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COGNITIVE ASSESSMENT OF A WEB MAP DEPICTING ACCESS TO UTILITIES IN INFORMAL SETTLEMENTS OF KAMPALA

Diploma thesis

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ANNOTATION

Information on the access to electricity utilities in the informal settlements of Kampala is important as it will drive efforts in achieving SDG 7 on access to clean energy and SDG11 on sustainable cities. In Uganda, the engineers at umeme, an electricity distribution company, rely on spatial data delivered via softcopy or hardcopy pdf documents, excel files, and GIS shapefiles for those with GIS expertise. This is challenging regarding updates and the amount of data that can be displayed and queried among others. Interactive web maps provide an alternative way to access and interact with spatial data. The objective of the thesis is to develop a web map to communicate findings on the access to electricity utilities in informal settlements and evaluate the usability aspects of the designed web map. A mixed approach is applied to the usability assessment, applying both qualitative and quantitative methods, including remote and in-person techniques to usability assessment, such as questionnaires, interviews, screen recording, and eye-tracking. At the end of the formative study, the challenges associated with using the web map are identified, and suggested improvements to the web map are presented.

KEYWORDS

Keywords – electricity utilities, informal settlements, interactive web map, usability assessment, eye-tracking

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This thesis has been composed by *Lydia LETARU* for the Erasmus Mundus Joint Master's Degree Program in Copernicus Master's in Digital Earth for the academic years 2020/2021 and 2022/2023 at the Department of Geoinformatics, Faculty of Natural Sciences, Paris Lodron University Salzburg, and Department of Geoinformatics, Faculty of Science, Palacký University Olomouc. The thesis was supported by the Czech Science Foundation project no. 23-06187S - Identification of barriers in the process of communication of spatial socio-demographic information.

Hereby, I declare that this piece of work is entirely my own, the references cited have been acknowledged, and the thesis has not been previously submitted to the fulfilment of the higher degree.

I would like to appreciate my advisors RNDr. Stanislav POPELKA, Ph.D., and Dr. Christoph Traun, for your patient guidance, teaching me how to use the instruments and analyse the resulting data. This research would have been impossible without your input.

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Finally, I express my utmost gratitude to my family for your continued support and sacrifice throughout this masters. This thesis is dedicated to you, Brian and Suubi.

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ASSIGNMENT OF DIPLOMA THESIS
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Theses guidelines

The aim of the thesis is to create a web map depicting access to utilities in informal settlements. User aspects will be involved in all phases of the project solution. In the first phase, interviews with the target users – electrical engineers in Uganda will be performed to reveal their needs and requirements. Then, an interactive web map will be created depicting access to utilities in informal settlements. Optionally, a downloadable variant of the map with infographics will be produced. The group of target users will thoroughly evaluate these outputs. The student will select adequate methods for this evaluation. Moreover, the usability of the outputs will be tested using an eye-tracking experiment performed in Olomouc. The final web map will be modified based on insights from both parts of the testing.

The student will create a website about the thesis following the rules available on the department's website and a poster about the diploma thesis in A2 format. The student will submit the entire text (text, attachments, poster, outputs, input and output data) in digital form on a storage medium and the text of the thesis in two bound copies to the secretary of the department.

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Barnum, C. M. (2020). Usability testing essentials: ready, set... test!. Morgan Kaufmann.
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Hertzum, M. (2020). Usability Testing: A Practitioner's Guide to Evaluating the User Experience. Synthesis Lectures on Human-Centered Informatics, 13(1), i-105.
Holmqvist, K., Örbom, S. L., Hooge, I. T., Niehorster, D. C., Alexander, R. G., Andersson, R., ... & Hessels, R. S. (2022). Eye tracking: empirical foundations for a minimal reporting guideline. Behavior research methods, 1-53.
Porti Suarez, A. (2022) User evaluation of interactive dashboard, Diploma thesis, Olomouc, Palacký University Olomouc.

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CONTENT

LIST OF ABBREVIATIONS

This is a list of the abbreviations used in this thesis document.

Abbreviation	Meaning
GIS	Geographic Information System
WFS	Web Feature Service
SQL	Structured Query Language
HOT	Humanitarian OpenStreetMap Team
UBOS	Uganda Bureau of Statistics
OSM	Open Street Map
SHP	Shapefile
MEMD	Ministry of Energy and Mineral Development
UEDCL	Uganda Electricity Distribution Company Limited
UEGCL	Uganda Electricity Generation Company Limited
UETCL	Uganda Electricity Transmission Company Limited
KCCA	Kampala Capital City Authority

INTRODUCTION

People living in informal settlements are vulnerable because of the nature of such settlements which are overcrowded, have limited resources, and temporary housing, among other issues. Such areas are usually left out of the planning process because they are unmapped, or the maps are not updated.

On the other hand, utility companies such as umeme, which has a concession to distribute electricity to households in Uganda, face challenges in informal settlements in the form of outdated data, unmapped and informal connections to the grid, and unfavourable means of accessing utility data.

To achieve SDG7 and SDG11 and support umeme's goal of reducing energy losses and increasing connections to the electricity grid, updated information in such areas is necessary. In addition to the updated data, a way to easily access this data is also necessary.

The main objective of this research was to develop a web map depicting access to electricity utilities in the informal settlements of Kampala, Uganda, and to perform a user assessment of the developed web map. The research began with an evaluation of the existing physical maps and web maps in the energy sector of Uganda. This information fed into the design of the resulting web map.

A formative assessment was conducted to identify problems with the designed web map. This study took a mixed approach, combining qualitative and quantitative analysis methods, objective, and subjective methods, and remote and in-person assessments. The methods used include questionnaires, interviews, screen recording, and eye-tracking.

The result of this research identifies problem areas and suggests changes that could improve user experience with the designed web map. The research also demonstrates the potential for combining remote and in-person user assessment, especially where a diverse group of users is required.

1 OBJECTIVES

The aim of this diploma thesis is to perform a usability assessment of a self-developed web map, depicting access to electricity utilities in the informal settlements of Kampala, Uganda.

The **first goal** was to determine the design requirements for the informal settlement electricity utilities web map. To do this, it was necessary to evaluate the existing maps used in the energy sector in Uganda, including those used at umeme. This required the collection of sample maps from umeme, evaluating the published web maps, and performing interviews with electrical engineers at umeme to determine their requirements of the web map. The output of this goal was the design requirements for the web map, which was the stimuli for the usability assessment.

The **second goal** was to perform a usability assessment of the designed web map. A formative study was performed to identify any problems associated with using the web map. The usability assessment took on a mixed approach, applying both quantitative and qualitative approaches, and was applied in remote and in-person assessments. The outputs of this goal are the identified problems and suggested improvements to the designed web map.

2 STATE OF THE ART

2.1 Informal Settlements

The number of people living in informal settlements has grown steadily over the years; as of 2020, more than 1 billion people are estimated to live in such areas. Of these, more than 85 percent are said to be living in Central and Southern Asia (359 million), Eastern and South-Eastern Asia (306 million), and sub-Saharan Africa (230 million) (United Nations, 2022).

No single word is used to refer to informal settlements; in practice, words such as slum, shantytown, or words in other languages are used interchangeably (Kovacic et al., 2019). According to the UN-Habitat, (2003), an informal settlement may be classified as a slum if it is characterized as having inadequate access to safe water, sanitation, and other infrastructure, has poor structural quality housing, is overcrowded, or is characterized by insecure residential status. UN-Habitat, (2003) and Kovacic et al. (2019) agree that such informal settlements are complex and difficult to define as varying physical and cultural situations prevail.

Individuals living in informal settlements are more vulnerable to varying conditions owing to the nature of their housing, the household income status, and their location in unplanned and unmanaged areas, among other reasons (Arimah, 2011). Because many informal settlements emerge rapidly, it is common for them to be unmapped. Unmapped areas are not considered during strategic planning for services such as electricity, education, health, and water supply among others (Cinnamon et al., 2023: Fan et al., 2022: Arimah, 2011). These services are essential for the population's well-being and should be provided equally. This aligns with goal 11 of the Sustainable Development Goals; "Make cities and human settlements inclusive, safe, resilient, and sustainable". The United Nations (2022) states that the development and implementation of policies will be a major driver toward achieving SDG 11 by 2030.

Another notable SDG in relation to informal settlements is goal 7, "Ensure access to affordable, reliable, sustainable and modern energy for all". Access to reliable and affordable electricity is important for economic development. This is because electricity drives innovation, encourages the creation of start-ups, and is necessary for education, among other benefits (Wabukala et al., 2022). On the progress of the achievement of Goal 7, 91 percent of the global population will have access to electricity by 2020. However, over 700 million people live in the dark, three-quarters of whom are in Sub-Saharan Africa, and 1.4 billion people cook with harmful and polluting fuels (United Nations, 2022). To facilitate the achievement of this goal by 2030, concerted efforts need to be employed in low-income countries and those affected by conflicts. These efforts are facilitated with up-to-date data (UN-Habitat, 2014).

