Digital Analytics and Robotics for Sustainable Forestry

CL4-2021-DIGITAL-EMERGING-01
Grant agreement no: 101070405

DELIVERABLE 6.4
Report on final project demo with end user feedback

Due date: month 39 (December 2025)
Deliverable type: R
Lead beneficiary: PARTNERHERE

Dissemination Level: PUBLIC

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1   Introduction

Overview   This document describes the above listed deliverable.

Relation to overall DigiForest project   Words here

2   User Study

Figure 1: User survey for the Frontier backpack device at Wytham Woods, UK

2.1   User Study at Wytham: Using Frontier Device for Forestry Mapping

We conducted a user study for using the Frontier mapping device developed within the Digiforest project. The device is intended to support field-based data collection and inventopry tasks in forest environments. The device is attached to a backpack, and requires the user to walk with in the forest plot in order to map the environment. As Frontier is a research prototype, understanding how users interact with the device in realistic conditions is essential for guiding further development.

The primary objective of the study was to assess the usability, learnability, and workflow compatibility of using the Frontier device during a representative forest mapping task. Specifically, the study aimed to examine how easily users could learn to operate the device, what challenges emerged during task execution, and how users perceived the device in terms of efficiency, comfort, and overall satisfaction .

2.1.1   Study protocol

The study was conducted as a field-based usability evaluation with eight participants. Participants were recruited from a population with basic forestry or surveying backgrounds and prior exposure to GPS or field data collection tools, reflecting the

intended user group for the device. All participants provided informed consent prior to participation, and no personally identifiable information was collected or reported. The complete study prototol is presented in Appendix A.

Each study session followed a structured protocol. Participants first received a brief introduction to the study and the device, followed by a short training session covering essential functionality such as starting and stopping a mapping session, recording and viewing collected data. Care was taken to avoid overtraining, in order to observe realistic learning behavior. Participants then completed a mapping task, which involved using Frontier to map a predefined forest plot as completely as possible. Observations were recorded throughout the task, including task duration, visible confusion, interruptions, navigation behavior, and ergonomic factors such as device handling and screen readability in field conditions .

2.1.2 Analysis

Following task completion, participants completed a post-task questionnaire consisting of three components: the System Usability Scale (SUS) [1], a set of custom usability and comfort questions related to using the device in the field, and a short NASA-TLX [2] workload assessment measuring perceived mental and physical effort, frustration, time pressure, and overall workload. For reference, the post-task quesstionaire is provided in Appendix B.

These quantitative measures were complemented by a semi-structured post-task interview (Appendix C), which explored participant experiences in greater depth, including their learning process, interaction strategies, decision-making during task completion, perceptions of hardware and interface design, and suggestions for improvement .

Overall, this study adopts a mixed approach, combining quantitative usability metrics with qualitative observations and interview data. The resulting dataset provides insight into both measurable usability outcomes and subjective user experiences, enabling a comprehensive assessment of Frontier's strengths and limitations in real-world forest mapping scenarios. The findings are intended to inform iterative refinement of the device hardware, interface, and workflow design.

2.2 Post-Task Questionnaire

Following completion of the mapping task, participants completed a post-task questionnaire consisting of three components: the System Usability Scale (SUS), a set of custom usability and comfort questions, and a short NASA-TLX workload assessment. Together, these measures provide a quantitative perspective on perceived usability, physical comfort, and cognitive and physical workload during use of the Frontier device.

2.2.1 System Usability Scale (SUS)

Overall, SUS responses in Tab. 1 indicate a high level of perceived usability across participants. Most participants strongly agreed that the device was easy to use, well integrated, and learnable, while disagreeing with statements suggesting unnecessary complexity or cumbersome operation.

Based on standard SUS scoring procedure [1], we computed individual participant scores which fall within a range of 62.5 to 85. The mean SUS score across participants was 74.38, placing Frontier device within the *good to excellent* usability range according

to the benchmark. Variability in scores was moderate and largely attributable to technical issues such as visualization lag or temporary signal loss reported by some participants. Item-level responses suggest that while basic usability and learnability were rated very positively, perceptions of system consistency were slightly more variable.

SUS Statement	Mean Rating (1–5)	Std. Dev.
I think I would like to use this device frequently.	4.375	0.69
I found the device unnecessarily complex.	1.875	1.05
I thought the device was easy to use.	4.125	0.92
I think I would need technical support to use this device.	3.5	0.70
I found the various functions well integrated.	4.25	0.66
I thought there was too much inconsistency in the device.	2.5	1.32
I would imagine most people could learn to use this quickly.	4.75	0.43
I found the device cumbersome to use.	1.875	1.36
I felt very confident using the device.	4.125	0.59
I needed to learn many things before I could get going.	2.125	0.78

Table 1: Mean ratings for individual System Usability Scale (SUS) items ($n = 8$).

2.2.2 Custom Usability and Comfort Ratings

Responses to the custom usability and comfort questions in Tab. 2 further support the SUS findings. Participants consistently reported that they could understand how to perform required actions with the device and that the system was generally comfortable to use during fieldwork.

Average ratings across participants were highest for understanding required actions and screen readability in field conditions, indicating strong learnability and adequate visual design for outdoor use. Ratings related to system consistency and physical comfort were slightly lower but remained positive overall. Written comments on the questionnaires frequently noted a desire for clearer feedback regarding mapping coverage and data completeness rather than difficulties with interaction itself.

These results suggest that Frontier's interface and physical design support effective use in the field, while highlighting opportunities to improve feedback.

