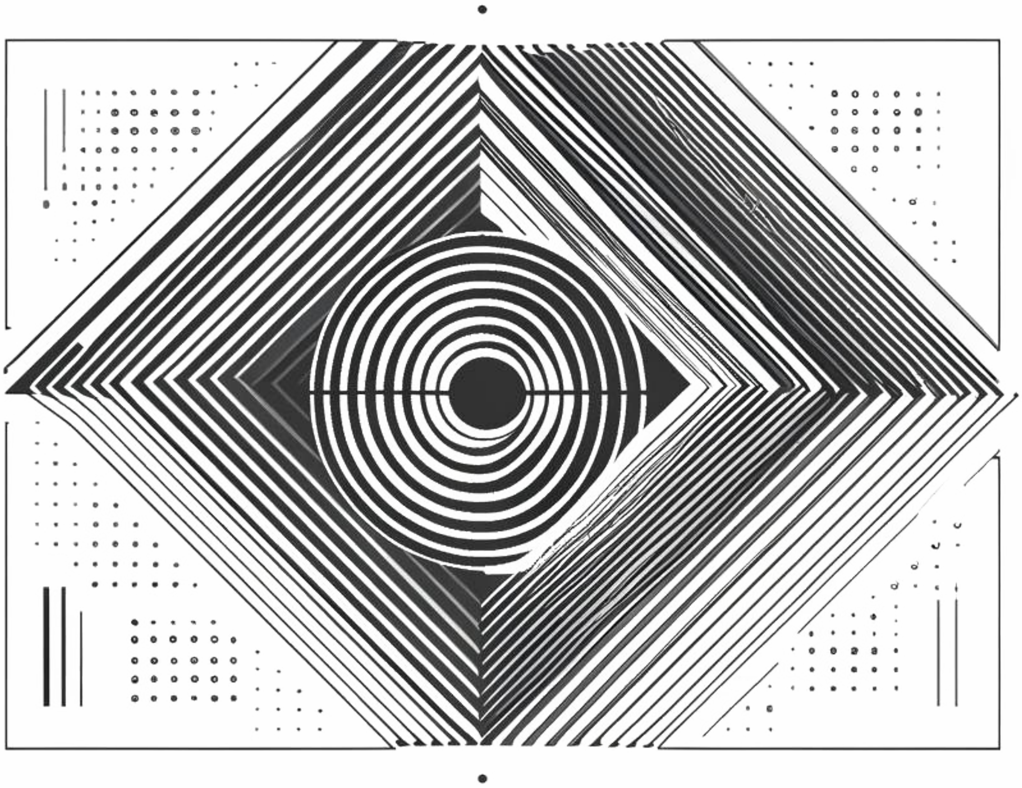
MSc. Geomatics Graduation Thesis

Usability of the vario-scale approach in interactive and dynamic mapping



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TU Delft

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Abstract

This thesis explores methods to enhance the usability of vario-scale maps, focusing on user interaction, cognitive load, and overall satisfaction. Vario-scale maps, based on a continuous zooming approach introduced by Van Oosterom and Meijers, aim to reduce visual disruptions by allowing smooth generalisation of geographic data in real time. The research highlights their potential to merge precision and aesthetic clarity wxhile advancing beyond the conventional snapping behaviour inherent in multi-scale interfaces.

A mixed-method approach was adopted to investigate whether vario-scale maps could improve navigation and user satisfaction. Data were collected through a pilot web-based usability study, followed by a laboratory eye-tracking study designed to capture detailed behavioural and cognitive processes. Quantitative metrics, such as fixation counts and scanpath lengths, were analysed to determine efficiency in map-use tasks, while think-aloud protocols and questionnaires provided qualitative insights into participant preferences and frustrations.

Findings indicate that vario-scale and multi-scale maps offer similar levels of efficiency based on objective eye-tracking metrics. However, participants generally reported higher satisfaction with vario-scale maps, citing smoother transitions, less visual interruption, and a more intuitive zooming experience. The pilot study underscored the importance of user familiarity with Cartography, the careful placement of icons, and task complexity as influential factors in map usability. These insights informed the final study, which showed that vario-scale maps align more closely with user expectations for modern digital interfaces.

By emphasising controlled task design, participant comfort, and iterative refinement through pilot testing, this thesis demonstrates how vario-scale maps can be optimised for enhanced usability. The results further suggest that leveraging cartographic principles—such as appropriate symbol density-plays an essential role in maintaining clarity and facilitating user orientation. Through comprehensive analysis of both objective metrics and subjective evaluations, this thesis provides evidence that improving vario-scale usability is both feasible and beneficial. Future research with broader user demographics and extended usage contexts is recommended to validate and refine the proposed design strategies, ultimately supporting a wider adoption of vario-scale technology for interactive and dynamic mapping applications.

Keywords: vario-scale maps, multi-scale maps, usability, eye-tracking, Cartography, continuous zooming, dynamic generalisation, user interaction, user satisfaction

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1 Introduction

In the quiet realm of parchment and ink, where ancient mariners and explorers charted their journeys, the art of Cartography reveals its stories. Since ancient times, this craft has not only involved the making of maps but also the blending of reality with the threads of imagination and knowledge. Cartography, derived from the Ancient Greek words χάρτης (chartēs), meaning 'papyrus, sheet of paper, map', and γράφειν (graphein), meaning 'to write', stands as a testament to humanity's enduring quest to understand and delineate the contours of Earth ((Moreland & Bannister, 1983; "Cartography", 2024)). It is a discipline that fuses art, science, and technology, a triad that navigates the vast seas of geographic mysteries and truths. In every line drawn and every feature symbolised, cartographers from ages past to the present day engage in an act of creation that is both scientific and profoundly artistic.

As we delve into the modern era, where digital realms and virtual landscapes begin to dominate, the essence of Cartography evolves yet remains anchored in its foundational principles. My thesis, set against the backdrop of this rich history, explores the usability of vario-scale maps through the lens of modern technology, particularly eye-tracking.

The concept of 'variable-scale' or vario-scale maps, as introduced by Van Oosterom and Meijers, allows for a seamless and smooth digital presentation of geographic data across multiple scales ((Oosterom, 2005; P. van Oosterom & Meijers, 2011; Huerta, Schade, & Granell, 2014)). This is achieved through the innovative tGAP data structure, which minimises redundancy and supports progressive map generalisation. Such technology permits the dynamic simplification of map features, prioritising them based on their importance, which could significantly alter the user's engagement with and understanding of spatial data (See Figure 1).

Addressing the usability of these vario-scale maps involves examining how users interact with and experience these dynamic representations compared to multi-scale maps. The most widely used and established web maps today are based on the multi-scale approach. However, it can be argued that multi-scale maps may lead to disorientation, particularly during navigation. In contrast, the vario-scale map approach aims to offer a smoother experience, potentially enhancing user experience by reducing cognitive load. Given the significant number of daily users of digital maps, their usability is crucial. This study aims to explore ways to improve the usability of vario-scale maps while comparing them to multi-scale maps. Utilising methodologies from the realm of eye-tracking provides critical insights into this interaction. Eye-tracking not only records where users look but also interprets these gazes as direct indicators of cognitive processing, thus connecting vision, attention, and action (Henderson & Ferreira, 2004; Fairbairn & Hepburn, 2023). The fixation and saccades data gathered during these sessions reveal the elements of the map that hold the user's attention the longest, providing invaluable feedback on map design and usability.

This thesis employs a mixed-method approach, integrating both qualitative and quantitative research methods such as observations, the think-aloud protocol, and structured questionnaires (Fairbairn & Hepburn, 2023). These methods are complemented by technological analyses such as keyboard and mouse tracking, which assess user interaction with digital interfaces. Such comprehensive methodology ensures a holistic view of the user experience, capturing the nuanced ways users navigate, understand, and prefer vario-scale maps over their multi-scale counterparts.

Ultimately, this study aims to suggest refined vario-scale mapping techniques by focusing on user satisfaction concerning map navigation settings, the saliency of labels, and overall map content density and presentation. This effort will hopefully contribute to the broader discourse on how digital maps can better serve our understanding of and interaction with the geographical landscapes they represent.

Figure 1: An example of a vario-scale map of the Netherlands at different zoom levels.

1.1 Scientific Relevance

The scientific relevance of this thesis lies in its comprehensive examination of the use of the vario-scale mapping approach, particularly through the innovative application of eye-tracking technology. By integrating eye-tracking into the usability study, this research provides a granular understanding of user interactions and cognitive processes offering insights that complement existing usability metrics. Eye-tracking offers precise data on how users navigate and interpret vario-scale maps, revealing patterns of visual attention and areas of difficulty. This method allows for a more nuanced analysis of usability, going beyond conventional metrics to capture real-time user engagement.

By comparing vario-scale maps with multi-scale maps, this study not only evaluates the effectiveness of vario-scale maps but also advances the broader field of interactive digital mapping. The insights gained from this research can inform the design of more intuitive and user-friendly mapping interfaces, ultimately enhancing the utility and accessibility of vario-scale maps. Therefore, this thesis, represents contribution to both cartographic science and the development of advanced geospatial technologies.

1.2 Social Relevance

Given that billions of people worldwide use digital, interactive maps for navigation every month (*Blog: 9 Things to Know about Google's Maps Data: Beyond the Map*, 2019), a small improvement in user experience, such as the smoother interactions and less confusion when changing scale, provided by vario-scale maps, can significantly enhance the quality of life for a large number of users.

For instance, commuters using navigation apps could benefit from more intuitive zooming and panning using the vario-scale technology, reducing cognitive load and making route planning more efficient. This improvement not only makes commuting smoother but also encourages greater use of public transit, reducing traffic congestion and environmental impact. Consequently, enhanced public transit can boost urban residents' mental well-being and quality of life by alleviating daily commuting stress.

Additionally, emergency responders could navigate complex urban environments more swiftly, potentially improving their response times. Tourists exploring unfamiliar cities could find it easier to navigate and discover points of interest, enhancing their travel experience.

Moreover, in educational settings, students and researchers could benefit from more engaging and accurate geographical tools, fostering a deeper understanding of spatial relationships and geographic concepts. Generally, it can be claimed that vario-scale technology enhances the functionality and usability of maps for every application it is used for, due to its profound capabilities.

By examining ways of enhancing the usability of digital maps through vario-scale technology, this research has the potential to contribute to improved societal efficiency, environmental sustainability, safety, and knowledge dissemination.

2 Theoretical Background and Related Work

2.1 Vario-scale Maps

Vario-scale maps represent a significant advancement in the field of Cartography, particularly in the realm of digital map visualisation and usability. These maps are designed to provide users with a seamless zooming experience, avoiding the common disruptions encountered with multi-scale maps. Central to this technology are the sophisticated data structures that enable continuous generalisation of map features, crucial for a smooth transition across different scales.

The concept of vario-scale maps was fundamentally advanced by P. van Oosterom and Meijers (2011), who introduced the tGAP (topological Generalised Area Partition) and SSC (Space Scale Cube) structures. These innovations represent a leap in handling continuous map generalisation, allowing maps to dynamically adjust detail and complexity according to user interaction (Oosterom, 2005). The tGAP model is particularly effective in minimising data redundancy while ensuring that both detailed and generalised versions of map features are readily accessible. This is achieved through a strategy where less important features are incrementally simplified based on a global criterion, and all changes are recorded in a database that supports scalable data retrieval (Oosterom, 2005; P. van Oosterom & Meijers, 2011). Moreover, the SSC, as a translation of tGAP in a 3D structure (2D+scale), conceptualises each terrain feature as a polyhedron within a volumetric space. This spatial arrangement allows for effective slicing at various altitudes to produce horizontal map slices that correspond to different levels of detail. By adjusting the slicing plane within the SSC, a smooth zoom effect is created, which simulates a continuous zooming capability (Šuba, 2017).

2.2 Eye-tracking in Usability Research

In recent studies, eye-tracking technology has increasingly demonstrated its robust capacity for enhancing our understanding of human-computer interaction and usability research, particularly in the context of map usability studies. Eye-tracking systems meticulously record eye movements, capturing crucial metrics such as saccades and fixations that indicate cognitive processing and visual attention (Strandvall, 2009). Rayner (1998) further underscores the importance of fixations in interpreting visual stimuli, providing a scientific basis for observing user behaviour through eye movements.

The integration of eye tracking in usability testing, particularly using think-aloud methods, has revealed varied applications depending on the task characteristics and interactivity required (Røsand, 2012). Figure 2 provides an illustration of a typical eye-tracking setup. Pernice and Nielsen (2009) highlight the additional dimension that eye tracking brings to traditional usability studies, allowing for a deeper, more intuitive understanding of user engagement and preventing common errors such as premature interruption during testing.

Moreover, Just and Carpenter (1976)'s exploration into the cognitive implications of eye fixations reveals the potential to dissect the processing stages within trials, enhancing the granularity of usability assessments. In cartographic research, the use of eye tracking is pivotal in studying how users interact with maps and geospatial displays. Fairbairn and Hepburn (2023) discuss the evolution of methodologies within this domain, emphasising the role of eye-tracking in understanding user interactions with maps, the selection of appropriate eye-tracking equipment, and the analysis of output data.

Krassanakis (2011) highlights the value of eye tracking for investigating visual perception and search in Cartography, underscoring the need to analyse cognitive processes triggered by map elements during map reading tasks. This approach is complemented by Wenclik and Touya (2024)'s exploration of saliency models that predict initial gaze behaviour in response

Figure 2: A screen-capture of a heatmap generated using RealEye. The heatmap shows the areas of the vario-scale map that attracted the most attention.

to salient map objects, suggesting a direction for future research into the visual attributes that attract attention.

In summary, the convergence of eye-tracking technology with usability testing methodologies offers a profound toolset for enhancing the effectiveness and efficiency of map usability studies. This blend not only enriches our understanding of user interactions with complex visual stimuli but also refines the process of interface design, ensuring that maps effectively meet their intended usability goals. The ongoing development and application of mixed-method approaches in this field, as suggested by Fairbairn and Hepburn (2023), ensure a comprehensive assessment of usability by integrating diverse data sources and analytical techniques. It is clear that in the context of usability research, eye-tracking technology offers a precise method for assessing how users interact with various interfaces, providing insights into their visual attention and cognitive processes. This technique involves defining specific tasks that users must perform, which are then analysed to evaluate both the quality and speed of task execution. These tasks are carefully designed to simulate real-world usage scenarios, allowing researchers to gather data on performance efficiency and the effectiveness of design elements in facilitating user goals. User satisfaction is gauged through post-task questionnaires, capturing subjective responses to the interface's usability. For data analysis, sophisticated tools such as heat maps, gaze plots, and fixation metrics are employed. These tools help identify patterns in eye movement and attention allocation, which are crucial for interpreting user interaction dynamics and refining interface design to enhance overall user experience.

2.3 Dynamic Labeling

The dynamic labelling of interactive maps is a pivotal aspect in enhancing user experience. Recent advancements underscore the importance of an effective labelling scheme that accommodates both areas and points of interest across varying scales (Krumpe, 2020). Krumpe (2020) highlights the challenges associated with naive label reduction strategies during map zooming, which often result in uneven label distribution across densely versus sparsely populated regions. This issue is addressed by adopting a 'relative importance' strategy to ensure that essential labels in less populated areas are retained, thus maintaining a balanced informational perspective across the map.

Further exploring the cognitive aspects of map navigation, Couclelis, Golledge, Gale, and Tobler (1987) discuss the anchor-point hypothesis, which assumes that certain geographical features serve as cognitive anchors in mental maps, facilitating spatial orientation and regional structuring. This theory complements the dynamic labelling process by suggesting that certain labels could act as anchor points, enhancing the memorability and navigational ease of maps. Krassanakis, Lelli, Lokka, and Nakos (2013) extend this idea into the realm of topographic maps, emphasising the need for salient locations that capture user attention and contribute to effective map design. The concept of pan-scalar anchors, as discussed by Gruget, Touya, Potié, and Muehlenhaus (2024), further enriches this perspective by illustrating how certain cartographic elements remain salient across various zoom levels, aiding in self-localisation during map navigation.

Dynamic label placement (Figure 3) is another critical component discussed by Been, Daiches, and Yap (2006) and Schwartges (2015), who argue for the need to maintain label consistency across different scales and interactive map manipulations. They emphasise the importance of avoiding label flickering and jumping during transitions, which can disrupt user orientation and degrade the usability of the map. Their approach involves sophisticated algorithms that prioritise labels based on their importance and manage their visibility across scale transitions smoothly. Gemsa, Nollenburg, and Rutter (2011)'s work on sliding labels for dynamic point labelling adds another layer to this discussion by addressing the technical challenges associated with maintaining label size and visibility during map zooming. This approach ensures that labels do not overlap or clutter as the map scale changes, thereby preserving the user's cognitive load and facilitating easier interpretation of the map's contents.

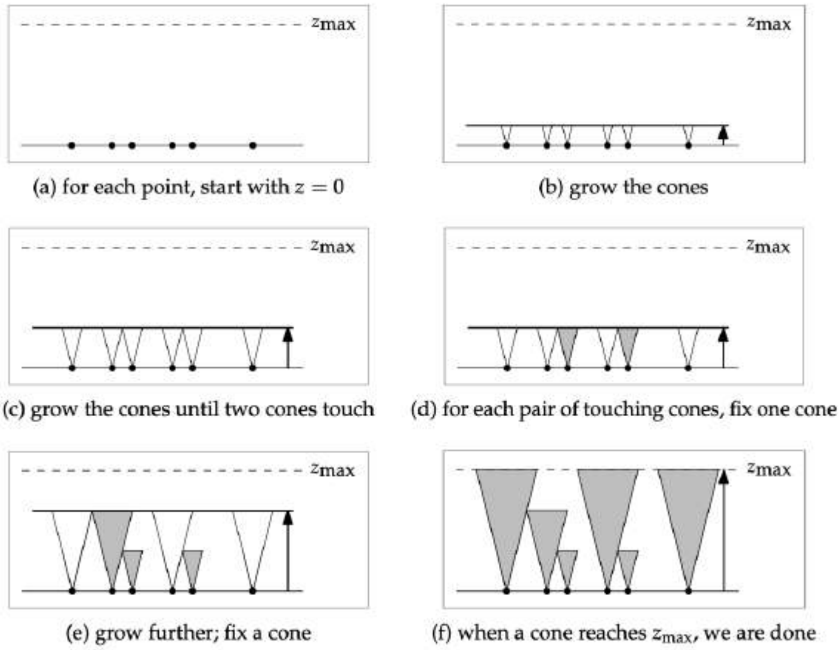


Figure 3: Illustration of the growing-cones heuristic for optimising active ranges in point feature labelling. (Figure from (Schwartges, 2015))

2.4 Cartographic Map Usability Studies

The domain of usability studies in map applications has seen a variety of approaches aiming to enhance user interaction through optimised map zoom and pan functions. These functions are crucial as they determine how users magnify, reduce, or shift the view of a map without altering its scale, which has a direct impact on user experience (You, Chen, Liu, & Lin, 2007). The development of vario-scale maps addresses some of these user interaction challenges by providing smoother transitions between various scales, thereby maintaining user orientation and reducing cognitive load during navigation (Šuba, 2017).

User profiling is a critical initial step in usability studies, ensuring that research encompasses a broad spectrum of user backgrounds, as highlighted by Šuba (2017), who emphasise the importance of accommodating a diverse range of users to better understand the universal applicability of map interfaces. Furthermore, the evaluation methodologies, such as field usability tests, highlight the significance of maintaining a 'mental link' between map displays during navigation tasks (Van Elzakker, Delikostidis, & Van Oosterom, 2008).

Additionally, the research on public usability testing of web-based systems by P. J. M. van Oosterom, Cemellini, and Thompson (2019) provides a framework for assessing the effectiveness, efficiency, and satisfaction, which are crucial metrics in the ISO standards for usability (International Organization for Standardization (ISO), 2018; P. J. M. van Oosterom et al., 2019). These metrics are essential for evaluating whether users can achieve their navigation goals effectively and with minimal effort, which is particularly relevant in the context of dynamic, interactive map applications.

The concept of vario-scale maps is further explored in a previous usability test where it is compared with multi-scale (Šuba, 2017). Twenty-four participants were given a task to zoom out from the starting location and then find their original location again. The study did not find significant differences between multi-scale and vario-scale in efficiency or user experience. This study, however, is based on one type of highly specific and controlled task on a thematic background map. A more detailed usability study, involving a range of realistic map tasks, and the addition of insight into cognitive processes using eye-tracking data, has the opportunity to reveal further insights into the usability of vario-scale maps and the relation to multi-scale maps. This is the aim of this thesis.

3 Research Objectives

Main Research Question

To what extent do vario-scale maps improve user interaction and satisfaction compared to multi-scale map interfaces?

Sub-questions

1. *How can cartographic principles be applied to develop effective vario-scale map prototypes?*
2. *What features, functionalities and settings (e.g. zooming and panning speed) are most critical to include in these prototypes to enhance user interaction?*
3. *How can the features and functionalities of vario-scale maps be optimised to improve user satisfaction and usability?*
4. *How does the vario-scale approach affect user performance and satisfaction in map-use tasks compared to multi-scale maps?*

3.1 Scope of Research

The primary scope of this thesis is to conduct a comprehensive usability study of the vario-scale mapping approach. This involves modifying prototypes based on cartographic principles and evaluating their usability through realistic map-use tasks performed by participants. Using advanced tools such as eye-tracking and screen-logging software, the study aims to capture detailed user interaction and cognitive processes, focusing on ease of use, user satisfaction, and interaction effectiveness. Additionally, the research aims to compare vario-scale maps with other dynamic mapping technologies, specifically the multi-scale approach, to assess their relative advantages and disadvantages. This broader investigation will provide valuable insights into the performance of vario-scale maps in relation to other interactive mapping solutions, ultimately contributing to the evolution of dynamic digital vario-scale mapping.

While this thesis investigates the usability of vario-scale maps, it does not encompass the development of new vario-scale algorithms or technical advancements in map generation. It will not focus on the technical implementation details of the vario-scale data structure beyond what is necessary for usability testing. Additionally, the study will not explore other forms of dynamic mapping technologies in-depth, such as multi-scale maps, except for the purpose of comparative usability analysis. Furthermore, the thesis will not delve into extensive field tests or long-term studies of vario-scale map usage in real-world applications beyond the controlled environment of the lab. Thus, it will not include testing how vario-scale maps perform in outdoor navigation scenarios. It will also not involve longitudinal studies to observe how users adapt to vario-scale maps over weeks or months, nor will it assess the maps' effectiveness in diverse environmental conditions. The focus remains on controlled usability testing within the lab setting, where immediate feedback and detailed interaction data can be collected and analysed.

4 Methodology

Overview

The ultimate goal of this thesis is to evaluate user satisfaction and the usability of vario-scale interactive maps, subsequently comparing them with multi-scale maps to determine which of the two approaches is more effective. To achieve this, a professional eye tracker was decided to be deployed to gain detailed insights into users' gaze patterns and how they experience the two types of maps. Eye-tracking technology offers the possibility to gather actual data on user interactions, providing a deeper understanding of usability aspects that might not be evident through observation alone.

However, the deployment of an eye tracker is a rather complex endeavour. It requires on-site testing, as participants need to be physically present to use the equipment. Recruiting participants is also a significant challenge. Understanding the complexities and the weight of integrating eye-tracking technology, especially given the inexperience in usability studies at the time, conducting a preliminary pilot study emerged as a necessary step. This approach would allow for a gradual immersion into the methodology, providing an opportunity to refine the study design before the final execution.

4.1 Pilot Study

The benefits of conducting a pilot study were immediately apparent. It would enable to become familiar with the tools and methodologies associated with usability testing, develop the mindset required for such studies, and create meaningful tasks that would effectively test the features of the maps. Additionally, it provided a chance to experiment with designing a pleasant user interface (UI) that ensures clear communication with the user. This would also be an opportunity for skills in web Cartography to be tested, ensuring that the map prototypes used in the study were functional and engaging.

The pilot study was designed to focus solely on the vario-scale approach. The primary aim was to explore the settings and features developed for vario-scale maps, evaluating user satisfaction and task completion effectiveness in relation to specific parameters. These parameters included the zooming speed used in the map, the duration of the panning animation, the symbols and place names placed on the map, and the overall communication of the map through its colours and labelling, following rules of Cartography. By testing these elements, the pilot study would provide insights into the most preferred and effective settings for the vario-scale map, which would then inform the design of the final study incorporating eye-tracking technology.

Conducting this initial pilot study was a crucial milestone in the overall planning of the thesis methodology. It necessitated an extensive literature review, not only on usability testing but also on eye-tracking studies. Papers and books on how to best conduct a usability study were consulted, discussions with experts in usability studies were held, and literature on dynamic label placement in maps and projects related to web Cartography, particularly in terms of user satisfaction and overall usability was reviewed. This comprehensive preparation was essential to gain a solid understanding of the challenges involved in testing web maps with users and to identify key features that required focused attention to design an effective study.

One of the significant challenges identified through this review was the issue of label placement on dynamic maps. Unlike traditional static maps, where labels are placed immovably following predefined hierarchical rules, dynamic interactive maps require labels to appear and disappear based on the map's scale and level of detail. This dynamic behaviour introduces complexities in maintaining the hierarchical nature of labels, avoiding interference with other map features, and ensuring readability at various zoom levels. Optimising label placement in dynamic maps is particularly important in navigation applications, where clarity and ease of use are paramount.

During the thesis, a very insightful meeting with Professor Mark Neerincx, who specialises in Human-Centred Computing, focusing on human-computer interaction and the cognitive engineering of electronic partners, was held. His expertise in usability studies and human-computer interaction provided valuable insights into the setup of the pilot study. Through our discussion, he helped identify key points in the study design, prompting to reconsider some of the initial decisions regarding the organisation of the study. This consultation was instrumental in setting a solid baseline for the overall setup of the pilot study, ensuring that it would be methodologically sound and effective in achieving its objectives.

4.1.1 Design and Development of the Pilot Study

The pilot study can be viewed at: `https://eirinitsipa.github.io/varioscale-usability-pilot-study/`

A crucial decision in the design of the pilot study was the selection of the base map to be used. Initially, the entire map of the Netherlands (Figure 4) was considered to be used, with the thought that it would provide a comprehensive canvas for testing. However, this approach posed significant challenges. Using such a large area would require extensive effort in hierarchical label placement across numerous municipalities, villages, and hamlets, based on their population sizes—a task that would be extremely labour-intensive and beyond the scope of the pilot study. Secondly, due to the size of the map of the entire Netherlands loading times were involved, which could have implications for the experience of the participants.

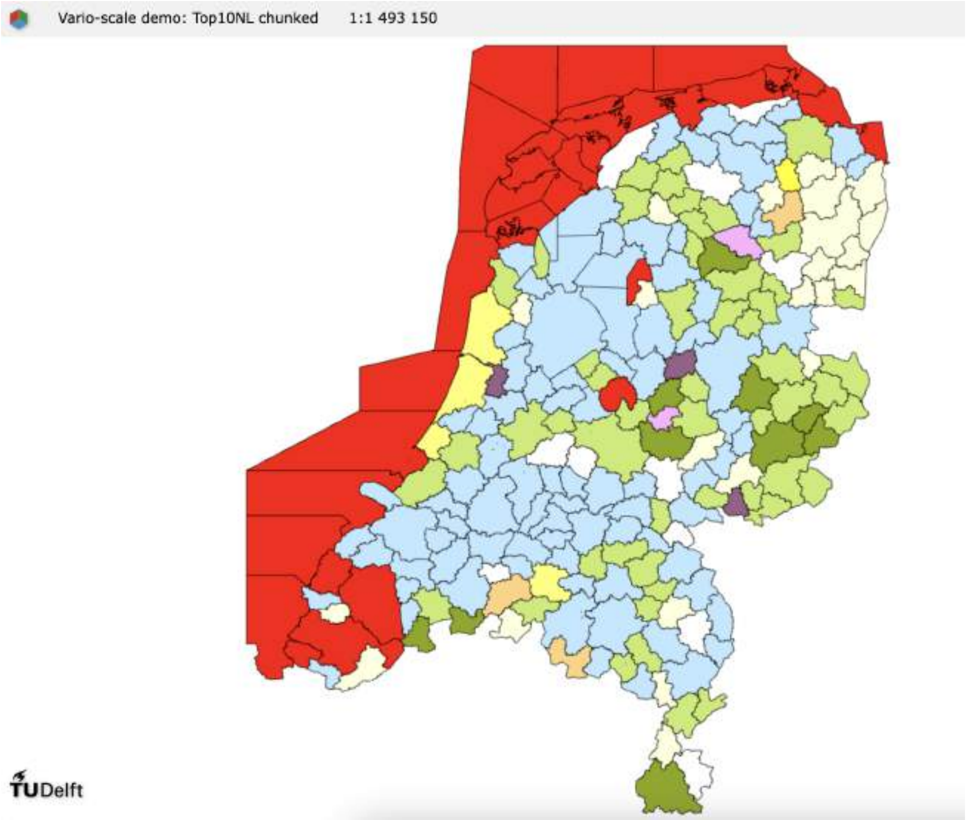


Figure 4: Screen capture of vario-scale prototype "Whole Country (The Netherlands), chunked SSC" developed in the TU Delft GDMC Lab.