2.2 Mapping Informal Settlements

The classification and mapping of informal settlements within a city play a critical role in sustainable development, the estimation of the poverty-stricken population, infrastructure construction, and future city planning (Fan et al., 2022). Research has been done in the automatic identification, classification, and population estimation of informal settlements (Kohli et al., 2016: Kanjir et al., 2012), disaster risk management and modelling (Tom et al., 2022), and participatory GIS (Falco et al., 2019: Karanja, 2010) among others. These studies employ GIS and remote sensing tools and datasets to provide information that can be used to improve the lives of people living in informal settlements. However, even though the studies acknowledge the dynamic nature of informal settlements, none of them makes use of interactive maps.

2.3 Interactive Maps

You et al. (2007) define a web map as a Web-based service on the internet that provides maps for users to search and browse spatial information. At the same time, Sack (2017) defines web maps simply as those published and accessed via the internet, further breaking them down into static and dynamic maps, including interactive web maps. Interactive web maps change their output in response to the user's actions, allowing access to additional information through such interaction.

Interactive web map interfaces, such as the one in Figure 1, are composed of two main display elements; a cartographic display area where the map itself is presented and a set of graphical user interface elements which allow for interaction with the map data (Çöltekin et al., 2009: You et al., 2007). The design choice for the inclusion and placement of the interactive elements on a web map is open; however, there are some guidelines on what should be included and how.

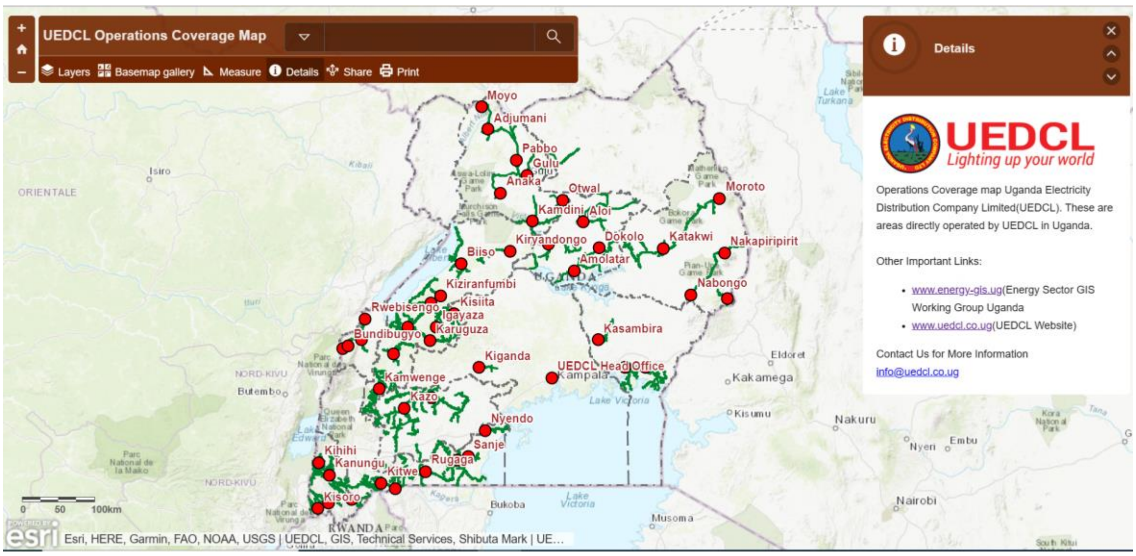

Figure 1 Example of electricity utilities webmap, showing the map canvas and elements for interactivity (UEDCL, 2023)

Sack (2017) provides a comprehensive list of interactive features that should or could be included in an interactive web map. Users predominantly interacted with web maps through panning and zooming; the possible interactions have greatly increased with technological advances, tools, and data. Users can search, view live data, and embed other websites, graphics, and media, including audio and video. Performing simple calculations and routing with these web maps is also possible. Technological advances have also expanded the possible means of interacting with web maps. These include mouse clicks, keyboard entries, voice prompts, and more. Web maps can be very complex; however, Sack (2017) and Çöltekin et al. (2009) agree that the web map should be simple, only including elements essential for the map's purpose.

Whereas web maps are popular, since there are no strict rules governing the design of their interactive elements, evaluating the effect of the design choices on using these maps is necessary. This is because the usability of such maps relies heavily on interface design (Norman, 2013; You et al., 2007), and usability determines the extent to which products continue to be used (Hertzum, 2020)

2.4 Usability Testing

A poor user experience derived from interacting with products results from low usability. Interacting with products of low usability leads to confusion, frustration, and is an inconvenience to users (Hertzum, 2020). To have a proper understanding of the concept of usability, it is important to define the key terms.

According to ISO 9241 (2010), usability is defined as the extent to which a system product or service can be used by specific users to achieve specific goals with effectiveness, efficiency, and satisfaction in a specified use context. Çöltekin et al. (2009) describe these three usability metrics in the use of a product, defining them as; satisfaction, a user's attitude or preferences about the system, efficiency, how quickly the tasks are completed, and effectiveness, whether a task is completed. From the definition, it can be noted that usability is not just about the product but about a specific use situation. Therefore, a usability test evaluates specified users exercising a specified product by solving specific tasks; that is, they work towards specified goals (Hertzum, 2020).

On the other hand, user experience is a person's perception and response resulting from their use and or anticipated use of a product, system, or service (ISO 9241, 2010). User experience is subjective in nature as it includes the user's emotions, beliefs, attitudes etc., before, during, and after interacting with the product. Since this definition focuses on the user and the product and considers the user expectations and experiences with using the product, it communicates the value of testing products while they are still under development (Hertzum, 2020). Nielsen (1993) states that iterative evaluations allow for the identification of problems associated with using a product, adding learnability, memorability, and error rate to the metrics for usability assessment. It can therefore be noted that usability assessment is multifaceted.

Hertzum (2010) presents other views of usability and user experience. He adopts the sensitizing concepts proposed by Blumer (1954), which "suggest directions along which to look". To properly understand usability and be exposed to the different elements that impact the use of a product, one must approach the concept from different viewpoints (Hertzum, 2020). Hertzum (2010) proposed six images of usability. These images show a different aspect of usability and further advise that more than one image is used to enrich the understanding of the usability of a product (Hertzum, 2020).

- Universal usability: is concerned with products that are made for use by everyone. This considers that people are diverse, and their experiences will be equally diverse.
- Situational usability: usability is studied under a particular use situation.
- Perceived usability: concerned with the user's subjective experience of the product.
- Hedonic usability: concerned with the joy derived from using a product.
- Organizational usability: concerned with overall usability derived when a group interacts with a product.
- Cultural usability: considers the difference in usability originating from different cultural backgrounds.

Large volumes of research have been done in the field of user experience and usability assessment, including research in the field of cartography. The question is, how have these metrics been applied or measured, and what methods are used in practice? Rohrer (2022) provides an overview of the methods in Figure 2.

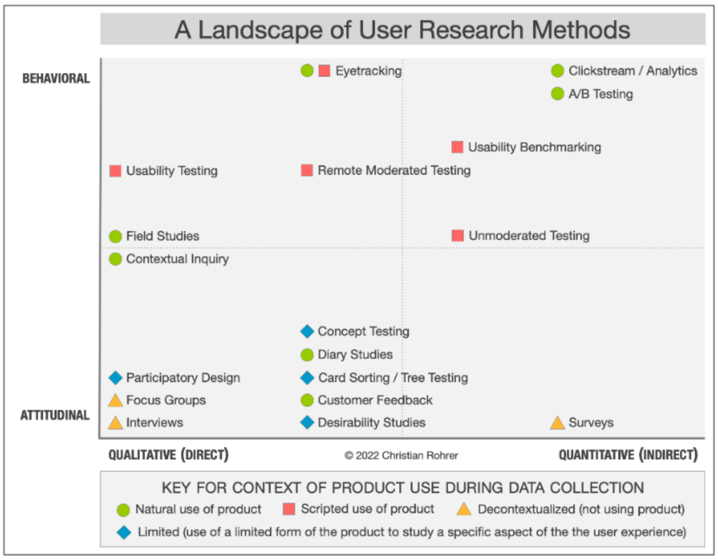

Figure 2 User experience research methods (Rohrer, 2022)

User experience research methods vary in three scales (Rohrer, 2022: Burian et al., 2018), in the qualitative-quantitative scale, the attitudinal-behavioural scale, and the use context.

Usability assessment can also be categorized as either attitudinal (subjective) or behavioural (objective). Subjective studies are those that measure the thoughts and opinions of the users by directly interacting with them. Cartographic research has successfully applied methods such as interviews, questionnaires, or focus group discussions. On the other hand, objective methods are relatively independent of the influence of the user as they record the user's actions. Examples of objective methods that have been applied in cartographic research include video analysis, keystrokes, mouse clicks recordings, and eye-tracking (Burian et al., 2018).