2.2.3 NASA-TLX Workload Assessment

NASA-TLX ratings in Tab. 3 show the overall workload for the participants while using Frontier. Mental effort and physical effort are fairly low with a score under 3.5. Frustration and time pressure were consistently rated low across participants, suggesting that the task was not perceived as stressful or rushed. Overall workload ratings fell in the low-to-moderate range, indicating that participants were able to complete the mapping task without excessive cognitive or physical strain.These workload results align with interview findings, where participants described the experience as engaging and manageable.

Statement	Mean Rating (1–5)	Std. Dev.
I could understand how to perform the required actions with the device.	4.5	0.5
The device behaved consistently and as I expected during use.	3.625	1.57
I could clearly read the information displayed on the screen in field conditions.	3.875	0.92
The physical design of the device supported comfortable operation during the task.	3.625	1.11

Table 2: Custom usability and comfort ratings ($n = 8$).

Workload Dimension	Mean Rating (0–10)	Std. Dev.
Mental effort required	2.375	1.31
Physical effort required	3.25	1.78
Frustration level	1.75	1.19
Time pressure felt	1.375	1.11
Overall workload	2.25	1.08

Table 3: NASA-TLX workload ratings ($n = 8$).

2.2.4 Summary

Taken together, the questionnaire results indicate that Frontier is perceived as highly usable, learnable, and physically manageable in a forest mapping context. Participants reported positive experiences across standardized and custom measures, with low frustration and acceptable workload levels. At the same time, moderate mental effort and slightly lower consistency ratings point to areas where improved system feedback and reliability could further enhance user confidence. The questionnaire findings complement the interview results in the following section.

2.3 Interviews

We conducted post-task semi-structured interviews with all eight participants to gain deeper insight into their experiences using the Frontier mapping device in a real forest environment. Interview summaries for each participant are presented in the Appendix E. The interviews are intended to complement quantitative usability measures by capturing participants subjective impressions, decision-making processes, and reflections on using the system in the field. The analysis is structured around the study's four main research questions: (1) learnability, (2) workflow fit, (3) comfort, and (4) user satisfaction.

2.3.1 Learnability

Overall, participants reported that Frontier device was relatively easy to begin using after a short introduction. Most were able to start mapping quickly and did not require extensive instruction to perform the basic actions needed for the task. This suggests that the system supports rapid learning for new users.

However, interviews revealed some challenges related to understanding of the UI elements and their sizes on the tablet screen. Several participants expressed initial confusion about multi-step controls, particularly the distinction between starting the

system and starting a recording session. Overall the findings suggest that while the device is easy to operate, the UI design needs to further simplified, made more intuitive, as well as adapt for field operations where users are often using gloves and have limited precision using the tablet interface.

2.3.2   Workflow Fit

Participants adopted a wide range of mapping strategies, including perimeter-first approaches, grid or lawnmower patterns, crisscross paths. These strategies were often adapted dynamically in response to vegetation density, terrain constraints, and perceived gaps in coverage.

Trajectory visualization on the tablet played an important role in supporting workflow fit. Many participants used the displayed path primarily as a memory aid to track where they had already walked, rather than as a detailed planning tool. In contrast, point cloud visualization was used less consistently and was often described as difficult to interpret in real time, particularly because the 2D top-down projection of the canopy-level points interfered with the visualization of ground-level tree trunk features.

Overall, participants treated Frontier backpack system as a background sensing system that supported the mapping task through the environment. While this aligns well with the realities of forest fieldwork, the lack of explicit guidance or an automated measure of completeness placed greater responsibility on users to decide how to cover the area and when to revisit locations. This suggests that Frontier device fits naturally into flexible, experience-driven workflows, but may benefit from optional guidance or feedback mechanisms to support less experienced users.

2.3.3   Comfort

In terms of physical comfort, most participants described the backpack-mounted system as lightweight and generally comfortable to wear, even during continuous walking. Several participants noted that the device felt less cumbersome than expected and did not significantly restrict movement.

At the same time, the physical configuration of the system introduced recurring challenges. The height of the sensor above the head required participants to be constantly aware of low branches, and several reported adjusting their posture or walking paths to avoid collisions. A lack of rigidity in the mounting system was also noted, with some participants describing wobbling that became more noticeable when bending or navigating uneven terrain.

These ergonomic factors did not merely affect comfort, but also influenced mapping behavior. Participants sometimes avoided certain areas, slowed their pace, or altered their routes in response to physical constraints. This highlights that comfort and ergonomics are closely tied to data collection practices in mobile mapping systems, particularly in cluttered natural environments such as forests.

2.3.4   Satisfaction

Participants generally reported positive overall experiences with Frontier, frequently describing the system as enjoyable, engaging, or "fun" to use. Several compared it favorably to static or slower scanning approaches, emphasizing the advantage of continuous data collection while walking naturally through the environment.

Despite this positive affect, interviews revealed a persistent lack of confidence

regarding data completeness and quality. Many participants were unsure when they had mapped an area sufficiently and relied on subjective judgment rather than explicit system feedback to decide when to stop. This uncertainty often led to conservative behaviors, such as making additional passes or revisiting areas "just in case."

Technical issues, including visualization lag and occasional disconnections, further affected the experience. When feedback was delayed or unreliable, participants tended to rely more heavily on their own spatial awareness rather than the device. These findings suggest that while satisfaction with the interaction experience was high, further improvements in the visualization, as well as the overall reliability are necessary.