Therefore, the focus was decided to be on a smaller area, which would still be representative but more manageable. After exploring existing vario-scale map prototypes developed by the

TU Delft's GDMC group, I selected the "Limburg 9x9" (Figure 5) map as the base for the pilot study. This map covers a 9×9-kilometre area focused on the region around Margraten in the Eijsden-Margraten municipality. It is a thematic map featuring line features and land use polygons derived from the Basisregistratie Topografie (BRT) TOPNL, TOP10NL dataset. This map was suitable because it provided a rich dataset for testing while being of a manageable size for the purposes of the pilot study.

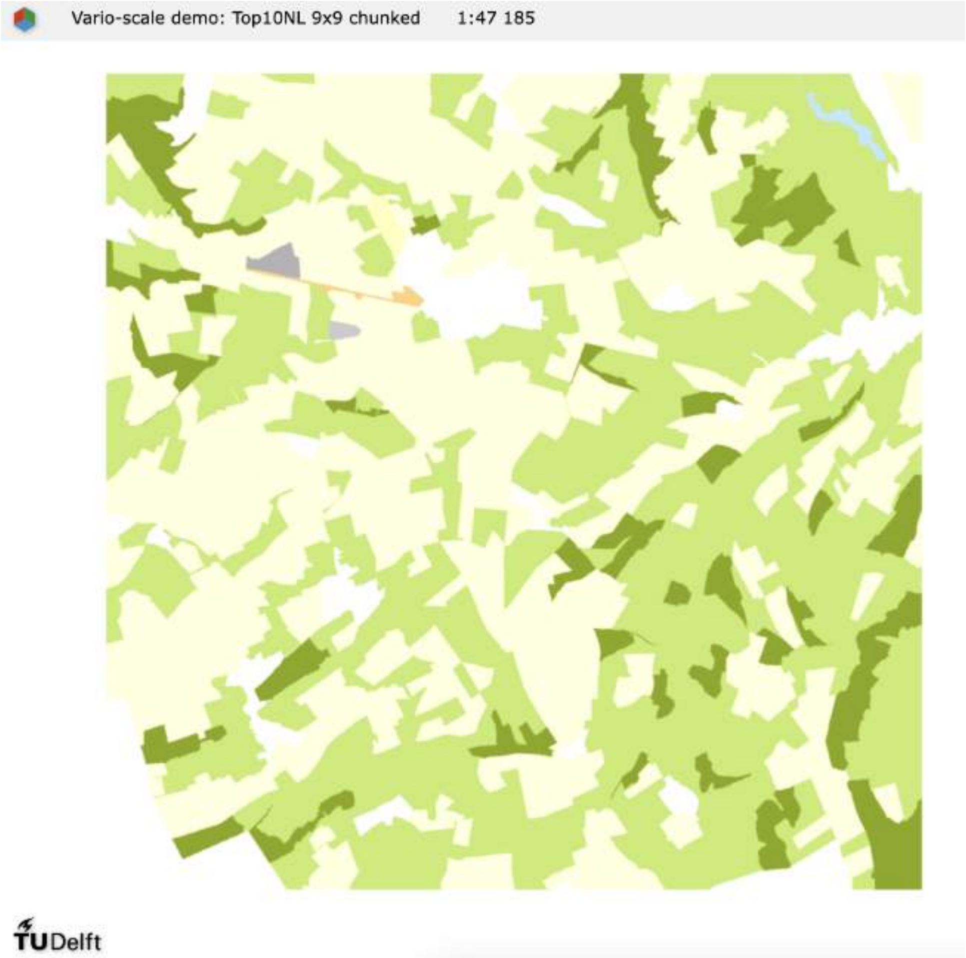


Figure 5: Screen capture from vario-scale prototype "Limburg 9x9 km, first try on chunking SSC" developed by the TU Delft GDMC Lab.

The selected base map required further enhancement to suit the needs of the study. Specifically, it needed labelling and the inclusion of points of interest (POIs) to serve as targets in the tasks designed for the participants. The inclusion of POIs such as cafés, castles, and other landmarks would provide engaging elements for the tasks, making them more realistic and relatable.

An important aspect of the map enhancement involved the placement of labels and the creation of a hierarchical labelling system. In dynamic maps, label placement loses the static character of traditional maps, as labels need to appear and disappear dynamically based on the zoom level and map scale. This requires careful consideration to maintain the hierarchical structure and readability. The challenge lies in selecting which labels should be visible at each scale, ensuring that larger cities and towns appear at higher zoom levels, while smaller villages and landmarks become visible as users zoom in. Additionally, it is crucial to avoid label collisions and interference with other map features, preserving the overall readability and usability of the map.

To address this, a hierarchical approach to label placement was utilised. The labels for place names (Figure 6) were added in a way that larger municipalities were labelled with a larger font size and a contrasting blue colour, making them prominent at smaller scales. Villages were labelled with a standard font size and black colour, while hamlets were labelled in all capitals with a smaller font size, using a condensed version of the font to differentiate them further. The label origin was placed at the centre of each respective location, ensuring consistency.

Figure 6: Resulting map from adding labels to the Limburg 9x9 map.

For the text labels, the Altinn-DIN font family was used. This font is an open-source version of the DIN font, which combines high legibility with a simple design and offers regular, bold, and condensed variations. The regular version was used for the villages and the municipality labels, while the condensed version was used for the hamlets, as mentioned previously. This choice of font and styling aimed to enhance readability and convey the hierarchical relationships between different place names effectively.

In addition to place names, symbols representing points of interest were added to the map (Figure 7). After exploring the region on web maps such as Google Maps and Apple Maps, several POIs were selected to be included in the prototype. These included:

- **The American War Cemetery and Memorial in Margraten**: Represented with a cross symbol.
- **Seminarie Redemptoris Mater Roermond**: Depicted with a castle icon, serving a specific purpose in one of the tasks.
- **Local Café**: Indicated with a standard café symbol.

These symbols were intended to enrich the map's informational content and provide relevant elements for the tasks. The FontAwesome icon set was used for the POIs, leveraging its

Figure 7: Resulting map after adding symbols to the Limburg 9x9 map.

representation of icons as Unicode characters. By generating multi-channel signed distance field (MSDF) data using the GPUText program, these symbols could be efficiently rendered on the map as font characters, suitable for fast GPU processing.

A design decision was to omit certain map accessories, such as the north arrow, since the map does not rotate and it was considered generally intuitive that the map's orientation is north-facing by default. Additionally, no legend was provided to the users. This was intentional, as it was desired to assess how well the map communicated its information through colours and symbols without explicit explanations. This would test the participants' ability to interpret the map's visual cues intuitively.

To enhance participant engagement, special attention was given to creating an appealing website design and ensuring a smooth user experience. This included implementing consistent CSS styling, using readable URLs, adding page titles on the browser tab, and including a favicon. These elements aimed to make the interface professional and user-friendly, encouraging participants to engage with the tasks.

The next critical step was developing the tasks that participants would be asked to complete. These tasks were designed to test different features of the vario-scale map separately, including the panning animation duration, zooming speed, symbol usage, and the map's overall communication through colours and labels. The tasks needed to be meaningful, engaging, and reflective of real-world scenarios in which users might interact with such maps.

To facilitate the study, it was decided to present the tasks through a website hosted through GitHub Pages. This approach allowed for easy distribution of the study to participants, who could access it simply by clicking on a link. Upon accessing the study, participants landed on a welcome page (Figure 8) that provided a brief explanation of the study's aim, rules, disclaimers, and details regarding task execution. A "Start" button at the end of the page invited them to commence the study. Each subsequent page included a page count indicator, allowing participants to track their progress and anticipate the study's length. The estimated completion time was communicated upfront as 10 to 15 minutes to set appropriate expectations.

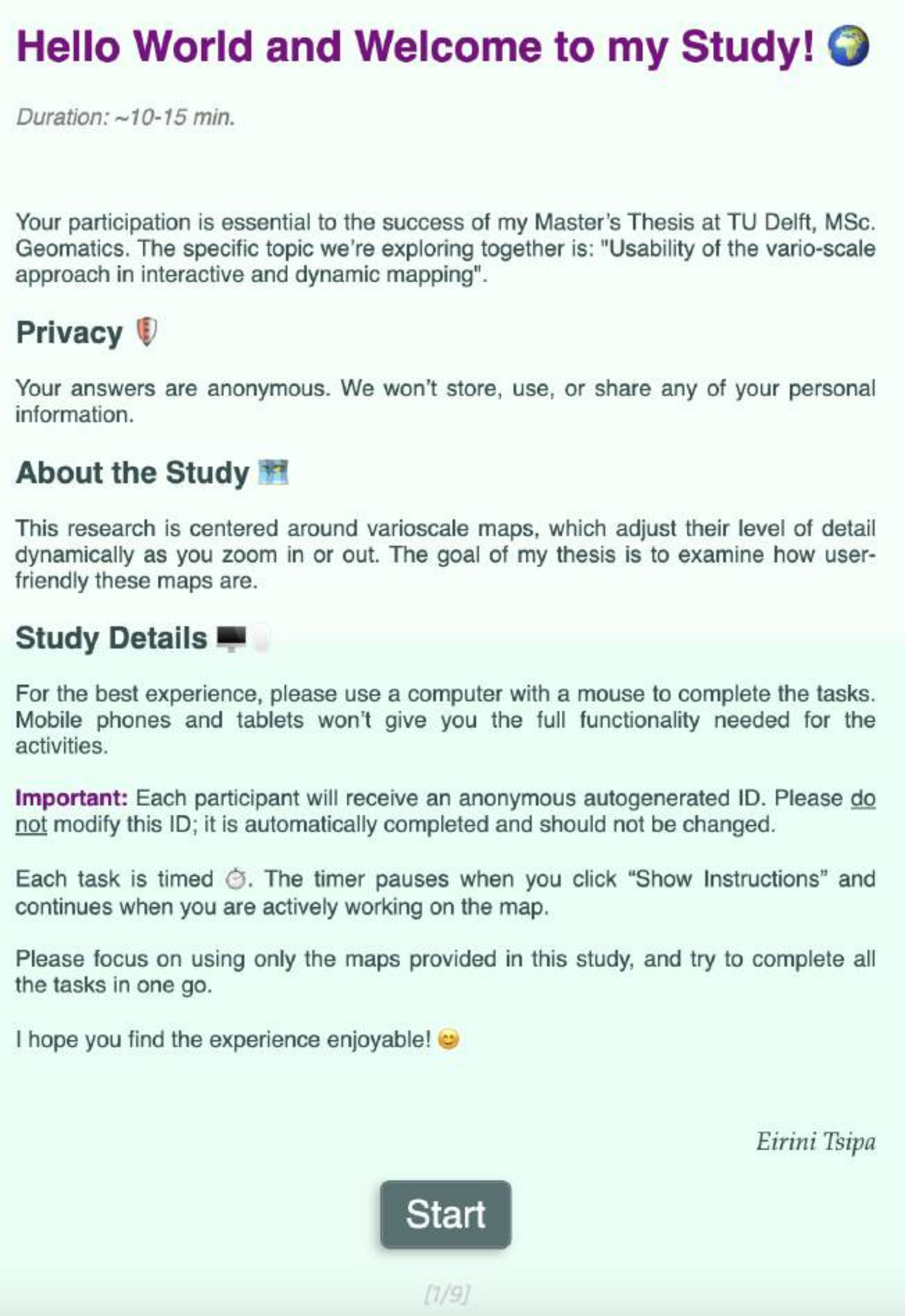
4.1.2 Task Development

Before beginning the tasks, participants were asked to complete an introductory questionnaire via Google Forms. The aim was to gather demographic information and insights into their familiarity with technology and web maps. Questions addressed their age group, proficiency with technology, background in Cartography, familiarity with web maps, frequency of web maps use, and the most common reasons for using web maps. Additionally, they were asked about the device they were using to execute the tasks. It was emphasised that the tasks were designed to be completed on a computer using a mouse or trackpad, rather than on a touchscreen device, to ensure compatibility with the map's functionality.

An important consideration was maintaining the anonymity of the participants. The study was designed to be completely anonymous if the participant desired, allowing them to provide honest feedback without feeling the need to suppress their thoughts or impressions. This approach was considered good practice, as it encourages candid participation.

To test the different parameters of the vario-scale map, task variations were developed. For instance, to determine the most preferred and effective zooming speed, three different zooming speeds were tested: slow, medium, and fast. Participants were randomly assigned to one of these variations. This randomisation ensured that the distribution of tasks among participants was fair and unbiased, preventing any skewing of results due to a particular variation being more prevalent.

Similarly, for testing the panning animation duration, three variations were tested: no panning animation, medium duration, and long duration. Again, participants were randomly assigned to one of these variations to ensure a fair distribution and to avoid biases. By comparing



Hello World and Welcome to my Study! 🌍

Duration: ~10-15 min.

Your participation is essential to the success of my Master's Thesis at TU Delft, MSc. Geomatics. The specific topic we're exploring together is: "Usability of the vario-scale approach in interactive and dynamic mapping".

Privacy 🛡

Your answers are anonymous. We won't store, use, or share any of your personal information.

About the Study 🗺

This research is centered around varioscale maps, which adjust their level of detail dynamically as you zoom in or out. The goal of my thesis is to examine how user-friendly these maps are.

Study Details 🖥

For the best experience, please use a computer with a mouse to complete the tasks. Mobile phones and tablets won't give you the full functionality needed for the activities.

Important: Each participant will receive an anonymous autogenerated ID. Please do not modify this ID; it is automatically completed and should not be changed.

Each task is timed ⏱. The timer pauses when you click "Show Instructions" and continues when you are actively working on the map.

Please focus on using only the maps provided in this study, and try to complete all the tasks in one go.

I hope you find the experience enjoyable! 😊

Eirini Tsipa

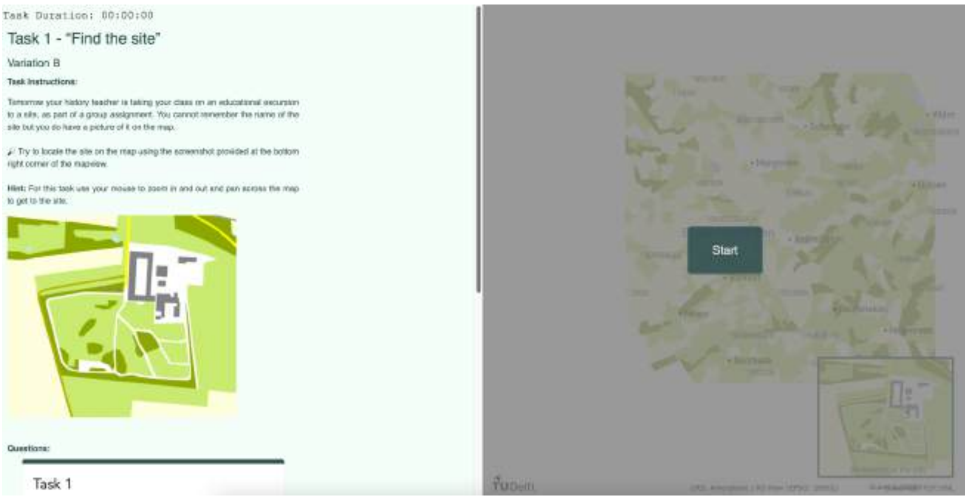
Figure 8: Screen capture of the welcome page of the pilot study.

the performance and feedback across these variations, insights could be gained into the most effective settings for the map's interaction features.

Regarding the communication of the maps and the effectiveness of icons placed on the map, the first task of the study tested this aspect. Two variations of this task were created: one with icons placed on the map and one without icons. By comparing the performance and feedback of participants across these variations, insights could be gained into the effectiveness of symbols in aiding task completion.

Task 1: Find the Site

In this task (Figure 9), participants got the role of a student tasked with locating a specific site on the map. A reference image of the site was provided in the bottom right corner (Figure 10) of the map view, maintaining its position throughout the whole task. Participants navigated the map by zooming in and out and panning across the area to identify the location that matched the reference.



Task Duration: 00:00:00

Task 1 - "Find the site"

Variation B

Task Instructions:

Tomorrow your history teacher is taking your class on an educational excursion to a site, as part of a group assignment. You cannot remember the name of the site but you do have a picture of it on the map.

Try to locate the site on the map using the screenshot provided at the bottom right corner of the mapview.

Hint: For this task use your mouse to zoom in and out and pan across the map to get to the site.

Questions:

Task 1

Figure 9: Screen capture of the interface of task 1 of the pilot study. The left side shows the instructions and the right side the map with a button to start the task.

This task aimed to assess the effectiveness of the map's communication through symbols and whether the inclusion of icons aided in task completion. By comparing completion times and participant feedback between the variation with icons and the one without, it was possible to determine the impact of symbols on user efficiency and satisfaction.

After locating the site (Figure 11), participants returned to the toggle drawer to submit their responses via a Google Form, providing the time taken, the task variation, and the name of the site to verify successful completion. They were reminded multiple times to ensure they submitted the form, including a pop-up window that appeared before they could proceed to the next page. This was necessary as it was not possible programmatically to verify the submission of the form.

Task 2: Find Your Classmate's House

Participants were instructed (Figure 12) to find their classmate's house, represented by an orange symbol in the southern part of the map (Figure 13). They navigated using zoom and pan functions, paying particular attention to the zooming experience - a focus of this task. The symbol they were looking for was only visible after a certain zoom level (scale 1:5600), requiring participants to utilise the zoom function effectively.

This task evaluated participants' preferences and effectiveness concerning different zooming speeds. By assigning different zoom speeds randomly to participants, it was possible to compare the time taken and the ease with which participants completed the task across the different

Figure 10: Screen capture of the interface of task 1 of the pilot study after the task execution has been started. The bottom right shows the reference image of the site.

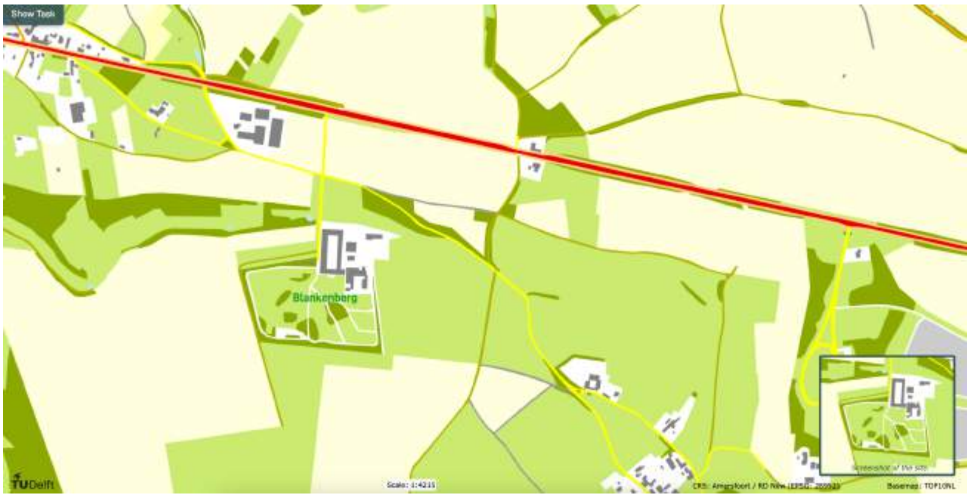
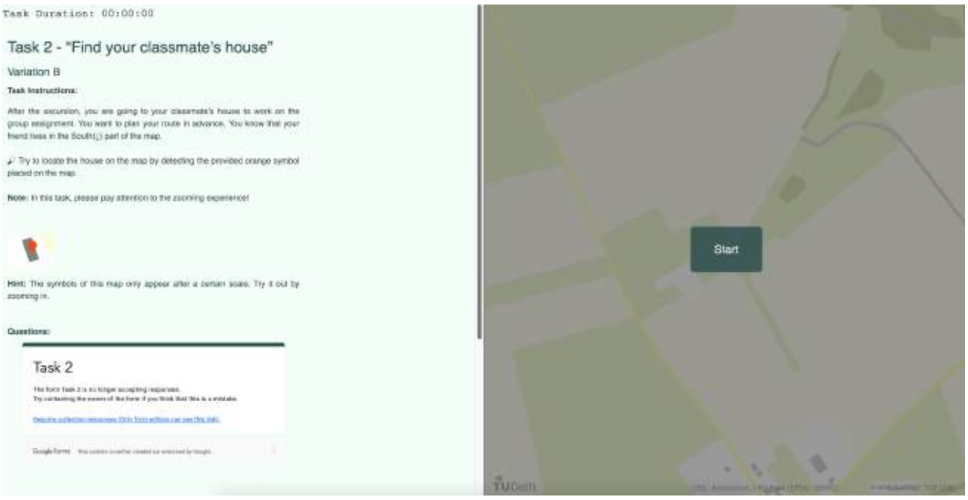


Figure 11: Screen capture of a zoomed in part of the map after the site has been located.



Task Duration: 00:00:00

Task 2 - "Find your classmate's house"

Variation B

Task Instructions:

After the excursion, you are going to your classmate's house to work on the group assignment. You want to plan your route in advance. You know that your friend lives in the South(!) part of the map.

Try to locate the house on the map by detecting the provided orange symbol placed on the map.

Note: In this task, please pay attention to the zooming experience!

Hint: The symbols of this map only appear after a certain scale. Try it out by zooming in.

Questions:

Task 2

Figure 12: Screen capture of the interface of task 2 of the pilot study. The left side shows the instructions and the right side the map with a button to start the task.

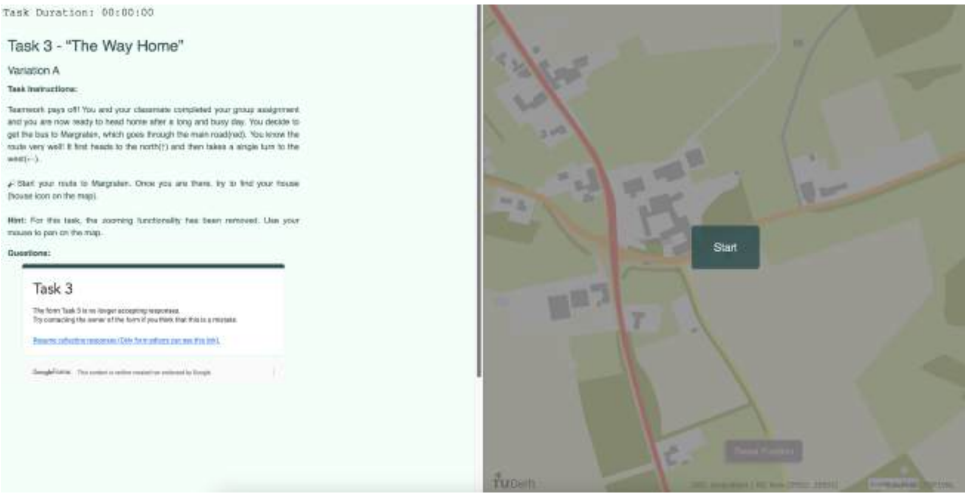
variations.

Figure 13: Screen capture of the zoomed in map after the classmate's house has been located.

Similar to Task 1, participants submitted their completion time, task variation, and the town where the house was located to confirm task completion. A feedback questionnaire followed, asking participants about any difficulties encountered, their opinion on the zoom speed, and suggestions for improvement.

Task 3: The Way Home

In the final task (Figure 14), participants planned a bus route to Margraten, following a red main road that went north and then west. They were asked to locate their own house, marked with a house icon in the village of Margraten (Figure 15). This task differed from the previous ones as the zooming functionality was disabled; participants could only use panning to navigate.



Task Duration: 00:00:00

Task 3 - "The Way Home"

Variation A

Task Instructions:

Teamwork pays off! You and your classmate completed your group assignment and you are now ready to head home after a long and busy day. You decide to get the bus to Margraten, which goes through the main road(red). You know the route very well! It first heads to the north(↑) and then takes a single turn to the west(←).

Start your route to Margraten. Once you are there, try to find your house (house icon on the map).

Hint: For this task, the zooming functionality has been removed. Use your mouse to pan on the map.

Questions:

Task 3

The form Task 3 is no longer accepting responses.
Try contacting the owner of the form if you think that this is a mistake.

Figure 14: Screen capture of the interface of task 3 of the pilot study. The left side shows the instructions and the right side the map with a button to start the task.

To accommodate potential disorientation due to the lack of zoom and varying panning speeds, a "Reset Position" button was provided to return to the starting point. The timer did not reset with the position, ensuring that the time recorded reflected the total time spent on the task.

This task aimed to evaluate the impact of different panning animation durations on user experience and efficiency. By comparing performance across variations with no panning

Figure 15: Screen capture of the map after the house icon has been located in the village of Margraten.

animation, medium duration, and long duration, insights could be gained into how panning animations affect navigation and user satisfaction.

Participants reported their completion time, task variation, and the colour of the house icon to verify successful task execution in a Google Form. A feedback questionnaire followed, focusing on their experience with the panning functionality.

4.1.3 Questionnaires and Feedback Collection

After each task, participants completed a feedback questionnaire to capture their immediate impressions and any difficulties they encountered. The questionnaires aimed to gather both quantitative data, such as ratings of task difficulty, and qualitative data, such as open-ended comments and suggestions.

Questions included:

- **Difficulties Encountered**: Participants could describe any issues they faced during the task.
- **Clarity of Instructions**: They were asked to rate how clear and understandable the instructions were.
- **Task Difficulty Rating**: A scale was provided for participants to rate the difficulty level of the task.
- **Additional Comments**: An open-ended section allowed participants to provide further thoughts or suggestions.

These questionnaires were placed immediately after each task to ensure that participants' feedback was fresh and accurate. The responses would be crucial in identifying areas for improvement in the task design and instructions.

4.1.4 Execution of the Pilot Study

Before distributing the study widely, it was tested with a small group of participants to identify and rectify any technical issues or ambiguities in the instructions. This testing phase was crucial to ensure that the study ran smoothly and that participants could complete the tasks without encountering significant obstacles.

Feedback from the test participants led to improvements in clarity and functionality. For example, adjustments were made to the wording of instructions, the placement of buttons, and the functioning of the timer and pop-up reminders. Ensuring that the study was user-friendly and free of technical glitches was essential for obtaining reliable data.

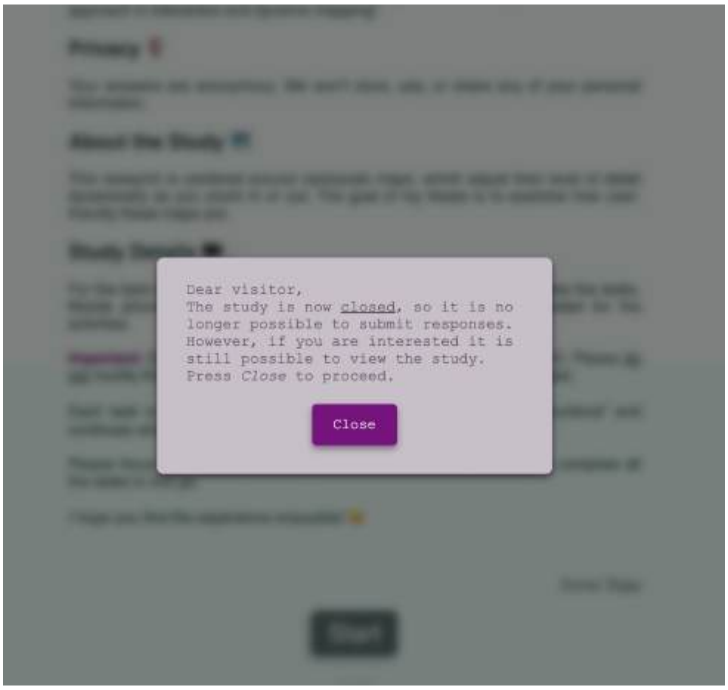
The study was then shared with a wider audience through various channels:

- **Social Media Outreach**: The study link was shared on platforms like LinkedIn, aiming to reach professionals and students interested in Cartography and GIS.
- **Email Invitations**: Emails were sent to contacts who might be interested or who could share the study within their networks.
- **Personal Requests**: Geomatics students were approached during lab hours and encouraged to participate.
- **Supervisor Networks**: Supervisors and colleagues assisted by sharing the study with their contacts and within relevant communities.

This approach aimed to reach a diverse group of participants, ensuring a variety of backgrounds, ages, and levels of familiarity with technology. The study was open for completion for 15 days. During this time, received:

- **85 submissions** for the introductory questionnaire.
- **55 responses** for Task 1.
- **53 responses** for the Task 1 feedback questionnaire.
- **52 responses** for Task 2.
- **49 responses** for the Task 2 feedback questionnaire.
- **56 responses** for Task 3.
- **53 responses** for the Task 3 feedback questionnaire.
- **48 responses** for the overall feedback questionnaire.

After the data collection period ended, the study remained accessible, although submissions of the Google Forms were no longer possible. Currently, a pop-up window informs potential visitors that the study is closed (Figure 16).



Dear visitor,
The study is now closed, so it is no longer possible to submit responses. However, if you are interested it is still possible to view the study.
Press *Close* to proceed.

Figure 16: Screen capture of the pop-up window that appears when trying to access the pilot study after the data collection period has ended.

4.1.5 Insights from the Pilot Study

The pilot study provided valuable insights that would inform the design of the final study incorporating eye-tracking technology. It highlighted areas where adjustments were needed, such as clarifying instructions, refining task designs, and adjusting map parameters based on participant feedback. For instance, the data collected on preferred zooming speeds and panning animation durations would help set the optimal parameters for the final study to enhance user experience.

