-50 and 51-60 age groups most strongly represented. However, the gender balance was nearly even, contrasting with some citizen science projects that show gender skew (Article I, Table 4, p. 5).

4.2 Augmented reality applications for environmental scanning (Article II)

To address the second research objective, examining how different gamification design choices influence user experience and data quality, four augmented reality (AR) applications were tested. The study's within-subjects design, where each of the 16 participants experienced all four scenarios in sequence, allowed for a direct comparison of the approaches while controlling for individual differences. The results showed that gamification significantly increased data collection (Figure 9), with the *Spider Vacuuming* scenario producing 350% more points than the control condition (the *Nothing* scenario, where users were asked to scan the forest with their phones as if taking a video), *Spray Painting* yielding 1,240% more, and *Environment Scanning* achieving a remarkable 2,030% increase.

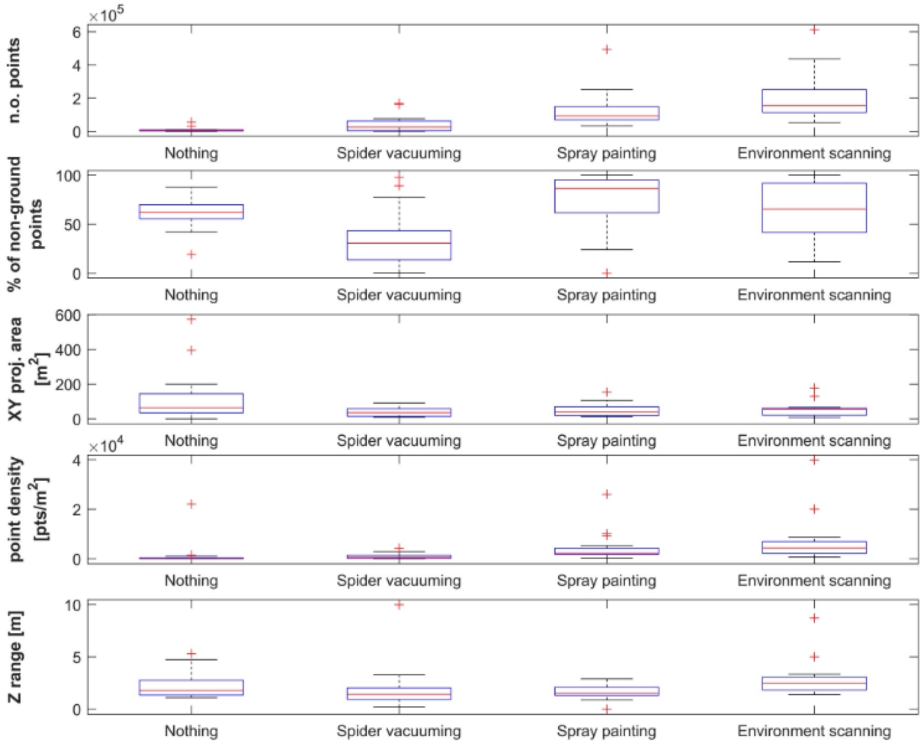

Figure 9. A box plot showing the variation in the point cloud-derived metrics by the applied gamified scenario (adapted from Article II, Figure 6, p. 12). In each box plot, the red vertical line indicates the median, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively. The whiskers extend to the most extreme data points not considered outliers, and the outliers are plotted individually using the “+” marker symbol.

However, quantity alone does not give the full picture. Each design produced distinctly different data characteristics that could serve different forest inventory purposes (Article II, Tables 5 & 6, p. 13). The *Spider Vacuuming* scenario generated data heavily weighted towards ground points (64.8% of total points). This ground-focused scanning pattern resulted from the spiders' movement patterns and users' tendency to follow them along the forest floor. In contrast, the *Spray Painting* and *Environment Scanning* scenarios produced more balanced vertical coverage, with average vertical height ranges (Z-axis) of 2.85 metres above the ground, making them more suitable for capturing tree structures and trunk and lower branch characteristics.

User experience varied greatly across different designs, with no clear link between enjoyment and data quality. *Spider Vacuuming* was the most preferred scenario, with participants valuing its clear objectives and game-like features (Article II, Figure 5, p. 9). However, it also caused the most frustration when the vacuuming mechanism was not immediately intuitive. *Spray Painting* was the most divisive, as some participants enjoyed the creative freedom while others felt uncomfortable with the concept of virtually painting nature. Several participants expressed that painting on trees felt disrespectful, even in a virtual context (Article II, Section 5.1.3, pp. 9 & 10). The *Environment Scanning* scenario, although producing the highest quality data, was described by some as more tool-like than game-like, although others found the real-time visualisation of point cloud formation captivating (Article II, Section 5.1.4, p. 10).

The behavioural analysis showed how different designs affected user movement and scanning patterns. In the control scenario (*Nothing*), participants typically remained stationary and moved the camera across the scenery from a distance. *Spider Vacuuming* prompted the most physical movement, as participants walked towards distant spiders. *Spray Painting* showed the greatest variation in user behaviour, with some participants carefully painting individual trees while others made broad gestural strokes across the landscape. *Environment Scanning* encouraged systematic coverage, as participants identified gaps in their point cloud and aimed to fill them. These behavioural differences directly affected data characteristics, demonstrating the connection between interaction design and data outcomes (Table 4).

Table 4. Suitable interactions for specific goals (adapted from Article II, Table 6, p. 13).

	Low density capture	**High density capture**
Focus on ground	Spider vacuuming	
Focus on above ground	Nothing	Spray painting, environment scanning

4.3 Cross-location comparison of gamified forest data collection (Article III)

To address the third research objective, examining how cultural factors influence gamified forest monitoring effectiveness, workshops were conducted in Finland and Japan. Participants in both contexts collected point clouds in urban forestry settings using gamified AR applications (Article III, Table 3, p. 7). While the applications' core functionalities, including surface detection, point cloud generation, and game interaction elements, operated reliably across both locations, notable differences emerged in participant behaviours, interaction patterns, and data collection outcomes. Statistical analysis revealed that workshop locations had a highly significant effect on all metrics ($p<0.0001$), indicating that contextual factors, including environmental conditions, participant expertise, and potentially cultural differences, substantially mediated implementation outcomes (Figure 10).

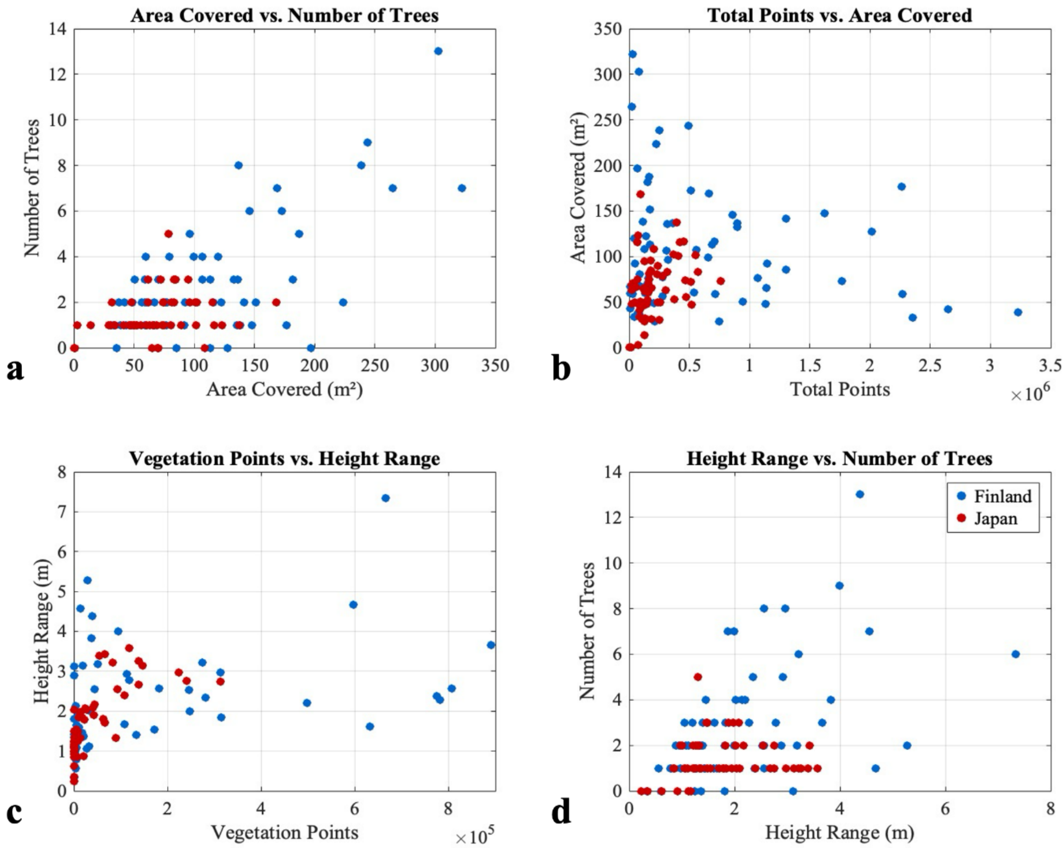

Figure 10. Scatter plots illustrating relationships between key point cloud metrics, with data points coloured by country (blue =Finland, red =Japan) (adapted from Article III, Figure 7, p. 10). (a) Area coverage vs. trees detected ($r = 0.66$, $p < 0.0001$); (b) total points vs. area; (c) height range vs. vegetation points; (d) height range vs. trees detected.