2.3.5 Summary

In Tab. 4, We have presented a summary of the interviews around a range of topics covered in the interviews. Taken together, the interview results indicate that Frontier is perceived as easy to use, physically manageable, and well suited to flexible forest mapping workflows. Participants were able to learn the system quickly and integrate it into their movement through the environment, often developing effective personal strategies for coverage.

At the same time, the interviews highlight some important design challenges. Physical height of the device in the field, lack of explicit measure about mapping completeness, and sensitivity to latency reduced the confidence in the data they were collecting. Ergonomic factors further shaped how and where participants chose to map. These qualitative findings help explain patterns observed in the quantitative results and point toward design opportunities for improving feedback, guidance, and physical integration in future iterations of the Frontier system.

3 Demo at Montagskolloquium

A short stakeholder survey ($N = 3$) was conducted at the Montagskolloquium (Fig. 2) event at ETH Zurich in January 2026, where experts from forest industry, cantonal offices and academia were present. The goal was to assess requirements and evaluate achievements within the Digiforest project for (i) autonomous under-canopy drone mapping, (ii) tree-level digital-twin information, (iii) Semi Autonomous Harvester (SAHA) autonomy support for in-stand operations, and (iv) infrastructure and integration constraints. Results are reported as mean scores for 1–10 rating items and as stated values for metric questions.
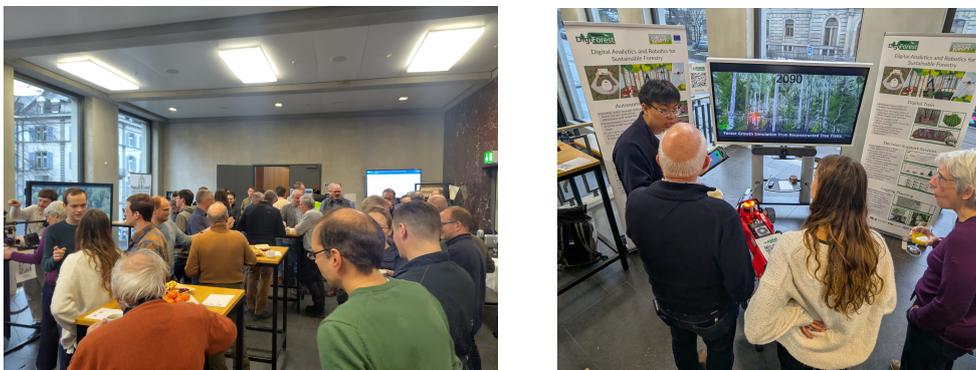
Figure 2: Impressions from the Digiforest demo booth at the Montagskolloquium event at ETH Zurich in January 2026.

3.1 Drones

The perceived value of automated under-canopy acquisition (LiDAR and camera) compared to manual data collection was rated positively ($\bar{x} = 7.67/10$). The expected maximum forest density for drone operation was moderate ($\bar{x} = 5.67/10$); interpreting this anchored scale approximately linearly between $> 10\,\text{m}$ spacing at score 1 and $< 1\,\text{m}$ free space at score 10 yields an indicative operable spacing of about $5.33\,\text{m}$, which roughly corresponds to plots used for evaluating drone flights during Digiforest field trials. Regarding additional sensors beyond LiDAR and RGB, one respondent explicitly stated that "color and LiDAR are enough", indicating that added modalities are not universally demanded. The aggregated willingness to invest in an autonomous mapping drone was 55,000 CHF. For mission productivity, stakeholders indicated an expected coverage of $55\,\text{km}^2$ per single drone mission, implying strong requirements on endurance, autonomy, and data throughput beyond, which are beyond the current state of drone technology.

3.2 Digital Twin

Exact tree locations were considered of limited day-to-day value relative to stand-level information ($\bar{x} = 4.0/10$), suggesting that high spatial detail is not a primary driver for daily operations in the current context. In contrast, tree-level inventory was rated as highly helpful for identifying environmental constraints ($\bar{x} = 7.67/10$), indicating that the inventory system developed within Digiforest is perceived beneficial for constraint-aware planning. The desired update frequency was 18 months, with an explicit preference for flexible scheduling rather than a rigid cadence. Automatic per-tree DBH estimation was rated as important ($\bar{x} = 8.0/10$), emphasizing the practical relevance of diameter-derived information for inventory and planning, that can be provided with Digiforest reconstruction pipelines. Regarding update strategy, responses indicated no clear preference: both complete updates and localized updates in intervention areas were requested. Access to an interactive reconstruction enabling views from arbitrary positions was rated low ($\bar{x} = 4.0/10$), implying that visualization-grade reconstruction is secondary to quantitative attributes. Open responses identified a consistent set of high-priority forest attributes: species, DBH, height, volume, and tree location, which is already represented in digital twin models developed within Digiforest. Addition state indicators such as dead/alive, regeneration presence (yes/no), and clear wood was deemed beneficial, which gives insight in how the digital twin models can be developed further beyond the scope of Digiforest.

3.3 SAHA

Perceived usefulness of SAHA's autonomous navigation with obstacle avoidance for reaching selected trees was low ($\bar{x} = 3.0/10$), and expected harvesting productivity gains were similarly low ($\bar{x} = 3.0/10$), suggesting limited confidence in near-term operational impact or fit to current workflows. However, the perceived economic value from reducing demand for human operation was moderate ($\bar{x} = 6.0/10$), indicating that labor substitution or supervision efficiency remains a credible value hypothesis if reliability and safety constraints are met. The feasibility of a single operator supervising multiple machines during autonomous transit was rated mid-range ($\bar{x} = 5.5/10$), pointing to partial perceived practicality contingent on robust exception handling and supervisory user interfaces.