Key findings and lessons from the pilot study include:

- **Optimising Interaction Parameters**: Participants' feedback indicated preferences for certain zooming speeds and panning durations. These preferences, combined with task completion times, provided evidence for setting these parameters in the final study.
- **Importance of Clear Instructions**: Some participants reported confusion or misunderstandings in the tasks. This underscored the need for clear, concise instructions and the provision of adequate hints or guidance.
- **Data Collection Practices**: The use of unique IDs and anonymous submissions proved effective in collecting consistent data while respecting participants' privacy.

Moreover, the pilot study underscored the importance of thorough preparation and testing in usability studies. It demonstrated that even small design decisions, such as the placement of buttons or the wording of instructions, could significantly impact participants' experiences. By addressing these in the pilot study, the design of the final study could be improved, increasing the likelihood of obtaining high-quality data.

In reflection, conducting the pilot study was an essential step in the research process. It provided a practical understanding of the challenges involved in designing and conducting a usability study involving interactive maps. It also reinforced the value of user feedback in refining the study design and highlighted the importance of considering the user's perspective at every stage of the process.

The pilot study allowed the development of a deeper understanding of vario-scale maps and the factors that influence their usability. It highlighted the complexities of dynamic label placement, the importance of intuitive map communication, and the nuances of user interaction with map interfaces.

As we moved forward to the final study, the lessons learned from the pilot guided the approach. The preferred settings identified in the pilot, such as the optimal zooming speed and panning animation duration were considered for the design of the final study. It was ensured that instructions are clear and that tasks are engaging and reflective of real-world scenarios. The aim was to create a study that not only provides valuable data but also offers a positive experience for participants.

Furthermore, the experience gained in the pilot study regarding participant recruitment, data collection, and analysis was invaluable. Understanding how to effectively reach potential participants, maintain their engagement, and manage the data ethically and efficiently could contribute to the success of the final study.

4.2 Final Study

The culmination of the pilot study and the subsequent analysis of its results led to the development and execution of the final research study, which is detailed in this chapter. The primary aim was to evaluate the usability and effectiveness of vario-scale and multi-scale map prototypes through a controlled experiment incorporating eye-tracking technology to capture detailed user interaction data. This chapter outlines the preparatory steps, the methodological approach, and the execution of the final study, ensuring a comprehensive understanding of the processes involved.

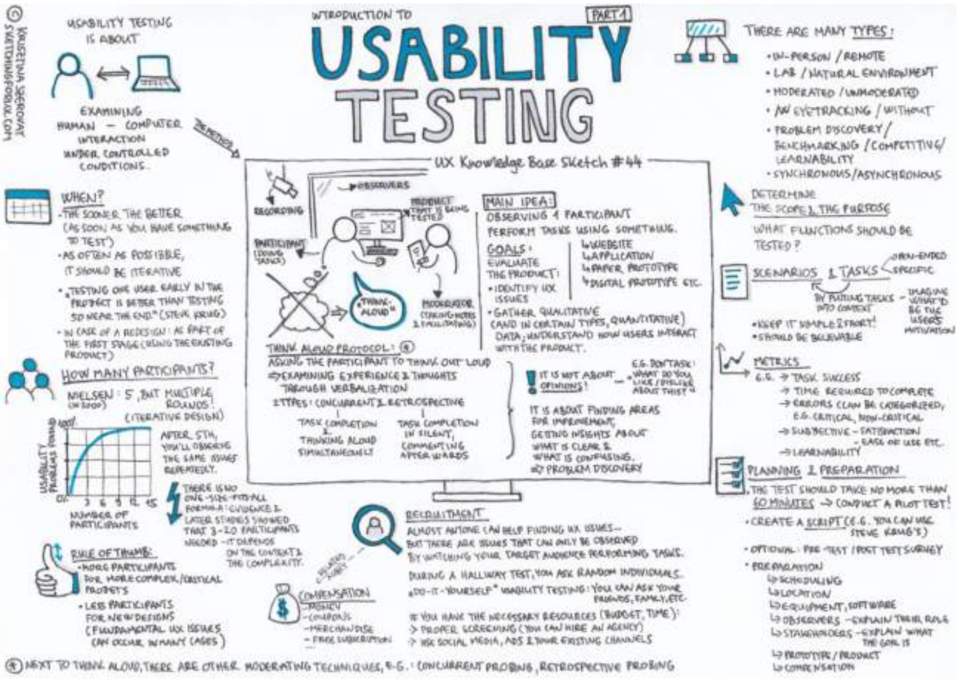


Figure 17: Descriptive infographic about usability testing that was used as a guide on how to approach usability testing. (Figure from (Szerovay, 2022))

4.2.1 Preparations and Equipment Familiarisation

To ensure the successful implementation of the study, thorough preparation was undertaken. An introductory session was provided by R. Bossink, staff from the ITC of the University of Twente, focusing on the operational handling of the eye-tracking software and hardware. This training was essential for getting acquainted with using the Tobii Pro Fusion eye tracker and the accompanying Tobii Pro Lab software, which were integral to the study's data collection methods. The eye tracker was borrowed from the University of Twente for several weeks, allowing time for experimentation and familiarisation with its various settings and capabilities.

During this period, several technical challenges were encountered and addressed. Notably, after consultation with Tobii's customer service, it was discovered that the integrated browser within the Tobii software did not support WebGL, which was necessary for the map stimuli. To circumvent this limitation, the screen recording option within the software was employed instead of the web stimulus option. The main difference between these options is that, unlike the Web Stimulus, which records mouse clicks, keystrokes, and web navigation behaviours, the Screen Recording Stimulus only captures video of the participant’s screen. While this approach allowed testing of the WebGL-based web map, it could not automatically track detailed web-specific interactions like clicks or navigation events. This adjustment ensured that participants' interactions with the web-based map applications could be effectively captured and analysed, albeit with some limitations.

Further technical considerations included the realisation that the laptop's built-in camera lacked a filter for the infrared light emitted by the eye tracker, which would result in participants' faces appearing green in the recordings. To resolve this issue, a laptop equipped with the appropriate infrared filter was deployed. This ensured that facial recordings displayed natural colours, which was important for qualitative assessments of participant engagement and comfort. Along with the eye tracker, a student licence for the Tobii Pro Lab software was obtained, facilitating the operation of the software during the study period.

The user manual of the Tobii Pro Lab software served as a valuable resource throughout this preparatory phase. It provided detailed explanations of the software's features, options, and functionalities, as well as guidelines for study design, execution, and data analysis. This knowledge informed critical decisions regarding task design, participant instructions, and the overall setup of the study. Reading the manual also proved useful in understanding the capabilities of the eye-tracking system.

4.2.2 Ethical Considerations and Data Management

Adherence to ethical guidelines and data privacy regulations was a paramount concern throughout the study. Consultations were held with the Human Research Ethics Committee (HREC) (Figure 18), a data steward, and the privacy team at Delft University of Technology to ensure compliance with institutional and legal requirements. These discussions guided the proper handling, storage, and anonymisation of participant data, particularly given the use of eye-tracking technology, which can be sensitive.

Anonymisation techniques were employed to protect participants' identities, and all collected data were securely stored on OneDrive as a backup measure, safeguarding against data loss. This approach also facilitated secure access and management of the data for analysis purposes while maintaining confidentiality and privacy. The data included map logs, recording data, and forms completed by the participants, ensuring a comprehensive dataset for subsequent analysis.

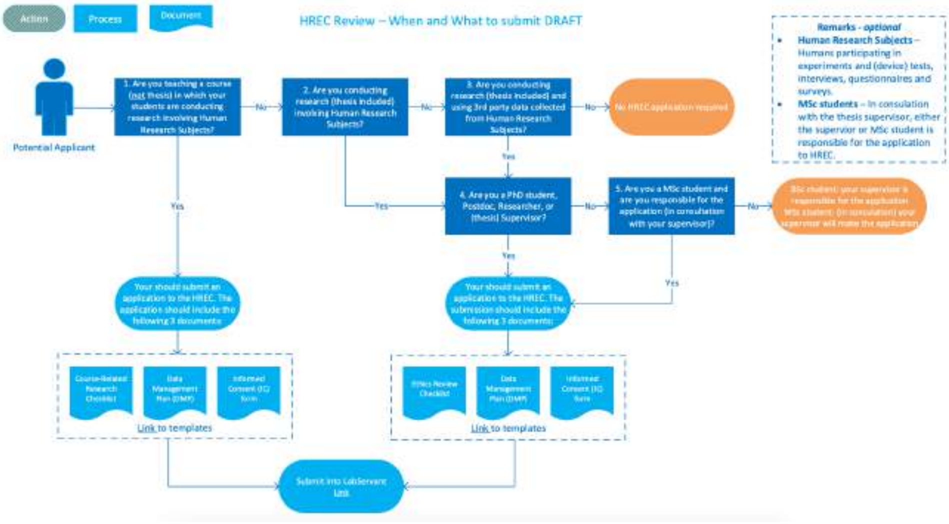


Figure 18: Flowchart of the TU Delft HREC Application Process (Figure from (TU Delft, 2024))

4.2.3 Participant Recruitment and Scheduling

Recruitment efforts targeted individuals who had not participated in the pilot study to avoid familiarity with the tasks or materials. However, some participants had potentially participated in the pilot study, so measures were taken to eliminate any prior familiarity with the map or tasks. Invitations were disseminated through social media platforms and messaging apps, providing potential participants with information about the study and a link to an appointment scheduling form created using Google Calendar (Figure 19). This form allowed participants to select preferred time slots from the available options, facilitating flexibility and convenience.

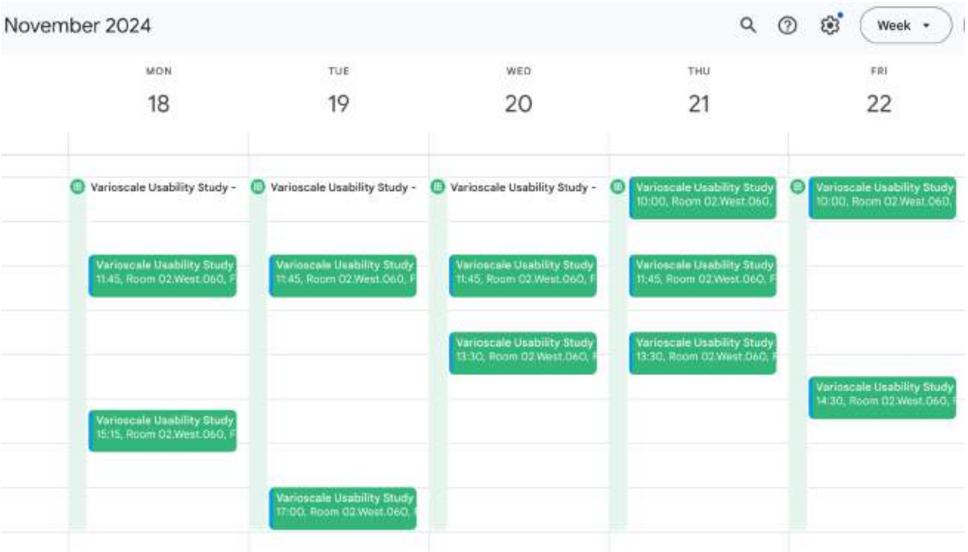
Invitations were sent out three weeks prior to the planned study period, which was scheduled for five consecutive working days, from 18 to 22 November 2024. To mitigate potential fatigue and maintain high-quality data collection, it was decided that no more than three sessions would be conducted per day. Each session was allocated a duration of one hour, although the anticipated time for task completion was approximately 45 minutes. A 45-minute interval was scheduled between sessions to accommodate any unforeseen delays, prevent overlap between participants, and ensure that each participant received undivided attention. This scheduling also preserved the anonymity of the participants, as they did not encounter one another.

A total of eleven participants were recruited, a number deemed appropriate for qualitative usability analysis based on established research methodologies. This sample size aligns with the literature suggesting that a small number of participants can provide valuable insights into usability studies, particularly when employing qualitative data collection methods such as think-aloud protocols and observational analysis. Both the researcher and participants received automatic email confirmations upon the successful booking of appointments, ensuring clear communication and organisation.

Study Environment and Protocol

The study was conducted in a quiet, private room provided by GEOS (Figure 20), the study association of MSc. Geomatics, which offered an environment free from distractions and appropriate for focused task execution. The choice of a quiet room was critical in ensuring that participants could concentrate fully on the tasks without external interruptions, thereby enhancing the reliability of the data collected. Before each session, the computer and eye-tracking equipment were set up and tested to ensure proper functioning. The eye tracker remained off until the participant's arrival to prevent any unnecessary exposure or discomfort.

Upon arrival, participants were warmly welcomed and seated in a designated chair positioned optimally for eye-tracking calibration. The computer was already on and connected to the



November 2024

MON 18	TUE 19	WED 20	THU 21	FRI 22
Varioscale Usability Study -	Varioscale Usability Study -	Varioscale Usability Study -	Varioscale Usability Study 10:00, Room 02.West.060,	Varioscale Usability Study 10:00, Room 02.West.060,
Varioscale Usability Study 11:45, Room 02.West.060, F	Varioscale Usability Study 11:45, Room 02.West.060, F	Varioscale Usability Study 11:45, Room 02.West.060, F	Varioscale Usability Study 11:45, Room 02.West.060, F	
		Varioscale Usability Study 13:30, Room 02.West.060, F	Varioscale Usability Study 13:30, Room 02.West.060, F	
				Varioscale Usability Study 14:30, Room 02.West.060,
Varioscale Usability Study 15:15, Room 02.West.060, F				
	Varioscale Usability Study 17:00, Room 02.West.060,			

Figure 19: Screen capture from the Google Calendar appointment scheduling system used for session planning.

Figure 20: Study setup showing the study room. Placed on the left is the researcher’s laptop, and on the right the participant’s laptop with the eye tracker.

Figure 21: Participant setup, with the eye tracker attached to the laptop.

eye tracker (Figure 21). The researcher provided a brief overview of the study's purpose and procedures, allowing participants to acclimate to the setting and ask any preliminary questions. This introduction aimed to reduce anxiety and promote a comfortable atmosphere. The researcher emphasised that there were no right or wrong answers and that the study aimed to understand their interaction with the maps.

Participants were then asked to read and sign an informed consent form, which detailed the nature of the study, the use of eye-tracking technology, data handling procedures, and their rights as participants, including the right to withdraw at any time. This step ensured that participants were fully informed and voluntarily agreed to partake in the study. Obtaining informed consent was a critical component in upholding research integrity.

The researcher, seated nearby on a separate laptop equipped with all necessary tools for monitoring and data collection, and a standardised script had been prepared to be read to each participant. This script was designed to maintain consistency in instructions and to prevent any unintentional bias or variation in the information provided. It included explanations of the tasks, reminders to think aloud during task execution, and reassurance that assistance was available if needed.

Participants were given time to read on-screen instructions displayed on the map interface. They indicated their readiness to begin, at which point the eye tracker was activated, and the tasks commenced. Stickers were placed near the buttons that participants would need to press during the tasks (e.g., f11 set the window in full-screen) to facilitate ease of use and reduce stress. This attention to detail aimed to create a user-friendly experience and minimise any potential confusion or frustration.

Throughout the session, the researcher kept notes and monitored the correctness of task execution without leading or interfering with the participant's performance. The participant was free to solve the tasks independently and was encouraged to verbalise their thoughts in a think-aloud method. Upon completion of the tasks, participants were offered refreshments and snacks as a token of appreciation. The participant was then escorted out, and the researcher prepared the setup for the next session, ensuring that all data were securely saved and backed up on OneDrive. One participant was selected to receive a €30 online shopping voucher through a random draw.

4.2.4 Design of the Map Prototypes

To avoid familiarity effects from the pilot study, a new map was generated depicting an 18×18-kilometre area around Helmond in the province of Noord-Brabant. This ensured that participants, some of whom had potentially participated in the pilot study, engaged with an entirely new and larger map, eliminating any prior knowledge that could influence the results. The decision to use a different region was also intended to eliminate any memory tasks, focusing instead on participants' ability to interact with the map interfaces and interpret new spatial information.

The map's colour palette was replaced with pastel colours to enhance visual appeal. Icons representing points of interest (POIs) such as bars, cafés, campsites, and castles were added to enrich the map's informational content. Some of the POIs provided relevant and engaging elements for the tasks, making them more realistic and relatable.

Labels of place names were added in a hierarchical manner, ensuring that larger cities and towns appeared at higher zoom levels, while smaller villages and landmarks became visible as participants zoomed in. This hierarchical labelling was crucial for tasks that involved searching for specific locations.

To create the multi-scale prototype, the code of the vario-scale prototype was adapted to change levels of detail only at predefined scales. This adaptation involved snapping the current scale of the vario-scale map to predefined multi-scale scales, ensuring neither map type had an inherent advantage. At certain scale levels, the multi-scale map might display more detailed information than the vario-scale map at that point, and vice versa. When rendering the geometry and labels, the current scale was snapped to the corresponding discrete multi-scale scale, and the map was rendered as if displayed at that scale. This approach provided consistency in map detail presentation between the two prototypes. The chosen discrete scales were based on the Geonovum Well-Known Scale Set for the Netherlands (EPSG: 28992).

Both the vario-scale and multi-scale map prototypes were developed to include specific interface elements: a switch button to toggle between map types, coordinates of the mouse pointer, scale information, data source attribution, a "Next" button to proceed through tasks, and reference system details (Amersfoort/RD New, EPSG: 28992). When the switch button was pressed, the map automatically zoomed out and reset to the original scale to ensure consistency in starting conditions for each map type. This design choice prevented any unfair advantages that might arise from one map type starting closer to a target location or at a more convenient zoom level.

The interface omitted the toggle drawer used in the pilot study, opting instead to allow participants to access the full extent of the maps at all times. This decision was made to test the full capabilities of each map type without restrictions, providing a more comprehensive assessment of their usability.

Upon loading the map interface, a progress bar was displayed, replaced by a "Start" button once the map was fully loaded. Participants were instructed to wait until the "Start" button appeared before beginning task execution, ensuring that all map elements were properly rendered and reducing the likelihood of technical issues during interaction.

Instructions were presented both verbally and on-screen, crafted to be concise and straightforward to minimise cognitive load and prevent fatigue. All instructions included a reminder for participants to think aloud, strategically placed above the "Start" button to reinforce this request just before task execution. The instructions were designed to be easily retained in memory, as participants could not revisit them once they began the tasks. Extra attention was given to ensure that participants did not struggle to comprehend the instructions, allowing them to focus on task execution with confidence.

4.2.5 Task Design and Execution

The final study tasks can be viewed at: `https://eirinitsipa.github.io/varioscale-usability-study/final-study/`

The tasks were carefully designed to assess various aspects of map usability, user interaction, and the effectiveness of vario-scale versus multi-scale map approaches. The theme of environmental awareness was chosen to provide meaningful and relatable context for the tasks, aiming to enhance engagement and realism. The tasks were also intended to be versatile to prevent fatigue due to repetitiveness, keeping participants interested and focused.

Task 0: Introduction Task

Participants began with an introductory task (Figure 22) that served multiple purposes. Firstly, it provided definitions and explanations of vario-scale and multi-scale maps, ensuring that participants had a foundational understanding of the two map types they would be using. Secondly, it allowed participants to freely explore both map types, utilising zooming and panning functionalities, and to switch between them as desired. They could switch as many times as they wished and were encouraged to express thoughts about features and differences they noticed between the two map types out loud. This exploratory phase was crucial for familiarising participants with the map interfaces, controls, and the "Switch" and "Next" buttons, thereby reducing the learning curve during subsequent tasks. By allowing participants to become accustomed to the interface and features provided, the study aimed to enhance their confidence and readiness for the tasks ahead.

Task 0: Introduction to Varioscale and Multiscale Maps

Varioscale maps change smoothly as you zoom, showing **continuous** levels of detail.

Multiscale maps change at predefined scales as you zoom, showing **discrete** levels of detail.

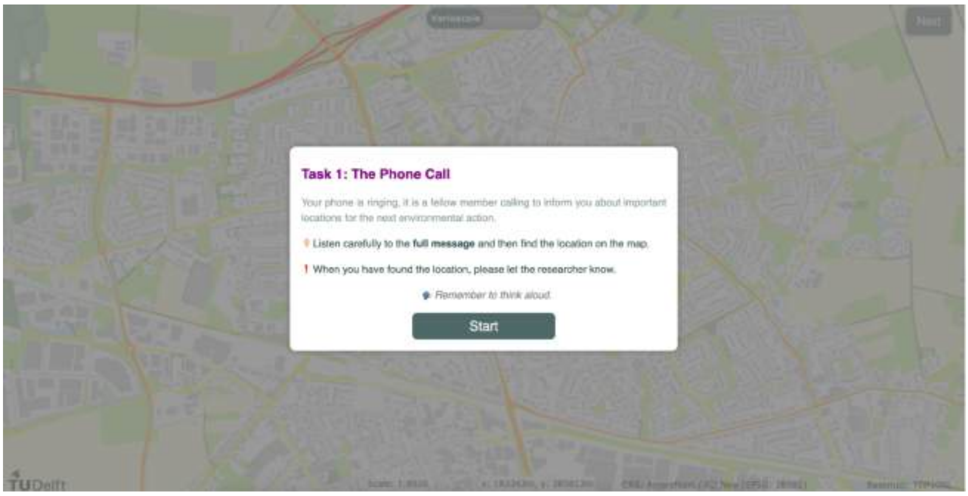
Freely **explore** the map. Zoom and pan using the mouse. Click on the *switch button* to experience the differences between Varioscale and Multiscale.

Remember to think aloud.

Figure 22: Screen capture of the interface of written instructions for task 0 of the final study.

Task 1: The Phone Call

The first main task (Figure 23) was a controlled experiment designed to evaluate the efficiency of each map type in facilitating the search for specific place names. Participants listened to pre-recorded phone messages, each describing a location for an environmental action. There were four locations in total, and the map types were alternated after each location to ensure balanced exposure—two locations were to be found using the vario-scale map and two using the multi-scale map.



Task 1: The Phone Call

Your phone is ringing, it is a fellow member calling to inform you about important locations for the next environmental action.

Listen carefully to the **full message** and then find the location on the map.

When you have found the location, please let the researcher know.

Remember to think aloud.

Figure 23: Screen capture of the interface of written instructions for task 1 of the final study.

The hypothetical phone messages were as follows:

1. "Hi there, welcome to the Environmental Action Group. We're so glad to have you with us. First, we're giving a pitch on the importance of recycling and we'd love for you to join us. It's in a tiny village called Benthem near the town called Bakel."
2. "Next, we'll repeat this pitch in a tiny village called Wolfsput, which is north of the city of Helmond."
3. "After that, we'll help with reforestation in the small town called Vlerken, which is west of the town called Asten." (Figure 25)

4. "For the last project, we will hang posters in the small town called Het Broek, which is near the big town called Mierlo." (Figure 24)

Figure 24: Screen capture of the zoomed in map on "Mierlo", showing the target "Het Broek" north west of it.

Figure 25: Screen capture of the zoomed in map on "Asten", showing the target "Vlerken" west of it.

The messages were carefully scripted and recorded to provide clear instructions and contextual clues. The names of the places were purposefully pronounced with an English accent to accommodate participants who might not be fluent in Dutch, thereby minimising miscommunication. The recordings were played at an appropriate volume to ensure audibility without causing discomfort. In most cases, participants understood the place names without the need for repetition. If a participant misheard a name, the recording could be replayed, or the researcher provided the place name in written form on a card.

Participants were instructed to find each location on the map based on the information provided in the messages and to inform the researcher once they had located it. They were encouraged to verbalise their thought processes, allowing for insights into their navigation strategies and interactions with the map. This task assessed how effectively participants could use zooming and panning features to locate targeted labels and whether one map type facilitated this process more efficiently than the other. It aimed to determine whether the smooth zoom of the vario-scale map provided quicker access to place names or if the fixed-scale visualisation approach of the multi-scale map was better for targeted label finding.

Task 2: The Cleanup

The second task (Figure 26) was semi-controlled and aimed to evaluate participants' abilities to locate specific symbols on the map, representing points of interest (POIs). Participants were informed by the researcher about the type of location to search for—either castles or campsites—and were instructed to find three instances of that type. The map types were alternated to maintain balance, with each participant using both map types for different sets of locations.

Task 2: The Cleanup

You are looking for locations to clean up waste from the environment.

🔎 Once you are ready, the researcher will tell you what type of locations you are looking for. For each type of location, there are 3 on the map to find.

! Try to find them all! For each location that you find, zoom in to see the name and say it out loud.

● *Remember to think aloud.*

Figure 26: Screen capture of the interface of written instructions for task 2 of the final study.

Symbols for castles and campsites were represented by tower icons and tent symbols, respectively. Both sets contained one icon that was easy to find, visible from a zoomed-out perspective (Figure 27). Another icon in each set was moderately difficult to find, being obstructed by a place name label and only appearing at a more zoomed-in scale. The final icon in each set was of higher difficulty to find, only appearing at a quite zoomed-in perspective, namely at around 1:20.000 scale. The difficulty lay in the fact that the user could only investigate a smaller area at a time at this more zoomed-in map view. This task tested the performance and effectiveness of the two map types in terms of icon finding on the map.

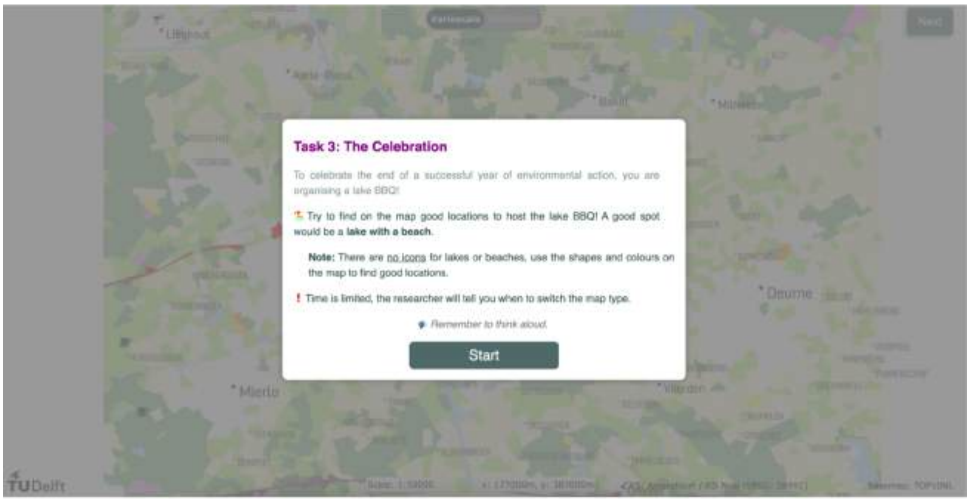
Participants were instructed to zoom in on each found location to read and verbalise the name, thereby confirming their discovery. They navigated the map more freely until they found the symbols, allowing the study to observe the strategies used by participants in icon searching. This task evaluated how each map type affected participants' search strategies, their ability to interpret map symbology, and the influence of zooming functionality on their search efficiency.

Task 3: The Celebration

The third task (Figure 28) was the least controlled and aimed to assess participants' exploratory behaviour and interpretation of map features without explicit guidance. The participant started from a scale of 1:50.000, meaning the full 18×18 km area fit in the viewport. Participants were tasked with finding suitable locations for a lake barbecue, specifically seeking lakes with beaches. Since there were no icons indicating lakes or beaches, participants had to rely on interpreting the map's shapes and colours to identify potential spots (Figure 29). The absence of explicit symbols required participants to utilise their spatial reasoning and understanding of cartographic representations.

The task was time-limited, with durations ranging from one to one and a half minutes, adjusted based on each participant's navigation speed and understanding of the task. The

Figure 27: Screen capture of a zoomed out view of the map, where one castle and one campsite are already visible.



Task 3: The Celebration

To celebrate the end of a successful year of environmental action, you are organising a lake BBQ!

Try to find on the map good locations to host the lake BBQ! A good spot would be a **lake with a beach**.

Note: There are no icons for lakes or beaches, use the shapes and colours on the map to find good locations.

! Time is limited, the researcher will tell you when to switch the map type.

Remember to think aloud.

Figure 28: Screen capture of the interface of written instructions for task 3 of the final study.

researcher indicated when to switch map types, ensuring that both vario-scale and multi-scale maps were used equally. This timing was carefully managed to prevent one map type from having an advantage due to longer exposure. Participants navigated the map freely and were encouraged to think aloud, providing insights into their reasoning, strategies, and any challenges encountered.

Figure 29: Example of the biggest suitable lake in the map, featuring a beach area in yellow.

This task aimed to evaluate how well participants could extract relevant information from the maps, the effectiveness of the map styles and symbology, and the impact of the different map scaling approaches on their exploratory navigation. It also assessed what differences in behaviour the participants exhibited on the two map types.

4.2.6 Ensuring Fairness and Mitigating Bias

Throughout the study, significant efforts were made to ensure the fairness of the comparison between the vario-scale and multi-scale map prototypes. Participants were assigned to start with either the vario-scale or multi-scale map, with six participants beginning with the multi-scale map and five with the vario-scale map. This alternation was crucial in mitigating potential biases arising from learning effects, familiarity, or first exposure, which could influence performance and perceptions regardless of the actual usability of the map types.