On the quantitative and qualitative axis, this is in relation to the type of analysis and results that can be derived from the user evaluation. Methods such as questionnaires that afford many participants allow for quantitative analysis, while methods like interviews provide more qualitative analysis and results (Rohrer, 2022).

Finally, the context of use describes the situation under which the user experience is evaluated. This ranges from the natural use of the product, where the user interacts with the product; limited use of the product, where the user interacts with certain portions of the product; scripted use of the product, where a particular use scenario is evaluated and decontextualization where the user does not interact with the product directly. A mixed approach to user assessment is preferred as product use and experience is multifaceted. This means that user evaluations should be able to capture all types of data that reflect the user's experience.

2.4.1 Remote usability assessment

When it is impractical for target users to travel to the usability assessment lab or for the evaluator to travel to them, remote usability assessment is a suitable method (Andrezejczak and Liu, 2010), which avoids distance biases while recruiting participants. Remote user assessments allow the recruitment of culturally diverse respondents that are more familiar with a local product; however, the researcher has limited control over the respondent's environment (Hertzum, 2020).

Remote usability evaluation may be synchronous, where the user and evaluator are in different physical locations but are connected via a video link. In such a case, the evaluator provides prompts, instructions and observes the user while they evaluate the product. This is the case when the product is evaluated over teleconferencing. According to Sauer at al. (2019), remote usability tests can yield the same outcome as standard usability tests.

On the other hand, remote usability tests may be asynchronous in the case of unmoderated tests. This is where the user and evaluator are involved with the test at different times (Hertzum, 2020). The evaluation ought to include a video recording that the evaluator can analyse after completing the test. The advantage of this method is that many more respondents can be added to the testing phase; however, like synchronous remote testing, the evaluator has little control over the environment in which the test is conducted and cannot prompt for additional feedback or provide guidance during the test execution. Both synchronous and unmoderated remote tests yield a similar number of problems; with the possibility of recruiting many more respondents and combining this method with standard methods, the usability assessment can identify all the problems with a product.

2.4.2 Eye-tracking

Eye movement recordings provide information on the internal cognitive processing that goes on while a user interacts with the product (Bojko, 2006). Nivala (2008) suggested this method as an alternative or supplement in cases where a high cognitive load from the given task interferes with giving feedback in methods that employ participant self-reporting. On the 'landscape of user experience research methods', eye-tracking is categorized as an objective method, both qualitative and quantitative, depending on how the data is analysed and may be applied in a natural or scripted manner (Rohrer, 2022: Burian et al., 2018).

Eye tracking provides key insights in both formative (Çöltekin et al., 2009: Nivala, 2008) and summative usability assessments. Formative studies are aimed at identifying the challenges associated with using the product, while summative studies are aimed at comparing versions of the product to identify which features provide a better user experience (Bojko, 2013). The author describes the so-called actionable eye-tracking insights, where eye-tracking is considered the most suitable method when the experiments objectives seek to provide qualitative insights in detecting or explaining usability problems or quantitative insights in the form of measuring attraction or performance.

The concept of eye tracking is based on the understanding of how the eyes work. Because only a small portion of what is viewed is seen by the eyes, people move their eyes to bring objects into focus. For purposes of eye tracking, measures focus on two main actions performed by the eyes, fixations which are when the eyes focus on a particular element, and saccades, which are the times when the eyes move between fixations (Holmqvist et al., 2011). The typical eye-tracking experiment is performed, as shown in Figure 3.

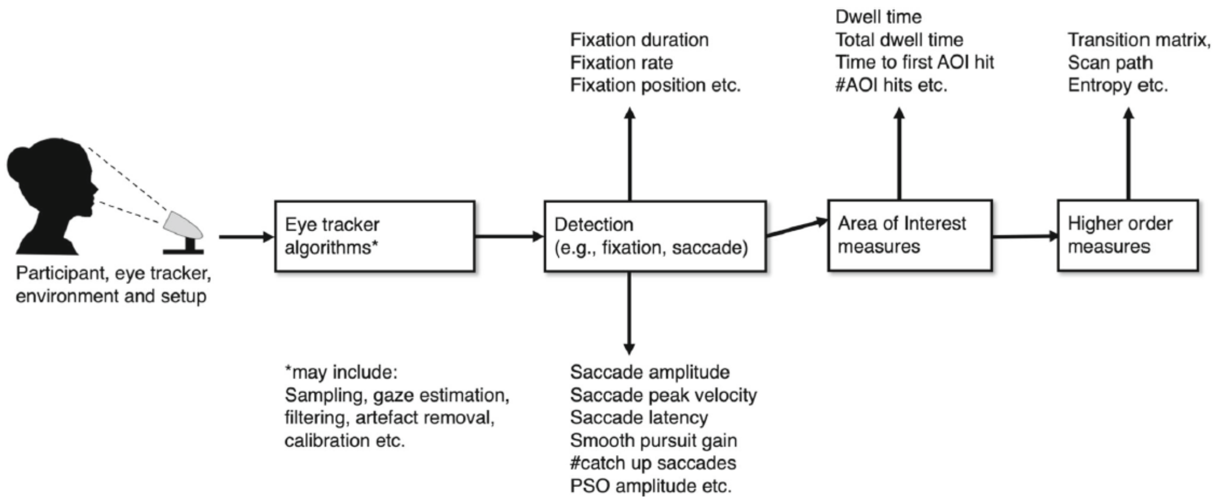

Figure 3 Typical eye-tracking experiment setup (Holmqvist et al., 2023)

The eye-tracking experiment consists of an eye-tracker that detects reflections from the participant's pupil and cornea. Using eye-tracking algorithms, these reflections are converted to meaningful data like the gaze pattern while artifacts are removed. Metrics such as the fixation duration, rate, and position are also provided by the eye-tracking algorithms. These can further be evaluated over different areas of interest, which are predefined areas of the stimulus space that are considered as being meaningful to the experiment (Holmqvist et al., 2023). Depending on the objective of the experiment, different metrics are derived from the eye-tracking experiment.

Formative studies

Since a formative study aims to identify challenges associated with using a particular tool, a qualitative approach is applied to data visualization and analysis (Bojko, 2013). Visualizations may include gaze plots - images showing fixations of individual participants as dots and saccades as lines between the fixations. In these plots, the size of the dot is a factor of the fixation duration or count, while the number indicates the order of fixations. Visualizations may also include heatmaps where the eye-tracking measure is shown with colours, warm tones for higher measures, and colder tones for lower measures. In the case of heatmaps, measures such as fixation count and absolute or relative gaze duration may be used. However, care must be taken as these measures have interpretation limitations (*ibid*).

Summative studies

On the other hand, summative studies are conducted to provide a comparison between versions of a product to decide which of them provides a better experience. During such studies, a quantitative approach is taken to data analysis. Either the participants or the product may be divided into groups, and a comparison of between-subject or within-subject is performed. It is possible to compare whether participants made more mistakes, had faster execution of tasks, or had a different gaze pattern from the product versions (ibid).

2.5 Similar research

Voldán (2010) performed a usability test for interactive web map portals. A formative approach was performed by presenting the participants with one of three map options: Amapy.cz, Google maps and Mapy.cz. The researcher then observed the participants as they executed the tasks while taking note of any challenges and benefits associated with using the portals.

In their study, Andrienko et al. (2002) evaluated the use of interactive tools implemented in their geo-visualization package CommonGIS. As part of their evaluation, the researchers tested the extent to which the participants understood the geo-visualizations and used them, retained the acquired skills, and developed a liking for the tools. As such, the researchers had to teach the participants how to use the tools before they tested them.

Hedlun (2018), applied the target search analysis framework in his study to evaluate two consumer clocks. Both quantitative and qualitative analysis of the eye-tracking data was performed. Using the target search analysis framework, and a qualitative analysis of the eye-tracking metrics, the researcher was able to give reasons why a particular search was not successful. This is useful in a formative study, where the intention is to identify problems with a product. The researcher also performed quantitative analysis of the eye-tracking data, and found no difference between the two products in question.

3 METHODOLOGY

This chapter provides an overview of the steps taken to achieve the objectives of this study. A graphical representation of the methodology is shown in Figure 4. The chapter is divided into two sections, the web map design and usability assessment.