3.4   Infrastructure and Integration

The cost of collecting and maintaining tree-level data was viewed as only weakly justified by planning benefits ($\bar{x} = 4.0/10$), consistent with cautious cost–benefit expectations under current conditions. Integration of tree-level inventory with existing planning tools/software was rated low ($\bar{x} = 3.5/10$), highlighting interoperability and workflow alignment as key adoption barriers. All respondents (3/3) preferred receiving relevant information already extracted from point clouds rather than managing raw point clouds themselves, indicating a strong demand for processed, decision-ready outputs that the Digiforest pipeline provides. Additional feedback reinforced this preference: stakeholders emphasized the need for high-resolution extracted information instead of point clouds, the ability to aggregate outputs flexibly over user-defined area selections, and straightforward integration of usable data into existing in-house software, without necessarily requiring additional standalone tools, suggesting high value in the spread sheet representation that Digiforest reconstruction algorithms use for reporting results.

Table 4: Cross-participant summary of post-task interviews

Topic	Summary of Participant Feedback	Participants
Overall Experience	Participants described the device as intuitive, lightweight, and enjoyable to use. Several found the experience engaging or "fun," particularly compared to static or slower mapping systems. Technical issues negatively affected experience for some participants.	P1, P2, P3, P5, P6, P7, P8
Learnability and Initial Understanding	Most participants found the system easy to learn after brief instruction. Common early confusion involved multi-step start/record actions and understanding what the red markers for loop-closures represented.	P1, P3, P5, P6, P8
Mapping Strategy and Workflow	Participants adopted varied strategies, including perimeter-first approaches, grid/lawnmower patterns, crisscross paths. Strategies were often adapted in response to vegetation density, lag, or uncertainty about coverage.	P1, P2, P3, P5, P6
Use of Visual Feedback	Trajectory/path visualization was widely used and valued for orientation and coverage tracking. In contrast, real-time point cloud visualization was underutilized, or considered difficult to interpret due to the canopy level points interfering with the ground features.	P1, P2, P5, P7, P8
Uncertainty About Coverage and Completion	Many participants expressed uncertainty about when sufficient coverage had been achieved. Decisions to stop were typically based on perceived evenness of coverage, boundary traversal, or visual judgment rather than explicit system feedback.	P1, P5, P7, P8
Latency and Technical Reliability	Visualization lag was frequently noted and led participants to slow down, or rely on personal spatial awareness. Several participants experienced disconnections, signal loss, or power issues that disrupted task flow.	P1, P2, P3, P4, P6
Ergonomics and Physical Design	The backpack-mounted system was generally considered comfortable and light. However, the height of the sensor and lack of rigidity caused difficulties under low branches and contributed to wobbling. Taller participants reported greater challenges.	P1, P2, P4, P6, P8
Interface and Interaction Issues	Participants noted small buttons, dense menus, and difficulty using the touchscreen with gloves or cold hands. Suggested improvements included larger UI elements, simplified controls, clearer labels, and fewer simultaneous options.	P4, P5, P6, P8
Perceived Applications and Future Use	Beyond forest inventory, participants suggested applications in trail mapping, architecture, construction, urban environments, interior spaces, ecological research, and community-based data collection.	P1, P3, P5, P6, P7, P8

A   User Study Protocol

User Study Protocol: Frontier Mapping Device for Forestry Applications

1. Study Overview

Title:
Evaluating the Usability of the Frontier Mapping Device for Forestry Mapping Tasks

Objective:
To assess how effectively and intuitively users (forestry/surveying students) can use the mobile mapping device to complete mapping tasks typical in forest inventory work, focusing on workflow, usability, and user experience.

Primary Research Questions:

1. How easily can users learn and operate the device for mapping forest plots?

2. What challenges or usability issues arise during typical field mapping tasks?

3. How do users perceive the device in terms of efficiency, comfort, and satisfaction?

2. Participants

- **Population:** Students with basic forestry or surveying background.

- **Number:** 5-6 participants.

- **Inclusion Criteria:**

    ○ Prior exposure to GPS or basic field data collection tools.
    ○ Physically capable of light walking and fieldwork.

- **Exclusion Criteria:**

    ○ No familiarity with mapping tools.
    ○ Any condition preventing outdoor participation.

3. Study Design

Type: Field-based usability study
Duration per participant: ~30 minutes
Study structure:

1. Introduction and consent

2. Short training session (jointly for all participants)

3. Task 1 – Mapping a prescribed region

4. Post-task questionnaire

4. Equipment and Materials

- Mobile mapping device (test unit)

- Clipboard or tablet for observer notes

- Predefined test plots (marked corners)

- Consent forms and questionnaires

- Stopwatch or timer

5. Procedure

5.1. Introduction (10 minutes)

1. Welcome participant and explain study purpose:

   "We're evaluating how this mapping device supports forestry mapping tasks. We're not testing your performance — we're studying how people interact with the device."

2. Review consent form and obtain signature.

3. Collect basic demographic data:

   ○ Age, program/major, mapping experience, devices previously used.

5.2. Training Session (10–15 minutes)

- Briefly explain key functions: starting/stopping mapping, recording points, viewing data, etc.

- Allow the participant to test with one or two sample points.

- Answer procedural questions, but avoid "training to perfection" — the goal is to keep it realistic.

5.3. Mapping a Prescribed Plot (10-15 minutes)

Objective: Assess how the user maps a defined plot.