This approach was taken to prevent biases that could result if all participants started with the same map type. If participants became more familiar or comfortable with the first map type they used, it could influence their performance and perceptions when using the second map type, irrespective of its actual usability. Such biases could skew the results, making it difficult to discern whether differences in performance were due to the map types themselves or the order in which they were presented.

Moreover, every time participants switched between map types, the map interface reset to the same starting position and scale. This standardisation eliminated any advantages that might arise from differences in initial views, such as being closer to target locations or at more convenient zoom levels. By maintaining consistent starting conditions, the study ensured a balanced and fair comparison, allowing for more reliable and generalisable results.

Instructions were meticulously crafted to be clear, concise, and easily understandable, reducing the cognitive load on participants and preventing misunderstandings that could affect task performance. Extra attention was given to ensure that participants did not struggle to comprehend the tasks, allowing them to focus on the execution without unnecessary confusion.

The instructions were designed to avoid fatigue and to be easily retained, as participants could not revisit them once the tasks commenced.

4.2.7 Data Collection and Management

Data collection encompassed both quantitative and qualitative methods. Quantitative data were obtained from the eye-tracking recordings and interaction logs. The eye tracker captured detailed information about participants' gaze patterns, fixation points, and saccades, providing insights into their visual attention and cognitive processing during task execution. These data were essential for understanding how participants interacted with different elements of the map and whether their attention was influenced by the map type.

Interaction logs were automatically stored each time a participant pressed the "Next" button to proceed to the subsequent task. These logs included information such as event type, centre coordinates of the map view, timestamp, lower-left coordinates, scale denominator, and the map type in use. The logs were designed to record critical interactions without overwhelming the analysis with unnecessary data. A record was added to the log for every update of mouse movement, clicking, scrolling, and animation.

To maximise the loading speed of the map, the space scale cube data was hosted on local host and the whole tree was loaded in advance. This ensured optimal performance and reduced potential latency issues that could arise.

The web browser used was Microsoft Edge. The display of downloads was deactivated so that task execution would not be interrupted by notifications. This attention to the testing environment aimed to provide a seamless experience for participants, minimising external variables that could affect their performance.

All collected data were securely stored on OneDrive, complying with data protection regulations and institutional guidelines. Anonymisation was applied to protect participant identities, and access to the data was restricted to authorised personnel involved in the analysis. Regular backups were made to prevent data loss, and data management practices were aligned with best practices in research data stewardship.

4.2.8 Post-Task Questionnaires and Participant Feedback

Upon completion of the tasks, participants were asked to fill out questionnaires designed to gather feedback on their experiences. The questionnaires were divided into sections corresponding to each task and an overall feedback section.

For each task, participants were asked to:

- Rate the overall difficulty level of the task.
- Assess the clarity of the given instructions.
- Indicate whether they found the task easier to execute with one map type over the other, with options to specify their preference (e.g., easier with vario-scale, easier with multi-scale, equally manageable, or unable to complete the task).
- Provide additional comments or observations in open-ended questions.

This feedback aimed to capture participants' subjective experiences, perceptions of task difficulty, and preferences between the map types, enriching the quantitative data with qualitative insights. Participants' comments provided valuable context to their ratings and could highlight specific issues or advantages encountered during the tasks.

In the overall feedback section, participants evaluated:

- The fairness of comparing the vario-scale and multi-scale maps, including whether they felt the test setup favoured one map type. They could rate the fairness on a scale ranging from "Very fair" to "Very unfair" and provide explanations if they perceived any bias.
- The realism and relevance of the tasks in relation to how they typically use web maps in real life, with options ranging from "Very realistic" to "Not realistic at all."
- Their perceived efficiency of each map type for completing tasks, indicating their preference on a graduated scale from "Strongly find vario-scale more efficient" to "Strongly find multi-scale more efficient."
- Advantages and disadvantages they perceived for both the vario-scale and multi-scale map types, providing qualitative insights into user preferences and experiences.
- Their comfort level while using the eye tracker, which provided insights into the usability of the equipment and any potential impact on their performance. Comfort levels ranged from "Very comfortable" to "Very uncomfortable," and participants could elaborate on any discomfort experienced.

Finally, they were prompted to identify basic features or settings they would like web maps to include, such as:

- A search bar for quick location searches.
- Layer options to switch between different map views (e.g., street map, satellite imagery, terrain).
- Bookmarks or the ability to save favourite or frequently visited locations.
- Measurement tools for calculating distances between points.
- Customisable zoom and pan controls, including adjustments to zooming speed and panning animation duration.
- Any other features they deemed useful or that could enhance the map prototypes if implemented.

This feedback could potentially inform future enhancements to the map prototypes and contribute to the development of more user-centric mapping applications. Understanding user desires and expectations is critical in designing tools that meet their needs and improve overall satisfaction.

5 Technical Implementation

5.1 Overview

This chapter addresses the implementation details of the prototypes used in both the pilot study and the final study, as well as the technical steps taken to analyse the results. The `sscview-js` project from the GDMC group at TU Delft served as the foundation for these prototypes, providing a framework on which further changes could be built. The modifications introduced were mainly aimed at enhancing the user experience and interaction, rather than focusing on significant vario-scale technical alterations, and included adjustments that enabled the prototypes to function effectively as website-based studies.

All codebases of this thesis can be found in the public repository: `https://eirinitsipa.github.io/varioscale-usability-study/pilot-study/`

5.2 Pilot Study

The prototype design was based on a public website that built on the existing sscview-js prototype and involved two separate codebases. The first was the sscview-js code, which was modified and bundled using rollup to be used in the other codebase. In its original form, this code rendered the map across two layers—one for the map and another for the labels. The modified version introduced multiple text layers, one for each label type, allowing each layer to be passed its own set of labels rather than relying on a single set of hardcoded labels. It also enabled multiple font options and made size and colour adjustable for each text layer. Parameters such as the zoom factor, zoom duration, and pan duration were added as arguments to the map constructor so that each prototype could be customised to test specific values.

The second codebase was the prototype website code, hosted on GitHub Pages. This project consisted of multiple webpages, each with its own HTML file. For each task, variations A, B, and where applicable C were assigned to participants via a random selection mechanism. Each variation passed different arguments to the Map constructor, for instance by adjusting the zoom factor. By random variation assignment, a fair distribution of the different variations could be achieved across participants. Google Forms were integrated to gather responses, with an auto-generated ID passed through the URL from one page to the next. That way, each separate Google Form could be anonymously connected to which belonged to the same participant. A timer started when the user pressed the start button, and there was a "drawer" with a toggle button that paused the timer while participants were reading or answering. A popup message reminded users not to forget submitting their Google Forms before moving to the next page. After the study period ended, the forms were closed and deactivated, but the overall study still remains available online.

For map content generation, RD New coordinates of selected toponyms were gathered manually, using the QGIS coordinate tool and OpenStreetMap as a basemap, and maxDenominator values were entered by determining the scales at which labels started overlapping. The reason the maxDenominator values needed to be determined manually was the lack of an automated algorithm that could determine appropriate values for labels of differing font sizes and lengths. When two labels conflicted, the one lower in the administrative hierarchy, such as a hamlet rather than a village, was set to disappear. If two labels of the same hierarchy overlapped, a choice was made to keep a less cluttered distribution, often by making the middle label between two other labels dissapear. Two icons of real locations (a cemetery and a historical site) and one icon of a fictional location (a cafe) were added manually.

The analysis stage merged the questionnaire responses by performing an inner join on the unique ID, removing duplicates and filtering out invalid or incomplete data. Participants who did not finish the entire study were excluded, as were those who used touch screens.

However, those who did not submit one or more intermediate forms were retained, based on the assumption that they likely performed the tasks but simply forgot to submit. In further analysis where these NULL values were encountered, these specific rows were left out. Python's pandas library and Excel were used for data exploration and manual filtering. Pearson's r and the associated p-value were calculated with scipy's pearsonr function, and p-values for comparisons between different data samples were computed using scipy's `ttest_ind` function. Plotting was carried out with matplotlib and seaborn.

5.3 Final Study

The final study prototype introduced the "maplog," which records user interaction with the map. Every time the map changes, a new record is written, triggered by specific events (mouse up, mouse down, mouse move, scroll) and by any anonymous update, because animations of map movement continue even if there is no event (this event type was named "animation" in this thesis). Each record includes the event type, the extents of the viewport given as lower left and centre coordinates, the current scale denominator, the current map type, and the timestamp. The original plan was to implement the maplog in a database, but ultimately it was realised via a downloadable CSV. This proved easier to implement, fast in performance due to only appending to an array at runtime, simpler for analysis, and a short task duration meant no substantial risk of memory issues. To reduce lag on larger study areas, all chunks were downloaded in advance by removing the condition that tested if a chunk was in view.

An option was added for the map to render as a multi-scale version with predefined scale levels, implemented by snapping the current scale denominator to one of these scales before rendering. Given a scale denominator s, it is first determined between what two predefined scale levels (s_{low} and s_{high}) s lies. Then, the snapped scale level is determined by Equation (1) and (2).

$$\text{mid} = \sqrt{s_{\text{low}} \times s_{\text{high}}} \tag{1}$$

$$\text{scale}_{\text{snapped}} = s_{\text{low}} \text{ if } s \leq \text{mid else } s_{\text{high}} \tag{2}$$

RD New coordinates for toponyms were automatically gathered from OpenStreetMap data based on the place key in OSM. The place types were simplified to town (including the city of Helmond), village, and hamlet, resulting in a three-level hierarchy. Additional data on castles, campsites, cafes, and bars was collected through OSM keys "amenity", "tourism", and "historic". The maxDenominator values for these were determined manually using the same strategy as in the pilot study.

For the analysis, every participant's input consisted of eye tracking data in TSV format from Tobii Pro Lab Software (with the fixation filter applied, so that fixations as well as raw data were available) and three maplogs per participant for each of the three tasks. Analysis was performed in Python using the pandas library. When processing the eye-tracking data, the records, which appear at a rate of 120 per second (due to the 120Hz eyetracker polling rate), served as the main time reference. This choice was more suitable than relying on the maplogs, because maplogs record data only during map updates rather than at regular intervals. Only the time periods in which participants were actually performing the tasks were analysed, rather than the entire duration the eyetracker was switched on. The maplog records made it possible to identify these time periods.

Firstly, the maplogs for each task were split into "splitlogs" based on the subtasks. For Task 1, for instance, the log was divided into Benthem, Wolsput, Het Broek, and Vlerken. The transition between subtasks was interpreted as the switch from vario-scale to multi-scale, because participants were instructed to alternate modes for each subtask. This process produced four splitlogs for Task 1, two for Task 2, and two for Task 3, totalling eight per participant and 80 altogether. Each was treated as a separate log and assigned a unique ID. For example, Benthem for Participant 1 might be ID 0, then Vlerken ID 3, and again Benthem for Participant 2, ID 8. This allowed every subtask to be regarded as a standalone sample. For each splitlog, the starting point was identified by zooming in beyond 1:250.000 for Task 1 and at the moment the user began moving for Tasks 2 and 3. The endpoint for the Task 1 splitlogs was the moment the participant located the target (details of how this was determined appear later). The endpoint for Task 2 was set when the participant had found all icons, and for Task 3, it was the end of that splitlog.

For each splitlog, the participant's complete eye-tracking data was joined with the closest-in-time splitlog record, determined as the maplog record with the smallest time difference for each eye-tracking record. This meant that each row—occurring every 1/120 of a second—contained both the participant's gaze position on the screen (from the eye-tracking log) and the map's viewport location at that moment (from the splitlog). Using this information, it was then possible to compute the participant's gaze location in geographic coordinates using factor f, see Equation (3) with x and y being the gaze position in pixels, x_{min} and x_{max} the minimum and maximum x coordinates of the viewport, and y_{min} and y_{max} the minimum and maximum y coordinates of the viewport. The viewport's width and height in pixels were 1920 and 1080, respectively. The RD New coordinates of the gaze position were then stored in a new column.

$$\begin{aligned} f &= \frac{x_{\text{max}} - x_{\text{min}}}{1920} \\ x_{\text{RD}} &= x_{\text{min}} + x \times f \\ y_{\text{RD}} &= y_{\text{min}} + y \times f \end{aligned} \tag{3}$$

By comparing that location with the known position in Amersfoort/RD New coordinates of the target—for instance, the Benthem location or the positions of campsites-it was possible to determine whether the participant was looking at the target (Equation (4)).

$$\begin{aligned} d &= \sqrt{(x_{\text{RD}} - x_{\text{target}})^2 + (y_{\text{RD}} - y_{\text{target}})^2} \\ \text{found} &= d < (r \times f) \text{ and denom} < \text{maxDenominator} \end{aligned} \tag{4}$$

With d as distance in meters, denom as current scale denominator, and maxDenominator the maximum scale denominator the target is visible at. A radius r of 100 pixels was chosen to allow for calibration inaccuracy and the fact that the label often sits slightly to the side of the actual feature. Whenever the participant's gaze fell within this radius at a sufficiently high zoom level to view the target, it was taken as the moment the target was found.

Various metrics were then computed over the entire task duration or only during the "visible period" between the moment the target appeared and the time the participant found it. Whether the target was visible was determined by checking if the target coordinates lay within the current viewport and if the target's max denominator exceeded the current denominator. Because the target might appear briefly and then go out of view, it was not the first time it became visible that mattered, but the most recent time it appeared before being found. The Fixation Count was derived by counting unique fixations in the data during the interval between the target becoming visible and the target being found. Unique fixations were identified by filtering out repeated combinations of fixation x,y coordinates. The Fixation Duration was taken directly from the "gaze event duration" column for each unique fixation, in milliseconds. The Scanpath Length was calculated by measuring the Euclidean distance, in pixels, between the current fixation coordinates and the previous ones for each unique fixation. Time to First Fixation on Target was computed as the difference between the target-found time and the target-visible time.

Further statistics included whether the participant was paused, scrolling, or zooming on each row in the log. If the closest-in-time maplog record was more than four milliseconds away compared to the eye-tracking row, the participant was assumed to be paused for that row. This threshold was selected empirically, based on the frequency of log entries in the maplog, mostly ranging from one to two milliseconds. If the participant was not paused and the closest maplog record reported an event type of “scroll” or “Animation,” it was interpreted as zooming; if “mouseDown,” “mouseUp,” or “mouseDrag,” it was interpreted as panning. The zoom and pan percentages were then calculated per splitlog as the proportion of rows showing zooming or panning. All the splitlogs were combined into a single CSV file for analysis and plotting, with the ID column identifying each splitlog. For the analysis itself, scipy’s pearsonr function was employed to calculate Pearson’s r and the corresponding p value, while `ttest_ind` determined the p value between different data samples. Visualisations were carried out using matplotlib and seaborn, and plotly’s Histogram2d was used to create a heatmap of the RD coordinates of the fixations layered over a background map.

These technical details, together with with the methodology outlined in the previous chapter, describe the process of implementing the prototypes and the steps taken to analyse the results.

6 Analysis and Results

6.1 Pilot Study

The pilot study aimed to investigate participants' experiences while interacting with a vario-scale web map interface. The tasks required them to locate specific places (a site, a house, and the town of Margraten) under different conditions: varying levels of map detail, the appearance or absence of labels, and the use of zooming and panning. Qualitative feedback and quantative statistics were gathered to help identify potential usability challenges and to shape the development of more refined vario-scale approaches.

Participants ranged in age from under 18 to over 65, with the majority belonging to the 25-34 age group (Figure 30). Approximately half of the participants were involved in activities related to Cartography (Figure 31) and regularly used web maps for navigation.

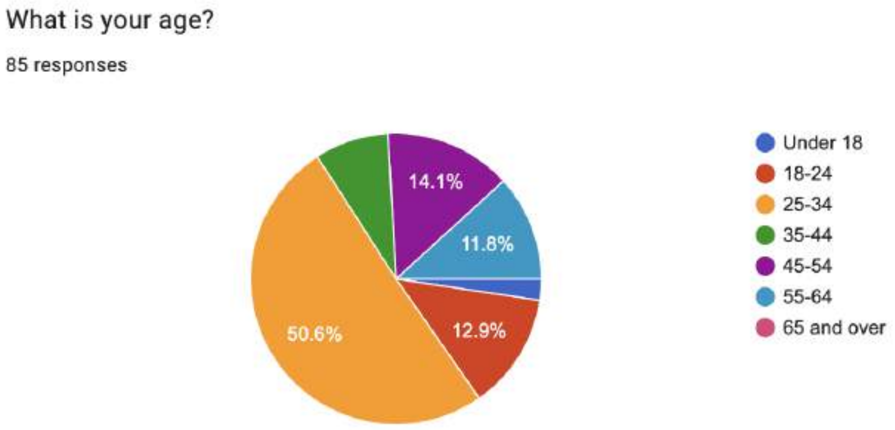


Figure 30: Response distribution of the participants' age range in the pilot study.

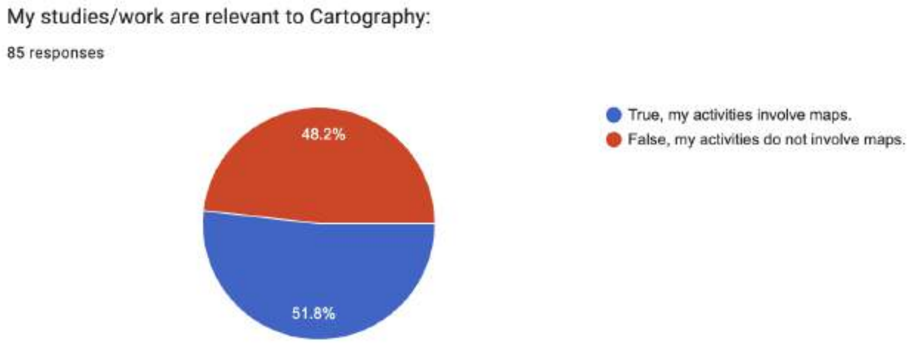


Figure 31: Response distribution of the participants' background in Cartography in the pilot study.

Most participants rated themself moderately to extremely proficient (Figure 32) in, meaning they were quite familiar with technology.

Similarly, most participants were moderately to very familiar with web maps (Figure 33). The biggest category used the web maps mainly on their mobile devices, less than 10% used the web maps mostly on computers (Figure 34).

Navigation was by far the most popular category for web map used (Figure 35). Work-related

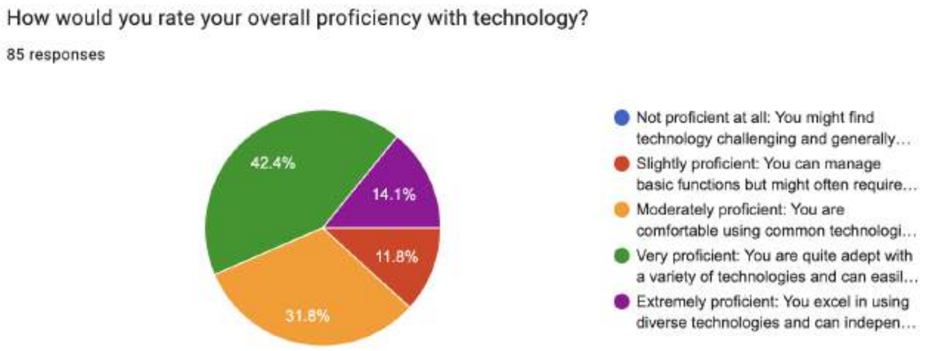


Figure 32: Response distribution of the participants' self-rated technological proficiency in the pilot study.

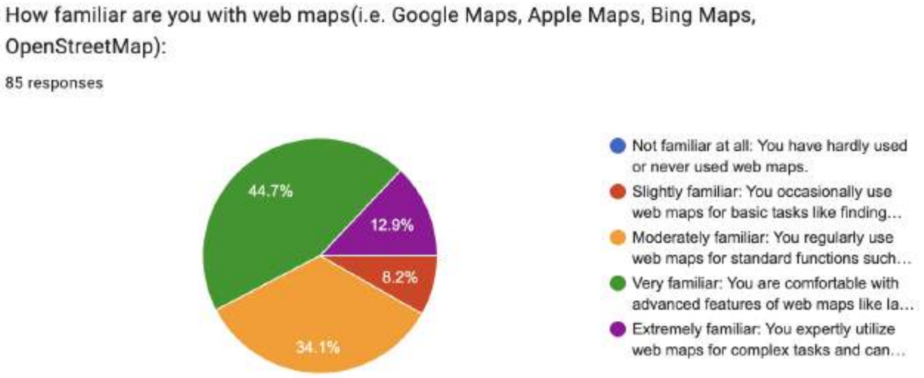


Figure 33: Response distribution of the participants' familiarity with web maps in the pilot study.

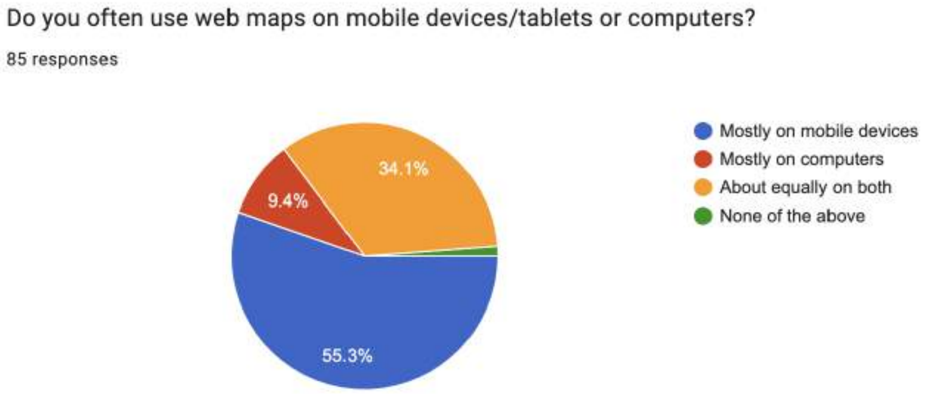


Figure 34: Response distribution of the participants' preferred device for using web maps in the pilot study.

tasks, educational purposes and recreation or leisure all were used by around 30 to 40% of participants.

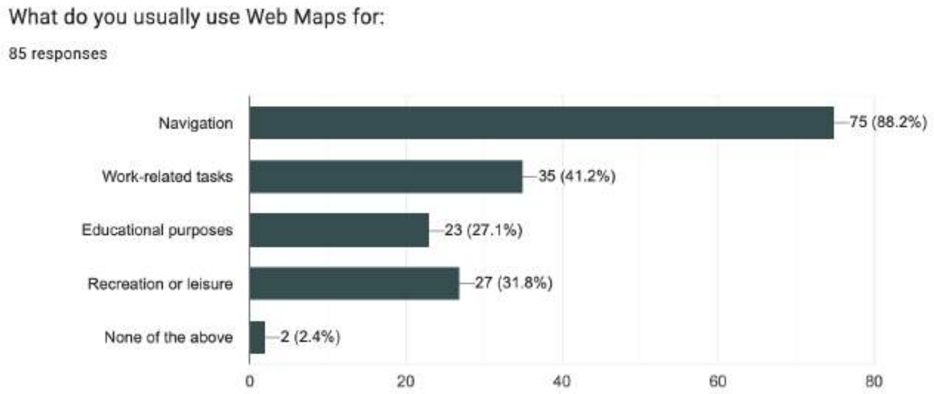


Figure 35: Response distribution of the participants' purposes for using web maps in the pilot study.

Out of 85 starting participants, only 44 completed the study to the end. A sharp dropoff was visible after the intro questions. The exact reasons for the drop off are not known, however it can be assumed due to factors like switching to a computer with a mouse (as recommended), the difficulty of task 1, deciding to start with the actual tasks at a later moment, and the realisation of the study requirements to fulfill map tasks and a decision to stop or continue at a later moment.

On average, participants completed the tasks in 22 minutes. 95% of participants answered the first task correctly, 94% succeeded in the second task, and 98% answered the third task correctly. The first and second tasks were generally rated as the most difficult. Execution times decreased in correlation with the perceived ease of the tasks - the easier the task was rated, the faster it was completed (Pearson's r -0.19, p 0.056) (Figure 38). This effect was most statistically significant in task 2 (Pearson's r -0.33, p 0.03). Notably, some of the quickest completion times were achieved by participants in the 25-34 and 55-64 age groups.

Technological proficiency and age did not have a significant effect on participants' perceptions of task difficulty. Pearson's r was found as 0.02 for technological proficiency with perceived task difficulty (Figure 41), and as 0.0 for participant age with perceived difficulty (Figure 40) with respective p values of 0.90 and 1.0. A slight, but not statistically significant correlation was found between participant age and task completion time (Pearson's r 0.2, p 0.11) (Figure 39). Those with a background in Cartography tended to complete tasks more quickly, with clear statistical significance (Pearson's r -0.50, p 0.001) (Figure 42).

Task 1: Presence of icons

Unexpectedly, variation B, which does not include the landmark icons, had a lower mean execution time (2 minutes 27 seconds) compared to variation A, which did include landmark icons (4 minutes 24 seconds) (p 0.14) (Figure 44). No significant difference in the perceived ease of the task was found between the two variations (mean 2.94 compared to 2.85, p 0.78) (Figure 43).