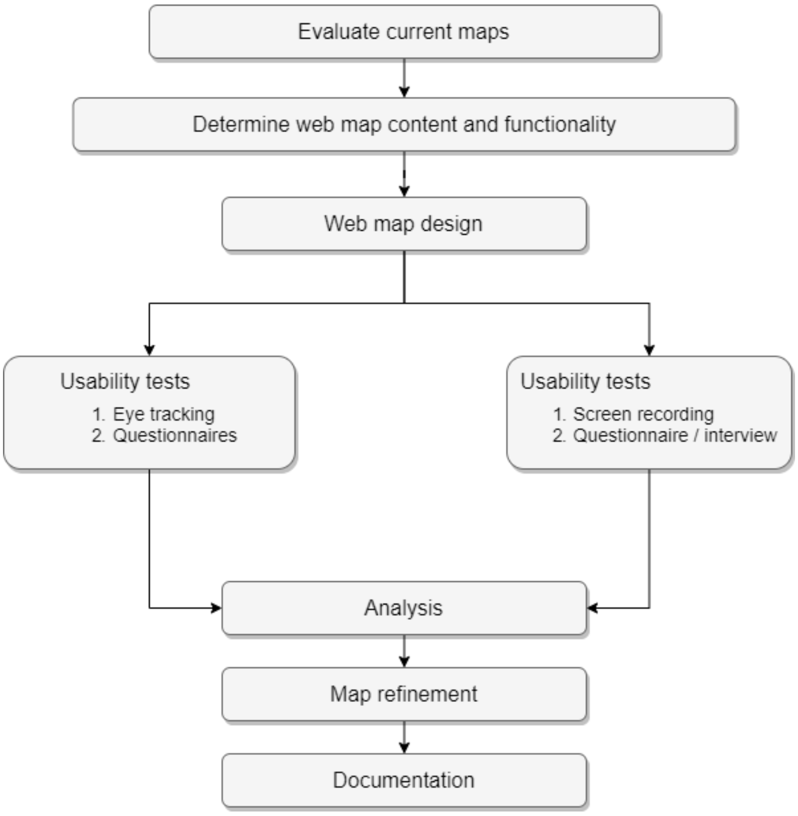

Figure 4 Methodology of the thesis

3.1 Webmap Design

Used methods

A web map was designed to provide information on the electricity infrastructure in 25 selected informal settlements in Kampala. The webmap was designed with insights from electrical engineers at umeme, and its user aspects were evaluated.

Used data

A primary dataset showing the electricity infrastructure in 25 of the more than 50 informal settlements was used. The electricity infrastructure data was captured between 20/02/2023 and 20/03/2023. The administrative boundaries data was accessed as .shp, and the population data from 2014 as .xls from the Uganda Bureau of Statistics (UBOS) website. The spatial extents of the informal settlements were provided by the Spotlight Kampala project after they were digitized from satellite imagery.

Used software

- KoboToolBox and Fieldpapers were used for data collection.
- Qgis was used for data cleaning and processing.
- PostGIS and PostgreSQL were used to manage data and correct datatype issues.
- MapBox studio and MapBox GL JS were used for tile publishing and scripting.
- WinSCP was used for hosting the webmap.

Processing procedure

The electricity infrastructure data was exported from KoboToolBox and pre-processed in Qgis. The pre-processing involved removal of infrastructure with the wrong geometry. The data was added into PostGIS, where the feature type was changed to integer. Data was then added to MapBox, and tiles were published. In MapBox JS GL, the web map was created and published using WinSCP.

3.2 Usability Assessment

Usability assessment was performed with a combination of in-person and remote assessment and qualitative and quantitative techniques. A formative approach was applied for user assessment, with the objective to identify any challenges associated with using the electricity infrastructure webmap of Kampala. The target search analysis framework by Bojko (2013) was applied in the usability assessment (Figure 5).

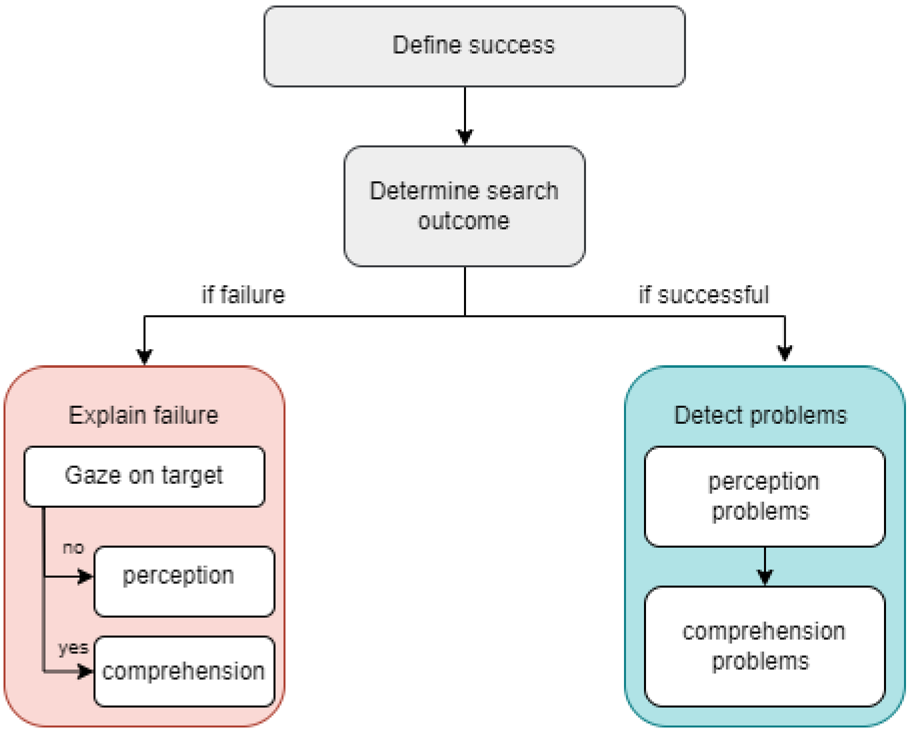

Figure 5 Target search analysis framework (adapted from Bojko, 2013)

Used methods

Remote usability assessment was performed through a combination of questionnaires, screen recordings, interviews, and task-solving. The tasks were designed with consideration of the target search analysis framework. Outputs from all three methods were analysed to compile a list of challenges.

An in-person usability assessment was performed with eye-tracking, questionnaires, and task-solving, considering the target search framework. The data was analysed with qualitative approaches, and the output provided additional information on the challenges encountered and was used during the refinement of the webmap.

Used data

Entries into the questionnaire with targeted questions were analysed. Videos of the screen recording and interview responses provided insights into webmap challenges. Data from the eye-tracking experiments were processed to provide additional insights.

Used software

- The questionnaire was designed in Google Forms.
- Bewisse recording software was used for screen recording.
- Zoom was used for teleconferencing.
- Tobii Pro Lab was used for eye-tracking and data analysis.
- Gazeplotter was used to plot the gaze data.

Processing procedure

Remote user assessment was performed by providing a questionnaire. The respondents recorded their screens while solving the tasks in the questionnaire. The responses from the questionnaire were analysed for the correctness of answers, videos were watched to identify any other challenges, and interviews were used to determine user preferences. Eye-tracking data was collected and processed to provide further insights into the challenges associated with using the electricity utilities web map.

4 WEB MAP FUNCTIONALITY AND DESIGN

This chapter documents the steps that were taken in designing the web map for the electricity infrastructure in Kampala's informal settlements.

4.1 Evaluation of existing maps

Samples of engineering drawings were obtained from umeme. These drawings include the infrastructure and their characteristics as indicated in the appendix. At the pole level, characteristics include the pole ID and its condition. The engineering drawings also feature a scale, legend, North arrow, and table with extra information about the bills of quantities required for a particular project. Engineering drawings are designed in requisite desktop GIS software and distributed in .pdf format.

In addition to the engineering drawings, web maps from the Uganda energy sector were evaluated. These include web maps from the Ministry of Energy and Mineral Development (MEMD), UEDCL, UEGCL, and UETCL. By the time of compiling this thesis, umeme had no published web maps. An evaluation of the existing web maps reveals that save for UEGCL, the energy sector web maps are produced with the Esri suite of software as shown in Figure 6.

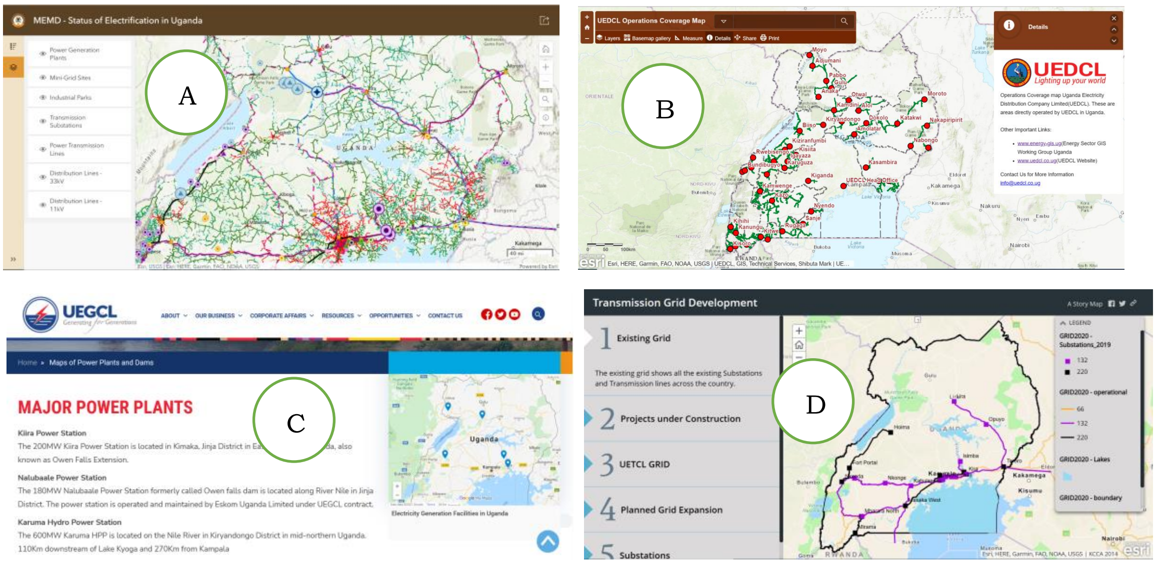

Figure 6 Web maps presented by Uganda's energy sector show electrification and electricity infrastructure status. A) Ministry of Energy and Mineral Development, B) UEDCL, C) UEGCL, D) UETCL

The web maps feature a combination of point and linear features, with the substations, power plants, industrial parks etc., shown as points, while the transmission and distribution lines appear with linear features. In terms of geometry, the point features are represented with varying geometric shapes, sizes, and colours depending on the feature type, voltage capacity, and operation status, among others. The web maps do not appear to conform to one standard.