Instructions to Participant:

"Your task is to map the area within this marked plot using the device. You are aiming to obtain as complete as possible reconstruction of the area. Start when you're ready, and let us know when you think you've completed mapping the plot."

Observer Records:

- Time to completion

- Number of pauses, restarts, or visible confusion

- Notes on path followed, obstacles, or errors

- Ergonomic aspects (screen readability, comfort)

- Any assistance required

5.5. Post-Task Questionnaires (10–15 minutes)

A. System Usability Scale (SUS)

Ask participants to rate 10 standard SUS items (1–5 scale from Strongly Disagree to Strongly Agree).
 (Keep standard wording — widely validated.)

B. Custom Usability and Comfort Questions (Likert scale, 1–5)

1. It was easy to understand how to use the device.

2. I felt confident using the device during mapping.

3. The interface was easy to read in field conditions.

4. The device was comfortable to hold and operate.

5. The workflow fit naturally with typical mapping tasks.

6. I would use this device for future fieldwork if available.

C. Workload (Short NASA-TLX, 0–10 rating)

- Mental effort required

- Physical effort required

- Frustration level

- Overall workload

5.6. Post-Task Interview (10–15 minutes)

Semi-Structured Questions:

1. What aspects of using the device did you find easiest?

2. What aspects did you find most challenging?

3. How did you decide when your mapping was complete?

4. Did you feel the device supported your mapping workflow?

5. Was there any point where you felt uncertain what to do next?

6. What improvements would you suggest (hardware, software, or workflow)?

(Take short notes; record audio if permitted.)

6. Data Collected

Category	Data Type	Description
Task duration	Quantitative	Time for each mapping task
Observations	Qualitative	Notes on usability issues, behaviors

Questionnaire scores   Quantitative   SUS, custom scales, workload ratings

Interview responses   Qualitative   Perceptions, suggestions

Environmental context   Descriptive   Weather, light, terrain, canopy conditions

7. Analysis Plan

- **Quantitative:**

    - Calculate average SUS score (and standard deviation).

    - Compare task completion times and workload ratings between tasks.

- **Qualitative:**

    - Thematic analysis of observational and interview data.

    - Identify recurring usability barriers or common satisfaction themes.

- **Integration:**

    - Combine metrics and quotes to highlight user experience trends.

8. Ethics and Safety

- All participants provide informed consent.

- No personally identifiable data reported.

- Field safety brief given before start (terrain, weather, etc.).

- Participants can withdraw at any time without penalty.

9. Expected Outcomes

- Identification of key usability challenges in field mapping workflows.

- Insights into user behavior during real-world forest mapping tasks.

- Recommendations for improving device interface, instructions, and ergonomics.

B Post-Task Questionnaire

Post-Task Questionnaire

Participant ID: _____

A. System Usability Scale (SUS)

Assuming you were asked to take more forest inventories, rate each statement from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

#	Statement	1	2	3	4	5
1	I think I would like to use this device frequently.	☐	☐	☐	☐	☐
2	I found the device unnecessarily complex.	☐	☐	☐	☐	☐
3	I thought the device was easy to use.	☐	☐	☐	☐	☐
4	I think I would need technical support to use this device.	☐	☐	☐	☐	☐
5	I found the various functions well integrated.	☐	☐	☐	☐	☐
6	I thought there was too much inconsistency in the device.	☐	☐	☐	☐	☐
7	I would imagine most people could learn to use this quickly.	☐	☐	☐	☐	☐
8	I found the device cumbersome to use.	☐	☐	☐	☐	☐
9	I felt very confident using the device.	☐	☐	☐	☐	☐
10	I needed to learn many things before I could get going.	☐	☐	☐	☐	☐

B. Custom Usability and Comfort Questions

Rate from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

Statement	1	2	3	4	5
I could understand how to perform the required actions with the device.	☐	☐	☐	☐	☐
The device behaved consistently and as I expected during use	☐	☐	☐	☐	☐
I could clearly read the information displayed on the screen in field conditions.	☐	☐	☐	☐	☐
The physical design of the device supported comfortable operation during the task.	☐	☐	☐	☐	☐

C. Short NASA-TLX (Workload Ratings)

Rate each aspect from **0 (Very Low)** to **10 (Very High)**.

Aspect	0	1	2	3	4	5	6	7	8	9	10
Mental effort required	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Physical effort required	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Frustration level	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Time pressure felt	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Overall workload	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

C   Interview Questions

Post-Study Interview Guide

Note: Ask for participant's consent to record audio. Record the interview on your phone. Start with asking the participant's ID.

Participant ID: _____

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 1. Overall Experience

• Can you walk me through your experience using the device during the mapping task?

2. Understanding & Learning

• How did you figure out how to use the main features needed for the task?

• Were there any moments where you were unsure about what to do? If so, can you describe them?

3. Interaction & Workflow

• How did the device fit into the way you approached the mapping task?

• What parts of the interaction with the device stood out to you—positively or negatively?

4. Task Completion Strategy

• How did you decide that you were finished with the mapping task?

5. Hardware, Interface & Ergonomics

• How did you experience the physical handling and visibility of the device in the field environment?

• Was there anything about the interface or controls that you would change?

6. Future Use & Final Thoughts

• In what situations do you think this device would be most useful, and why?

• Is there anything else about your experience that you think we should know?