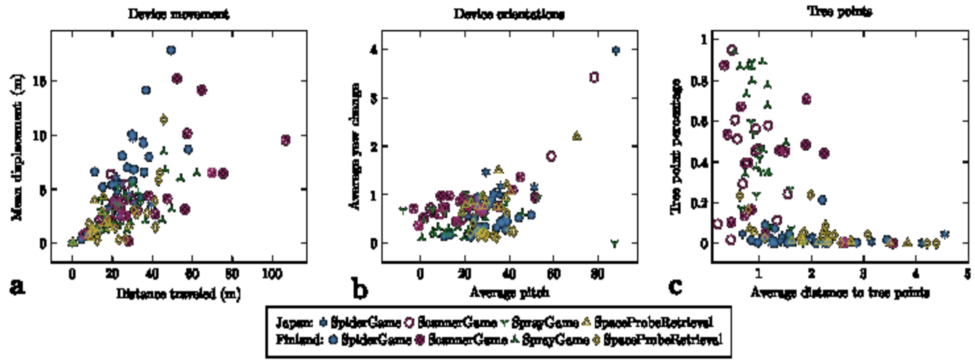

Figure 11. Device location, orientation, and tree capture metrics by scenario and country (adapted from Article III, Figure 8, p. 10)

Behavioural analysis revealed distinct patterns between the two groups (Figure 11). Participants in Finland demonstrated significantly greater physical movement, with higher displacement from starting points and longer distances travelled across all game scenarios. Their scanning approaches varied considerably by game design, with tree-detection rates ranging from 1.25 to 4.38 trees per participant. This variation appeared to reflect their forestry training, as they performed particularly well in scenarios resembling professional tree marking tasks (Scanner and Spray Paint scenarios). Participants in Japan exhibited more consistent performance across game scenarios (1.40-1.53 trees detected), with higher device rotation rates and more uniform scanning patterns. These differences likely stemmed from the interaction of multiple factors: the significant disparity in LiDAR experience between groups ($p = 0.03$), differing educational backgrounds (forestry sciences versus information systems and design), environmental conditions (snow-covered winter versus autumn), and potentially broader cultural differences in spatial exploration strategies and human-technology interaction patterns.

Quantitative analysis of point cloud metrics revealed significant location effects (Table 5). The *Scanner Game* in Finland produced a substantially larger area coverage (151.78 m^2) compared to Japan (52.69 m^2), despite having similar total point counts (247,415 vs 242,033 points). The percentage of vegetation points varied widely depending on both location and game design, with the Finland *Spray Paint* scenario reaching 66.64% vegetation points, whereas in Japan it reached only 34.32%. Statistical tests confirmed that the workshop location had a highly significant impact on all metrics ($p<0.0001$). The strongest correlation was observed between area coverage and tree detection ($r=0.66$, $p<0.0001$), suggesting that games promoting broader spatial exploration lead to better tree identification (Article III, Section 4.2.4, p. 10).

Table 5. Mean values for point cloud and movement metrics by country and game scenario (adapted from Article III, Table 3, p 7).

Sample	N	Tot. Pts	Veg%	Area	Hght	Trees	Dist.	Disp	Pitch	Δ yaw	Tree Dist.
Finland Scanner	16	247,415	38.06	151.78	2.97	4.38	51.82	6.04	18.16	0.75	1.47
Finland Space	16	646,387	6.28	67.95	1.41	1.25	29.19	3.01	30.41	0.24	2.27
Finland Spider	16	846,363	3.18	114.83	1.21	1.38	28.46	7.55	30.79	0.35	1.66
Finland Spray	16	785,019	66.64	106.75	2.83	3.88	34.29	3.75	15.93	0.33	0.9
Japan Scanner	15	242,033	39.9	52.69	2.31	1.53	20.1	3.16	23.78	0.94	0.76
Japan Space	15	115,490	1.91	53.92	1.23	0.8	13.12	1.73	33.39	1	2.03
Japan Spider	15	288,349	1.64	99.5	1.19	1.6	24.81	5.13	33.62	1.09	1.94
Japan Spray	14	204,372	34.32	59.21	2.07	1.5	20.26	3.16	25.91	0.72	1.07

N = sample size; Tot. Pts = total point cloud points collected; Veg % = percentage of points classified as vegetation; Area = spatial coverage (m^2); Height = vertical range covered (m); Trees = number of trees detected; Dist. = total distance travelled (m); Disp. = net displacement from starting position (m); Pitch = average device pitch angle (°); ΔYaw = average change in device yaw rotation (°); Tree Dist. = average distance to tree points (m).

5 DISCUSSION

5.1 Effectiveness of gamification for forest data collection (RQs 1-3)

Addressing RQ1 (investigating whether location-based games can effectively collect preference data) and RQ2 (examining how gamification strategies affect data quality), the collective findings from the three studies provide strong evidence for the effectiveness of gamification as a tool for forest data collection, while also highlighting important nuances in how effectiveness should be conceptualised and measured. In this thesis, effectiveness is operationalised through three dimensions: (1) participant engagement, which includes voluntary participation and ongoing contribution; (2) data quality, ensuring relevant characteristics and adequate spatial coverage for forest planning needs; (3) cross-context applicability, meaning the method reliably functions across diverse cultural and environmental settings. The progression from leveraging existing games to developing purpose-built applications demonstrates that the effectiveness of gamification operates across multiple dimensions that need to be balanced according to specific forest planning objectives, whether prioritising broad public engagement or technical precision.

Conventional public consultation methods can struggle with low participation and limited representativeness, often failing to attract a broad cross-section of the public while requiring substantial resources for venue hire, facilitation, and outreach (Primmer & Kyllönen, 2006; Sipilä & Tyrväinen, 2005). In contrast, the response rates achieved through geocaching (22.9%-38.6%) indicate a shift in the potential for public engagement in forest planning. Importantly, the voluntary nature of game-based participation overcomes a critical limitation whereby obligatory consultation tends to yield perfunctory responses (A. Kangas et al., 2015). These findings demonstrate that data quality improves when participants actively choose to engage rather than feel obligated to provide input. The 89% completion rate for open-ended questions and the identification of 15 distinct themes about human-forest relationships (Article I, Tables 5 & 6, pp. 9 & 10), substantially exceeds typical qualitative response rates in forest planning surveys, as optional text fields present a greater cognitive burden on respondents and often have higher item non-response (Dillman et al., 2014). This level of engagement challenges the notion that gamification inherently trivialises serious issues, suggesting that well-designed gamified public participation can enhance rather than diminish respondents' reflection on environmental values (Hamari et al., 2014). However, reliance on gamified methods may exclude participants lacking digital access or comfort with game-like interactions, suggesting the need for hybrid approaches that combine accessible gamification with traditional participation modalities to ensure representative engagement (Bowser et al., 2014).

The significant increases in data collection observed in Article II, ranging from 350% to 2,030% relative to the control condition, demonstrate gamification's ability to motivate detailed environmental laser-scanning behaviour. These findings contribute to emerging questions about how 3D data collection technologies can be applied in forestry contexts (Murtiyoso et al., 2024). These increases cannot be attributed solely to novelty effects, as all participants experienced the same innovative technology across conditions. Instead, the game elements themselves - whether clear goals (*Spider Vacuuming*), creative expression (*Spray Painting*), or progress visualisation (*Environment Scanning*) - fundamentally changed how participants approached the data collection task. This finding has important implications for forest inventory and monitoring, suggesting that gamification can mitigate the labour intensity of forest data collection while simultaneously improving worker well-being (Ryan & Deci, 2000b). By reframing repetitive scanning activities as playful challenges or opportunities for self-expression, gamified systems may promote intrinsic motivation, engagement, and a deeper sense of purpose in fieldwork (Sailer et al., 2017). In forestry contexts, research has shown that forest workers value the independence of their work and that meaningful work characteristics contribute to well-being in isolated forest work (Kymäläinen et al., 2021). Furthermore, research on forest planners has found that meaning significantly drives work satisfaction (Hokajärvi et al., 2009), supporting eudaimonic views of well-being, where purposeful activities foster human flourishing (Ryan & Deci, 2001). Therefore, gamified approaches to forest data collection that emphasise the purpose and impact of participants' contributions could enhance both engagement and motivation.

However, effectiveness cannot be measured solely through participation rates or the quantity of data collected. The quality and characteristics of the data can vary significantly depending on design choices, as demonstrated by the distinct point cloud features generated by the different AR scenarios. This variation presents both opportunities and challenges. The opportunity lies in the potential to develop specific gamification approaches optimised for forest mensuration data requirements. For example, ground vegetation assessment and tree positioning can be more effectively achieved through mechanics like those in the spider vacuuming game, which generated 64.8% ground points (Article II, Table 5, p. 13). Conversely, trunk and lower branch assessment could benefit from AR experiences like the spray painting or scanning games, which encourage vertical scanning behaviours, producing average height ranges of 2.85 meters (Article II, Table 5, p. 13). The challenge is that no single design can optimise all desired outcomes at once, and different approaches might need to be combined to produce more detailed scans.