Participants frequently mentioned that labels significantly influenced their ability to identify the site. Many noted that a lack of labels complicated the task, often making it "way harder" or "pretty difficult," because they had to rely on the colour and shape of features to locate the correct area. Several individuals reported that they relied solely on shape and land use even without labels, but the majority expressed a clear preference for labelled maps. Others remarked that while they could still identify the site using contextual clues (such as roads or landmarks), the process was considerably slower. Some felt confident without labels if the site's layout was

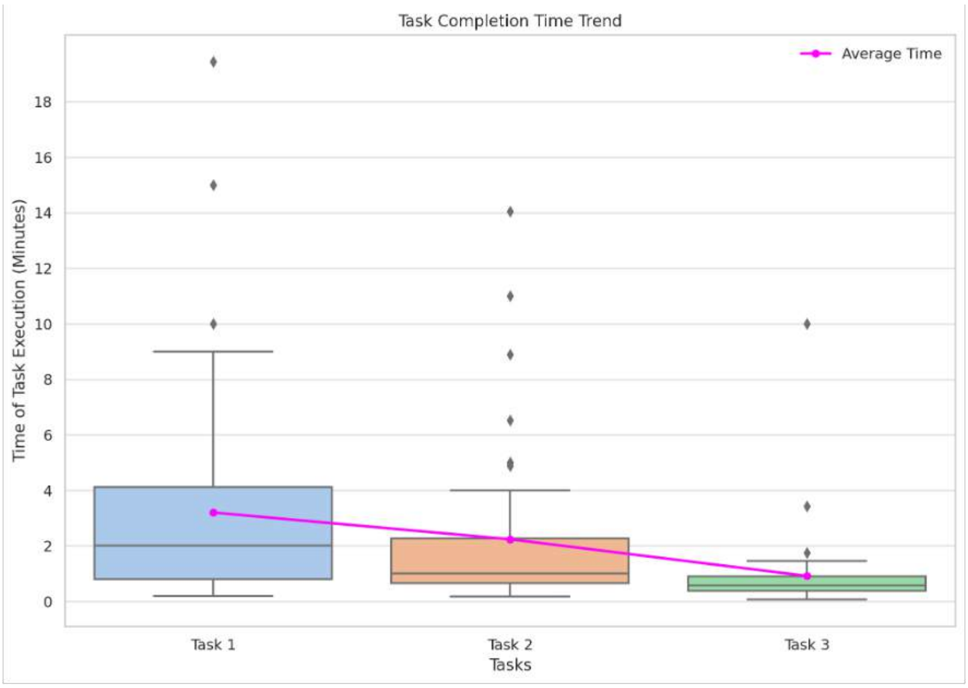


Figure 36: Task Completion Time Trend for Pilot Study

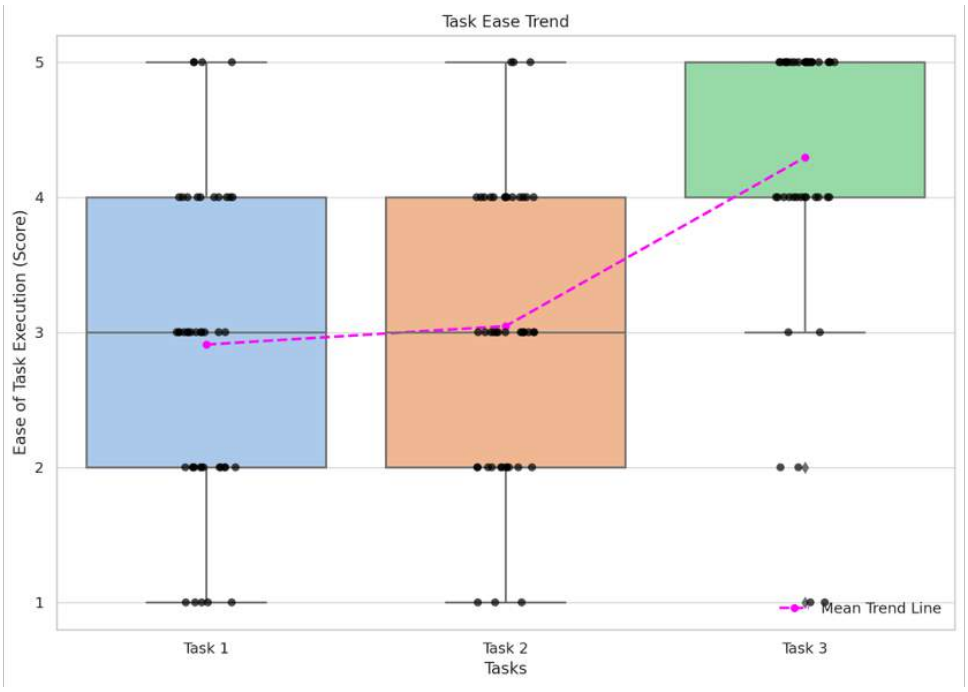


Figure 37: Task Ease Trend for Pilot Study

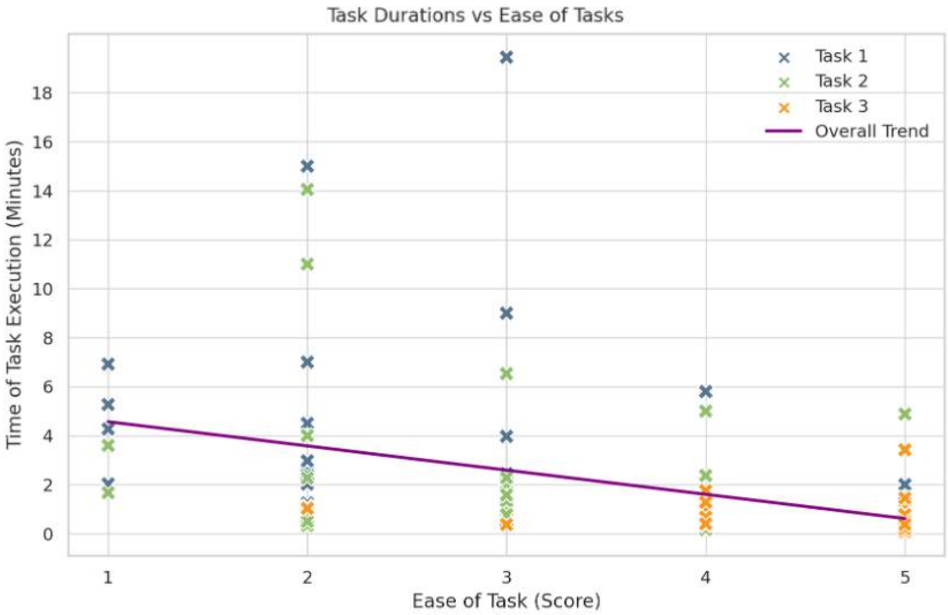


Figure 38: Task Durations vs Ease of Tasks for Pilot Study

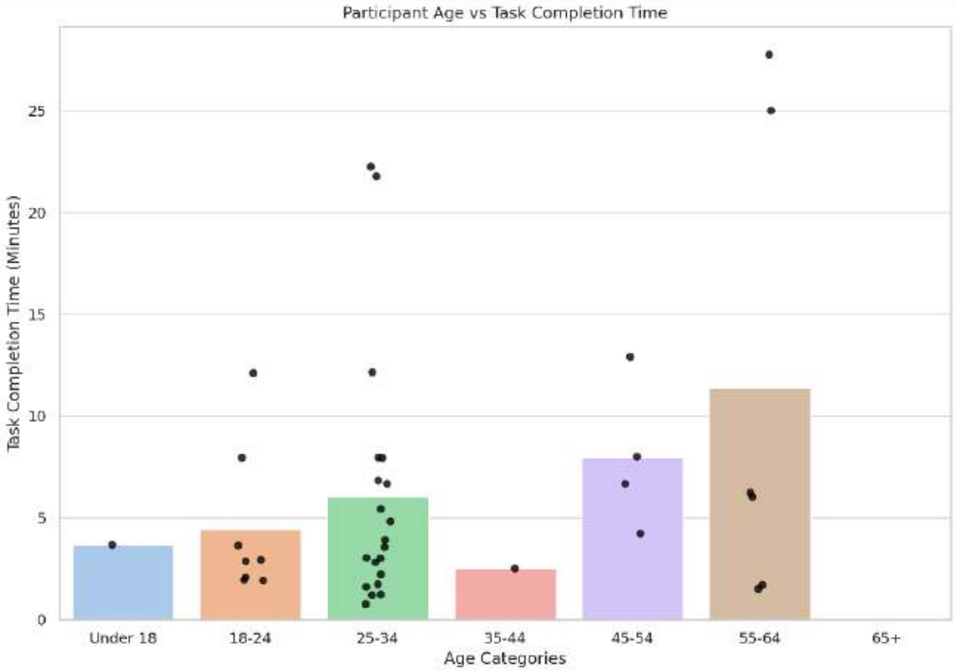


Figure 39: Participant Age vs Task Completion Time for Pilot Study

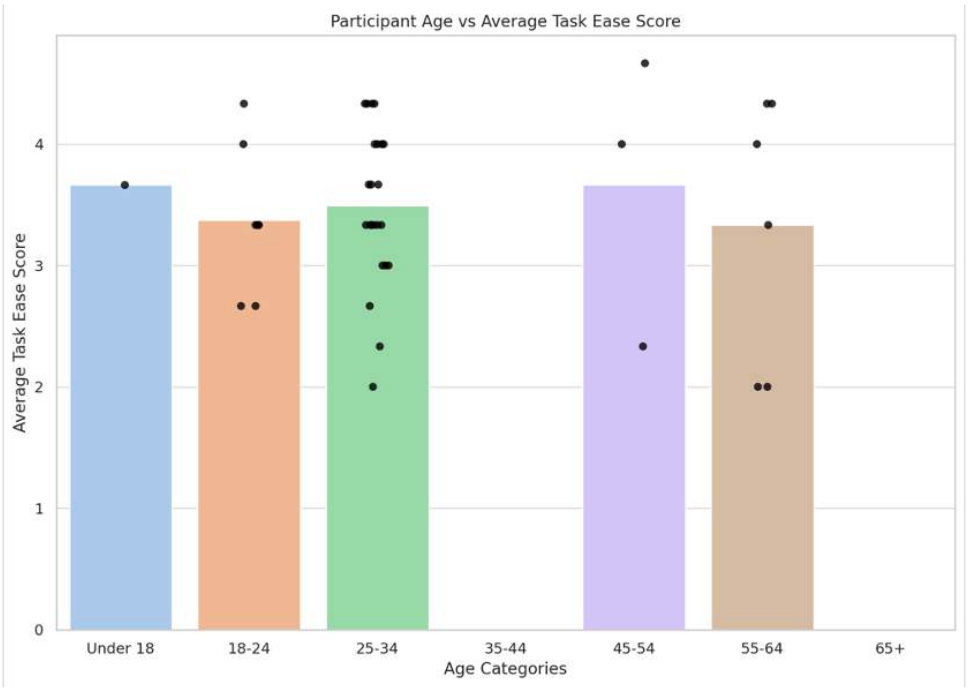


Figure 40: Participant Age vs Average Task Ease Score for Pilot Study

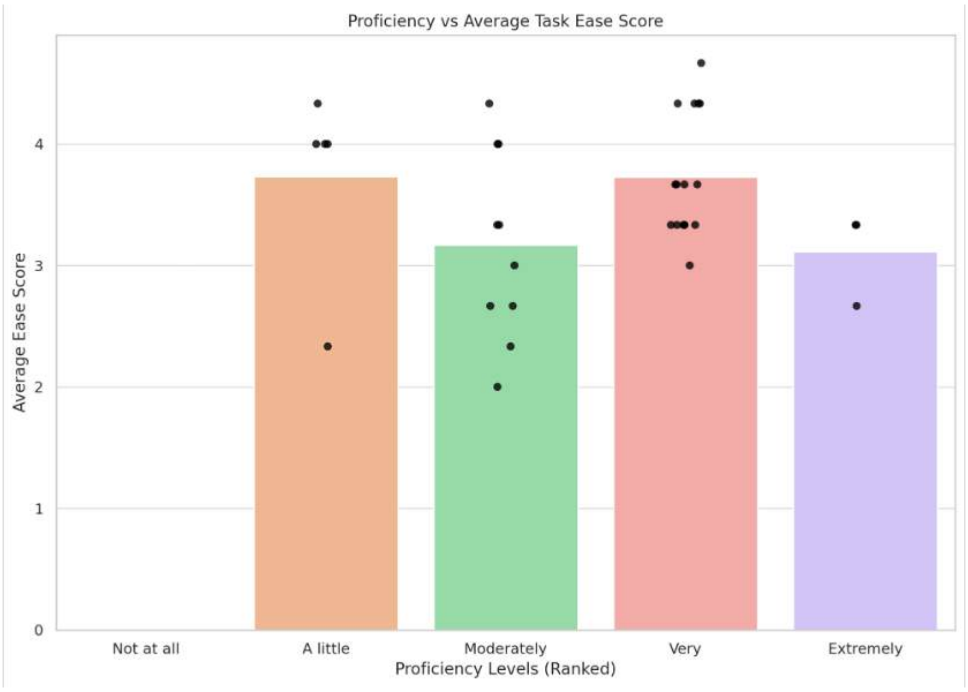


Figure 41: Proficiency vs Average Task Ease Score for Pilot Study

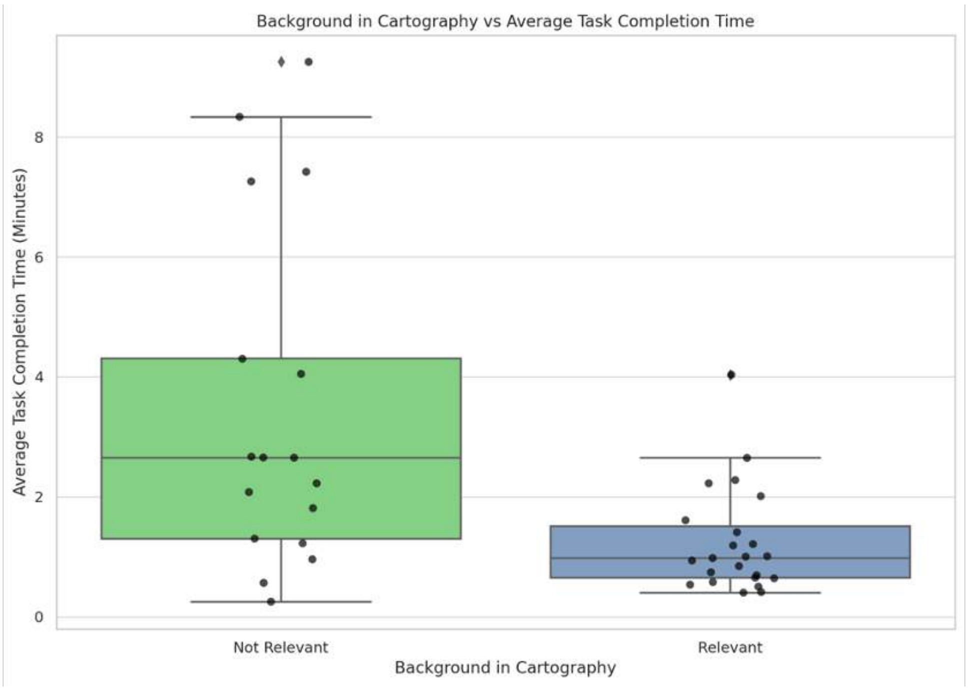


Figure 42: Background in Cartography vs Average Task Completion Time for Pilot Study

distinct enough, but a sizable portion found the task “very hard” without textual information.

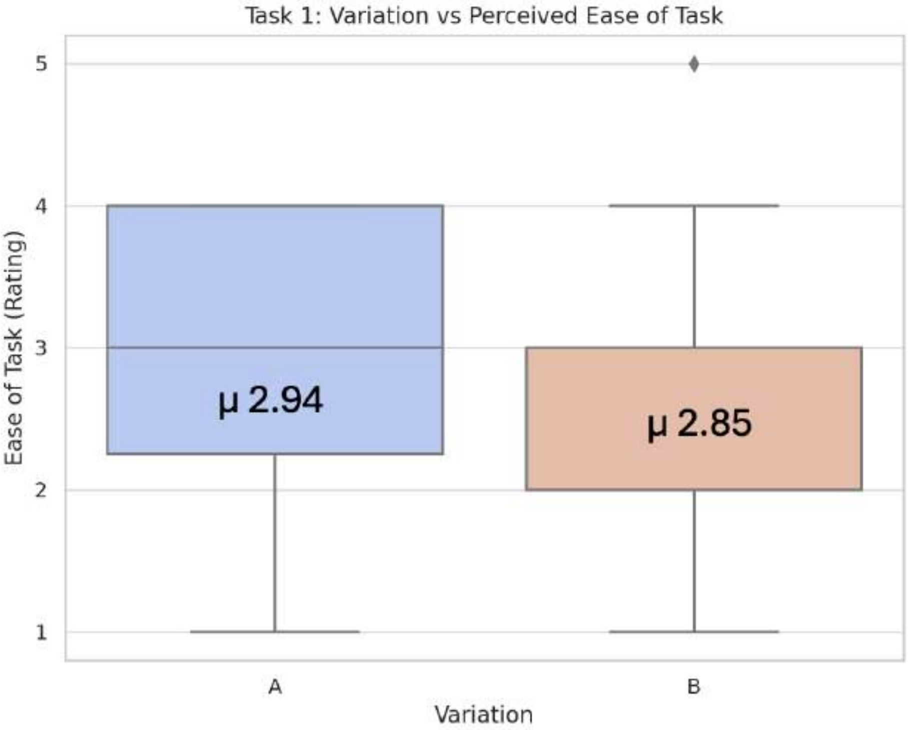


Figure 43: Pilot Study Task 1: Variation vs Perceived Ease of Task

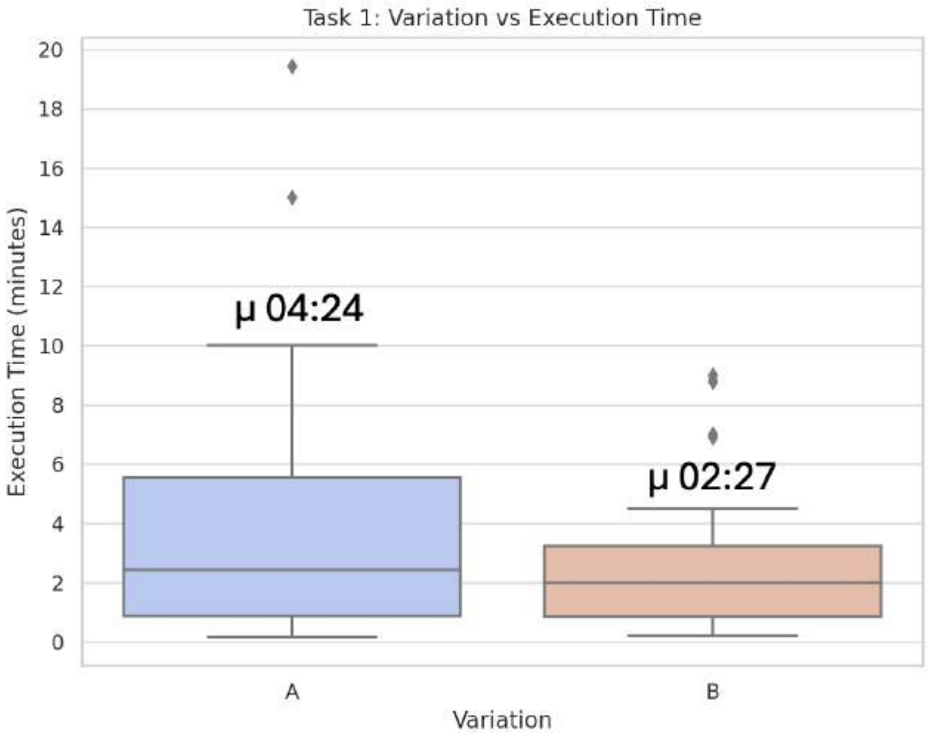


Figure 44: Pilot Study Task 1: Variation vs Execution Time

Task 2: Zooming speed

In terms of task completion time, variation A with slow zooming speed had a higher mean value (3 minutes 2 seconds), compared to variation B (regular speed, 1 minute 59 second) and variation C (fast speed, 2 minutes 6 seconds) (p A/B 0.32, p A/C 0.38, p B/C 0.89) (Figure 46).

However, variation A did have the highest average perceived ease of task (A: 3.33, B 2.88, C 2.69, p A/B 0.25, p A/C 0.15, p B/C 0.63) (Figure 45).

Regarding the difficulty of finding the house, participants often mentioned the need to zoom in quite far before any house markers appeared. This requirement sometimes caused frustration, since many were uncertain at which scale the marker would become visible. Some participants considered the zooming speed pleasant, but others found it too slow or lacking smoothness, stating that it felt discrete rather than continuous. The responses suggest that different users have different preferences for zoom speed: some wanted a faster transition for efficiency, whereas others favoured gradual zooming to avoid disorientation. Several comments also indicated that a consistent and earlier appearance of markers during zooming would have improved the ease of identifying the target house.

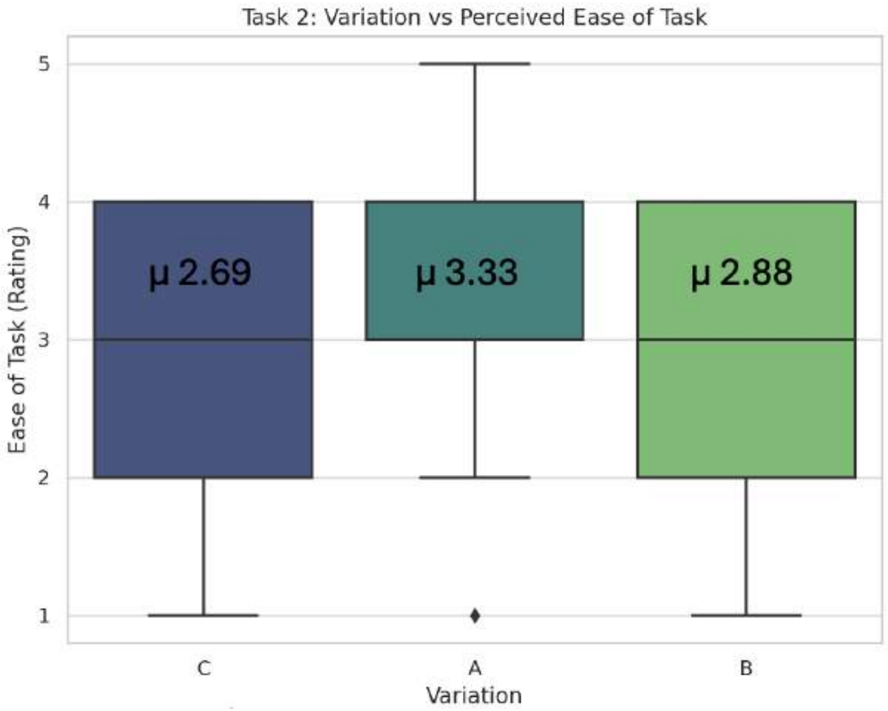


Figure 45: Pilot Study Task 2: Variation vs Perceived Ease of Task

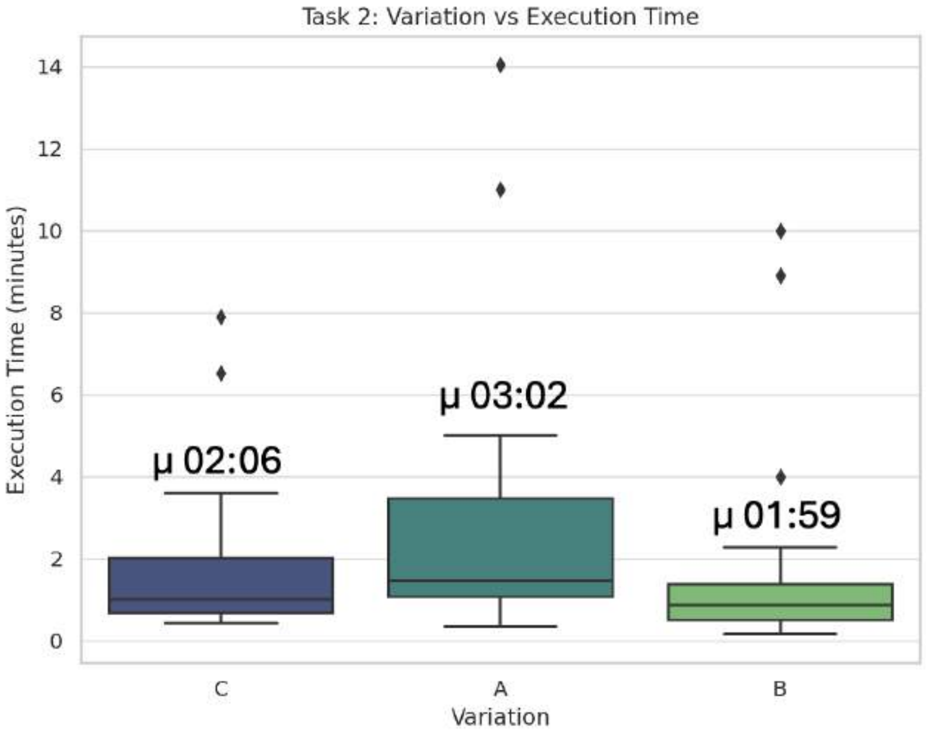


Figure 46: Pilot Study Task 2: Variation vs Execution Time

Task 3: Panning animation

Variation A, no panning animation, saw the lowest average task execution time (0 minutes 37 seconds), compared with Variation B (medium animation duration, 1 minute 37 seconds) and variation C (long animation duration, 1 minute 19 seconds) (p A/B 0.16, p A/C 0.12, p B/C 0.70) (Figure 48). Variation B saw the lowest average perceived ease of task (A 4.4, B 3.6, C 4.5, p

A/B 0.13, p A/C 0.70, p B/C 0.09) (Figure 47).

Participants noted that panning could be useful when a location was labelled or when the route was distinctive, but they encountered difficulties when the map continued to pan briefly after they stopped dragging (inertia). Some considered this behaviour a helpful feature for scanning larger distances quickly, whereas others perceived it as an unexpected loss of precise control. The ability to zoom in while panning was highlighted as a beneficial capability, which unfortunately was not always possible in this particular setup. As with zooming, panning speed seemed to be a matter of personal preference: some wished it was faster, while others found it adequate for focusing on local areas.

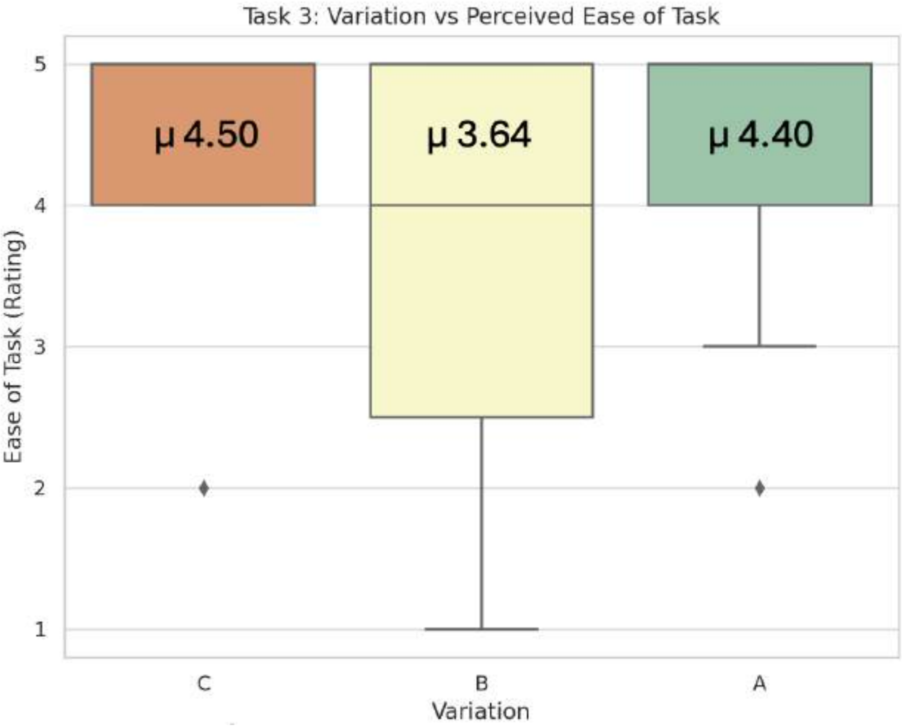


Figure 47: Pilot Study Task 3: Variation vs Perceived Ease of Task

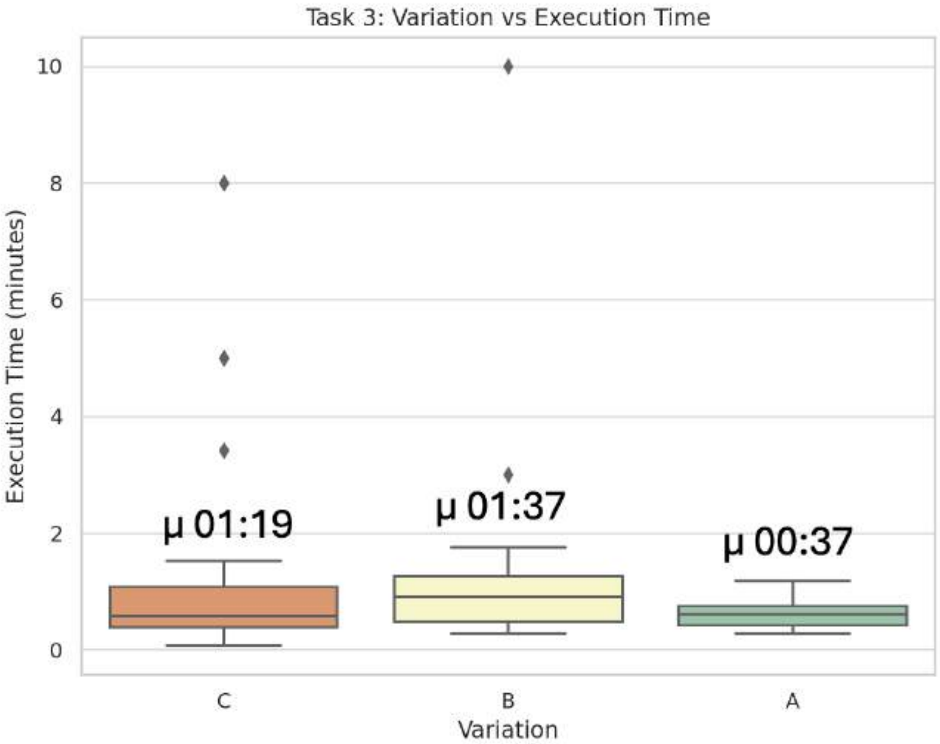


Figure 48: Pilot Study Task 3: Variation vs Execution Time

Overall Impressions and Suggestions for Improvement. Many participants found the vario-scale map concept appealing, especially the way map detail changes with scale. However, some expressed a desire for better control or transparency over how features appear or disappear during zooming. Participants identified labels as a crucial aspect of navigation and recommended making them visible at more scales or allowing dynamic toggles for certain map elements. A search function, additional thematic layers, and the option to view satellite imagery were recurrent suggestions. Participants also commented on the need for more distinct colours for roads, buildings, or important landmarks, noting that certain colour schemes made recognition more challenging. Others wished to see major markers or points of interest at a broader range of scales, so they would not have to guess when zooming in to a very fine level.

The pilot study's qualitative responses indicate that participants rely heavily on labels to orient themselves, particularly in unfamiliar regions. They also highlighted varying preferences for zooming and panning speeds, suggesting that a single default approach might not suit all users. The vario-scale approach was generally seen as helpful, but feedback emphasised the importance of balanced cartographic generalisation and clear feature visibility at different scales. A user-centred approach to designing vario-scale map interfaces could incorporate customisable label visibility ranges, more flexible zoom and pan settings, and tools for rapid navigation (such as a search box or dynamic highlighting of key landmarks). Overall, these findings underline the need to refine map interface design by accommodating diverse user preferences and ensuring that crucial navigational elements remain accessible at a wide range of scales.

6.2 Final Study

6.2.1 Analysis Methodology

Firstly, the responses of the questionnaires are analysed and summarised to understand how the user experiences vario-scale and the differences between vario-scale and multi-scale.

Numerically, eye-tracking metrics have been identified as valuable indicators of usability and cognitive processes. According to the eye-mind hypothesis proposed by Just and Carpenter (1980), a fixation on an object corresponds to the time the brain spends processing that object, providing direct insight into cognitive processing during task performance. Several specific eye-tracking metrics are utilised in this study:

- **Fixation Count**: As suggested by Goldberg and Kotval (1999), a higher number of fixations may indicate less efficient searching, as the user needs to fixate on more points to locate the target.
- **Fixation Duration**: Longer fixation durations can signify difficulty with the display or the information presented, implying increased cognitive load (Goldberg & Kotval, 1999).
- **Scanpath Length**: A longer scanpath may indicate less efficient searching patterns, reflecting more extensive eye movements across the display (Goldberg, Stimson, Lewenstein, Scott, & Wichansky, 2002).
- **Time to First Fixation on Target**: This metric measures the time it takes for the participant to fixate on the target after it becomes visible, indicating search efficiency (Byrne, Anderson, Douglas, & Matessa, 1999).

These metrics together form an overview of efficiency and cognitive processes regarding vario-scale and multi-scale maps.

In addition to using eye-tracking metrics to assess efficiency, the analysis focuses on identifying differences in user behaviour between multi-scale and vario-scale maps.