D   Questionnaire Responses

Post-Task Questionnaire

Participant ID: _____1_____

A. System Usability Scale (SUS)

Assuming you were asked to take more forest inventories, rate each statement from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

#	Statement	1	2	3	4	5
1	I think I would like to use this device frequently.	☐	☐	☐	☐	☒
2	I found the device unnecessarily complex.	☒	☐	☐	☐	☐
3	I thought the device was easy to use.	☐	☐	☐	☒	☐
4	I think I would need technical support to use this device.	☐	☐	☐	☒	☐
5	I found the various functions well integrated.	☐	☐	☐	☐	☒
6	I thought there was too much inconsistency in the device.	☒	☐	☐	☐	☐
7	I would imagine most people could learn to use this quickly.	☐	☐	☐	☐	☒
8	I found the device cumbersome to use.	☒	☐	☐	☐	☐
9	I felt very confident using the device.	☐	☐	☐	☒	☐
10	I needed to learn many things before I could get going.	☐	☐	☒	☐	☐

B. Custom Usability and Comfort Questions

Rate from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

Statement	1	2	3	4	5
I could understand how to perform the required actions with the device.	☐	☐	☐	☒	☐
The device behaved consistently and as I expected during use	☐	☐	☐	☐	☒
I could clearly read the information displayed on the screen in field conditions.	☐	☐	☐	☐	☒
The physical design of the device supported comfortable operation during the task.	☐	☐	☐	☐	☒

→ I would love to have some tips on how to ensure proper coverage.

e.g.: -recomended speed

- is it better constant moving?

- is it good to see stiching points in the screen?

C. Short NASA-TLX (Workload Ratings)

Rate each aspect from **0 (Very Low)** to **10 (Very High)**.

Aspect	0	1	2	3	4	5	6	7	8	9	10
Mental effort required	☐	☐	☐	☐	☐	☒	☐	☐	☐	☐	☐
Physical effort required	☐	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐
Frustration level	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Time pressure felt	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐
Overall workload	☐	☐	☐	☒	☐	☐	☐	☐	☐	☐	☐

You have to be aware of your relative position due to the lag

Post-Task Questionnaire

Participant ID: _____2_____

A. System Usability Scale (SUS)

Assuming you were asked to take more forest inventories, rate each statement from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

#	Statement	1	2	3	4	5
1	I think I would like to use this device frequently.	☐	☐	☐	☑	☐
2	I found the device unnecessarily complex.	☐	☐	☐	☑	☐
3	I thought the device was easy to use.	☐	☐	☐	☑	☐
4	I think I would need technical support to use this device.	☐	☐	☐	☑	☐
5	I found the various functions well integrated.	☐	☐	☑	☐	☐
6	I thought there was too much inconsistency in the device.	☐	☐	☐	☑	☐
7	I would imagine most people could learn to use this quickly.	☐	☐	☐	☐	☑
8	I found the device cumbersome to use.	☑	☐	☐	☐	☐
9	I felt very confident using the device.	☐	☐	☐	☐	☑
10	I needed to learn many things before I could get going.	☑	☐	☐	☐	☐

B. Custom Usability and Comfort Questions

Rate from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

Statement	1	2	3	4	5
I could understand how to perform the required actions with the device.	☐	☐	☐	☐	☑
The device behaved consistently and as I expected during use	☐	☐	☐	☑	☐
I could clearly read the information displayed on the screen in field conditions.	☐	☐	☑	☐	☐
The physical design of the device supported comfortable operation during the task.	☐	☑	☐	☐	☐

C. Short NASA-TLX (Workload Ratings)

Rate each aspect from **0 (Very Low)** to **10 (Very High)**.

Aspect	0	1	2	3	4	5	6	7	8	9	10
Mental effort required	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Physical effort required	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Frustration level	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Time pressure felt	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Overall workload	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐

Post-Task Questionnaire

Participant ID: _3_

A. System Usability Scale (SUS)

Assuming you were asked to take more forest inventories, rate each statement from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

#	Statement	1	2	3	4	5
1	I think I would like to use this device frequently.	☐	☐	☐	☑	☐
2	I found the device unnecessarily complex.	☑	☐	☐	☐	☐
3	I thought the device was easy to use.	☐	☐	☐	☐	☑
4	I think I would need technical support to use this device.	☐	☐	☑	☐	☐
5	I found the various functions well integrated.	☐	☐	☐	☐	☑
6	I thought there was too much inconsistency in the device.	☐	☑	☐	☐	☐
7	I would imagine most people could learn to use this quickly.	☐	☐	☐	☑	☐
8	I found the device cumbersome to use.	☐	☑	☐	☐	☐
9	I felt very confident using the device.	☐	☐	☐	☑	☐
10	I needed to learn many things before I could get going.	☐	☐	☑	☐	☐

B. Custom Usability and Comfort Questions

Rate from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

Statement	1	2	3	4	5
I could understand how to perform the required actions with the device.	☐	☐	☐	☐	☑
The device behaved consistently and as I expected during use	☐	☐	☐	☑	☐
I could clearly read the information displayed on the screen in field conditions.	☐	☐	☐	☑	☐
The physical design of the device supported comfortable operation during the task.	☐	☐	☐	☑	☐

C. Short NASA-TLX (Workload Ratings)

Rate each aspect from **0 (Very Low)** to **10 (Very High)**.