The cross-cultural validation in Article III enhances understanding of gamification's effectiveness. The successful collection of forest inventory data in different cultural contexts demonstrates that gamification's effectiveness is not tied to a specific location; however, adapting it to the local geographic setting is likely important for optimal data collection. This is particularly relevant for international forest monitoring projects and global environmental agreements that require consistent data collection from diverse regions. The core gamification mechanics of goal setting, feedback, and progress tracking appear to transcend cultural differences, even though their specific application requires localisation.

These findings align with the Technology-Mediated Environmental Engagement pillar of the conceptual framework, as they demonstrate how game mechanics can be successfully applied to bridge the gap between technical data requirements and voluntary public participation in forest planning processes.

5.2 Data quality across different approaches (RQs 1-2)

Addressing RQ1 (investigating whether location-based games can effectively collect preference data) and RQ2 (how gamification design affects data quality), the relationship between gamification design and data quality emerges as a central finding with important implications for real-world applications. Data quality in this context encompasses several key aspects: completeness, accuracy, spatial distribution, consistency, and suitability for purpose. The studies show that these aspects cannot all be optimised at once with a single gamification approach, requiring careful prioritisation in design choices.

Article I demonstrated that even simple integration of surveys into existing games can produce high-quality subjective data. The 89% completion rate for qualitative questions significantly exceeds typical response rates for open-ended questions in traditional surveys (Miller & Lambert, 2014). The thematic richness of responses, encompassing aesthetic, emotional, ecological, and management-related themes, indicates that the geocaching context did not limit the depth of engagement with forest preference questions. However, the study also identified quality assurance challenges, with approximately 25% of responses likely having been completed off-site, as determined by temporal analysis. This finding underscores the importance of designing validation mechanisms into gamified data collection systems.

The technical data quality analysis in Article II offers quantitative evidence for the impact of gamification design on data characteristics. The Spider Vacuuming scenario's focus on ground points (64.8%) makes it ideal for understory vegetation assessment, but less suitable for analysing trunk and vertical structure. In contrast, the Environment Scanning scenario's high point density (7,279 points per square metre) and vertical coverage make it optimal for detailed structural analysis. However, it may be overly data-intensive for quick forest assessments. The Spray Painting scenario sits in the middle, producing moderate density with balanced coverage, indicating its appropriateness for general forest inventory.

These quality variations reflect deeper principles regarding how gamification mechanics affect user behaviour and, in turn, data characteristics. Goal-oriented designs (such as *Spider Vacuuming*) produce targeted but potentially limited data-collection patterns. Creative designs (*Spray Painting*) generate variable results depending on individual user choices. Feedback-oriented designs (*Environment Scanning*) promote completeness but may reduce efficiency. Understanding these relationships enables informed design decisions based on specific data needs rather than aiming for an elusive universal optimum.

Article III's cross-cultural comparison adds the important finding that data quality can remain consistent across different cultural settings even when user experience varies. The technical quality of point clouds produced in Finland and Japan showed no notable differences, suggesting that cultural factors influence how users perceive and approach the task more than their ability to generate quality data. This distinction between experience and output quality has significant implications for global deployment, indicating that cultural adaptation of interfaces and instructions may be more important than technical training.

In practice, this suggests the need for differentiated deployment strategies. In countries such as Finland, where historically strong forest access rights prevail, designs supporting autonomous exploration should be prioritised, whereas in countries such as Japan, where collective stewardship traditions frame human-forest interactions, structured guidance and collaborative progress tracking would be more appropriate. This ensures that technical infrastructure (LiDAR sensors, point cloud processing, quality validation) remains standardised globally, with localisation focused on interface design, instructional framing, feedback mechanisms and participation contexts.

The complex relationship between gamification design and data quality underscores that effective participatory forest planning requires balancing technical accuracy with accessible engagement without sacrificing either. This aligns with the Participatory Forest Planning pillar of the conceptual framework.

5.3 Cultural considerations (RQ3)

Addressing the RQ3 (how cultural factors influence gamification effectiveness), Article III operationalises the *Cultural Adaptation* pillar of the conceptual framework of this research by comparing gamified forest data collection across Finnish and Japanese contexts. While both groups achieved similar forest scanning outcomes, their distinct interaction styles illustrate how gamification mechanics intersect with culturally specific human-forest relationships, values, and technological practices.

Participants in Finland exhibited more exploratory and physically active scanning patterns, likely reflecting not only their technical expertise ($p = 0.03$ for the difference in LiDAR experience) but also a cultural orientation towards autonomy in forest use, consistent with the "jokaisenoikeus" (everyone's rights) tradition of independent access to nature. In contrast, participants in Japan, with their more methodical and instruction-oriented behaviour, may align with collective, community-centred approaches to environmental management embedded in Japanese socio-ecological stewardship traditions such as "satoyama" and “jibatsu” (Berglund et al., 2014; Indrawan et al., 2014). These behavioural differences suggest possible contrasting cultural models of human-nature interaction, as anticipated by the *Cultural Adaptation* pillar, though the limited sample size and single-site design in each country warrant cautious interpretation of cultural effects.

Environmental conditions (winter in Finland versus autumn in Japan) and site differences influenced scanning performance, yet cultural norms around technology engagement and environmental participation appear to have guided how participants interpreted and enacted gamified tasks. This finding supports the framework’s proposition that effective gamified design requires alignment with local forest values, technology-use norms, and participation expectations (Mustalahti, 2009; Sarkki et al., 2019).

The strong effect of workshop location on all point cloud metrics ($p < 0.0001$) supports this interpretation. Although some variation can be linked to environmental and technical factors, such as snow-covered terrain in Finland and autumn foliage in Japan, the result also reflects the cultural–ecological contexts that influence how participants engaged with the gamified task. As detailed in the *Cultural Adaptation* pillar section of the conceptual framework, technological involvement is rooted in local forest-use values, experiential familiarity, and participation norms. Therefore, “location” in this study represents more than just a physical space; it captures the interaction between environment, culture, and practice that shapes how gamification motivates behaviour. This view is consistent with broader evidence that participation and motivation in environmental technology are influenced by cultural patterns (Markus & Kitayama, 1991)

Consequently, while gamification mechanisms may be universally recognisable, their motivational effects depend on cultural alignment. In Finnish contexts, elements rewarding autonomy and exploration may resonate more strongly, whereas in Japan, collaborative progress indicators and shared achievement may foster engagement. These insights advance the *Cultural Adaptation* pillar by empirically demonstrating that gamification’s success in forest monitoring relies on locally tailored, culturally embedded design, rather than on one-size-fits-all technological solutions.

5.4 Framework for implementation (RQs 1-3)

The synthesis of findings across all three studies allows the development of a comprehensive implementation framework for gamified forest data collection. This framework, building on the three conceptual pillars presented in section 2, *Technology-Mediated Environmental Engagement, Participatory Forest Planning, and Cultural Adaptation*, addresses the practical challenge of translating theoretical gamification principles into operational forest planning tools. The framework recognises that successful implementation requires balancing multiple objectives that may sometimes conflict, necessitating context-specific design decisions rather than universal solutions.

The framework identifies three key design dimensions that practitioners must consider, each reflecting aspects of the *Technology-Mediated Environmental Engagement* pillar. First, the engagement spectrum ranges from leveraging knowledge gained from existing platforms (as in Article I) to aid the development of purpose-built applications (Studies II & III). Existing platforms offer immediate access to established user communities and proven engagement mechanics but may have limits on customisation for specific data needs. Purpose-built applications provide complete control over data collection protocols but require significant development investment and user recruitment efforts. Second, the gamification intensity dimension spans from light game elements (simple points and badges) to full game experiences with narratives, avatars, and virtual worlds.

Third, the data optimisation focus varies from quantity-focused designs that maximise participation and data volume to quality-focused approaches that prioritise data precision and completeness. Article I exemplified a participation-optimised approach, achieving high response rates with relatively simple data requirements, demonstrating the Participatory Forest Planning pillar's emphasis on inclusive engagement. Article II's Environment Scanning scenario represented quality optimisation, generating detailed point clouds suitable for technical forest inventory. Article III demonstrated that both approaches can function across cultural contexts, though their effectiveness depends on local adaptation, validating the *Cultural Adaptation* pillar.

The framework provides selection criteria to guide design choices based on project objectives. For public consultation and preference mapping, where the *Technology-Mediated Environmental Engagement* and *Participatory Forest Planning* pillars intersect, low-intensity gamification using existing platforms may be most appropriate. For technical forest inventory requiring precise measurements, high-intensity purpose-built applications are justified, though they require careful *Cultural Adaptation* when deployed across different contexts. Mixed approaches combining multiple gamification strategies may be optimal for comprehensive forest planning initiatives.