Interviews

To determine the required functionality of the designed webmap, interviews were conducted with five engineers from umeme over teleconferencing with Zoom. Interview questions were designed to guide the process, and additional questions were asked depending on the direction in which the interview was going. The interview questions and transcript of the responses are shown in the appendix, while a summary of the findings is discussed as follows.

The engineers were from different offices ranging from design, management, project execution, and network management. They also had varying levels of experience ranging between five and seven years. From the interview, it was determined that the different departments interact with spatial data at varying scales and during different parts of their routine work. Spatial data is typically provided by the GIS department, which extracts and provides the engineers with the necessary data for the selected piece of work. The data is accessed in .pdf format, digital or printed pdfs, or Excel tables. For the engineers with GIS training, shapefiles are provided to facilitate department analysis and project planning.

Among the discussions during the interview was the issue of challenges encountered by the engineers. All the engineers expressed disappointment at the inconvenience they experienced while accessing GIS data, with one saying, "*You have to go to the GIS office if you want data; if you ask for it via email, they take forever to send it*". Others mentioned that you cannot visually compare maps because the symbols differ depending on who created the map. The engineers also intimated the fact that each department uses different tools or methods, and they are not required to submit coordinates while submitting the reports of the projects they have done.

The interview session also included a review of the existing web maps in the energy sector of Uganda. Only one of the interviewees indicated that he had ever seen the web map. However, he admitted that he had not interacted with it. While reviewing the web map, the engineers expressed their excitement about accessing and viewing information online. They went on to state what data they could add to the web map and how they would apply it to their daily work.

Since the electrical engineers had no GIS technical experience, they could not verbalize what functionality they hoped to see in the web map; however, they stated the kind of information and data they would want to visualize for the informal settlements of Kampala.

- The physical location of the infrastructure
- Number of people in an area
- Orientation data like the background map with streets or satellite images

The outcome of the interview, review of the engineering drawings, and web maps were the functionality and data requirements for the utility web map of Kampala's informal settlements.

4.2 Webmap design

Data

The initial dataset used for the preliminary design of the webmap was a sample of the electricity network in selected informal settlements of Kampala. This sample data was provided to give insight into the attributes represented by the different infrastructures managed by umeme. The data was provided as ESRI shapefiles, converted to geojson, and used in the prototype of the web map.

Since access to the data used at umeme is restricted, information on the electricity infrastructure was captured under the Spotlight Kampala project. This is a project to bring focus to the disparity in services provided in informal and formal settlements in response to SDG 7 and SDG 11.

Scope of study

The web map was designed to show electricity utilities mapped in 25 informal settlements in Kampala. These settlements were selected randomly among the settlements in which the Slum Federation of Uganda has engagements. This was done to ensure the safety and smooth process of mapping the electricity infrastructure within these settlements. The team at Spotlight Kampala modified the spatial boundaries of the settlements beyond the official administrative boundaries shown in Figure 7. This was done because of a mismatch between the official boundaries and the physical extent of the informal settlements on the ground.

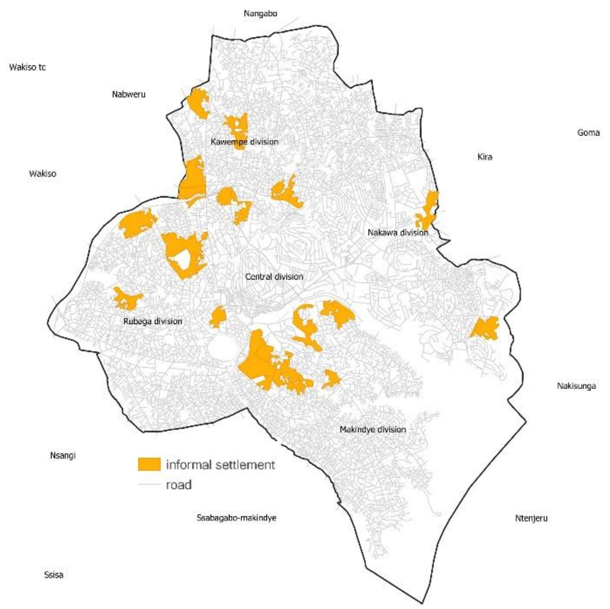

Figure 7 Selected informal settlements of Kampala

Data collection

The data was collected using a combination of KoboToolBox and field papers. KoboToolBox is a free and open-source suite of tools for data collection and analysis in humanitarian and development settings. It includes web-based and mobile applications for data collection, management, and analysis, as well as a suite of tools for data visualization and sharing.

On the other hand, FieldPapers is another open-source web-based platform for creating and printing custom maps that can be used for data collection and fieldwork. It was developed by the Humanitarian OpenStreetMap Team (HOT) and is widely used by organizations and individuals for community mapping, disaster response, and other fieldwork activities.

In KoboToolBox, a form was designed in which the data collectors selected among three amenity options, utility pole, streetlight, and transformer. The form then included additional information requirements for each amenity type, such as the number of prepaid meters, the number of poles on the ground, the material, and pole status. In the field, the data collectors worked in teams of three, with two students from Makerere University and one community member. The teams used a mobile phone with the KoboToolBox form and a printed field paper to map all the electricity infrastructure in the informal settlements, as seen in Figure 8. Examples of the mapped infrastructure are shown in the appendix.

Figure 8 Students using KoboToolBox and FieldPapers to map electricity infrastructure.

A validation exercise was performed after each mapping day. The mapping teams checked to see that all the data was captured, and additional information was added before the data was uploaded onto OpenStreetMap. In cases where the data was unsatisfactory, the team was redeployed to capture any missing data and correct any errors.

Design of web map

The prototype of the webmap was designed with OpenLayers library and used data stored as geojson. This webmap included functionality like the layer switcher, zoom capabilities, and pop-ups. However, when the final dataset, including all the data from the mapped informal settlements, was added to the web map, it was too heavy, and therefore the web map could not load. To counter this challenge, the web map was designed to work with tiles instead. In this case, the data was uploaded into geoserver installed on the host computer. This allowed for access to the data via a WFS. Since there was no access to the geoserver at the time of publishing the designed webmap, the end users would not be able to access or assess the map's capabilities. This ultimately led to the design and choice of the final capabilities of the web map.

The final web map was designed with MapBox GL JS. This is a JavaScript library for rendering interactive, customizable vector maps. It uses WebGL technology to render maps with hardware acceleration and allows developers to create highly responsive and performant mapping applications that work across all platforms.

The data was imported into MapBox studio in a geojson format and published as vector tiles. These vector tiles were then used to load all the data into the webmap, and styling and functionality were applied.

Results of web map design

The designed web map features the following capabilities, Figure 9:

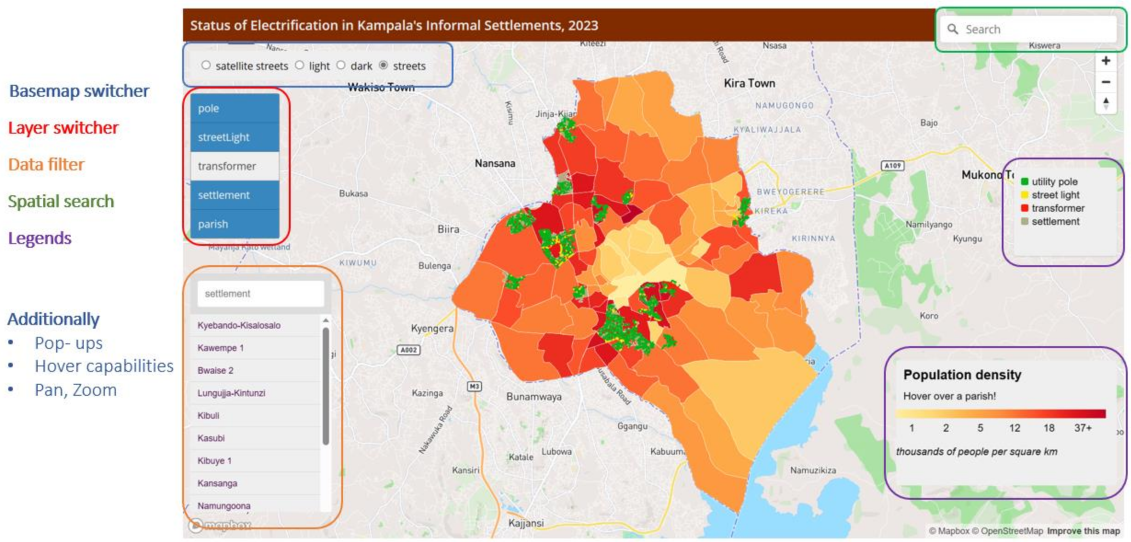

Figure 9 Electricity utilities webmap, data, and functionality

Out of the 25 selected informal settlements, only 19 had been mapped by the time of publishing the web map. The population density was achieved by enriching the parish administrative boundaries with the population data. The webmap was published on 03-04-2023 and made available for user assessments.