Aspect	0	1	2	3	4	5	6	7	8	9	10
Mental effort required	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐
Physical effort required	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐
Frustration level	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐
Time pressure felt	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐
Overall workload	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐

Post-Task Questionnaire

Participant ID: _5_

A. System Usability Scale (SUS)

Assuming you were asked to take more forest inventories, rate each statement from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

#	Statement	1	2	3	4	5
1	I think I would like to use this device frequently.	☐	☐	☐	☐	☑
2	I found the device unnecessarily complex.	☐	☑	☐	☐	☐
3	I thought the device was easy to use.	☐	☐	☐	☑	☐
4	I think I would need technical support to use this device.	☐	☐	☐	☑	☐
5	I found the various functions well integrated.	☐	☐	☐	☑	☐
6	I thought there was too much inconsistency in the device.	☑	☐	☐	☐	☐
7	I would imagine most people could learn to use this quickly.	☐	☐	☐	☑	☐
8	I found the device cumbersome to use.	☑	☐	☐	☐	☐
9	I felt very confident using the device.	☐	☐	☐	☑	☐
10	I needed to learn many things before I could get going.	☐	☐	☑	☑	☐

B. Custom Usability and Comfort Questions

Rate from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

Statement	1	2	3	4	5
I could understand how to perform the required actions with the device.	☐	☐	☐	☑	☐
The device behaved consistently and as I expected during use	☐	☐	☐	☑	☑
I could clearly read the information displayed on the screen in field conditions.	☐	☐	☐	☐	☑
The physical design of the device supported comfortable operation during the task.	☐	☐	☐	☑	☐

C. Short NASA-TLX (Workload Ratings)

Rate each aspect from **0 (Very Low)** to **10 (Very High)**.

Aspect	0	1	2	3	4	5	6	7	8	9	10
Mental effort required	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐
Physical effort required	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐
Frustration level	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐
Time pressure felt	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐
Overall workload	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐

Post-Task Questionnaire

Participant ID: _6_

A. System Usability Scale (SUS)

Assuming you were asked to take more forest inventories, rate each statement from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

#	Statement	1	2	3	4	5
1	I think I would like to use this device frequently.	☐	☐	☐	☐	☑
2	I found the device unnecessarily complex.	☑	☐	☐	☐	☐
3	I thought the device was easy to use.	☐	☐	☐	☑	☐
4	I think I would need technical support to use this device.	☐	☐	☐	☑	☐
5	I found the various functions well integrated.	☐	☐	☐	☑	☐
6	I thought there was too much inconsistency in the device.	☐	☐	☑	☐	☐
7	I would imagine most people could learn to use this quickly.	☐	☐	☐	☐	☑
8	I found the device cumbersome to use.	☐	☐	☐	☐	☑
9	I felt very confident using the device.	☐	☐	☐	☑	☐
10	I needed to learn many things before I could get going.	☐	☑	☐	☐	☐

B. Custom Usability and Comfort Questions

Rate from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

Statement	1	2	3	4	5
I could understand how to perform the required actions with the device.	☐	☐	☐	☐	☑
The device behaved consistently and as I expected during use	☑	☐	☐	☐	☐
I could clearly read the information displayed on the screen in field conditions.	☐	☐	☑	☐	☐
The physical design of the device supported comfortable operation during the task.	☐	☑	☐	☐	☐

C. Short NASA-TLX (Workload Ratings)

Rate each aspect from **0 (Very Low)** to **10 (Very High)**.

Aspect	0	1	2	3	4	5	6	7	8	9	10
Mental effort required	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Physical effort required	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐
Frustration level	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐
Time pressure felt	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Overall workload	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐

Post-Task Questionnaire

Participant ID: _7_

A. System Usability Scale (SUS)

Assuming you were asked to take more forest inventories, rate each statement from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

#	Statement	1	2	3	4	5
1	I think I would like to use this device frequently.	☐	☐	☒	☐	☐
2	I found the device unnecessarily complex.	☒	☐	☐	☐	☐
3	I thought the device was easy to use.	☐	☐	☐	☐	☒
4	I think I would need technical support to use this device.	☐	☒	☐	☐	☐
5	I found the various functions well integrated.	☐	☐	☐	☒	☐
6	I thought there was too much inconsistency in the device.	☐	☒	☐	☐	☐
7	I would imagine most people could learn to use this quickly.	☐	☐	☐	☐	☒
8	I found the device cumbersome to use.	☒	☐	☐	☐	☐
9	I felt very confident using the device.	☐	☐	☐	☒	☐
10	I needed to learn many things before I could get going.	☒	☐	☐	☐	☐

B. Custom Usability and Comfort Questions

Rate from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

Statement	1	2	3	4	5
I could understand how to perform the required actions with the device.	☐	☐	☐	☐	☒
The device behaved consistently and as I expected during use	☐	☐	☐	☒	☐
I could clearly read the information displayed on the screen in field conditions.	☐	☐	☐	☐	☒
The physical design of the device supported comfortable operation during the task.	☐	☐	☐	☒	☐

C. Short NASA-TLX (Workload Ratings)

Rate each aspect from **0 (Very Low)** to **10 (Very High)**.

Aspect	0	1	2	3	4	5	6	7	8	9	10
Mental effort required	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐
Physical effort required	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐
Frustration level	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐
Time pressure felt	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐
Overall workload	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐

Post-Task Questionnaire

Participant ID: ___8___

A. System Usability Scale (SUS)

Assuming you were asked to take more forest inventories, rate each statement from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

#	Statement	1	2	3	4	5
1	I think I would like to use this device frequently.	☐	☐	☐	☐	☑
2	I found the device unnecessarily complex.	☐	☑	☐	☐	☐
3	I thought the device was easy to use.	☐	☐	☐	☐	☑
4	I think I would need technical support to use this device.	☐	☐	☐	☑	☐
5	I found the various functions well integrated.	☐	☐	☐	☐	☑
6	I thought there was too much inconsistency in the device.	☐	☐	☐	☐	☑
7	I would imagine most people could learn to use this quickly.	☐	☐	☐	☐	☑
8	I found the device cumbersome to use.	☑	☐	☐	☐	☐
9	I felt very confident using the device.	☐	☐	☐	☐	☑
10	I needed to learn many things before I could get going.	☐	☑	☐	☐	☐

B. Custom Usability and Comfort Questions

Rate from **1 (Strongly Disagree)** to **5 (Strongly Agree)**.