5.4.1 Key Design Principles

The collective findings yield several critical principles for effective implementation:

Spatial Accessibility: In Article I, accessibility emerged as the main factor affecting participation, with urban locations showing higher engagement rates and participation decreasing by 50% at distances over 2 kilometres from parking facilities. While Studies II and III were conducted in urban forest settings near university campuses, Article I's comparison of urban and rural sites demonstrated clear accessibility effects. Instead of viewing this as a limitation, strategic deployment can exploit high accessibility in urban forests for extensive data collection, while tailoring approaches for rural areas based on the findings of Article I.

Progressive Engagement: The finding that most geocaching data collection occurred during the first summer suggests that episodic rather than continuous monitoring might be more effective. This has implications for planning seasonal campaigns aligned with specific forest planning phases, but this may be location-specific. Consideration must also be paid to building and maintaining participant communities. Examples of how to do this can be gathered from existing successful location-based game communities where novelty and unique experiences are used to foster engagement (Article I). Community building through gamified activities should recognise the human tendency toward novelty-seeking, designing for periodic refreshment of game elements rather than assuming sustained long-term engagement with unchanging mechanics.

Cultural Adaptation Requirements: Successful cross-cultural deployment involves more than just translation; it requires co-creation with local communities to adapt interaction mechanics and guidance systems to the local context and values. Cultural sensitivity in forestry contexts is particularly important, as forest use traditions vary significantly, and gamification design for forest planning purposes requires that these differences are acknowledged (Article III). These cultural indicators should be thoughtfully incorporated, acknowledging that forestry practices themselves inherently carry cultural significance that influences how users perceive and interact with any gamified systems that may be implemented in their value chain. Additionally, future implementations must ensure participants provide informed consent specifically for technical data collection (such as point cloud capture) and clearly communicate how collected data will be used.

5.4.2 Integration with Forest Planning Processes

Contemporary forest planning increasingly functions as a design process that integrates multiple objectives beyond timber production optimisation. This trend is especially clear in Nordic countries such as Finland and, notably, in the United Kingdom, where forest planning explicitly results in detailed 'forest design plans’ (Bell, 2013). This design-oriented approach recognises that forest planning requires both quantitative analysis and adaptive problem-solving to balance multiple objectives while remaining responsive to diverse stakeholder perspectives (Baskent et al., 2024). Gamified data collection naturally complements this design framework by providing continuous streams of technical measurements and stakeholder-preference data, thereby enabling planners to iteratively refine management options. The geocaching method (Article I) facilitates the collection of social preference data during a forest design process, while AR-based gamified scanning (Articles II and III) provides the technical data necessary to visualise and evaluate different design options. However, effective integration requires that gamified data collection be embedded into existing forest design planning workflows rather than being treated as isolated exercises.

Forest planning operates across various temporal and spatial scales, each with distinct data requirements and varying stakeholder involvement. For the purposes of this discussion, the integration opportunities are structured according to the hierarchical model of forest planning (strategic: 5–20-year cycles, though longer timelines are also common; tactical: 1–5-year cycles; and operational: immediate implementation), commonly used in Nordic forestry contexts (Weintraub & Cholaky, 1991; Ulvdal et al., 2023). The findings of this research suggest multiple areas where gamified methods could enhance current planning processes, provided that careful alignment with specific contexts and goals is achieved for successful implementation.

Strategic Planning (5–20-year cycles) presents opportunities for broad stakeholder engagement and long-term monitoring. Geocaching-style preference collection could complement traditional public consultation processes, particularly for understanding recreational values and landscape preferences (Article I). Location-based games could provide continuous monitoring of forest condition changes, wildlife observations, and emerging recreational patterns. Community-based environmental monitoring games could track long-term ecological indicators while building local environmental knowledge and stewardship capacity (Danielsen et al., 2022).

Tactical Planning (1–5-year cycles) requires more detailed technical data and applications that bridge professional and stakeholder needs. AR-based technical scanning could augment professional forest inventories, particularly in accessible areas or for specific assessment needs (Article II). Incorporating citizen-collected point clouds into operational forest planning will require creating data processing workflows, quality assessment protocols, and integration strategies with professional inventory systems. Gamified professional tools could improve routine data-collection tasks for forest managers, making repetitive measurements more engaging while improving data quality (Warmelink et al., 2020). Collaborative planning games could assist in facilitating scenario evaluation with stakeholders, allowing communities to visualise and respond to proposed management alternatives (Bengston et al., 2022). Future research in this area could extend gamification beyond data collection to interactive scenario simulation, allowing stakeholders to explore trade-offs between forest management objectives through immersive decision-support tools.

Operational Planning (immediate implementation) involves real-time decision-making and opportunities for adaptive management. Mobile applications could enable forest workers to contribute observational data during routine operations, gamifying safety reporting, equipment monitoring, or documenting unexpected events. Real-time community feedback systems could allow rapid responses to management concerns or emerging recreational conflicts. Adaptive monitoring games could track implementation effectiveness by engaging local users in documenting changes following management interventions, creating feedback loops that inform subsequent management decisions.

Cross-cutting applications cover multiple planning stages and scales. Educational gaming tools can promote forest literacy among diverse user groups, leading to more informed participants in planning processes (Kangas et al., 2015; Lalicic & Weber-Sabil, 2022). Professional development games can enhance technical skills and decision-making capabilities among forest managers and workers (de Vries et al., 2025). Gamified cross-cultural exchange platforms could, in theory, facilitate knowledge sharing among forest management communities worldwide, though implementation would require substantial infrastructure and coordination.

Sector-specific applications require tailored approaches. Urban forestry provides opportunities for close community engagement, thanks to its high accessibility and diverse stakeholder interests. Rural and remote forest management might emphasise seasonal engagement strategies and hybrid digital and traditional methods. Gamified approaches could also operate across the urban-rural continuum, adapting engagement intensity and data focus to population density gradients. Protected area management presents opportunities for visitor engagement for monitoring and education while managing recreational impacts, though implementation must carefully balance engagement goals with conservation priorities and visitor management constraints. Integration with bioeconomy value chains could connect citizens to forest product flows, from sustainable harvesting to wood product traceability, thereby furthering awareness and understanding of circular forest economic systems.

The key insight from this research is not that gamification offers universal solutions, but that it presents a flexible design approach that can be adapted to specific planning needs, stakeholder capabilities, and cultural contexts. Successful implementation requires a systematic assessment of local conditions, collaborative design processes with relevant communities, and integration with existing planning institutions and practices.

5.5 From citizen science to citizen play

The findings support a transition of environmental citizen science, focused on scientific data collection, to crowdsourced citizen play, where playful interaction with forests becomes not merely a form of recreation but a legitimate mode of environmental knowledge production, yielding both social preference data (Article I) and technical forest inventory data (Articles II & III).

This perspective aligns with ongoing discussions about playful participation and gamified citizen science (Prestopnik & Crowston, 2012; Laato et al., 2022). Conventional citizen science approaches often assume that participants are mainly motivated by a desire to contribute to science and environmental stewardship (Rotman et al., 2012). However, this research demonstrates that recreational motivations can be equally effective in producing high-quality crowdsourced data for forest management. The high response rates in the geocaching study, achieved through purely recreational framing, suggest that "stealth" data collection may be more inclusive than methods that require explicit scientific engagement.

This transition from citizen science to "citizen play" has important implications for environmental engagement strategies. Instead of urging citizens to become amateur scientists, gamified methods utilise existing recreational motivations to achieve scientific objectives. The rich qualitative responses from geocaching participants show that playful engagement can encourage deep environmental reflection, even without formal environmental education.

The AR studies further demonstrate this principle by illustrating how game mechanics can be designed to prioritise crowdsourcing for specific data-collection needs while keeping the experience engaging. Participants focused on gameplay rather than data collection, yet produced technically advanced point clouds suitable for forest inventory purposes. This separation of user experience from data collection goals allows for broader participation while maintaining scientific value.

However, this approach raises important questions about the nature of environmental citizenship and scientific participation (Hadjichambis et al., 2024; Haklay, 2013). Does recreational data contribution constitute meaningful environmental engagement, or does it represent an extractive relationship where scientific value is obtained from unwitting participants? The research indicates that the answer largely depends on transparency, community benefit, and how playful engagement leads to a deeper understanding and stewardship of the environment.

The concept of citizen play also underlines the potential for gamification to benefit various stakeholder groups involved in forest planning processes. While recreational users may be motivated by playful challenges, forest professionals could gain from gamified tools that make routine data collection more engaging and efficient (Ahmed et al., 2025). The key is designing motivational systems that align with, rather than oppose, users' existing connections to forest environments (Altarriba Bertran et al., 2025).

5.6 The paradox of purpose and play

A central tension arises from this research between the deliberate aims of forest planning and the intrinsically motivated nature of play. This paradox has important implications for the design and implementation of gamified environmental technologies.

Play, by definition, is characterised by voluntary participation, intrinsic motivation, and freedom from external objectives (Tekinbas & Zimmerman, 2003). However, this research intentionally uses playful engagement to gather specific data. The difficulty is in preserving the core features of play while also pursuing instrumental aims that participants might not share or even be aware of.