The functionality and design of the electricity utilities web map of Kampala's informal settlements were based on insights from interviews with electrical engineers at umeme, a review of existing web maps from the energy sector of Uganda, and the engineering drawings used at umeme. The web map was designed with MapBox JS GL, works with vector tiles, and features data collected under the Spotlight Kampala project. The web map interface includes a basemap, layer switcher, data filter, search button, and legends. The interactive elements include pop-ups, a hover effect, a side window, and a display of additional information at a particular zoom level. The web map was made available online for usability assessment*. (*Electrification in infromal Settlements of Kampala (upol.cz))

5 REMOTE USABILITY ASSESSMENT OF WEB MAP

Usability tests

As the final users of the designed web map were electrical engineers in Uganda, it was necessary to employ multiple approaches to the usability assessment to capture the final users' potential technical and cultural characteristics. This was achieved through a mixed remote and in-person assessment of both qualitative and quantitative usability metrics. The main objective of the user assessment was to identify challenges associated with using the webmap; therefore, a formative study was performed. In both the remote and in-person assessments, the target search analysis framework by Bojko (2013) was applied.

5.1 Students

Remote usability assessment was performed using three main tools, a questionnaire with targeted tasks, screen recording, and interviews with selected participants. Each of these techniques and requisite parameters are discussed in the following sections.

5.1.1 Questionnaire

The designed questionnaire was divided into three main sections. For the remote studies, the first section covered demographic information, the second section consisted of targeted questions and tasks that required the users to interact with the map, and the third section evaluated the use of tools, including subjective feedback. In addition to the demographic questions, section 1 included information on the project, the research, and instructions on participating in the exercise. The questionnaire was distributed to the participants via email, along with instructions on accessing and using the tools.

5.1.2 Participants

Between 04-04-2023 and 25-04-2023, remote usability assessments were performed. These were performed with four broad groups of participants, including students from Makerere University in 1st year land surveying with minimal GIS training, 4th year land surveying with advanced GIS training, 4th year electrical engineering with beginner's level engineering training, and electrical engineers from umeme with advanced engineering training. Except for the assessment with the electrical engineers, the other assessments were performed in a computer lab at Makerere University in Uganda. This was done in a classroom setting, with each student working at their own computer and with the supervision of a lecturer. At the beginning of the evaluation, the lecturer provided information on the project, the objective of the evaluation, and instructions for students to work individually.

5.1.3 Tasks

The second section of the questionnaire featured tasks to be completed while interacting with the map. These tasks were designed in such a way as to have the participants interact with all the elements of the designed map as shown in Table 1. In addition to responding to the questionnaire, participants recorded their screens starting before responding to section two of the questionnaire. Screen recording was done using Bewisse, a web tool that does not require installation. Both the entries into the questionnaire and screen recording were analysed to identify challenges associated with using the web map.

Table 1 Tasks and targeted tools

	Task	Targeted tool
A01	Which basemap do you prefer?	Basemap switcher
A02	Switch all the layers off	Layer switcher
A03	Which parish has the lowest population density?	Graduated colours and legend
A04	What is the lowest population density in the parish layer?	legend
A05	Which parish has the highest population density?	Graduated colours and legend
A06	What is the highest population density in the parish layer?	legend
A07	How many prepaid meters were mapped in Bwaise 2 settlement?	Layer switcher, filter, pop-ups
A08	How many post-paid meters were mapped in the Kansanga settlement?	Layer switcher, filter, pop-ups
A09	What colour is used to represent the utility poles?	legend
A10	How many transformers are in Bwaise 2 settlement?	Zoom, legend, layer switcher, filter
A11	Zoom in and give an example of the pole IDs in the Bwaise 2 settlement	Zoom
A12	Bwaise 2 settlement was fully mapped?	Zoom, pan

The third section of the questionnaire focused on the map tools and subjective feedback, as captured in Table 2. This allowed the respondents to perform a self-evaluation of the tools that they used and to provide feedback on their opinion on the web map design and functionality.

Table 2 Questions and objectives

	Question	Objective
B01	What is the value of the circled item?	Legend interpretation
B02	I used this tool	Self-evaluation of used tools
B03	The map was easy to use	Subjective feedback on ease of use
B04	comment on the use of colour	Subjective feedback
B05	What would you change in this map?	Subjective feedback on satisfaction
B06	How long did it take you to finish the exercise?	Indication of overall efficiency or ease of use

5.1.4 Results

Demographics

The distribution of demographics is indicated in Table 3. In terms of demographics, there were generally more male than female students, with about 70% male students in the surveying classes while there was an equal representation of male and female students from the electrical engineering class. In terms of age, about 80% of all the student participants were between the age of 19 and 25. On the other hand Table 4 provides information of the level of GIS and engineering. While most of the engineering students have no GIS training, most of the surveying students have no engineering training.

Table 3 Demographics from the questionnaire

	Gender		Age				Total
	Female	Male	19-22	23-25	26-30	31-35	
Surveying 1^{st} year	30%	70%	65%	22%	4%	9%	23
Surveying 4^{th} year	35%	65%	48%	48%	0%	4%	23
Engineering 4^{th} year	50%	50%	17%	67%	8%	8%	12

Table 4 Training information from the questionnaire

		None	Beginner	Intermediate	Advanced	Expert
GIS training	Surveying 1^{st} year		96%	4%		
	Surveying 4^{th} year		4%	18%	74%	4%
	Engineering 4^{th} year	67%	17%	17%		
Engineering training	Surveying 1^{st} year	82%	9%	9%		
	Surveying 4^{th} year	86%	9%	5%		
	Engineering 4^{th} year		42%	33%	25%	

Correctness of answers

A commonly used metric in usability assessment is the correctness/ success rate, which indicates the effectiveness of the evaluated product (Zuo et al., 2020). Table 5 shows the rate of correctness of answers, with the respondents divided into the groups in which the usability assessment was conducted.

Table 5 Rate of correct responses to tasks

	1st year surveying		**4th year surveying**		**4th year engineering**	
	correct	**wrong**	**correct**	**wrong**	**correct**	**wrong**
A01	74%	26%	83%	17%	100%	0%
A02	87%	13%	100%	0%	100%	0%
A03	96%	4%	96%	4%	100%	0%
A04	96%	4%	96%	4%	100%	0%
A05	78%	22%	87%	13%	100%	0%
A06	78%	22%	87%	13%	100%	0%
A07	96%	4%	100%	0%	100%	0%
A08	87%	13%	91%	9%	92%	8%
A09	100%	0%	100%	0%	100%	0%
A10	91%	9%	100%	0%	75%	25%
A11	96%	4%	100%	0%	100%	0%
B01	65%	35%	70%	30%	92%	8%

The highest success rate of 100% by all participants was registered for question A09. This question was on the colour used to represent the utility poles. The correct answer to this question could be obtained either by reading the simple legend or by switching the layers on and off.

Typing and reading errors

Questions A07 and A11 both had an equally high correctness rate, with 100% registered for the 4th year surveying and 4th year engineering students. In the case of the 1st year students, the success rate was 96% for both questions. This corresponds to one participant getting the answer wrong in each instance. Further investigation of the questions and responses was performed: A07 required the use of the pop-up tool to retrieve the number of prepaid meters, whereas the correct answer was 396 the respondent entered 392.

Similarly, question A11 required the participants to zoom in and provide an example of the utility pole IDs, which were only visible at a particular zoom level. Whereas the correct values were in the thousands, for example, 5563 (Figure 10), the respondent entered the value 563, which was not among the pole IDs. In both cases, the wrong response was attributed to a typing error.