Statement	1	2	3	4	5
I could understand how to perform the required actions with the device.	☐	☐	☐	☑	☐
The device behaved consistently and as I expected during use	☐	☐	☐	☐	☑
I could clearly read the information displayed on the screen in field conditions.	☐	☐	☑	☐	☐
The physical design of the device supported comfortable operation during the task.	☐	☐	☐	☐	☑

C. Short NASA-TLX (Workload Ratings)

Rate each aspect from **0 (Very Low)** to **10 (Very High)**.

Aspect	0	1	2	3	4	5	6	7	8	9	10
Mental effort required	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐
Physical effort required	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐
Frustration level	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Time pressure felt	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Overall workload	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐

E Interview Summaries

Participant 1

- Found the device lighter and more stable than expected; comfortable to wear.

- Adopted a "drone-style" lawnmower/S-pattern strategy after first mapping the perimeter.

- Initially confused by separate "start" and "start recording" controls but resolved quickly.

- Found it difficult to judge mapping completeness and point density in real time.

- Valued GPS orientation and trajectory visualization but noted noticeable lag.

- Suggested feedback indicating insufficient coverage or excessive walking speed.

- Reported good ergonomics overall, though the device height felt slightly awkward.

- Saw potential for forest surveys and trail mapping, with limitations in inaccessible or very dense areas.

Participant 2

- Described the device as light and easy to wear but fragile and height-constrained under branches.

- Initially used a grid pattern, then switched to perimeter-based and tree-focused mapping.

- Experienced signal loss and visualization delays, reducing reliance on the screen.

- Relied more on spatial awareness than the real-time map due to lag.

- Found canopy-level visualization less useful than trunk-level information.

- Reported high comfort but concerns about robustness and durability.

- Questioned applicability in dense plantation forests; better suited to open or semi-natural woodlands.

Participant 3

- Enjoyed the experience and felt able to focus on walking rather than constantly checking the screen.

- Initially walked slowly due to display lag, later adjusted pace after clarification.

- Expressed uncertainty about walking straight lines and connecting coverage paths.

- Experienced occasional GPS issues and difficulty handling the device after collisions.

- Found holding the tablet for extended periods uncomfortable.

- Noted confusion caused by separate "start" and "record" actions.

- Saw strong potential for forest structure reconstruction and integration with drone data.

Participant 4

- Encountered repeated technical issues, including disconnections and loss of visualization.

- Was unable to complete the task due to persistent system instability.

- Found the interface intuitive during brief periods when it functioned correctly.

- Noted that buttons were small and difficult to use, especially while wearing gloves.

- Felt the device was tall and required conscious effort to avoid branches.

- Expressed interest in repeating the study once technical issues were resolved.

- Considered the device suitable for open forest settings but challenging in dense understory.

Participant 5

- Found the device easier to use than expected and quickly adapted to wearing it.

- Used a grid-based strategy and frequently circled trees to increase point density.

- Found the evolving point cloud visually satisfying and informative.

- Relied primarily on trajectory and point density rather than directional arrows.

- Was unsure when mapping was "complete" but assumed sufficient coverage once the area was fully traversed.

- Suggested simplifying controls into a single start/stop toggle.

- Proposed UI improvements such as larger fonts and fewer, better-grouped options.

- Envisioned use in tropical forests, urban environments, and other ecosystems.

Participant 6

- Described the experience as enjoyable and fast compared to static terrestrial laser scanning.

- Encountered a battery-related interruption that required assistance to resolve.

- Used crossing paths and crisscross patterns to ensure connectivity of mapped areas.

- Praised the speed of data collection as a major advantage.

- Identified device height and wobbling as primary ergonomic drawbacks.

- Suggested a more rigid backpack frame and improved adjustability.

- Recommended larger buttons and distributing UI elements across both sides of the screen.

- Saw potential applications in architecture, construction, and urban mapping.

Participant 7

- Had no prior experience with similar devices but found the system simple and enjoyable.

- Understood the interface quickly, describing it as intuitive and minimal.

- Noted initial confusion caused by visualization lag but adapted easily.

- Relied on path visualization rather than point cloud density to judge progress.

- Was uncertain about when to stop and sought confirmation from the researcher.

- Found the device more comfortable than expected, though assistance was needed to put it on.

- Saw strong relevance for work in open environments such as dunes or invasive plant studies.

Participant 8

- Found the device intuitive, lightweight, and less bulky than comparable systems.

- Appreciated portability and cautioned against making the system too rigid or heavy.

- Used orientation cues extensively but did not fully understand point cloud indicators.

- Lacked real-time feedback on mapping quality or completeness.

- Stopped mapping once coverage appeared reasonable, despite minor gaps.

- Suggested larger UI elements, clearer labeling, and reconsideration of color choices (e.g., red implying errors).

- Identified broad potential beyond forestry, including interior mapping, safety assessment, and large indoor spaces.

- Raised questions about long transects, data streaming, and partial data saving.