The geocaching study clearly demonstrates this tension. Participants voluntarily took part in recreational activities, yet their responses provided valuable data for forest planning professionals. The high quality of responses shows that meaningful participation occurred; however, questions remain about whether participants understood their data could potentially contribute to future forest management decisions that could influence their future recreational experiences.

The AR studies reveal similar complexities. While participants enjoyed the playful interactions, the underlying aim was to evaluate the effectiveness of data collection. The gap between user preference (Spider Vacuuming) and data quality (Environment Scanning) highlights the potential conflict between optimising for engagement and scientific objectives.

This paradox indicates that successful gamified environmental technologies must be carefully designed with ethical considerations in mind. Transparency about data collection and usage becomes crucial. However, excessive emphasis on data collection may undermine the intrinsic motivation that makes play effective. The solution lies in creating systems where recreational enjoyment and scientific objectives naturally align rather than conflict. To achieve this, a co-design framework offers a promising approach, allowing user communities to help define both game mechanics and data governance practices. This can include clear disclosure of data use at game entry points (Del-Real et al., 2025), community benefit-sharing agreements (Masso et al., 2025), and user participation in shaping data application protocols (Cooper et al., 2023). By embedding transparency into the process from the start and sharing the benefits equitably, such frameworks can align user motivation with research goals.

The research also reveals that different cultural contexts might resolve this paradox in different ways. Differences in technical expertise (Finnish participants had a stronger forestry background), educational contexts (forestry vs information systems and design sciences students), and possibly cultural factors all contributed to varied engagement patterns between the groups. These differences suggest that the balance between purpose and play should be tailored to specific cultural contexts and user groups.

Ultimately, the paradox underscores the necessity for ongoing dialogue between recreational users and forest planning professionals regarding the role of play in environmental management. Rather than treating this tension as a problem to be fixed, it may be more useful to view it as an ongoing negotiation among different ways of valuing and engaging with forest environments.

5.7 Limitations

This research examined only a small portion of the possibilities for gamified forest data collection. However, it also identified several important limitations, highlighting key areas for future investigation.

From a technical and methodological perspective, the workshop format in Studies II and III offered limited time for interface familiarisation, and the fixed scenario order may have introduced learning effects that influenced subsequent scenarios. The geocaching study's temporal analysis revealed that about 25% of responses were probably completed off-site, highlighting the need for more robust validation mechanisms in location-based data collection.

Sampling and generalisability present further constraints. The small, specialised participant groups in Studies II and III (N = 16 and N = 31) from university settings limit broader generalisability. The high educational levels across all studies (89% college-educated in Article I) suggest that these approaches may mainly engage already motivated populations. The cultural comparison was limited to two technologically advanced countries with well-established gaming cultures.

Regarding integration and implementation, a significant limitation is the lack of integration testing with real forest planning processes. While this research demonstrates data-collection capabilities, questions remain about how citizen-generated data aligns with professional forest inventories, how planners interpret and use such data, and what institutional changes are needed for effective implementation. The study focused on data collection rather than its integration into decision-making.

Finally, the scope of this research did not extend to assessing whether gamified environmental engagement leads to changes in environmental attitudes, behaviours, or stewardship practices.

These limitations, while significant, also reveal important opportunities for advancing this field of research.

5.8 Future research directions

Future efforts should explore real-time location verification and establish protocols to ensure in-situ data quality without compromising the user experience. Research should investigate more robust validation mechanisms in location-based data collection.

Expanding the demographic scope is essential. Future research should include a broader range of participants with different levels of technology literacy, environmental experience, and educational backgrounds to better understand barriers to wider adoption. Also, as the cultural comparison was limited to two countries, future research in this area should extend to encompass diverse global contexts, especially communities with different patterns of technology access, indigenous knowledge systems, and forest-use traditions.

Integration with real forest planning processes remains unexplored. Future research should investigate real-world deployment within existing planning frameworks. Research into how gamified data affects actual forest management decisions, stakeholder reactions to citizen-generated information, and long-term planning outcomes is essential for understanding its practical value.

The novelty-driven engagement patterns identified in Article I require examination through longitudinal studies that investigate how gamified environmental involvement develops over time. Key questions include whether initial recreational motivation leads to lasting environmental stewardship, how to sustain engagement beyond the novelty period, and what adaptive strategies can foster deeper environmental connections while maintaining the benefits of data collection. Understanding societal impacts requires longitudinal studies that track participants' relationships with forests over time. Such research would offer essential insights into wider societal impacts beyond data collection.

Equity considerations warrant particular attention. Future research should also examine the equity implications of technology-dependent environmental participation and consider alternative approaches for communities with limited device access, poor telecommunications infrastructure, or unreliable power sources. For forest communities with these digital access limitations, conventional or culturally traditional methods may be more practical and legitimate. Future research should therefore explore hybrid models that are technologically inclusive and culturally sensitive, ensuring access to environmental decision-making processes.

Scaling presents further challenges. Future research should investigate coordination across multiple forest management jurisdictions, balancing standardisation with local adaptation needs, and building institutional capacity to incorporate citizen-generated data into formal planning processes. The legal, regulatory, and certification implications of citizen-generated forest data also warrant exploration.

These future research directions suggest a comprehensive research agenda that could advance the understanding of technology-mediated environmental engagement and democratic forest governance.

6 CONCLUSIONS

This dissertation investigated the application of gamification approaches for collecting forest data in support of participatory forest planning processes. In contemporary practice, forest planning increasingly functions as a design process integrating multiple objectives and stakeholder values, particularly evident where planning results in comprehensive 'forest design plans'. Through three successive studies, this research demonstrates that game-based approaches can effectively collect both stakeholder preferences and forest inventory information necessary for contemporary forest design processes (addressing RQ1-3). The conceptual framework developed in this research, combining *Technology-Mediated Environmental Engagement*, *Participatory Forest Planning*, and *Cultural Adaptation*, provides a strong foundation for understanding how gamification can connect technical forest planning data collection needs with stakeholder participation across diverse contexts.

First, this thesis established that existing location-based gaming infrastructure, specifically geocaching, can be utilised to collect meaningful social data revealing diverse landscape preferences and human-forest relationships. However, the first study also identified important spatial accessibility constraints and a decline in engagement beyond an initial novelty period. Second, the thesis built upon these findings by demonstrating that gamification design choices fundamentally influence data collection behaviours, quantity and characteristics. Different play experiences produced distinct point clouds suitable for different forest inventory purposes, with ground-focused designs supporting understory assessment, while balanced vertical coverage designs proved suitable for structural analysis. Third, this thesis extended this work cross-culturally, confirming the technical transferability of gamified AR applications across Finnish and Japanese contexts, though significant location effects indicated that cultural adaptation of interfaces and guidance systems, rather than simple translation, is essential for optimal implementation.

The research reveals fundamental tensions inherent in applying gamification to forest planning. The paradox between purpose and play, where recreational engagement is instrumentalised for scientific data collection, requires careful ethical consideration regarding transparency and participant understanding of how their contributions influence forest management decisions. Successful implementation requires balancing multiple dimensions (participation rates, data quality, spatial coverage, user experience, and cultural appropriateness) according to specific planning contexts rather than seeking universal solutions. The three-pillar framework presented in this research identifies integration opportunities across strategic, tactical, and operational planning timescales. These findings validate the framework's core principles while revealing that successful implementation requires integration of all three pillars rather than isolated consideration of individual dimensions. Implementation, however, remains contingent on institutional capacity to incorporate citizen-generated data into formal planning processes.

Future research should address critical gaps through long-term studies examining whether initial recreational participation leads to sustained environmental stewardship, real-world integration testing within operational forest planning workflows to assess how practitioners interpret and use citizen-generated data, broader sampling beyond the demographically homogeneous participant groups in this research to include communities with limited technological access to understand equity implications, and assessment of whether gamified engagement produces measurable changes in environmental attitudes and behaviours. While this dissertation demonstrates the technical feasibility and potential effectiveness of gamified approaches for forest data collection, the transition from proof-of-concept to operational implementation requires a systematic assessment of institutional readiness, the development of protocols for data validation and integration, and the establishment of ethical frameworks that ensure transparency and equitable participation. As forest planning continues evolving from hierarchical, expert-led processes toward more inclusive forest design approaches that balance technical precision with social license to operate, gamification emerges as a flexible methodological approach that, when thoughtfully designed and culturally adapted, can meaningfully contribute to participatory forest management while maintaining scientific rigour.