Task 1 Analysis

Task 1 was designed as a controlled, structured search to simulate a realistic map use case while enhancing comparability between participants. The primary metric analysed was the **Time to First Fixation on Target**, calculated as the difference between the time when the target became visible in the viewport and the time when the participant found the target.

To determine whether the participant found the target, the following method was employed:

- **Target Visibility**: The target was considered visible if the map's scale (after any snapping adjustments) was below the maximum denominator threshold, and the target's geographic coordinates fell within the viewport boundaries.
- **Participant's Gaze on Target**: The participant was deemed to be looking at the target if a fixation occurred within a 100-pixel radius of the target's location.

To achieve accurate spatial correlation between eye movements and map elements, fixation coordinates in pixels relative to the viewport were transformed into geographic coordinates using the corresponding viewport coordinates from the closest map log record (See Section 5.3). The **Scanpath Length** was calculated as the sum of all saccade lengths in pixels during the task, providing an indication of the actual physical eye movement across the screen.

Additional metrics analysed included:

- **Fixation Duration**

- **Fixation Count**

Task 2 Analysis

For Task 2, the **Time to First Fixation on Target** was calculated separately for each of the three targets in both the castles and campsites categories. This metric was determined by the difference between the time when it became visible in the viewport and when the participant found each target. The **Time to Complete** the task was measured as the difference between the start time and the found time of the last target among the three.

Additional metrics analysed included:

- **Fixation Duration**
- **Total Scanpath Length**: Summing the lengths of all saccades to evaluate search efficiency.
- **Fixation Count**

Task 3 Analysis

In Task 3, the analysis focused on the following metrics:

- **Total Scanpath Length**
- **Total Fixation Count**
- **Average Fixation Duration**: Calculated to infer cognitive load and processing challenges.

Additionally, the study compared **panning versus zooming behaviour** between multi-scale and vario-scale map users to identify significant differences in navigation strategies and map interaction patterns.

6.2.2 Analysis Results - Introduction

Most participants (7) have prior experience with usability testing for digital interfaces, indicating a reasonable familiarity with the evaluation process. The group also demonstrates a high level of technological proficiency, as shown in Table 1.

Table 1: Technological Proficiency of Participants

Proficiency Level	**Number of Participants**
Extremely proficient	3
Very proficient	4
Moderately proficient	3
Not proficient	0

A significant proportion of participants (9) engage in activities involving maps, emphasising the relevance of this group to Cartography-related evaluations. However, knowledge about the specific differences between vario-scale and multi-scale maps is limited. Only 3 respondents could describe the distinction, while the majority (8) were unsure (Table 2).

Familiarity with web maps, such as Google Maps, is widespread, with the majority being “Very familiar” (7) or “Extremely familiar” (2), and only a small portion being “Moderately familiar” (2). None reported unfamiliarity, underscoring the suitability of the chosen platform (Table 3).

The experience of “local shock,” where sudden changes in map detail or orientation occur while zooming, was reported as “Occasional” by 6 participants and “Frequent” by 5 (Table 4). This

Table 2: Understanding of Vario-scale vs. Multi-scale Maps

Response	**Number of Participants**
Confident in describing the distinction	3
Unsure	8

Table 3: Familiarity with Web Maps

Familiarity Level	**Number of Participants**
Extremely familiar	2
Very familiar	7
Moderately familiar	2
Not familiar	0

Table 4: Local Shock During Zooming

Frequency	**Number of Participants**
Frequent	5
Occasional	6
Rarely or never	0

indicates local shock is a common phenomenon. Smooth and continuous transitions were highly valued, with 6 respondents rating them as "Very important" and 1 as "Extremely important." When asked about preferred map behaviour during zooming, the majority (10) favoured maps that gradually reveal more details as they zoom in, and fewer participants (4) supported the gradual hiding of details while zooming out. Minimal preference was expressed for maintaining the same detail level or having no preference.
Navigation emerged as the dominant use case for web maps (11 responses), followed by recreation or leisure (5), work-related tasks (4), and education (4). No participants selected "None of the above" or added other options (Table 5).

Table 5: Common Web Map Use Cases

Use Case	**Number of Responses**
Navigation	11
Recreation or leisure	5
Work-related tasks	4
Education	4
Other or none	0

Device preferences were evenly split, with participants reporting equal use of mobile devices and computers (5 each), while only 1 favoured using maps "Mostly on computers."

6.2.3 Analysis Results - Task 1

Questionnaire Analysis:
The task was generally perceived as moderate in difficulty. As shown in Table 6, most participants rated the task in the mid-range (*i.e.*, "2" or "3"), indicating a manageable level of challenge. Only one participant found the task very easy, and none considered it very difficult.

The instructions were well received, with nearly all participants finding them clear or very clear (see Table 7). No one rated the instructions as genuinely unclear, suggesting that the guidance was adequate for the majority of users.

Table 6: Distribution of difficulty ratings (1 = very easy, 5 = very difficult)

Difficulty Rating	**Count**
1 (very easy)	1
2	4
3	5
4	1
5 (very difficult)	0

Table 7: Distribution of instruction clarity ratings (1 = unclear, 5 = very clear)

Clarity Rating	**Count**
1 (unclear)	0
2	0
3	2
4	3
5 (very clear)	6

Most participants found both map types equally manageable, though some preferred the vario-scale map, and very few favored the multi-scale map (see Table 8). Overall, participants highlighted vario-scale maps for smoother transitions and more intuitive navigation, but certain aspects, such as continuously updating features, were perceived as distracting by a few. By contrast, multi-scale maps were criticised for abrupt updates, which required users to reorient themselves repeatedly.

Table 8: Map type preferences

Map Preference	**Count**
Vario-scale easier	4
Multi-scale easier	1
No preference (equal)	6

Participants reported that the gradual appearance of labels in vario-scale maps allowed them to process new information smoothly, reducing confusion. One participant specifically noted the benefit of efficient information processing during a concurrent phone call. Conversely, the multi-scale map faced criticism for disruptive label changes at each scale level, which some found jarring. Nonetheless, a subset of participants provided neutral feedback, indicating no strong preference between the two map types.

Metrics analysis

The analysis of user behaviour metrics revealed no statistically significant differences between vario-scale and multi-scale mapping interfaces across several key usability indicators. Regarding fixation count, the mean fixation count during the visible period was slightly higher for vario-scale maps (10.00) compared to multi-scale maps (8.68) (Figure 50), but this difference was not statistically significant (p = 0.72). Similarly, there was no significant difference in fixation duration for the full task, with means of 0.281 seconds for multi-scale and 0.277 seconds for vario-scale (p = 0.70).

The time to the first fixation also showed no significant difference between the two approaches, with mean times of 2.02 seconds for multi-scale and 2.47 seconds for vario-scale maps (p = 0.61). Furthermore, while the average scanpath length was consistently higher for vario-scale maps, both for the full task (mean: 13.409 px vs. 9.100 px, p = 0.27) and the visible period (mean: 2.462 px vs. 1.666 px, p = 0.39), these differences were not statistically significant.

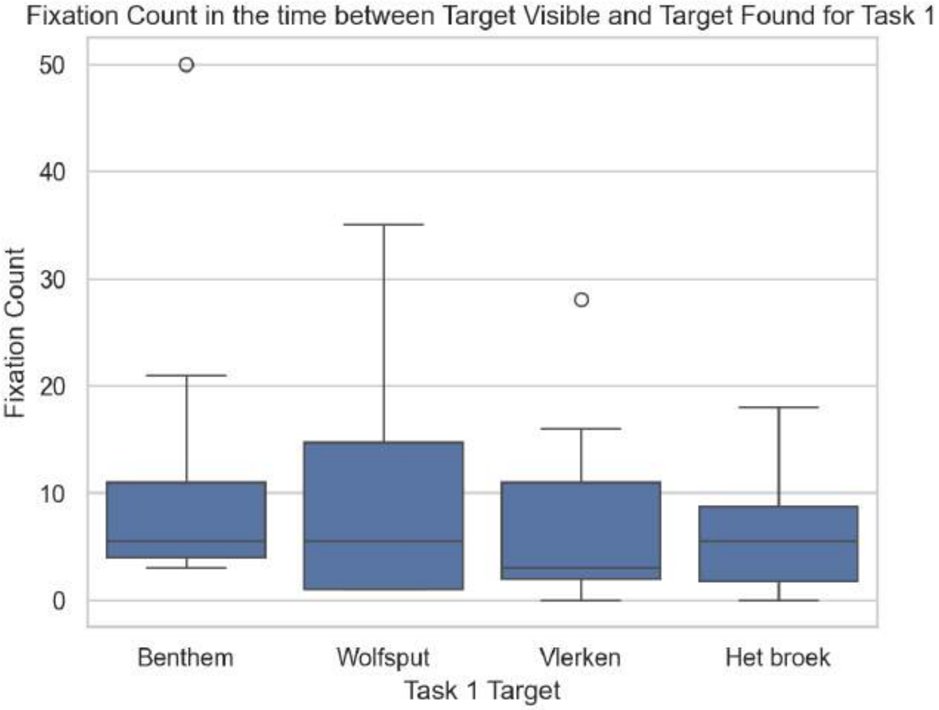


Figure 49: Fixation Count in the time between Target Visible and Target Found for Final Study Task 1 - Box Plot by Target

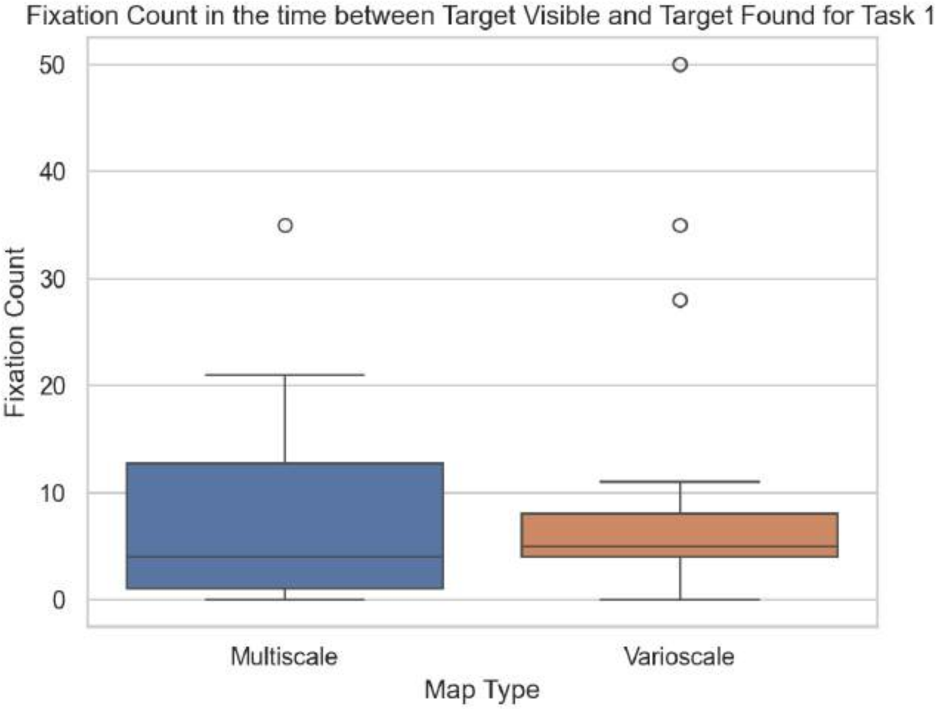


Figure 50: Fixation Count in the time between Target Visible and Target Found for Final Study Task 1 - Box Plot by Map Type

In contrast, the analysis of zooming and panning behaviour revealed a significant effect on task completion time. Specifically, the proportion of panning was positively correlated with task completion time (Pearson's r = 0.39, p = 0.01) (Figure 51), indicating that increased panning was associated with longer task durations. Conversely, the proportion of zooming was negatively correlated with task completion time (Pearson's r = -0.52, p < 0.01) (Figure 52), suggesting that increased zooming contributed to faster task completion. These findings underscore the importance of interaction patterns, particularly zooming and panning, in influencing user performance, while other visual metrics showed limited differentiation between the mapping approaches.

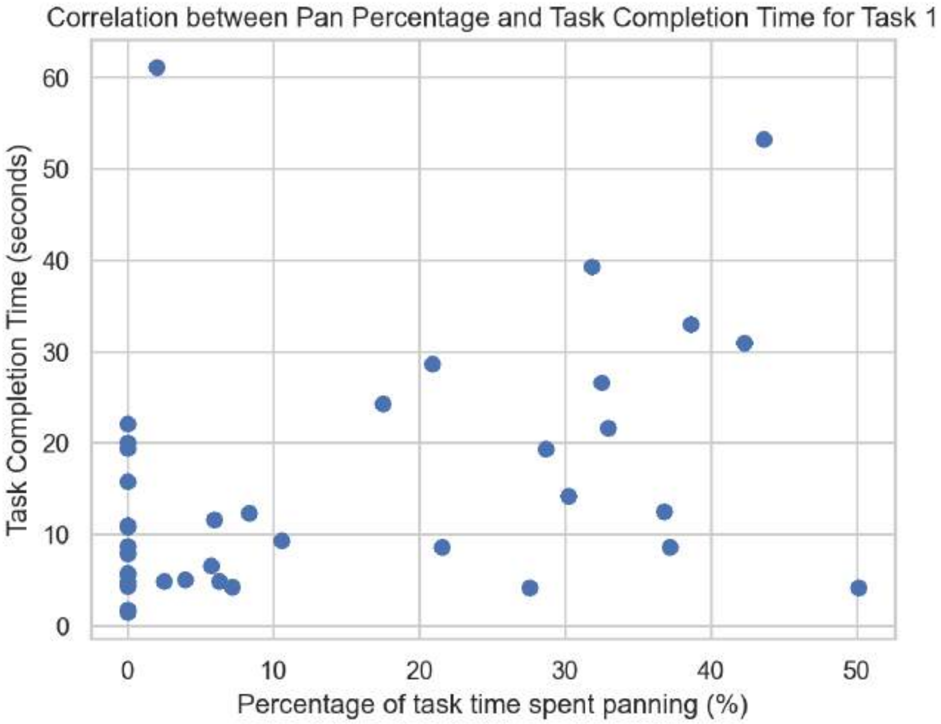


Figure 51: Correlation between Pan Percentage and Task Completion Time for Final Study Task 1

6.2.4 Analysis Results - Task 2

Questionnaire Analysis

Task 2 was generally perceived as manageable yet slightly more challenging than Task 1. As shown in Table 9, most participants found the task moderately or somewhat difficult, with only a small number rating it as easier and none considering it very difficult.

Table 9: Difficulty ratings for Task 2 (1 = very easy, 5 = very difficult)

Difficulty Rating	Count
1 (very easy)	0
2	2
3	5
4	4
5 (very difficult)	0

All participants rated the instructions for Task 2 as 5 (very clear), indicating that the task

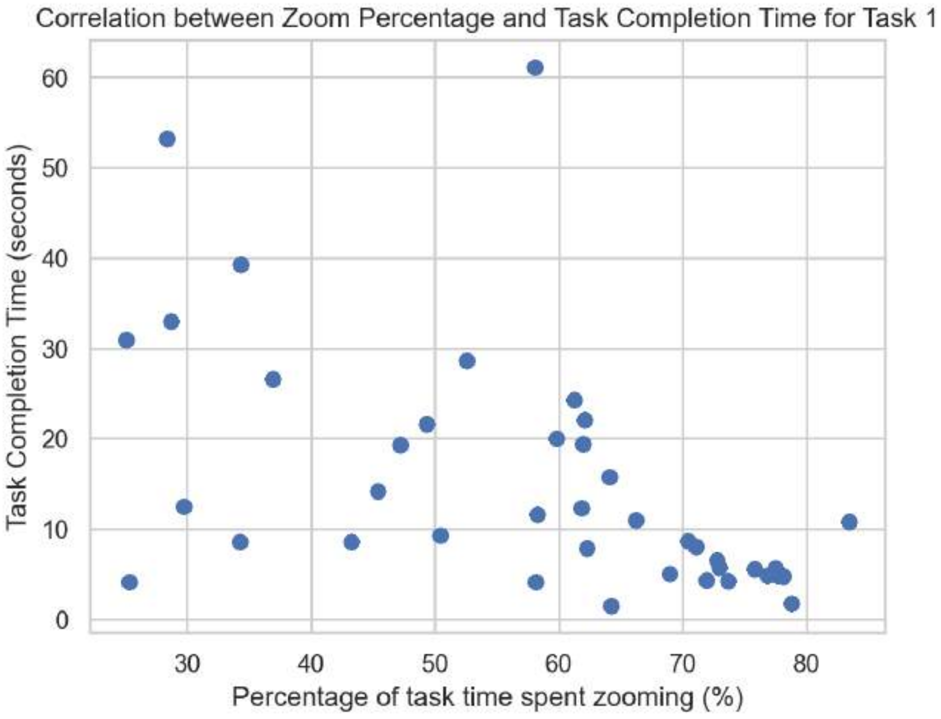


Figure 52: Correlation between Zoom Percentage and Task Completion Time for Final Study Task 1

requirements were fully understood.

Participant preferences were more divided in Task 2 compared to Task 1. Table 10 shows that while some found the vario-scale map easier to use, others favored the multi-scale map, and several had no strong preference.

Table 10: Map type preferences for Task 2

Map Preference	**Count**
Vario-scale easier	3
Multi-scale easier	4
No preference (equal)	4

The vario-scale map continued to be lauded for smooth zooming, which was seen as facilitating seamless tracking of map elements. However, the continuous updates occasionally made locating specific features more time-consuming. By contrast, some participants found that abrupt scale changes in the multi-scale map helped quickly identify certain symbols, though these sudden updates sometimes prompted the need for reorientation. Regardless of map type, many found that the inherent complexity of the final location search posed a significant challenge.

Metrics analysis

The results for Task 2 closely align with those observed in Task 1, showing no significant differences between vario-scale and multi-scale mapping interfaces across key usability metrics. The time to first fixation (TTFF) was nearly identical for both approaches, with mean values of 0.97 seconds for multi-scale and 0.96 seconds for vario-scale ($p = 0.96$) (Figure 55).

Similarly, no significant differences were found in fixation duration, with mean durations of 0.245 seconds for multi-scale and 0.241 seconds for vario-scale in Task 2 ($p = 0.52$), consistent

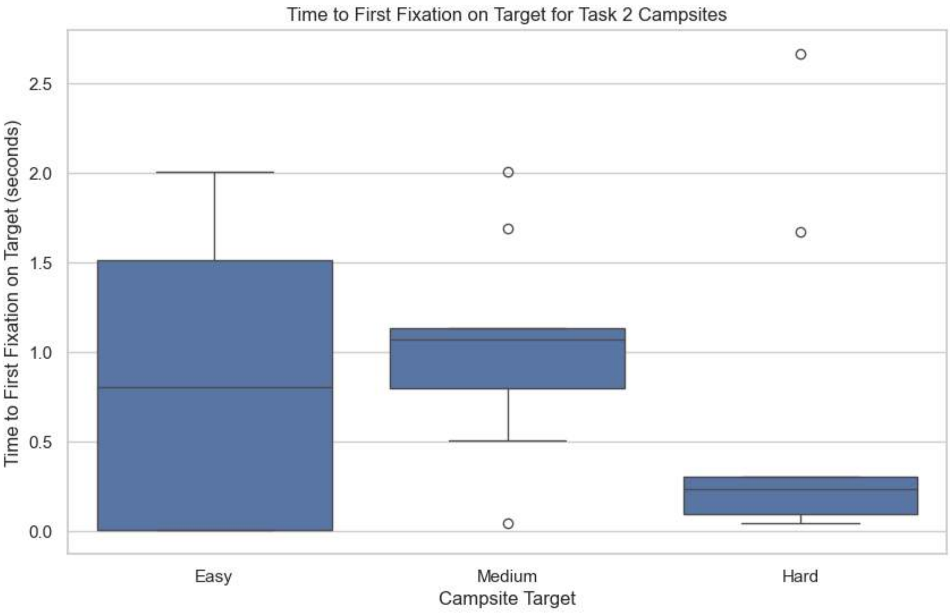


Figure 53: Time to First Fixation on Target for Final Study Task 2 Campsites - Box Plot by Target

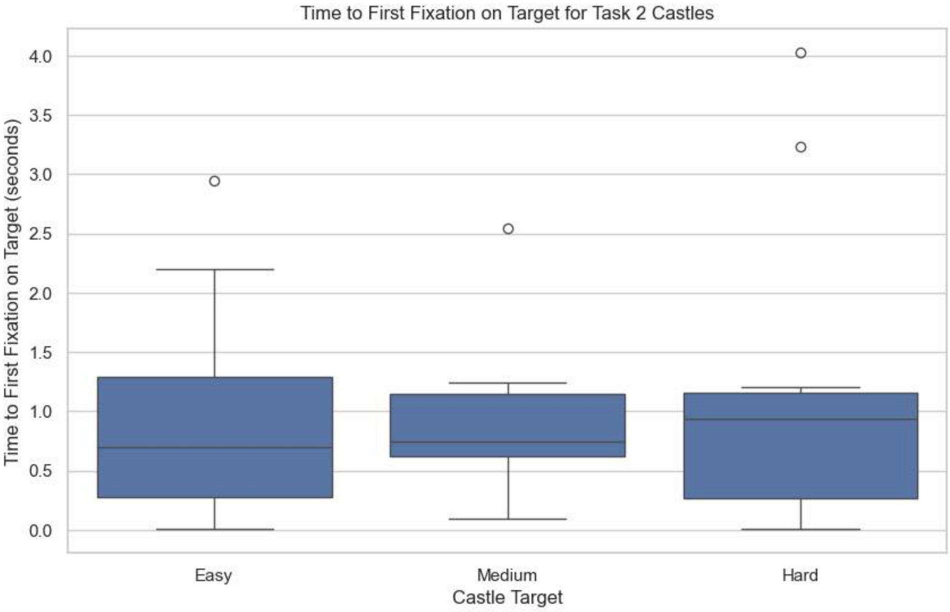


Figure 54: Time to First Fixation on Target for Final Study Task 2 Castles - Box Plot by Target

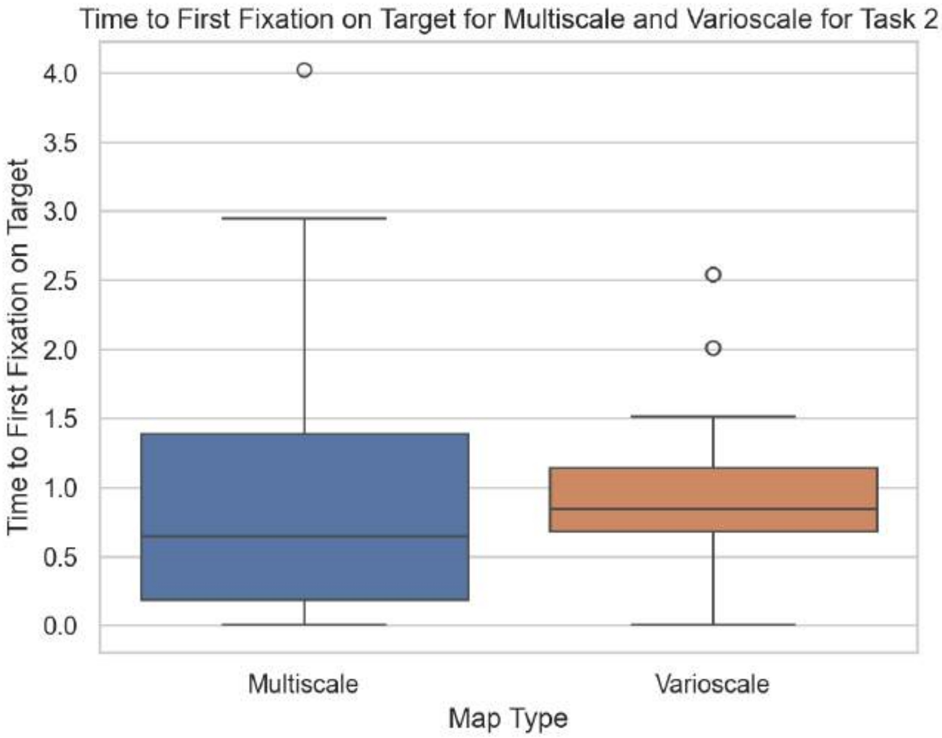


Figure 55: Time to First Fixation on Target for Final Study Task 2 - Box Plot by Map Type

with the pattern from Task 1. The scanpath length for the full task also showed no significant difference between the two mapping approaches, with mean values of 120.451 px for multi-scale and 118.546 px for vario-scale (p = 0.97). Additionally, fixation count during the full task was virtually identical between multi-scale (mean: 404.5) and vario-scale (mean: 404.3), with no significant difference (p = 1.00).

Task completion time showed similar parity, with multi-scale and vario-scale maps yielding mean times of 104 seconds and 97 seconds, respectively, and no significant difference (p = 0.85). These findings suggest similar performance according to eye-tracking metrics between the two mapping approaches across tasks.

In Task 2, the correlations between zooming and panning behaviour and task completion time showed some divergence from Task 1. While panning percentage was positively correlated with task completion time (Pearson's r = 0.43) (Figure 56), this relationship was marginally significant (p = 0.06), contrasting with the significant correlation observed in Task 1. The negative correlation between zooming percentage and task completion time (Pearson's r = -0.39) (Figure 57) was not statistically significant (p = 0.10), again differing from the significant finding in Task 1. These subtle variations suggest that while interaction patterns remain influential, their statistical significance may vary depending on the task context.

6.2.5 Analysis Results - Task 3

Questionnaire Analysis

Task 3 was generally perceived as slightly easier overall compared to Task 1 and 2. As shown in Table 11, more participants rated this task as easy, and no one considered it very difficult.

The instructions were widely regarded as clear. As illustrated in Table 12, the majority rated them very clear, with only one participant providing a neutral rating.

Task 3 also showed a higher proportion of participants who found both map types equally manageable, suggesting that familiarity reduced usability differences (Table 13). Those who did

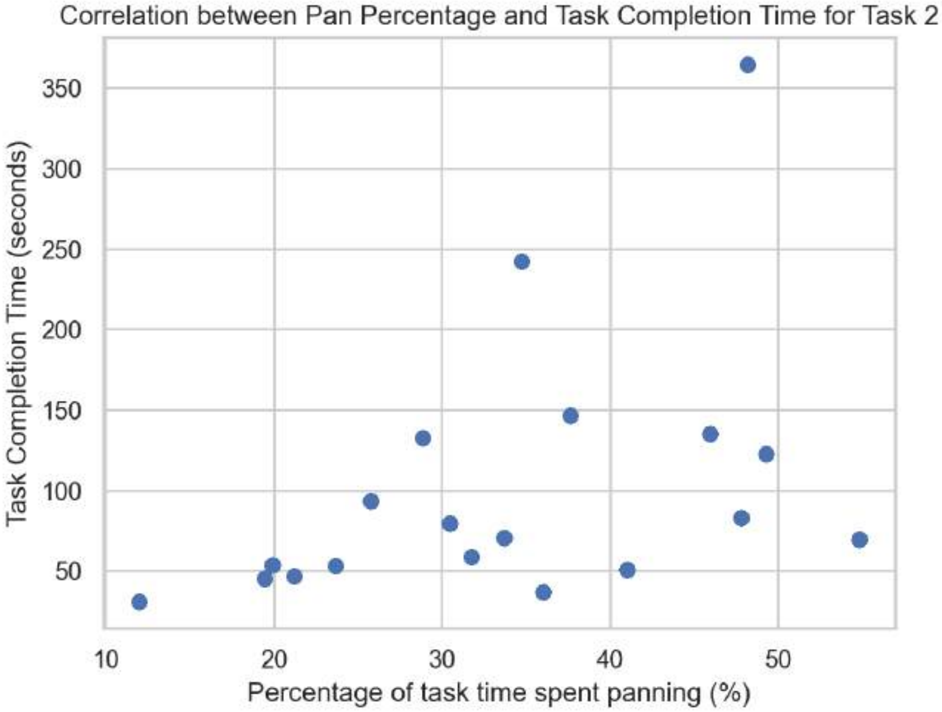


Figure 56: Correlation between Pan Percentage and Task Completion Time for Final Study Task 2

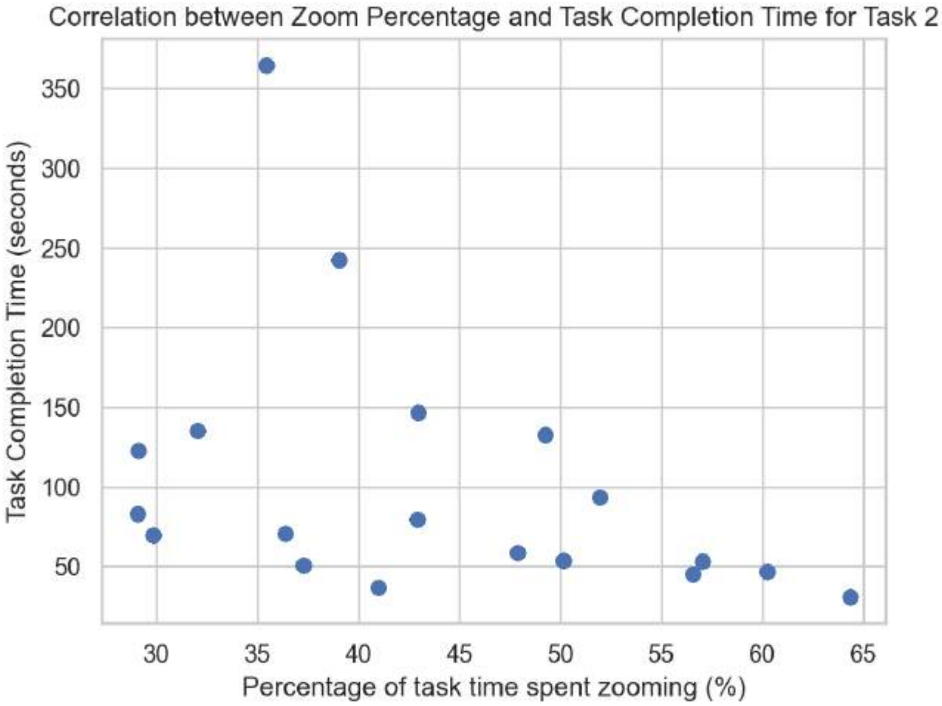


Figure 57: Correlation between Zoom Percentage and Task Completion Time for Final Study Task 2

Table 11: Difficulty ratings for Task 3 (1 = very easy, 5 = very difficult)

Difficulty Rating	Count
1 (very easy)	1
2	4
3	3
4	3
5 (very difficult)	0

Table 12: Instruction clarity ratings for Task 3 (1 = unclear, 5 = very clear)

Clarity Rating	Count
1 (unclear)	0
2	0
3	1
4	0
5 (very clear)	10

have a preference remained split between the vario-scale and multi-scale maps.