Figure 10 Example of utility pole IDs

Whereas A07 and A08 required the use of the same tool, there is a general decline in the success rate for each group of respondents. The registered drop was 96%-87% for 1st year surveying students, 100%-91% for 4th year surveying students and 100%-92% for engineering students. The correct response to this question was 1,273 post-paid meters, retrieved from the pop-up, but all the other respondents entered 759 except one that entered 758. The value 759 was the number of post-paid meters from the previous question, shown in Figure 11. This meant the respondents did not read the question clearly, while response 758 was likely a typing error for the intended 759.

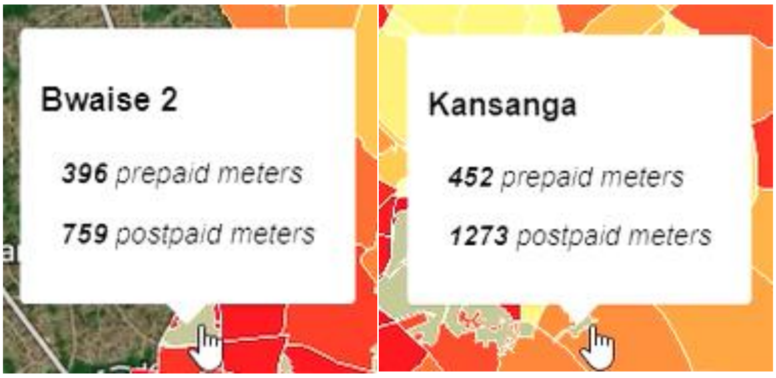

Figure 11 Correct responses to questions A07 and A08

Questions A03, A04, and A05, A06 required the use of the same tools; however, there was a decline in the success rate for the surveying students, while the engineering students registered a 100% success rate. In the case of questions A05 and A06, which inquired for the parish with the highest population density, the 4th year surveying students that did not enter the correct response all entered the value for the parish with the second-highest population density. This differed from the 1st year students whose responses included the parish with the second highest population density, one with a much lower value, and one with a typing error. To understand why this occurred, video recordings were reviewed.

These recordings revealed several issues, including some respondents did not associate graduating colours with population density; therefore, they scanned each parish to identify the population density without considering the colours. In these cases, the respondents took much longer, and 80% of those who used this method arrived at the wrong value. Another issue that the videos revealed was insufficient zooming, resulting in the selection of polygons neighbouring the highest or lowest population density for the

1st year students. Finally, some participants switched all the layers on while performing the different tasks. This resulted in obstructions and possible confusion.

The lowest rate of correctness

The most challenging task was different for each of the participant groups. For instance, in the case of both land surveying groups, question B01 had the lowest rate of correctness at 65% for the 1st year and 70% for the 4th year participants, while it was 100% for the 4th year engineering participants. Question B01 required the participant to interpret the legend with graduating colours, which could have presented a challenge for participants that did not associate graduating colours with population density. On the other hand, the 4th year engineering students registered the lowest success rate of 75% in question A10, which was about the number of transformers in a particular settlement. This question required sufficient zooming in and searching for the correct settlement. A review of the recordings showed that the participants that responded wrongly to this question did not zoom in sufficiently.

Subjective insights

Participants were tasked with performing a self-evaluation of the tools that were used in executing the tasks. Filter, zoom, and search widgets were evaluated.

Questions B03, B04, and B05 provided the following general insights regarding satisfaction. More than 50% of all participant groups agreed that the map was easy to use, and less than 10% of the participants disagreed with this statement, as shown in Figure 12.

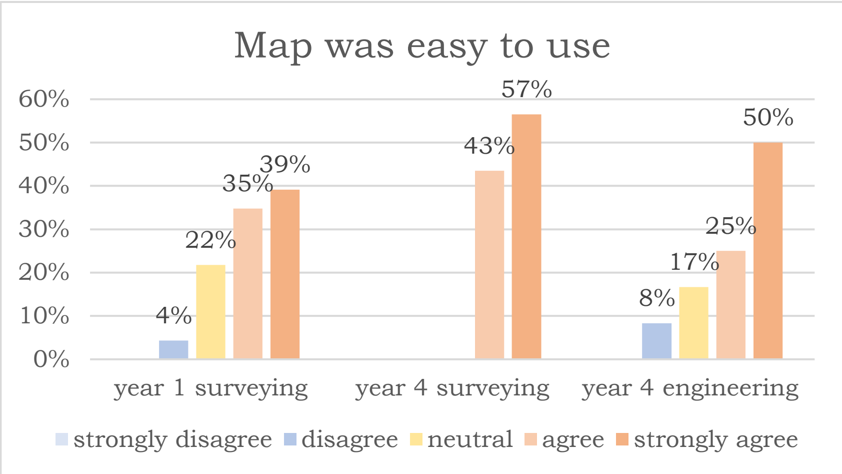

Figure 12 Subjective insights showing that the participants found the map easy to use

The evaluation of colours used revealed that the engineering students had no negative comments on the use of colours, with some of them stating that the colours were fairly or well used and that they were distinctive and made the process of interpreting the map much easier. The 4th year surveying students also presented similar opinions towards the colours, stating that the appropriate colours were used and that these supported the topic positively. Whereas there was much positive feedback on the use of colours, there was also negative feedback on the use of colours and the map in general.

Even though about 10% of the surveying students and 25% of the engineering students said they would not change anything in the map, both positive and negative feedback was captured in questions B04 and B05, as illustrated in Figure 13.

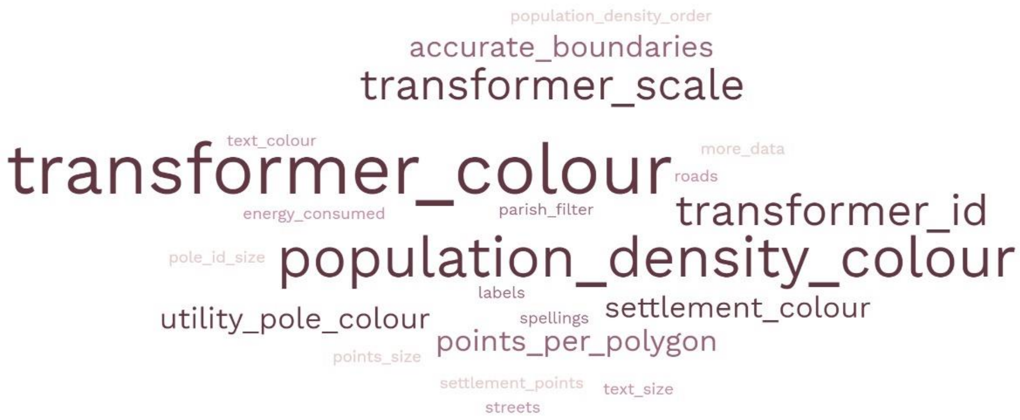

Figure 13 Subjective insights on what could be changed in the web map from the unmoderated remote usability assessments.

Generally, the feedback can be divided into four groups: colour, size, data, and functionality. In terms of colour, the respondents suggested that the colour of transformers and utility poles be changed. This could be attributed to the fact that the transformer colour clashes with the population density, while the green colour is associated with vegetation and not utility poles. The respondents also suggested a darker colour for the text. Respondents suggested that the font size, especially for the pole IDs, be increased in addition to increasing the size of the point features.

Whereas the objective of the map was to communicate the findings of a particular mapping exercise, the respondents felt that the map could do with more data, such as the roads which provide context for the utility infrastructure and transformer grades as these communicate on electricity capacity and power consumption instead of population density. The respondents also felt that the administrative boundaries were not accurately captured. Finally, in terms of functionality, the respondents suggested the addition of a filter for parish data and a way to count the number of transformers per administrative boundary automatically.

5.2 Electrical Engineers

5.2.1 Interview

The final part of the user assessment was an interview session with the electrical engineers at umeme. This was conducted to acquire qualitative feedback in terms of design, preferences, and applicability. Like the remote assessments, the engineers were provided with a link to the questionnaire, which included a link to the map. During a teleconferencing meeting, the engineers interacted with the map and answered the questions in the questionnaire.

5.2.2 Participants

Four electrical engineers and one GIS technician evaluated the map. Of this group of experts in electrical engineering, one had beginner's level experience with GIS; three had no experience, while the GIS technician had advanced experience.

5.2.3 Results

All the participants were able to change the basemaps. In terms of choice of basemap, the engineers prefer the satellite streets basemap. This is because it shows physical features as they exist on the ground, which is important for the engineers who use this for orientation and directions. One engineer stated, *"when you send someone to the field, you can tell them to go to the transformer next to the big house with a green roof and x road".*

The engineers were also able to identify the parish with the highest and lowest population density using the legend and considering the graduating colours. They stated that this was a good feature and could be replaced or enriched with the household density as this directly indicates potential clients.

The engineers were able to identify the number of prepaid and post-paid meters in each settlement. This information was very important as it provides insights into potential illegal connections if the number of registered meters does not correspond with their expectation. They were happy to see an overview of each settlement, allowing them to put it in perspective.

The engineers easily found the colour used to represent the utility poles from the legend. They stated that since colours represent the voltage level of infrastructure, then using any colour in the web map was okay as it does not include voltage data.