REFERENCES

Afsar B, Silvennoinen J, Eyvindson K, Miettinen K, Ovaskainen O (2026) Identifying key components for multiobjective forest management decisions: A case study of state-owned Finnish forests. For Policy Econ 182, article id 103681. https://doi.org/10.1016/j.forpol.2025.103681

Ahmed E, Chambers P, Nummenmaa T, Selkimäki M, Hujala T, Hamari J, Buruk O 'Oz' (2025) Forest-Robot-Stormin': Exploring Play for Eliciting More-than-Human (MtH) Forest-Robot Interactions. Companion Proceedings of the Annual Symposium on Computer-Human Interaction in Play. Association for Computing Machinery, pp 73–79. https://doi.org/10.1145/3744736.3749334

Altarriba Bertran F, Buruk O 'Oz', Márquez Puig J, Hamari J (2025) How Can Interactive Technology Help Us to Experience Joy With(in) the Forest? Towards a Taxonomy of Tech for Joyful Human-Forest Interactions. Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, pp 1–21. https://doi.org/10.1145/3706598.3713151

Althoff T, White RW, Horvitz E (2016) Influence of Pokémon Go on Physical Activity: Study and Implications. J Med Internet Res 18(12), article id e315. https://doi.org/10.2196/jmir.6759

Atran S, Medin DL (2008) The Native Mind and the Cultural Construction of Nature. MIT Press. https://doi.org/10.7551/mitpress/7683.001.0001

Bakhanova E, Garcia JA, Raffe WL, Voinov A (2023) Gamification Framework for Participatory Modeling: A Proposal. Group Decis Negot 32(5): 1167–1182. https://doi.org/10.1007/s10726-023-09838-w

Baldessari S, Paletto A, De Meo I (2024) Rethinking Public Participation in Forest Policies: A Literature Review of Participatory Techniques. Forests 15(9), article id 9. https://doi.org/10.3390/f15091514

Başkent E (2018) A Review of the Development of the Multiple Use Forest Management Planning Concept. Int For Rev 20: 296–313. https://doi.org/10.1505/146554818824063023

Baskent EZ, Borges JG, Kašpar J (2024) An Updated Review of Spatial Forest Planning: Approaches, Techniques, Challenges, and Future Directions. Curr For Rep 10(5): 299–321. https://doi.org/10.1007/s40725-024-00222-8

Bell S (2013) Landscape: Pattern, Perception and Process. Taylor & Francis. https://doi.org/10.4324/9780203014882

Bell S, Blom D, Rautamäki M, Castel-Branco C, Simson A, Asger Olsen I (2005) Design of Urban Forests. In: Konijnendijk C, Nilsson K, Randrup T, Schipperijn J (eds) Urban Forests and Trees: A Reference Book. Springer, Berlin, Heidelberg, pp 149–186. https://doi.org/10.1007/3-540-27684-X_7

Bengston DN, Westphal LM, Dockry MJ, Crabtree J (2022) A "Serious Game" to Explore Alternative Forestry Futures. J For 120(2): 222–226. https://doi.org/10.1093/jofore/fvab059

Berger PL, Luckmann T (1966) The Social Construction of Reality: A Treatise in the Sociology of Knowledge. Anchor Books, Penguin Group.

Berglund BE, Kitagawa J, Lagerås P, Nakamura K, Sasaki N, Yasuda Y (2014) Traditional Farming Landscapes for Sustainable Living in Scandinavia and Japan: Global

Revival Through the Satoyama Initiative. AMBIO 43(5): 559–578. https://doi.org/10.1007/s13280-014-0499-6

Bettinger P, Boston K (2017) Forest Planning Heuristics—Current Recommendations and Research Opportunities for s-Metaheuristics. Forests 8(12), article id 12. https://doi.org/10.3390/f8120476

Bhaskar R (1975) A Realist Theory of Science. Leeds Books.

Boissière M, Bastide F, Basuki I, Pfund JL, Boucard A (2014) Can we make participatory NTFP monitoring work? Lessons learnt from the development of a multi-stakeholder system in Northern Laos. Biodivers Conserv 23(1): 149–170. https://doi.org/10.1007/s10531-013-0589-y

Bonney R, Cooper CB, Dickinson J, Kelling S, Phillips T, Rosenberg KV, Shirk J (2009) Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. Bioscience 59(11): 977–984. https://doi.org/10.1525/bio.2009.59.11.9

Bowser A, Hansen D, Preece J, He Y, Boston C, Hammock J (2014) Gamifying citizen science: A study of two user groups. Proceedings of the Companion Publication of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing, pp 137–140. https://doi.org/10.1145/2556420.2556502

Buchy M, Hoverman S (2000) Understanding public participation in forest planning: A review. For Policy Econ 1(1): 15–25. https://doi.org/10.1016/S1389-9341(00)00006-X

Cechanowicz J, Gutwin C, Brownell B, Goodfellow L (2013) Effects of gamification on participation and data quality in a real-world market research domain. Proceedings of the First International Conference on Gameful Design, Research, and Applications, pp 58–65. https://doi.org/10.1145/2583008.2583016

Cocks ML (2006) Biocultural diversity: Moving beyond the realm of ‘indigenous’ and ‘local’ people. Hum Ecol 34(2): 185–200. https://doi.org/10.1007/s10745-006-9013-5

Cooper C, Martin V, Wilson O, Rasmussen L (2023) Equitable Data Governance Models for the Participatory Sciences. Community Sci 2(2), article id e2022CSJ000025. https://doi.org/10.1029/2022CSJ000025

Cresswell J, Clarke V (2025) Designing and Conducting Mixed Methods Research. Sage Publications. https://us.sagepub.com/en-us/nam/designing-and-conducting-mixed-methods-research/book241842

Danielsen F, Eicken H, Funder M, Johnson N, Lee O, Theilade I, Argyriou D, Burgess ND (2022) Community Monitoring of Natural Resource Systems and the Environment. Annu Rev Environ Resour 47: 637–670. https://doi.org/10.1146/annurev-environ-012220-022325

Dare M (Lain), Schirmer J, Vanclay F (2014) Community engagement and social licence to operate. Impact Assess Proj Apprais 32(3): 188–197. https://doi.org/10.1080/14615517.2014.927108

de Vries JR, Cacciapaglia MA, Flores D, Stoof CR (2025) Pyrotown: A serious educational game for Integrated Fire Management students. Zenodo. https://doi.org/10.5281/zenodo.15318803

Del-Real C, De Busser E, van den Berg B (2025) A systematic literature review of security and privacy by design principles, norms, and strategies for digital technologies. Int Rev Law Comput Technol 39(3): 374–405. https://doi.org/10.1080/13600869.2025.2457227

Deterding S, Dixon D, Khaled R, Nacke L (2011) From game design elements to gamefulness: Defining 'gamification'. Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, pp 9–15. https://doi.org/10.1145/2181037.2181040

Dillman DA, Smyth JD, Christian LM (2014) Internet, phone, mail, and mixed mode surveys: The tailored design method, 4th ed. John Wiley & Sons, Inc. https://doi.org/10.1002/9781394260645

Döllner J, De Amicis R, Burmeister J-M, Richter R (2023) Forests in the Digital Age: Concepts and Technologies for Designing and Deploying Forest Digital Twins. The 28th International ACM Conference on 3D Web Technology, pp 1–12. https://doi.org/10.1145/3611314.3616067

Edwards D, Jay M, Jensen FS, Lucas B, Marzano M, Montagné C, Peace A, Weiss G (2012) Public preferences for structural attributes of forests: Towards a pan-European perspective. For Policy Econ 19: 12–19. https://doi.org/10.1016/j.forpol.2011.07.006

Eyvindson K, Burgas D, Antón Fernández C, Hakanen J, Emmerich M, Klein J, Monkkonen M, Snäll T, Toraño Caicoya A, Vergarechea M, Blattert C (2023) MultiOptForest: An interactive multi-objective optimization tool for forest planning and scenario analysis. Open Research Europe 3, article id 103. https://doi.org/10.12688/openreseurope.15812.1

Falk T, Zhang W, Meinzen-Dick R, Bartels L, Sanil R, Priyadarshini P, Soliev I (2023) Games for experiential learning: Triggering collective changes in commons management. Ecol Soc 28(1), article id 30. https://doi.org/10.5751/ES-13862-280130

Farinha J, Pina M de F (2025) Cross-Cultural Perspectives on Gamification in Business Environments: How Cultural Differences Influence Design and Reception. In: Marcão R, Santos V (eds) Evolving Strategies for Organizational Management and Performance Evaluation. IGI Global Scientific Publishing, pp 77–88. https://doi.org/10.4018/979-8-3373-0149-5.ch005

Finfgeld-Connett D (2014) Use of content analysis to conduct knowledge-building and theory-generating qualitative systematic reviews. Qual Res 14(3): 341–352. https://doi.org/10.1177/1468794113481790

Finlay L (2002) Negotiating the swamp: The opportunity and challenge of reflexivity in research practice. Qual Res 2(2) 209–230. https://doi.org/10.1177/146879410200200205

Flyvbjerg B (2006) Five Misunderstandings About Case-Study Research. Qual Inq 12(2): 219–245. https://doi.org/10.1177/1077800405284363

Friedman RS, Guerrero AM, McAllister RRJ, Rhodes JR, Santika T, Budiharta S, Indrawan T, Hutabarat JA, Kusworo A, Yogaswara H, Meijaard E, St John FAV, Struebig MJ, Wilson KA (2020) Beyond the community in participatory forest management: A governance network perspective. Land Use Policy 97, article id 104738. https://doi.org/10.1016/j.landusepol.2020.104738

Fukamachi K, Miki Y, Oku H, Miyoshi I (2011) The biocultural link: Isolated trees and hedges in Satoyama landscapes indicate a strong connection between biodiversity and local cultural features. Landsc Ecol Eng 7(2): 195–206. https://doi.org/10.1007/s11355-011-0164-1

Goldkuhl G (2012) Pragmatism vs interpretivism in qualitative information systems research. Eur J Inf Syst 21(2): 135–146. https://doi.org/10.1057/ejis.2011.54

Gollob C, Ritter T, Kraßnitzer R, Tockner A, Nothdurft A (2021) Measurement of Forest Inventory Parameters with Apple iPad Pro and Integrated LiDAR Technology. Remote Sens 13(16), article id 16. https://doi.org/10.3390/rs13163129

Gómez-Barrón J-P, Manso-Callejo M-Á, Alcarria R (2019) Needs, drivers, participants and engagement actions: A framework for motivating contributions to volunteered geographic information systems. J Geogr Syst 21(1): 5–41. https://doi.org/10.1007/s10109-018-00289-5

Greider T, Garkovich L (1994) Landscapes: The Social Construction of Nature and the Environment. Rural Sociol 59(1): 1–24. https://doi.org/10.1111/j.1549-0831.1994.tb00519.x

Habermas J (1971) Knowledge and human interests. Beacon Press.