Table 13: Map type preferences for Task 3

Map Preference	Count
Vario-scale easier	3
Multi-scale easier	2
No preference (equal)	6

Feedback on the vario-scale map highlighted its ability to offer a better overview of natural features, thanks to smooth transitions and gradual detail appearance. However, some participants reported that continuous updates could make it hard to distinguish between similarly coloured features (such as roads and beaches) and occasionally hindered the interpretation of feature scale.

Impressions of the multi-scale map were mixed. Familiarity improved its usability for some, and the quick pop-up of details helped in locating certain elements such as water bodies. Yet its reliance on zoom steps to show finer details (like beach width) remained a drawback, especially when compared to the vario-scale map. Several participants noticed fewer relevant features at each scale level, prompting extra zoom actions to find certain elements.

A number of participants expressed neutral opinions, reporting no major differences between map types for this task. This lack of distinction may have stemmed from accumulated experience using both maps over the course of the study.

Metrics Analysis

The results for Task 3 further reinforce the patterns observed in the previous tasks, with no statistically significant differences identified between vario-scale and multi-scale maps across most usability metrics. Participants' fixation behaviour, as reflected in the heatmap analysis (Figure 58 and 59), demonstrated a strong focus on large, recognisable lakes. Fixation frequencies were particularly high at lakes with beaches and a lake located within a town, which participants explicitly identified as suitable for hosting barbecues.

Regarding interaction patterns, multi-scale maps appear to encourage slightly more frequent zooming into smaller scales, with a peak in usage at the 1:2500 to 1:5000 range. In contrast, vario-scale maps exhibited a broader peak in the 1:2500 to 1:7500 range.

Quantitative metrics also confirmed the absence of significant differences. The scanpath

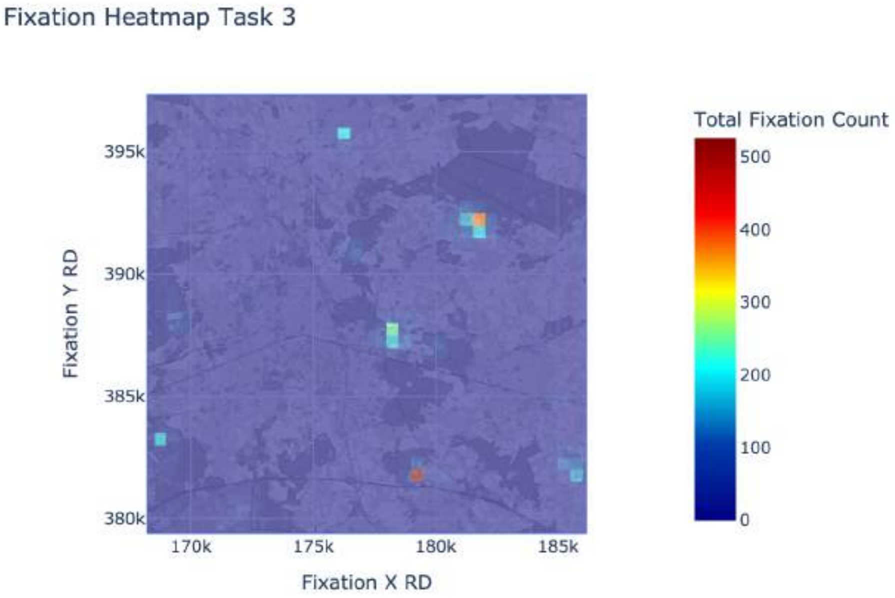


Figure 58: Fixation Heatmap for Final Study Task 3, showing fixation frequency across all participants for different areas of the map. Basemap from (OpenStreetMap contributors, 2017).

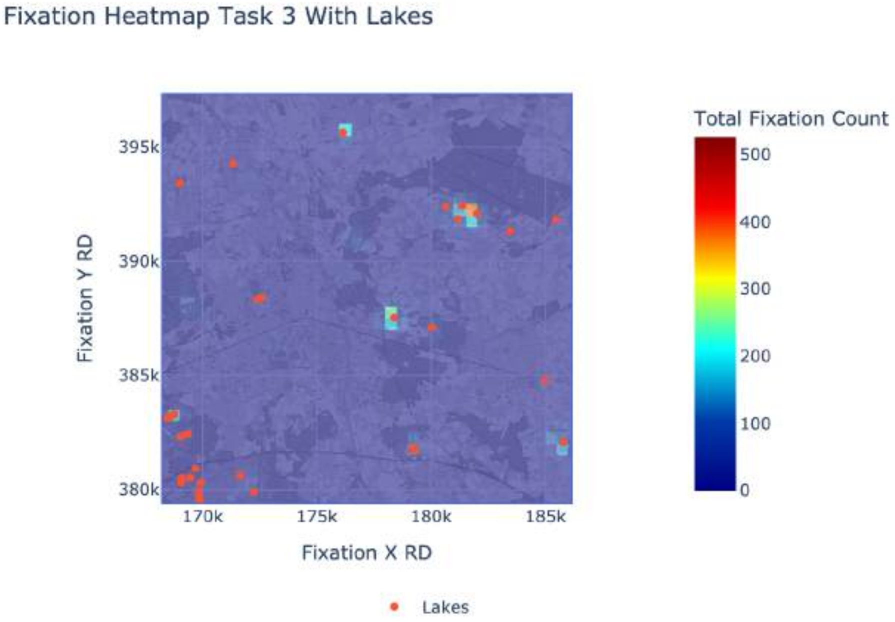


Figure 59: Fixation Heatmap for Final Study Task 3, with lake locations overlayed as points. Basemap from (OpenStreetMap contributors, 2017).

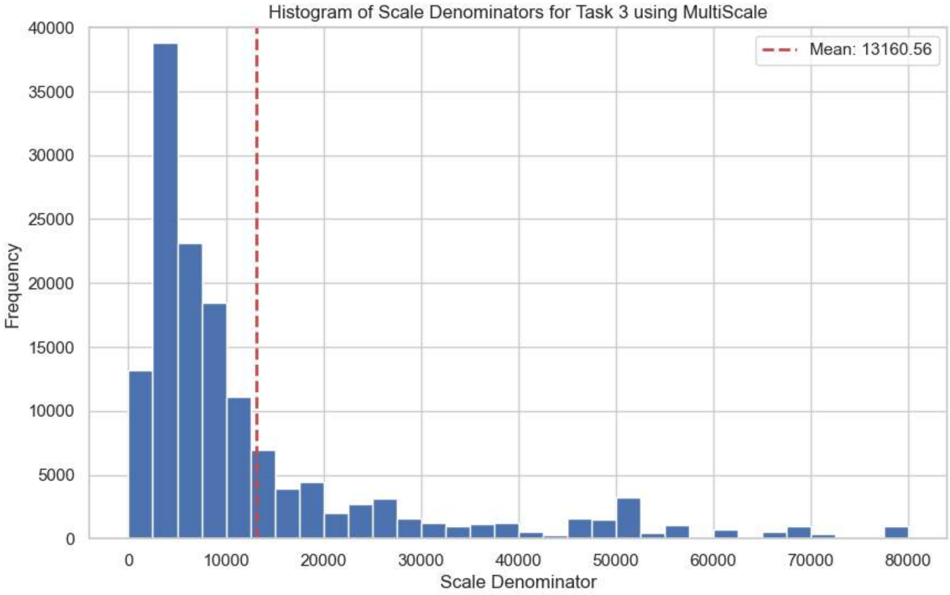


Figure 60: Histograms of Scale Denominators for Task 3 using Multi-Scale.

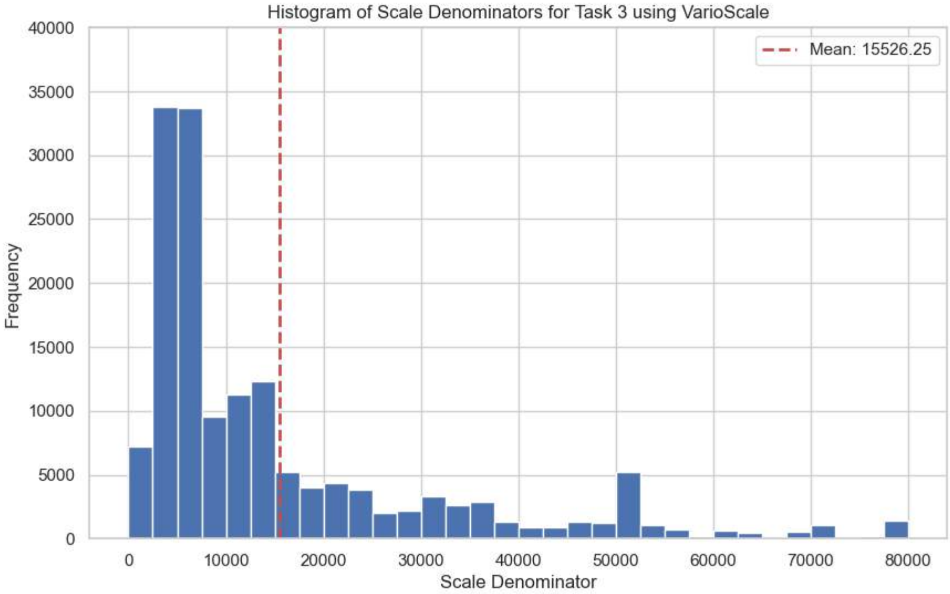


Figure 61: Histograms of Scale Denominators for Task 3 using Vario-Scale.

lengths for multi-scale (mean: 86.252 px) and vario-scale (mean: 86.787 px) were nearly identical (p = 0.96). Fixation counts and durations were similarly comparable, with fixation counts averaging 336.8 for multi-scale and 351.6 for vario-scale (p = 0.56), and fixation durations averaging 0.266 seconds for multi-scale and 0.261 seconds for vario-scale (p = 0.34). Slightly higher panning percentages and lower zooming percentages were observed for vario-scale maps (pan: 0.24, zoom: 0.19) compared to multi-scale maps, but these differences were not statistically significant (p = 0.39).

Overall, the findings from Task 3 align closely with those from Tasks 1 and 2, demonstrating continuity in similarity between the vario-scale and multi-scale approaches in terms of both visual attention metrics and interaction patterns. The consistent focus on recognisable features, such as lakes, further underscores the influence of visual salience on user behaviour across tasks.

6.2.6 Analysis Results - Overall

Questionnaire analysis

Most participants (5) rated the comparison between vario-scale and multi-scale maps as "Mostly fair," with 3 considering it "Very fair" (Table 14). Two participants were neutral, while one found the comparison "Somewhat unfair," citing task-specific biases. These findings indicate that the comparison was largely perceived as fair overall.

Table 14: Perceived fairness of comparison

Fairness Rating	Count
Very fair	3
Mostly fair	5
Neutral	2
Somewhat unfair	1
Very unfair	0

The tasks were widely regarded as realistic for real-life web map use, with 7 participants describing them as "Very realistic" and 4 as "Somewhat realistic" (Table 15). No one considered the tasks unrealistic, suggesting that they successfully mirrored typical user interactions with web maps.

Table 15: Realism of tasks

Realism Rating	Count
Very realistic	7
Somewhat realistic	4
Neutral	0
Not very realistic	0
Not realistic at all	0

Participant preferences for map efficiency showed an overall tilt towards vario-scale maps, as shown in Table 16. Three participants strongly preferred vario-scale maps, two slightly favoured them, and four found both map types equally efficient. Two slightly preferred multi-scale maps, with none strongly favouring them. Feedback often highlighted vario-scale maps for their smooth and gradual transitions, which many found modern and intuitive. Some, however, reported that constant updates were distracting when focusing on small features like buildings. The lack of visible POIs at broader zoom levels—across both map types—necessitated additional scanning for relevant information.

Table 16: Map efficiency preferences

Preference	Count
I strongly find varioscale more efficient	3
I slightly find varioscale more efficient	2
I find both equally efficient	4
I slightly find multiscale more efficient	2
I strongly find multiscale more efficient	0

By contrast, the predefined zoom levels of multi-scale maps offered clarity and familiarity for tasks demanding large area exploration. Some participants felt this approach made it easier to identify high-level features, even though abrupt transitions and sudden influxes of information occasionally caused confusion. The intermittent lack of features at broader scales was reported for both map types, highlighting the need to zoom further in to retrieve relevant POIs.

The eye tracker was well-received: the majority of participants (8) reported feeling "Very comfortable," with 3 feeling "Somewhat comfortable" (Table 17). No one reported discomfort, indicating that the technology did not interfere with participant performance or study outcomes.

Table 17: Eye tracker comfort

Comfort Level	Count
Very comfortable	8
Somewhat comfortable	3
Neutral	0
Somewhat unconfortable	0
Very uncomfortable	0

Participants identified several key features as critical for usability, detailed in Table 18. A search bar and layer options were unanimously requested, indicating their fundamental importance for map interaction. Bookmarks or saved locations were also frequently mentioned, highlighting the value of personalisation in real-life tasks. Likewise, a measurement tool was viewed as beneficial for spatial analysis, while zoom and pan controls remained useful for manual navigation.

Table 18: Key features requested

Feature	Count of Requests
Search bar	10
Layer options	10
Bookmarks/saved locations	8
Measurement tool	6
Zoom/pan controls	3

Metrics analysis

Overall, the analysis of zooming and panning behaviours across tasks reveals consistent and significant correlations with task completion time. Panning percentage exhibited a positive correlation with task completion time (Pearson's $r = 0.52$, $p < 0.01$) (Figure 62), indicating that higher panning activity tends to result in longer task durations. In contrast, zooming percentage demonstrated a negative correlation with task completion time (Pearson's $r = -0.44$, $p < 0.01$) (Figure 63), suggesting that increased zooming is associated with faster task completion.

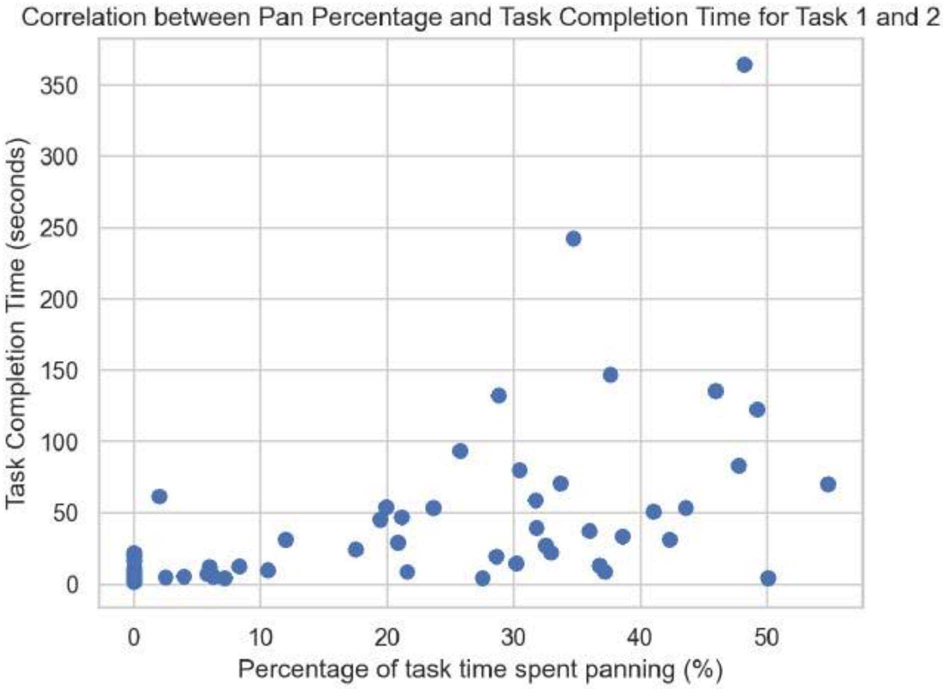


Figure 62: Correlation between Pan Percentage and Task Completion Time for Task 1 and Task 2 of the Final Study

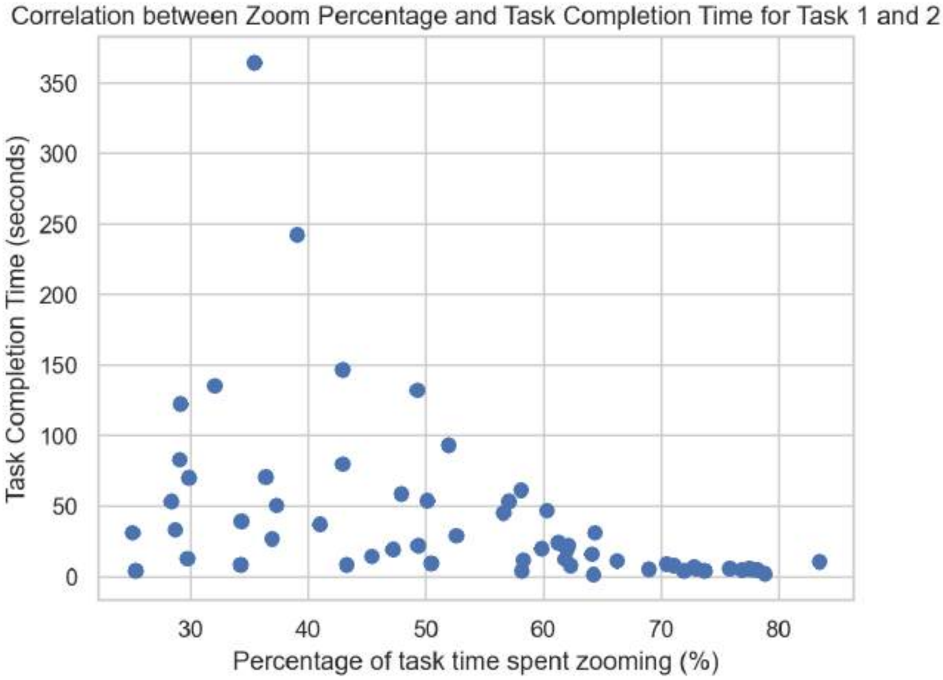


Figure 63: Correlation between Zoom Percentage and Task Completion Time for Task 1 and Task 2 of the Final Study

7 Discussion

This study aimed to evaluate the usability of vario-scale maps compared to multi-scale maps by incorporating realistic map use tasks, eye-tracking data, and participant feedback. By expanding upon the work of Šuba (2017), a more comprehensive understanding was sought regarding how users interact with these map types in practical scenarios. This chapter discusses the findings in relation to previous research, the statistical significance of the results, and the implications for future map design and usability studies.

This research builds upon the work of Šuba (2017), who conducted a usability test comparing vario-scale and multi-scale maps using a single, controlled task on a thematic background map. Šuba's study did not find significant differences in efficiency or user experience between the two map types, and participants reported not observing differences in their interactions.

In contrast, the current study introduced multiple realistic tasks, including the use of labels, icons, symbology, and colours on a realistic background map, along with eye-tracking data and further questionnaire inquiries. This comprehensive approach allowed for capturing a broader range of user interactions and preferences. While the eye-tracking metrics similarly indicated no significant differences in efficiency between vario-scale and multi-scale maps, participants in this study perceived differences and generally favoured vario-scale maps. This suggests that while objective efficiency may be comparable in this study context, subjective user experience can vary, highlighting the importance of incorporating qualitative feedback in usability studies.

Statistical Significance and Study Design

The eye-tracking metrics analysed—fixation count, fixation duration, scanpath length, and time to first fixation—revealed no statistically significant differences in efficiency between vario-scale and multi-scale maps across all tasks in this study context. This aligns with the findings of Šuba (2017), suggesting that both map types perform similarly in terms of objective measures of efficiency in this study context and efficiency differences could be more nuanced.

However, it is important to consider that the lack of significant differences may be influenced by the study design and sample size. The small number of participants limits the statistical power to detect subtle differences. Ensuring that tasks are appropriately challenging and that the sample size is sufficient are critical factors in achieving statistically significant results. Future research with larger participant groups could provide more definitive conclusions regarding efficiency and may uncover nuanced differences not detectable in this study.

Influence of Participant Background

The pilot study revealed that participants with a background in Cartography completed tasks significantly faster than those without such expertise (Pearson's r -0.50, p 0.001). This finding underscores the impact of domain-specific knowledge on task performance and suggests that familiarity with cartographic principles enhances usability. It highlights the importance of designing maps that are accessible and efficient for users with varying levels of expertise.

This insight suggests that vario-scale maps, as well as multi-scale maps, should be optimised to cater to a broad audience, including users who may not have specialised knowledge in Cartography. By considering the needs of users, map interfaces can be made more intuitive and user-friendly, thereby improving overall user satisfaction and interaction effectiveness.

Unexpected Findings from the Pilot Study

An unexpected result from the pilot study was that participants completed Task 1 faster without icons (variation B) than with icons (variation A), although this difference was not statistically significant (p 0.14). This counterintuitive outcome suggests that the presence of icons may introduce additional cognitive load or visual complexity, potentially slowing down task performance. The expectation was that icons would aid in navigation and information retrieval, but the results indicate that they may sometimes hinder performance.

Impact of Pilot Study on Final Study Design

Feedback from the pilot study was instrumental in refining the final study design. The pilot indicated that task difficulty significantly influenced task completion time, emphasising the need for tasks that are solvable within anticipated time frames to prevent participant stress and frustration. This was achieved in the final study, with tasks being completed within expected times by most participants and only one outlier taking longer than anticipated.

The pilot study also highlighted the importance of clear instructions and realistic scenarios, which were incorporated into the final study to enhance participant engagement and data validity. By ensuring that tasks did not take longer than expected and were fully solvable, participant satisfaction was improved, and data quality was enhanced.

Participant Preferences and Perceptions

In the final study, participants expressed a preference for vario-scale maps, citing advantages such as smoother transitions, gradual appearance of labels and symbols, and a more intuitive navigation experience. These preferences were reflected in the questionnaire responses, where participants frequently praised vario-scale maps for enhancing usability and providing a modern, aesthetically pleasing interface.

Conversely, multi-scale maps were criticised for abrupt transitions and "local shocks" during zooming, which disrupted user orientation and required reorientation at each scale level. Participants noted that the sudden influx of information during scale changes in multi-scale maps was less user-friendly compared to the continuous and gradual updates in vario-scale maps.

These subjective preferences suggest that vario-scale maps may improve user interaction and satisfaction compared to multi-scale map interfaces, even if objective efficiency measures are similar. The smooth and continuous transitions in vario-scale maps align with user expectations for modern, interactive applications, potentially enhancing the overall user experience.

Eye-Tracking Metrics and Cognitive Processes

The eye-tracking metrics used in this study were grounded in established research on visual attention and cognitive processing. The eye-mind hypothesis states that fixations correspond to cognitive processing (Just & Carpenter, 1980), making metrics such as fixation count and duration valuable indicators of cognitive load and search efficiency. Fixation count can indicate the efficiency of search patterns, while longer fixation durations may reflect increased difficulty with the display or information presented (Goldberg & Kotval, 1999).

Scanpath length provides insight into the extent of visual search and navigation strategies (Goldberg & Kotval, 1999). Time to first fixation on target measures search efficiency and the ability to locate relevant information quickly (Byrne et al., 1999). By employing these metrics, the study provides a robust assessment of usability and cognitive processes during map interactions, consistent with best practices in eye-tracking research.

The lack of significant differences in these metrics between vario-scale and multi-scale maps suggests that both map types are comparable in terms of cognitive load and search efficiency in this study context. This finding indicates that, in this study context, users can perform tasks equally efficiently with either map type, despite subjective preferences for vario-scale maps. It emphasises the importance of considering both objective and subjective measures in usability studies to gain a comprehensive understanding of user experiences.

Insights from Questionnaires

The questionnaires yielded several insightful findings. In the pilot study, a fair distribution of age groups was achieved, enhancing the generalisability of the results. The majority of participants in the final study rated the comparison between vario-scale and multi-scale maps as fair, indicating that the study design was balanced and unbiased.

Participants highlighted the importance of certain map features, such as search bars, layer options, and bookmarks, for enhancing usability. These preferences suggest areas for further development in map interfaces to meet user needs. Incorporating these features into vario-scale maps could further improve user satisfaction and interaction effectiveness.

Additionally, the pilot study indicated that mobile devices are the most commonly used platform for web maps, underscoring the necessity of optimising vario-scale maps for mobile applications. Since most users access maps on mobile devices for navigation purposes, ensuring that vario-scale maps function effectively on these platforms is critical for widespread adoption and user satisfaction.

8 Conclusion

This study explored the usability of vario-scale maps and compared the efficiency and user satisfaction with multi-scale maps by incorporating realistic map-use tasks, eye-tracking data, and participant feedback. The aim was to determine whether vario-scale maps enhance user interaction and satisfaction.

The main research question of this thesis was:
"To what extent do vario-scale maps improve user interaction and satisfaction compared to multi-scale map interfaces?"
The findings indicate that vario-scale maps significantly enhance user satisfaction and interaction compared to multi-scale maps (Section 6.2). Participants preferred vario-scale maps due to smoother transitions, the gradual appearance of labels and symbols, and a more intuitive navigation experience. While objective efficiency measures—such as fixation count, fixation duration, scanpath length, and time to first fixation—showed no significant differences between the two map types, subjective feedback strongly favoured vario-scale maps. This suggests that vario-scale maps improve user interaction and satisfaction by aligning with modern user expectations for seamless and continuous navigation.

The subquestions of this thesis were:
"How can cartographic principles be applied to develop effective vario-scale map prototypes?"
Cartographic principles can be effectively applied to vario-scale map prototypes by incorporating elements like labels, icons, symbology, and colours on realistic background maps. By carefully designing these visual elements to enhance readability and minimise cognitive load, vario-scale maps can facilitate better user navigation and information retrieval. The study showed that applying these principles results in prototypes that users find intuitive and visually appealing (Section 4.1).

"What features, functionalities, and settings (e.g., zooming and panning speed) are most critical to include in these prototypes to enhance user interaction?"
Critical features and functionalities identified include smooth and continuous zooming and panning transitions, appropriate zooming and panning speeds, and user interface elements such as search bars, layer options, and bookmarks (Section 6.1 and 6.2). Participants emphasised that seamless transitions without abrupt changes are essential for maintaining orientation and enhancing usability (Section 6.2). Incorporating these features makes the map interface more intuitive and user-friendly, thus enhancing user interaction.

"How can the features and functionalities of vario-scale maps be optimised to improve user satisfaction and usability?"
Optimising vario-scale maps involves balancing visual elements and functionality to minimise cognitive load. The study found that excessive icons might introduce additional cognitive load, potentially slowing down task performance (Section 6.1). Therefore, visual complexity should be carefully managed. Incorporating user feedback to refine features and ensuring compatibility with mobile devices—since they are the most common platform for map access—are crucial steps to improve user satisfaction and usability (Section 6.1).
"How does the vario-scale approach affect user performance and satisfaction in map-use tasks compared to multi-scale maps?"
The vario-scale approach positively affects user satisfaction by providing smoother transitions and a more intuitive navigation experience compared to multi-scale maps. Although eye-tracking metrics showed no significant differences in user performance between the two map types, participants reported a clear preference for vario-scale maps (Section 6.2). They found

multi-scale maps' abrupt transitions disruptive, requiring reorientation at each scale level. Thus, vario-scale maps enhance the overall user experience, even if objective performance measures are similar.

In summary, while vario-scale and multi-scale maps perform similarly in terms of objective efficiency, vario-scale maps improve user interaction and satisfaction by offering a seamless and intuitive navigation experience. This study underscores the importance of integrating cartographic principles, critical features, and user feedback into the development of vario-scale map prototypes. By addressing both objective metrics and subjective experiences, vario-scale maps can be optimised to meet user needs more effectively. Future research with larger and more diverse participant groups could further investigate nuanced differences in efficiency and explore additional strategies to enhance vario-scale maps for broader adoption.

9 Future Work

The comparative analysis of vario-scale and multi-scale maps has revealed user preferences and interactions while also highlighting limitations and unexplored opportunities.