Hadjichambis A, Paraskeva-Hadjichambi D, Georgiou Y, Adamou A (2024) How can we transform citizens into 'environmental agents of change'? Towards the citizen science for environmental citizenship (CS4EC) theoretical framework based on a meta-synthesis approach. Int J Sci Educ B 14(1): 72–92. https://doi.org/10.1080/21548455.2023.2199129

Häggström M (2019) Lived experiences of being-in-the-forest as experiential sharing with the more-than-human world. Environ Educ Res 25(9): 1334–1346. https://doi.org/10.1080/13504622.2019.1633275

Haklay M (2013) Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation. In: Sui D, Elwood S, Goodchild M (eds) Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice. Springer Netherlands, pp 105–122. https://doi.org/10.1007/978-94-007-4587-2_7

Halla T, Holz J, Karhunkorva R, Laine J (2023) The concept of the human-forest relationship (HFR) – Definition and potentials for forest policy research. For Policy Econ 153, article id 102995. https://doi.org/10.1016/j.forpol.2023.102995

Hamari J, Koivisto J, Sarsa H (2014) Does Gamification Work? – A Literature Review of Empirical Studies on Gamification. 47th Hawaii International Conference on System Sciences, pp 3025–3034. https://doi.org/10.1109/HICSS.2014.377

Haraway D (1988) Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. Fem Stud 14(3): 575–599. https://doi.org/10.2307/3178066

Hokajärvi R, Hujala T, Leskinen LA, Tikkanen J (2009) Effectiveness of sermon policy instruments: Forest management planning practices applying the activity theory approach. Silva Fenn 43(5): 889–906. https://doi.org/10.14214/sf.178

Hölzl R (2010) Historicizing Sustainability: German Scientific Forestry in the Eighteenth and Nineteenth Centuries. Sci Cult 19(4): 431–460. https://doi.org/10.1080/09505431.2010.519866

Hoogstra-Klein MA, Permadi DB, Yasmi Y (2012. The value of cultural theory for participatory processes in natural resource management. For Policy Econ 20, 99–106. https://doi.org/10.1016/j.forpol.2011.12.001

Hsu C-L, Chen M-C (2021) Advocating recycling and encouraging environmentally friendly habits through gamification: An empirical investigation. Technol Soc 66, article id 101621. https://doi.org/10.1016/j.techsoc.2021.101621

Indrawan M, Yabe M, Nomura H, Harrison R (2014) Deconstructing satoyama – The socio-ecological landscape in Japan. Ecol Eng 64: 77–84. https://doi.org/10.1016/j.ecoleng.2013.12.038

Jhagroe S (2024) Fences, seeds and bees: The more-than-human politics of community gardening in Rotterdam. Urban Stud 61(8): 1488–1507. https://doi.org/10.1177/00420980231208830

Kalana MHA, Junaini SN (2025) Gamification and technology acceptance model: A systematic review and future research directions. EduLearn 19(3), article id 3. https://doi.org/10.11591/edulearn.v19i3.22154

Kangas J (1994) An approach to public participation in strategic forest management planning. For Ecol Manag 70(1–3): 75–88. https://doi.org/10.1016/0378-1127(94)90076-0

Kangas J, Kangas A (2005) Multiple criteria decision support in forest management—The approach, methods applied, and experiences gained. For Ecol Manag 207(1–2): 133–143. https://doi.org/10.1016/j.foreco.2004.10.023

Kangas A, Laukkanen S, Kangas J (2006). Social choice theory and its applications in sustainable forest management—A review. For Policy Econ 9(1): 77–92. https://doi.org/10.1016/j.forpol.2005.02.004

Kangas A, Kurttila M, Hujala T, Eyvindson K, Kangas J (2015a) Participatory Planning Processes in Action. In: Kangas A, Kurttila M, Hujala T, Eyvindson K, Kangas J (eds) Decision Support for Forest Management. Springer International Publishing, pp 253–286. https://doi.org/10.1007/978-3-319-23522-6_11

Kangas A, Rasinmäki J, Eyvindson K, Chambers P (2015b). A mobile phone application for the collection of opinion data for forest planning purposes. Environ Manag 55: 961–971. https://doi.org/10.1007/s00267-014-0438-0

Kelly LM, Cordeiro M (2020) Three principles of pragmatism for research on organizational processes. Methodol Innov 13(2). https://doi.org/10.1177/2059799120937242

Kleres J (2011) Emotions and Narrative Analysis: A Methodological Approach. J Theory Soc Behav 41(2): 182–202. https://doi.org/10.1111/j.1468-5914.2010.00451.x

Kymäläinen H, Laitila J, Väätäinen K, Malinen J (2021) Workability and Well-Being at Work Among Cut-To-Length Forest Machine Operators. Croat J For Eng 42(3): 405–417. https://doi.org/10.5552/crojfe.2021.874

Laato S, Pynnönen S, Kangas A (2022) Gamification of forest-going: Opportunities for players, landowners and the forest industry. In: Bujić M, Koivisto J, Hamari J (eds) Proceedings of the 6th International GamiFIN Conference 2022 (GamiFIN 2022). CEUR-WS, pp 146–155.

Lalicic L, Weber-Sabil J (2022) Stakeholder engagement in sustainable tourism planning through serious gaming. In: Ivanova M, Buda D-M, Burrai E (eds) Qualitative Methodologies in Tourism Studies. Routledge. https://doi.org/10.4324/9781003274117-13

Lawrence A, Gatto P, Bogataj N, Lidestav G (2021) Forests in common: Learning from diversity of community forest arrangements in Europe. Ambio 50(2): 448–464. https://doi.org/10.1007/s13280-020-01377-x

Liang X, Kankare V, Hyyppä J, Wang Y, Kukko A, Haggrén H, Yu X, Kaartinen H, Jaakkola A, Guan F, Holopainen M, Vastaranta M (2016) Terrestrial laser scanning in forest inventories. ISPRS J Photogramm Remote Sens 115: 63–77. https://doi.org/10.1016/j.isprsjprs.2016.01.006

Lindenmayer DB, Likens GE (2018) Effective Ecological Monitoring. CSIRO Publishing. https://doi.org/10.1071/9781486308934

Markus HR, Kitayama S (1991) Culture and the self: Implications for cognition, emotion, and motivation. Psychol Rev 98(2): 224–253. https://doi.org/10.1037/0033-295X.98.2.224

Masso A, Puura A, Gerassimenko J, Järv O (2025) Using gamification to engage citizens in micro-mobility data sharing. Data Brief 61, article id 111676. https://doi.org/10.1016/j.dib.2025.111676

Maxwell J (2010) Understanding and Validity in Qual Res. Harv Educ Rev 62(3): 279–301. https://doi.org/10.17763/haer.62.3.8323320856251826

Menzel S, Nordström E-M, Buchecker M, Marques A, Saarikoski H, Kangas A (2012) Decision support systems in forest management: Requirements from a participatory planning perspective. Eur J For Res 131(5): 1367–1379. https://doi.org/10.1007/s10342-012-0604-y

Miller AL, Lambert AD (2014) Open-Ended Survey Questions: Item Nonresponse Nightmare or Qualitative Data Dream? Surv Pract 7(5). https://doi.org/10.29115/SP-2014-0024

Moffat K, Lacey J, Zhang A, Leipold S (2016) The social licence to operate: A critical review. Forestry 89(5): 477–488. https://doi.org/10.1093/forestry/cpv044

Morgan DL (2014) Integrating Qualitative and Quantitative Methods: A Pragmatic Approach. SAGE Publications, Inc. https://doi.org/10.4135/9781544304533

Morschheuser B, Hassan L, Werder K, Hamari J (2018) How to design gamification? A method for engineering gamified software. Inf Softw Technol 95: 219–237. https://doi.org/10.1016/j.infsof.2017.10.015

Murtiyoso A, Holm S, Riihimäki H, Krucher A, Griess H, Griess VC, Schweier J (2024) Virtual forests: A review on emerging questions in the use and application of 3D data in forestry. Int J For Eng 35(1): 29–42. https://doi.org/10.1080/14942119.2023.2217065

Mustalahti I (2009) Sustaining Participatory Forest Management: Case Study Analyses of Forestry Assistance from Tanzania, Mozambique, Laos and Vietnam. Small Scale For 8(1): 109–129. https://doi.org/10.1007/s11842-008-9072-0

Muttilainen H, Hallikainen V, Miina J, Vornanen J, Vanhanen H (2023) Forest Owners' Perspectives Concerning Non-Timber Forest Products, Everyman's Rights, and Organic Certification of Forests in Eastern Finland. Small Scale For 22(1): 69–101. https://doi.org/10.1007/s11842-022-09528-6

Nightingale A (2003) A Feminist in the Forest: Situated Knowledges and Mixing Methods in Natural Resource Management. ACME 2(1): 77–90. https://doi.org/10.14288/acme.v2i1.709

Nousiainen D, Mola-Yudego B (2022) Characteristics and emerging patterns of forest conflicts in Europe—What can they tell us? For Policy Econ 136, article id 102671. https://doi.org/10.1016/j.forpol.2021.102671

O'Brien L, McConnachie S, Hall C, Forster J, Dyke A, Saraev V, Jones G (2024) Exploring the social and cultural values of trees and woodlands in England: A new composite measure. People Nat 6(3): 1334–1354. https://doi.org/10.1002/pan3.10644

Palacin-Silva MV, Knutas A, Ferrario MA, Porras J, Ikonen J, Chea C (2018) The Role of Gamification in Participatory Environmental Sensing: A Study In the Wild. Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, Association for Computer Machinery (ACM), pp 1–13. https://doi.org/10.1145/3173574.3173795

Palmquist A (2024) Stakeholders' design preferences for instructional gamification. Behav Inform Technol 43(12): 2717–2749. https://doi.org/10.1080/0144929X.2023.2255905

Papagiannidis S, Marikyan D (2022) Environmental sustainability: A technology acceptance perspective. Int J Inf Manage 63, article id 102445. https://doi.org/10.1016/j.ijinfomgt.2021.102445

Pappila M, Pölönen I (2012) Reconsidering the role of public participation in the Finnish forest planning system. Scand J For Res 27(2): 177–185. https://doi.org/10.1080/02827581.2011.635084

Parrotta JA, Trosper RL (eds) (2012) Traditional Forest-Related Knowledge – Sustaining Communities, Ecosystems and Biocultural Diversity. World Forests 12. Springer Netherlands. https://doi.org/10.1007/978-94-007-2144-9

Phillips DC, Burbules NC (2000). Postpositivism and educational research. Rowman & Littlefield. https://doi.org/10.5771/9781442202702-101

Prestopnik N, Crowston K (2012) Purposeful gaming & socio-computational systems: A citizen science design case. Proceedings of the 2012 ACM International Conference on Supporting Group Work. Association for Computing Machinery, pp 75–84. https://doi.org/10.1145/2389176.2389188

Primmer E, Kyllönen S (2006) Goals for public participation implied by sustainable development, and the preparatory process of the Finnish National Forest Programme. For Policy Econ 8(8): 838–853. https://doi.org/10.1016/j.forpol.2005.01.002

Puettmann KJ, Coates KD, Messier CC (2008) A Critique of Silviculture: Managing for Complexity. Island Press. ISBN: 978-1-59726-145-6.

Pukkala T (2008) Integrating Multiple Services in the Numerical Analysis of Landscape Design. In: von Gadow K, Pukkala T (eds) Designing Green Landscapes. Springer Netherlands, pp 137–167. https://doi.org/10.1007/978-1-4020-6759-4_6

Reed MS (2008) Stakeholder participation for environmental management: A literature review. Biol Conserv 141(10): 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014

Reed MS, Graves A, Dandy N, Posthumus H, Hubacek K, Morris J, Prell C, Quinn CH, Stringer LC (2009) Who's in and why? A typology of stakeholder analysis methods for natural resource management. J Environ Manage 90(5): 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001

Rose G (1997) Situating knowledges: Positionality, reflexivities and other tactics. Prog Hum Geogr 21(3): 305–320. https://doi.org/10.1191/030913297673302122

Rotman D, Preece J, Hammock J, Procita K, Hansen D, Parr C, Lewis D, Jacobs D (2012) Dynamic changes in motivation in collaborative citizen-science projects. Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work. Association for Computing Machinery, pp 217–226. https://doi.org/10.1145/2145204.2145238

Ryan RM, Deci EL (2000) Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. Am Psychol 55(1): 68–78. https://doi.org/10.1037/0003-066X.55.1.68

Ryan RM, Deci EL (2001) On Happiness and Human Potentials: A Review of Research on Hedonic and Eudaimonic Well-Being. Annu Rev Psychol 52: 141–166. https://doi.org/10.1146/annurev.psych.52.1.141

Sailer M, Hense JU, Mayr SK, Mandl H (2017) How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction. Comput Hum Behav 69: 371–380. https://doi.org/10.1016/j.chb.2016.12.033

Sarkar D, Chapman CA (2021) The Smart Forest Conundrum: Contextualizing Pitfalls of Sensors and AI in Conservation Science for Tropical Forests. Trop Conserv Sci 14. https://doi.org/10.1177/19400829211014740

Sarkki S, Parpan T, Melnykovych M, Zahvoyska L, Derbal J, Voloshyna N, Nijnik M (2019) Beyond participation! Social innovations facilitating movement from authoritative state to participatory forest governance in Ukraine. Landsc Ecol 34(7): 1601–1618. https://doi.org/10.1007/s10980-019-00787-x

Schlieder C, Matyas C (2009) Photographing a City: An Analysis of Place Concepts Based on Spatial Choices. Spat Cogn Comput 9(3): 212–228. https://doi.org/10.1080/13875860903121848

Silvennoinen H, Pukkala T, Tahvanainen L (2002. Effect of Cuttings on the Scenic Beauty of a Tree Stand. Scand J For Res 17(3): 263–273. https://doi.org/10.1080/028275802753742936

Sipilä M, Tyrväinen L (2005) Evaluation of collaborative urban forest planning in Helsinki, Finland. Urban For Urban Green 4(1): 1–12. https://doi.org/10.1016/j.ufug.2005.06.002

Speelman EN., van Noordwijk M, Garcia C (2018) Gaming to better manage complex natural resource landscapes. In: Namirembe S, Leimona B, van Noordwijk M, Minang PA (eds) Co-investment in ecosystem services: Global lessons from payment and incentive schemes. World Agroforestry (ICRAF), pp 452–462.

Tahvanainen L, Tyrväinen L, Ihalainen M, Vuorela N, Kolehmainen O (2001) Forest management and public perceptions—Visual versus verbal information. Landsc Urban Plan 53(1): 53–70. https://doi.org/10.1016/S0169-2046(00)00137-7

Tatsumi S, Yamaguchi K, Furuya N (2023) ForestScanner: A mobile application for measuring and mapping trees with LiDAR-equipped iPhone and iPad. Methods in Ecol Evol 14(7): 1603–1609. https://doi.org/10.1111/2041-210X.13900

Tekinbas KS, Zimmerman E (2003) Rules of Play: Game Design Fundamentals. MIT Press.

Tikkanen J, Hokajärvi R, Hujala T (2010) Development Phases of Forest Planning on Non-Industrial Private Lands in Finland: Perspective of Planners' Work. Small Scale For 9(3): 331–347. https://doi.org/10.1007/s11842-010-9119-x

Toda A, Klock ACT, Pereira FD, Rodrigues LA, Palomino PT, Lopes V (2022) Towards the understanding of cultural differences in between gamification preferences: A data-driven comparison between the US and Brazil. In: Mitrovic A, Bosch N (eds) In: Proceedings of the 15th International Conference on Educational Data Mining. International Educational Data Mining Society. https://doi.org/10.5281/zenodo.6853030

Ulvdal P, Öhman K, Eriksson LO, Wästerlund DS, Lämås T (2023) Handling uncertainties in forest information: The hierarchical forest planning process and its use of information at large forest companies. Forestry 96(1): 62–75. https://doi.org/10.1093/forestry/cpac028

Upton V, Dhubháin ÁN, Bullock C (2012). Preferences and values for afforestation: The effects of location and respondent understanding on forest attributes in a labelled choice experiment. For Policy Econ 23: 17–27. https://doi.org/10.1016/j.forpol.2012.06.006

Vastaranta M, Wulder MA, Hamari J, Hyyppä J, Junttila S (2022) Forest Data to Insights and Experiences Using Gamification. Front For Glob Change 5, article id 799346. https://doi.org/10.3389/ffgc.2022.799346

Von Gadow K, Pukkala T (eds) (2008) Designing Green Landscapes. Managing Forest Ecosystems 15. Springer Netherlands. https://doi.org/10.1007/978-1-4020-6759-4

Warmelink H, Koivisto J, Mayer I, Vesa M, Hamari J (2020) Gamification of production and logistics operations: Status quo and future directions. J Bus Res 106: 331–340. https://doi.org/10.1016/j.jbusres.2018.09.011

Weintraub A, Cholaky A (1991) A Hierarchical Approach to Forest Planning. For Sci 37(2): 439–460. https://doi.org/10.1093/forestscience/37.2.439