Maps in this study focused on specific geographic extents, limited to relatively small areas (9x9 and 18x18 km). Future research could test vario-scale maps with larger extents. **How do scale transitions and data generalisation affect the user experience in broader regions?** Understanding the impact of spatial complexity on cognitive load and task performance could deepen insights into map usability.

The initial eye-tracking study was qualitative, with a limited participant pool. Expanding to a larger, more diverse sample could strengthen statistical validity. **Could a broader participant base reveal significant differences between vario-scale and multi-scale maps?** Applying quantitative methods would provide more robust evidence for observed behaviours and preferences.

Current map designs did not account for colour vision deficiencies, potentially affecting accessibility. For this research, this was deemed out of scope. Future work could consider designing colour schemes and symbology suitable for users with various types of colour blindness. **Could incorporating distinguishable palettes or alternative visual cues like patterns enhance usability?** Testing adapted designs could make vario-scale maps more inclusive.

This research tested desktop environments with mouse-based interactions. With mobile devices and tablets introducing touch gestures and varied screen sizes, future studies could evaluate vario-scale maps on diverse platforms. **Do zooming, panning, and icons remain intuitive in touch-based interfaces?** Investigating screen size and resolution impacts would inform responsive design principles for map interfaces.

Additionally, future research could explore the impact of customisable map features, such as adjusting detail levels, selecting colour schemes, or toggling data layers. **How does customisation affect user engagement and satisfaction?** Insights could lead to more flexible applications catering to diverse user needs.

A critical challenge in vario-scale mapping is ensuring smooth transitions, particularly for streets, which may abruptly appear or disappear. **How can algorithms improve street continuity across scales?** Addressing this issue could enhance navigation and provide a more seamless user experience.

Labelling remains a significant challenge, especially during dynamic scale changes. Future studies could develop advanced strategies for adaptive label placement, size, and prioritisation. **Can algorithms for dynamic label prioritisation be developed to ensure that the most relevant information is displayed at each scale?** Animated transitions for labels during zooming and panning could further reduce cognitive load and enhance usability.

Answering these questions in the context of future work could prove beneficial for the significant improvement of the user experience and the usability of the vario-scale maps approach.

10 Insights and Reflection

This chapter shares the key insights gained from conducting both the eye-tracking studies and the pilot web-based usability study. These findings reflect the lessons learned along the way, offering practical guidance and thoughtful recommendations for improving future research in Cartography and user experience. By exploring what worked well and what could be refined, this chapter aims to provide a richer understanding of how to design and conduct effective studies that yield meaningful, actionable results.

One of the primary challenges encountered was the difficulty in recruiting participants for the eye-tracking studies. Given the complexity of such studies, it is crucial to minimise potential data loss by eliminating mistakes wherever possible. Utilising a professional eye-tracker ensures higher data quality and reliability. Having a well-prepared script written in advance, coupled with thorough pre-testing with initial participants, proved essential in refining the study protocol and addressing unforeseen issues.

An important consideration for quantitative analysis in eye-tracking studies is the impact of participants wearing glasses. To enhance data accuracy, it is advisable to request participants who typically wear glasses to opt for contact lenses during the study. This adjustment can significantly improve the calibration and tracking accuracy of the eye-tracking equipment.

Creating a comfortable environment for participants at the outset and maintaining that comfort throughout the process is vital for obtaining genuine and reliable results. The researcher's demeanour plays a significant role in this regard. It is important not to lead participants toward the correct answers but rather to give them ample time to respond independently. If a participant becomes stuck, inquiring about their thought process in an open and interested manner can help unblock them without making them feel judged. This approach serves as a form of debugging, allowing participants to articulate their strategies and reasoning.

Reliance on a consistent script ensures that all participants receive the same instructions, thereby reducing variability introduced by the researcher and enhancing the fairness of the study. Breaking the ice with a touch of humour can make the interaction more personable and reduce anxiety, fostering a more natural and relaxed participant response.

The physical setup of the eye-tracking equipment also influences participant comfort. Using a discreet setup helps participants feel less like they are being monitored, which can mitigate performance anxiety. Conducting the study in a quiet and professional-looking environment further contributes to participant ease, minimising distractions and promoting focus.

Designing controlled tasks with definite answers proved more effective and easier to analyse. Such tasks reduce ambiguity in responses and facilitate clearer interpretations of the data. Providing sufficient and clear instructions is crucial to prevent misunderstandings that could compromise the validity of the results. Any technical issues that arise are the responsibility of the researcher; maintaining professionalism and composure is essential, as frustration or dissatisfaction from the researcher's side can induce stress in participants and negatively affect their performance.

Participants are dedicating their time and effort to contribute to the study and should be treated with the utmost respect. Encouraging participants when they encounter difficulties reinforces the researcher's role as an ally rather than a judge, fostering a supportive atmosphere that can lead to more authentic and valuable data.

Recruiting a diverse group of participants enhances the study's applicability across different demographics. Individuals of varying ages, professions, and levels of technical familiarity may exhibit different interaction behaviours, providing a more comprehensive understanding of user experiences.

Ensuring calibration consistency of the eye-tracker for each participant is imperative to avoid inaccurate data collection. Setting reasonable time limits for each task helps balance participant focus and prevent fatigue, while maintaining flexibility allows participants to engage fully without feeling rushed.

Controlling the testing environment by ensuring consistent lighting and minimal distractions helps prevent interference with eye-tracking accuracy. Creating tasks that mimic real-world scenarios increases the relevance of the data and its applicability to practical use cases. Combining eye-tracking data with additional methods, such as think-aloud protocols, questionnaires, or post-task interviews, enriches the qualitative and quantitative insights gathered from the study.

Avoiding researcher bias is essential for maintaining the integrity of the study. This involves being mindful of tone, body language, and phrasing to ensure impartiality and not influence participant responses. Maintaining detailed and organised records of participant data, task completion metrics, and qualitative feedback is critical for efficient analysis and should include creating backups at the end of each study session.

Politeness and professionalism should be upheld at all times, even when providing specific instructions or commands to participants. Expressing gratitude for their contributions reinforces their value to the research and encourages a positive experience.

In the pilot web-based usability study, not being physically present with participants introduced challenges in controlling the study environment. This lack of control meant that results could be influenced by a multitude of external factors, potentially deviating from expected outcomes. To mitigate this, tasks were designed to be as straightforward as possible without undermining the participants' intelligence. This balance aimed to reduce frustration and encourage completion of the entire questionnaire.

Providing hints to participants who could not find the answer after an extended period helped maintain engagement without directly providing solutions. Crafting a sequential story within the tasks increased participant interest and motivation to progress through the study. Recognising that participants would be using monitors with different aspect ratios, the study was tested on various devices to ensure compatibility and accessibility for all users.

Clear and comprehensive written instructions, possibly including examples, were essential to prevent confusion in the absence of a researcher. Ensuring device compatibility by testing the study interface across a wide range of devices and browsers was important for inclusivity. Preparing for potential user errors by designing tasks with built-in checkpoints or recovery options, such as "Reset Task" buttons, enhanced the user experience and data reliability.

Including mechanisms to measure the time taken to complete tasks provided additional insights into user efficiency and engagement levels. Offering optional open-ended questions at the end of the study allowed participants to share their experiences and provide suggestions for improvement, contributing valuable qualitative data.

Conducting a small pre-test pilot with a diverse group of participants identified potential issues before the full study launch. This step was crucial in refining the study design and ensuring a smoother experience for all participants.

Reflecting on the overall insights gained from both studies, several key themes emerged. Clear instructions are paramount to minimise confusion and ensure participants understand the tasks. Treating participants with respect and appreciation enhances their experience and the quality of their contributions. Pre-test pilots and iterative refinement of the study design, based on participant feedback and observed challenges, are essential for continuous improvement.

Designing tasks that are straightforward yet engaging, and that mimic real-world scenarios, increases the relevance and applicability of the results. Gathering participant feedback through open-ended questions or interviews provides deeper insights into their experiences and areas for improvement. Recruiting a diverse participant pool ensures that the findings are representative and applicable to a wider audience.

Controlled task designs with definitive outcomes facilitate easier analysis and more reliable data. Tracking the time taken to complete tasks and setting reasonable time limits help balance focus and prevent fatigue, contributing to the overall effectiveness of the study.

In conclusion, these insights highlight the importance of meticulous planning, participant consideration, and adaptability in conducting usability studies. By applying these lessons, future research can build upon this foundation to enhance study design, data quality, and the overall understanding of user interactions with cartographic applications.

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Acronyms

HREC: Human Research Ethics Committee
ITC: Faculty of Geo-Information Science and Earth Observation (University of Twente)
GIS: Geographic Information System
tGAP: topological Generalized Area Partition
PDOK: Publieke Dienstverlening Op de Kaart (Public Service on the Map - Dutch geodata portal)
OSM: OpenStreetMap
SSC: Space Scale Cube
GDMC: Geo-Database Management Center
UI: User Interface
URL: Uniform Resource Locator
EPSG: European Petroleum Survey Group
POI: Point of Interest
BRT: Basisregistratie Topografie (Dutch Key Register of Topography)
MSDF: Multi-channel Signed Distance Field
GPU: Graphics Processing Unit
TTF: TrueType Font
OTF: OpenType Font
CSS: Cascading Style Sheets
HTML: Hyper Text Markup Language
QGIS: Quantum Geographic Information System
CSV: Comma-Separated Values
TSV: Tab-Separated Values

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Script

Welcoming

Hi! My name is Eirini, and I'll be guiding you through this session today. Before we get started, I'd like to go over some information with you to make sure everything is clear.

You probably have a general idea of why I asked you to join me, but let me explain briefly. We're conducting a study to compare two types of interactive map interfaces: **vario-scale maps** and **multi-scale maps**. We want to understand how each type of map impacts user experience. This session will last around 45 minutes, depending on the tasks and any follow-up questions.

First, I want to emphasise that we're testing the maps, not you. There are no right or wrong answers here, and you can't make any mistakes. In fact, anything you find confusing or challenging will help me better understand how users experience the two types of maps.

As you work with each map, I'd like you to think out loud as much as possible. This means sharing what you're looking at, what you're trying to do, and what's going through your mind. Your honest reactions will help me understand how you interact with the maps and identify any challenges you encounter.

Please don't worry about hurting my feelings. This is a research study, and genuine feedback is needed to understand how users interact with each map design. If something doesn't make sense or feels frustrating, please let me know!

If you have any questions as we go along, feel free to ask. I may not be able to answer them immediately, as I'm interested in observing how you navigate the maps without additional guidance. However, I'll be happy to answer any remaining questions at the end of the session.

You'll notice we have a Tobii Pro Fusion eye tracker set up. With your permission, I'll be recording your eye movements on the screen, along with our conversation. This helps us understand where you focus your attention as you interact with each map. Only I will view this recording, and it will be used solely for analysis.

If you're comfortable with this, I'll ask you to sign a permission form that confirms you agree.

[Hand over the informed consent form]

Now I would like to ask you to fill out an intro questionnaire to help me understand a bit more about you.

[Hand out Intro Questionnaire]

Introduction

Thank you for completing the questionnaire! Now, let's get started with the eye tracking!

Please sit back comfortably into a position you can maintain yourself to throughout the whole process. Since everyone's eyes differ, we will first start by calibrating them on the eye tracker. Then we will move on to the task execution.

Do you have any questions so far?

[Calibration Eye Tracker Manager]

[Calibration Tobii Pro Lab]

[Remind the participant to keep their eyes on the screen from now on]

The Tasks

Great, now let's move on to the tasks. There will be one introductory task and 3 tasks for execution. For each task, you will be given instructions on the screen. Please try to remember the instructions. While you are executing the tasks, I will be here in the room with you. If you have questions during the execution of the tasks, you can ask me, but please make sure to **not** break eye contact with the screen as the calibration may be affected.

We will now set the page on full screen pressing **fn + f11** / **f11** and please try to **not** minimise it during the task execution. Remember, it helps if you can think out loud as you work through each task.

Intro page

Let's start!

While I am reading to you the instructions, please keep your eyes on the screen.

Task 0

Task 0 aims to familiarise you with the vario-scale and the multi-scale map types. Read the instructions carefully, and after the map finishes loading, press start to begin. Use the switch button at the top to select **[Assigned map type]**. Once you've explored the **[Assigned map type]** map please switch to the **[other type]**. You can switch between the maps as many times as you wish. Try to experience the differences. Please do not press the "Next" button until instructed.

[Allow the participant to work through the task]

[Instruct the participant to press Next to move to the next task]

Task 1

That was task 0. Let's move on to Task 1. I will now read the briefing of this task for you.

Briefing

You have just joined your local environmental group. Congratulations!! We're excited to have you on board! As part of the team, you'll be exploring maps to help identify key features in our area, from green spaces and natural reserves to areas where we can make a positive impact.

These tasks will give you a hands-on experience with how we use maps to better understand and care for our environment.

Your input is valuable and will contribute to the team's ongoing efforts to care for our local environment. Take your time with the tasks, and approach them with curiosity and care—we're counting on you to help us make a difference!

Please read the instructions and let me know when you are ready.

[Participant reads instructions]

You can now press start to begin with the task. Please use the switch button at the top to select **[Assigned map type]**.

When you are ready to start I will play a recording of the phone call. **If one of the place names mentioned in the phone call is not clear, I will show it to you written down.**

Ready to begin with the first recording of the phone call?

[Play Recording 1 (Assigned map type)]

[Participant finds the place]

Now, please switch to **[other map type]**, and I will play the next recording of the phone call. Ready?

[Play Recording 2 (other map type)]

[Participant finds the place]

Now, please switch to **[other map type]**, and I will play the next recording of the phone call.

Ready?

[Play Recording 3 (assigned map type)]

[Participant finds the place]

Now, please switch to **[other map type]**, and I will play the last recording of the phone call.

[Play Recording 4 (other map type)]

[Participant finds the place]

[Instruct the participant to press Next to move to the next task]

Task 2

Please read the instructions and let me know when you are ready.

[Participant says that they are ready]

Please press start to begin after the map has loaded**.**

You are looking for 3 **castles** using **(assigned map type).**

Please say out loud the name of each castle you find.

[Keep track if all castles have been found by the participant. When all are found:]

[Participant finds all castles]

Now you are looking for 3 **campsites** using **[other map type].**

Please say out loud the name of each campsite you find.

[Participant finds all campsites]

[Keep track if all campsites have been found by the participant]

[Instruct the participant to press Next to move to the next task]

Task 3

Please read the instructions and let me know when you are finished.

For every lake you find, please let me know and tell me if it seems suitable for the BBQ. Start this task with **(assigned map type).**

[Keep a timer with __ seconds. When it is time:]

Time is up.

Now switch to **[other map type]** and see if you can find DIFFERENT suitable locations.

[Keep a timer with __ seconds. When it is time:]

Time is up.

[Instruct the participant to press Next to move to the final page]

[Stop the screen recorder]

[Select shift + Esc / Esc]

Follow-Up and Probing

Thank you—that was very insightful! We have now completed all tasks!

Wrapping Up

Lastly, I'd like to ask you to complete these questionnaires with some quick, feedback questions. Your responses will provide valuable insights into your experience and opinions.

[Task 1 Questionnaire]

[Task 2 Questionnaire]

[Task 3 Questionnaire]

[Overall feedback]

Thank you so much for your time and feedback today—I truly appreciate it! If you're the lucky winner of the voucher, I'll contact you to let you know!

[Escort the participant out]

[Save logfiles and project data in the folder of the participant on the computer]

[Prepare for the next participant]

Intro Questionnaire

Participant: [ ]

For some questions, more than one option may apply. Please select all that apply.

1. **Have you previously participated in usability testing for digital interfaces?**
    - ☐ Yes
    - ☐ No

2. **How would you rate your overall proficiency with technology?**
    - ☐ **Not proficient**: You might find technology challenging and generally need help with basic tasks.
    - ☐ **Slightly proficient**: You can manage basic functions but might often require assistance for more complex tasks.
    - ☐ **Moderately proficient**: You are comfortable using common technologies and can solve basic issues on your own.
    - ☐ **Very proficient**: You are quite adept with a variety of technologies and can easily learn new tools and software.
    - ☐ **Extremely proficient**: You excel in using diverse technologies and can independently resolve complex issues.

3. **Are your studies/work relevant to Cartography:**
    - ☐ Yes, my activities involve maps.
    - ☐ No, my activities do not involve maps.

4. **Do you know the difference between vario-scale and multi-scale maps?**
    - ☐ Yes:____
      ____
    - ☐ I am not sure

5. **How familiar are you with web maps (i.e. Google Maps, Apple Maps, Bing Maps, OpenStreetMap):**
    - ☐ **Not familiar**: You have hardly used or never used web maps.
    - ☐ **Slightly familiar**: You occasionally use web maps for basic tasks like finding a location.
    - ☐ **Moderately familiar**: You regularly use web maps for standard functions such as getting directions.
    - ☐ **Very familiar**: You are comfortable with advanced features of web maps like layer switching and route optimisation.
    - ☐ **Extremely familiar**: You expertly utilise web maps for complex tasks and can customise features to suit specific needs.

6. **How often do you experience a sudden change in map detail or orientation when zooming (sometimes called "local shock")?**
    - ☐ Never
    - ☐ Occasionally
    - ☐ Frequently
    - ☐ Very often
    - ☐ I’m not sure what "local shock" is

7. **When you zoom in or out on a web map, how important is it to you that the transition feels smooth and continuous?**
    - ☐ Not important
    - ☐ Slightly important
    - ☐ Moderately important
    - ☐ Very important
    - ☐ Extremely important

8. **How do you prefer the map to behave as you zoom in or out?**
    - ☐ Maintain the same level of detail and only change the scale
    - ☐ Gradually reveal more details as I zoom in
    - ☐ Gradually hide details as I zoom out
    - ☐ I don’t have a preference

9. What do you usually use Web Maps for:

- ☐ Navigation
- ☐ Work-related tasks
- ☐ Educational purposes
- ☐ Recreation or leisure
- ☐ None of the above
- ☐ Other____

10. Do you often use web maps on mobile devices/tablets or computers?

- ☐ Mostly on mobile devices
- ☐ Mostly on computers
- ☐ About equally on both
- ☐ None of the above
- ☐ Other:____

Task 1,2,3 Feedback

1. **What did you think about the overall difficulty level of the task?**

	1	2	3	4	5	
Too easy	○	○	○	○	○	Too difficult

2. **How clear were the given instructions?**

	1	2	3	4	5	
Not very clear	○	○	○	○	○	Very clear

3. **Did you find the task easier to execute with one map type than the other?**

☐ Yes, easier with the vario-scale map
☐ Yes, easier with the multi-scale map
☐ No, I found the tasks equally manageable with both
☐ I didn't manage to complete the task

4. **Comments**

Overall Feedback

Participant: [ ]

For some questions, more than one option may apply. Please select all that apply.

1. **How would you rate the fairness of comparing the two types of maps (vario-scale and multi-scale) in this test?**

   ☐ **Very fair:** The comparison feels balanced and unbiased.
   ☐ **Mostly fair:** There are minor differences, but overall, the test is fair.
   ☐ **Neutral:** I don't feel strongly about the fairness of the comparison.
   ☐ **Somewhat unfair:** One map type seems to have an advantage in the test setup. Please indicate which one:___________________________________
   ☐ **Very unfair:** The comparison feels biased towards one map type.'

2. **Did the tasks feel realistic and relevant to how you would use web maps in real life?**
   ☐ Yes, very realistic
   ☐ Somewhat realistic
   ☐ Neutral
   ☐ Not very realistic
   ☐ Not realistic at all

3. **Which map type did you find more efficient for completing tasks?**
   ☐ I strongly find vario-scale more efficient
   ☐ I slightly find vario-scale more efficient
   ☐ I find both equally efficient
   ☐ I slightly find multi-scale more efficient
   ☐ I strongly find multi-scale more efficient

4. **What did you see as advantages of vario-scale?**

---

5. **What did you see as disadvantages of vario-scale?**

6. **What did you see as advantages of multi-scale?**

7. **What did you see as disadvantages of multi-scale?**

8. **How comfortable did you feel using the eye tracker during the study?**
   - ☐ Very comfortable
   - ☐ Somewhat comfortable
   - ☐ Neutral
   - ☐ Somewhat uncomfortable
   - ☐ Very uncomfortable

9. **What basic feature(s) or settings would you like a web map to include?**

☐ **Search Bar**: Quick search function to find locations or addresses.
☐ **Layer Options**: Ability to switch between map views (e.g., street map, satellite, terrain).
☐ **Bookmarks or Saved Locations**: Ability to save favourite or frequently visited places.
☐ **Measurement Tool**: Option to measure distances between points.
☐ **Zoom and Pan Controls**: Ability to adjust zooming speed and panning animation duration.
☐ **Other:** ____

Experiment Notes

Participant:

Tobii Project:

Glasses: Yes / No

Starting Map Type: Varioscale / Multiscale

Task 0

Task 1

Task 2

Task 3

Additional Comments:

Tools

The tools used throughout this thesis were carefully selected to support the research, analysis, and presentation processes, ensuring both precision and efficiency in achieving the project objectives. Each tool played a distinct role in addressing specific requirements of the study, from data processing and visualisation to usability testing and documentation.

For programming, **PyCharm** and **Visual Studio Code** were employed as versatile integrated development environments (IDEs), chosen for their rich feature sets and debugging capabilities. These tools streamlined the development of scripts in **Python,** used for analysis**.** Python's robust libraries such as **pandas**, **seaborn**, **Matplotlib**, **Plotly**, and **SciPy** were instrumental in analysing data and creating visualisations. These libraries ensured the efficient processing of experimental data, such as eye-tracking metrics, and supported the generation of meaningful insights.

To manage the front-end components of the study, **HTML**, **CSS**, and **JavaScript** were used. The starting point of the prototypes, **sscviewer-js**, builds upon these to create an interactive map interface. More specifically, **Node.js** was employed to manage dependencies, while **Rollup** was utilised for the efficient bundling of JavaScript modules. Rendering of the map was powered by **WebGL**, enabling high-performance interactive prototypes. **GPUText** was used to generate new MSDF fonts.

To generate a new basemap for the needs of the final study this research benefited from **OpenJUMP** and **QGIS**, both handy tools for transforming the TOP10NL source data to the required format for **tgap-ng**, a JavaScript-based tgap generation library. Geospatial data sources like **Apple Maps**, **OpenStreetMap**, and **PDOK** were leveraged to provide real-world contextual data, ensuring the maps tested in the experiments reflected realistic environments. These resources enhanced the credibility of the usability study by grounding it in authentic spatial data.

The usability experiments centred around eye-tracking data collection, which necessitated specialised tools and hardware. The **Tobii Pro Fusion eye tracker**, along with **Tobii Pro Lab** and **Tobii Eye Tracker Manager**, enabled precise tracking of user gaze behaviour during map interactions. These tools were critical in capturing the data needed to evaluate the effectiveness of the vario-scale approach and to compare the multi-scale and vario-scale mapping approaches.

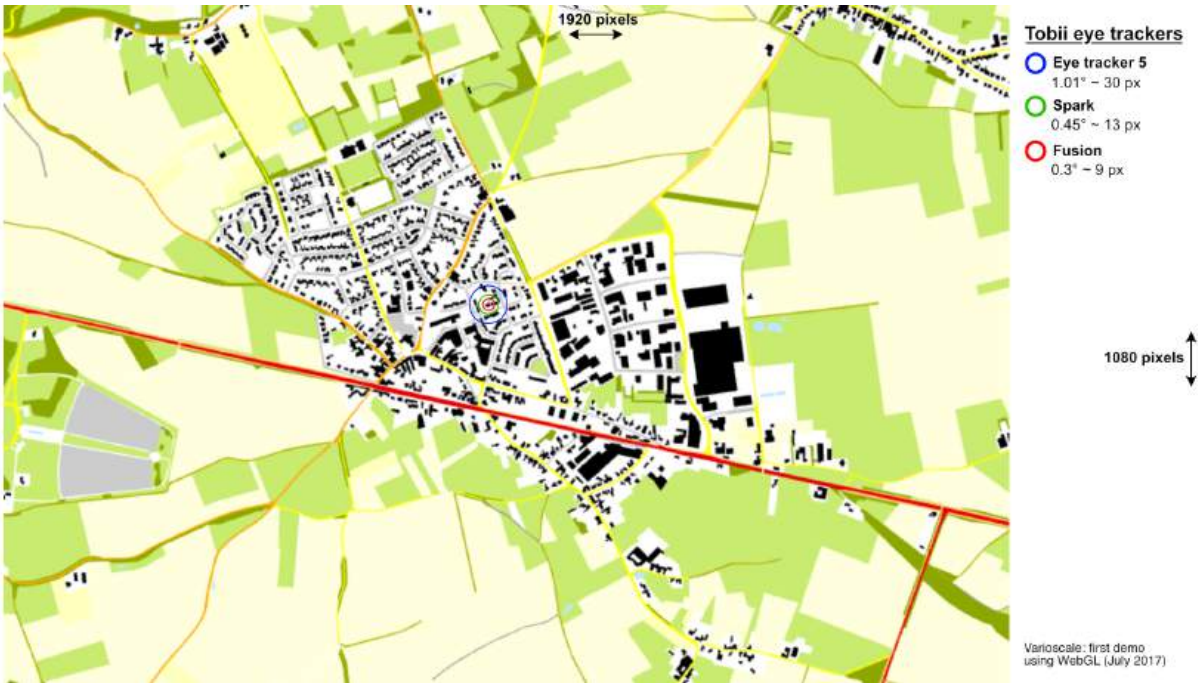
In terms of survey and data collection, **Google Forms** served as a simple yet effective tool for gathering user feedback. Post-experiment data analysis often required tabulation and preliminary calculations, for which **Microsoft Excel** was utilised. For communicating findings and progress, **Microsoft PowerPoint** was used to create clear and engaging presentations, while **Microsoft Edge** supported web-based activities like prototype testing and online access.

Document preparation and writing were carried out using **LaTeX**, chosen for its superior capabilities in handling complex formatting and producing high-quality documents. Scheduling and planning of the eye-tracking sessions with the participants were efficiently managed using Google Calendar, ensuring that appointments were well-organised, conflicts were avoided, and participants received timely reminders, contributing to a smooth and coordinated research process.

Lastly, **GitHub Desktop** facilitated version control and collaboration by providing an intuitive interface for managing the project's repositories. This ensured that code and data were systematically organised and backed up, safeguarding the integrity of the research outputs.

Together, these tools formed an integrated ecosystem that enabled the seamless execution of this thesis project. Their selection was guided by their relevance, functionality, and compatibility with the research objectives, ensuring that every aspect of the study was supported by reliable and effective software and hardware solutions.

Eye-tracking Device Research



Screenshot of one of the prototypes(the very first one), and with a screenshotting tool, I select the resolution to be 1920x1080 Full HD. Based on that I created the three circles.
[Evaluating Accuracy of the Tobii Eye Tracker 5 | SpringerLink]

a/n	Model	Screen compatibility (inches)	Sampling Rate (HZ)	Operating distance(cm)	Precision (°)	Accuracy (°)	Pros	Cons	Software
1	**Tobii Pro - Spectrum**	24	1200	55-75	0.02	0.17	Extremely high precision and sampling rate, ideal for detailed research.	Very expensive, may be over-spec for basic usability studies.	

2	**Tobii Pro Fusion**	24	250	50-80	0.04	0.3	High precision, sleek.	Quite expensive, might be more than needed for usability tasks.	
3	**Tobii Pro X3(Enschede lab)**	25	120	50-90	0.24	0.4			

4	**Tobii Pro - Spark**	27	60	45-95	0.26	0.45	Good balance of performance and cost, suitable for larger screens.	Lower sampling rate than other high-end models.	· Tobii Pro Lab · Tobii Pro SDK (requires programming knowledge)
5	**Tobii Eye Tracker 5**	27/30	133	50-95		1.01	Very affordable and sufficient for entry-level research.	Lower precision and sampling rate, not ideal for detailed eye movement analysis,	SDK(?)

								gaming focused.	
6	**Eye Link 1000 Plus**	N/A	1000	60-150	0.05	0.25	High precision and accuracy, best for complex and detailed eye tracking.	Very expensive,quite large setup, perhaps overqualified.	EyeLink Data Viewer **Output:** X and Y position data and pupil size

7	**GP3 HD**	24	60/150	N/A	N/A	0.5	Affordable, adequate precision for most usability studies, recommended for developers and researchers.	Precision and sampling rate not suited for highly detailed tracking, extra monitor bracket mount.	API/SDK included

8	**GP3**	24	60	50-80	N/A	0.5	Affordable model, suitable for basic research needs, recommended for eye tracking software developers.	Limited in high-detail tracking capabilities.	API/SDK included
9	**Smart Eye AI-X**	24	60	45-85	0.1	0.5	High sampling rate, sleek, fast setup, UX suitable	High-cost	Smart Eye Tracker **Ouput:** Gaze point, pupil diameter, time stamp

10	Smart Eye Aurora	24	60/120/250	50-80	0.1	0.3	Small and discrete, quick setup.	Expensive and may provide more functionality than necessary.	- iMotions - PST E-Prime 3.0 **Output:** TCP/UDP/Text log
11	EyeTech VT3 Mini	22	40/60/120/200	50-70	N/A	0.5	Compact and one of the most affordable, good for basic studies.	Low sampling rate, limited in capturing quick or subtle eye movements.	