The engineers used the mouse to zoom and scroll to count the number of transformers in the settlement. One of the engineers identified the need to zoom in adequately, stating that when he did not zoom in enough, he saw four transformers, yet there were five.

Some of the engineers explored the filter and search tools with success. They carefully checked for the correct spelling before clicking on the names of places in the search tool.

The labels implemented at a particular zoom level were also well appreciated, making the web map look like the engineering drawings they are familiar with.

One of the most challenging map elements was the legend. This was not the case for the electrical engineers who could interpret it easily. One of the engineers stated that since the legend window showed the actual population density, they only needed to identify which colours showed the higher or low values without needing to read the legend explicitly.

At the end of the interview, all the engineers stated that they were able to extract information with the web map. They stated that implementing it at umeme would make life easier for them, and they could quickly make decisions.

5.3 Summary of remote user assessment

Success rate, user feedback, and observation were applied in identifying usability challenges for the informal settlements' web map of Kampala. These three methods were applied using questionnaires and screen recordings. The methods were applied to three groups of Ugandan students with varying GIS training and experience. An evaluation of the differences in the groups is beyond the scope of this study.

Whereas the remote assessment methods could identify all the expected problems, these methods could not provide information on why some respondents were not able to change the basemap or layers and why the legend with graduated colours was difficult to read. For this reason, an eye-tracking experiment was conducted.

6 EYE-TRACKING TESTING OF WEB MAP

An eye-tracking experiment was conducted to evaluate user experience while working with the electricity utility's web map of Kampala. Data and output from this experiment identified problems associated with using the web map. This section describes the experiment setup, data, analysis, and conclusions.

6.1 Experiment design

Before the experiment began, the participants were welcomed and made to feel comfortable. They were informed that their abilities were not being tested but that the map was being investigated. This allowed them to relax before the experiment was conducted. The setup was explained, and the participants were allowed some time to read through the project and research information before commencing.

The experiment was designed and conducted with Tobii Pro Lab *version 1.194*. The process began with calibration to ensure accurate data capture. After successful calibration, a welcome message was displayed, and the stimuli were presented. In keeping with the methods applied during the remote assessment, the stimuli consisted of the same map canvas, and the tasks were presented in the same questionnaire, except that the order of sections was altered to include the questions on demographics at the end of the experiment. Participants used the map stimuli to work through the tasks in the questionnaire. In addition to the entries into the questionnaire, eye-tracking and video recordings of the experiment were captured. After the participants responded to all the questions and submitted the questionnaire, a goodbye and appreciation message were displayed, and the experiment ended.

6.2 Equipment

The Tobii Spectrum 300 eye-tracker was used during this experiment. The eye-tracker is housed in the eye-tracking laboratory at the Department of Geoinformatics at Palacký University Olomouc, Czechia. A webcam: Logitech c920s HD was also used. The stimuli were displayed via Tobii Pro Lab software as a Screen recording stimulus displayed in a Google Chrome browser on the participant's 24-inch screen in the same room. The observer used another 24-inch screen to run and observe the experiment.

6.3 Participants

From 18th to 19th April 2023, eleven individuals participated in the designed eye-tracking experiment. However, owing to calibration issues and a low amount of data recorded, data from one of the participants was left out. All the participants were international students, with 50% being of African descent. Regarding GIS training, 60% of the participants had none, while the rest, being students of a geo-informatics course, had advanced training. None of the participants had formal electrical engineering training. However, some listed beginners' training based on personal experience.

6.4 Data analysis

Following the recording of data from the eye-tracking experiment, the assisted mapping tool was run. This was done with reference to a screenshot of the web-map stimuli. Areas of Interest (AOIs) were drawn, as illustrated in Figure 14, and these became the basis for the eye-tracking metrics. Whereas many more metrics were calculated, only a few were used for analysis in this research: time to first fixation, fixation count, and dwell time per AOI. The fixation data were exported for viewing in a sequence chart plot produced with the Gazeplotter web tool (Gazeplotter.com). The sequence charts provide a spatiotemporal illustration of how participants interacted with the web map. Spatial as they show the different AOIs, and temporal as they show the time and duration for which the AOIs were visited.

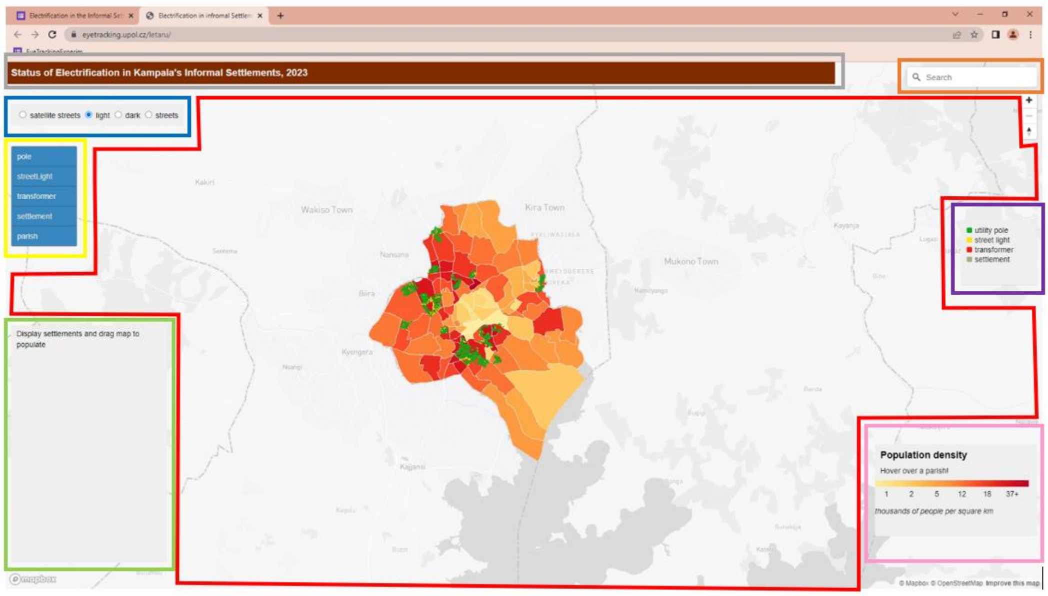

Figure 14 Web map Areas of Interest

In addition to the eye-tracking data, entries into the questionnaire, participant comments, and general observations made during the experiment were considered as they contributed to the objective and subjective feedback. The correctness of answers was considered following the target search analysis framework proposed by Bojko (2013). In this case, for each task, the correct answer was decided beforehand, and successful arrival at the target answer was noted, while unsuccessful attempts were investigated to inquire why they occurred.

6.5 Results

6.5.1 Correctness of answers

From the questionnaire entries, the first evaluation was the correctness of responses, as captured in Table 6.

Table 6 Correctness of answers in an eye-tracking experiment

	A01	A02	A03	A04	A05	A06	A07	A08	A09	A10	A11	B01
P01	Correct	Wrong	Correct	Correct	Wrong	Wrong	Wrong	Wrong	Correct	Correct	Correct	Wrong
P02	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Wrong
P03	Correct	Correct	Wrong	Wrong	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Wrong
P04	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct
P05	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Wrong	Correct	Correct	Correct	Correct
P06	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Wrong	Correct	Correct	Correct	Correct
P07	Wrong	Correct	Correct	Correct	Wrong	Wrong	Correct	Wrong	Correct	Wrong	Correct	Correct
P08	Correct	Correct	Wrong	Wrong	Correct	Correct	Correct	Correct	Correct	Correct	Wrong	Wrong
P09	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct
P10	Wrong	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Wrong
	80%	***90%***	***80%***	***80%***	***80%***	***80%***	***90%***	***60%***	***100%***	***90%***	***90%***	***50%***

Correct
Wrong

Like the outcome from the remote assessment, A09 was answered correctly by all respondents, while B01 and A08 were similarly challenging to the respondents. In the case of A08, the findings were the same as those from the remote assessment, where respondents entered the value of 759, which was the number of post-paid meters from the previous question. It was noted that the respondents did not try another method or tool but simply assumed that the area in question was the same as the previous question. This was apart from P01, who was not able to access the pop-up tool.

For question B01, the challenge arose with reading the legend, where respondents that entered the wrong value did not read the entire legend. Out of those that read the entire legend, three respondents had to read it multiple times before entering the correct response. According to Geisen and Bergstrom (2017) and Bojko (2013), this is a sign of high cognitive load and would constitute a problem area.

6.5.2 Eye-tracking metrics

Fixation count per AOI

Multiple eye-tracking metrics were applied during this experiment, including the number of fixations per AOI. The map had the largest number of fixations, followed by legend2 and the layer switcher, as shown in Figure 15. This corresponds well to the way the web map was designed, to have most of the information retrieved from the map and legends. The search button had the lowest number of fixations, which could point to the fact that participants did not need to search for any places as they could be found using other tools. It is necessary to evaluate individual fixations in AOIs (Figure 16).

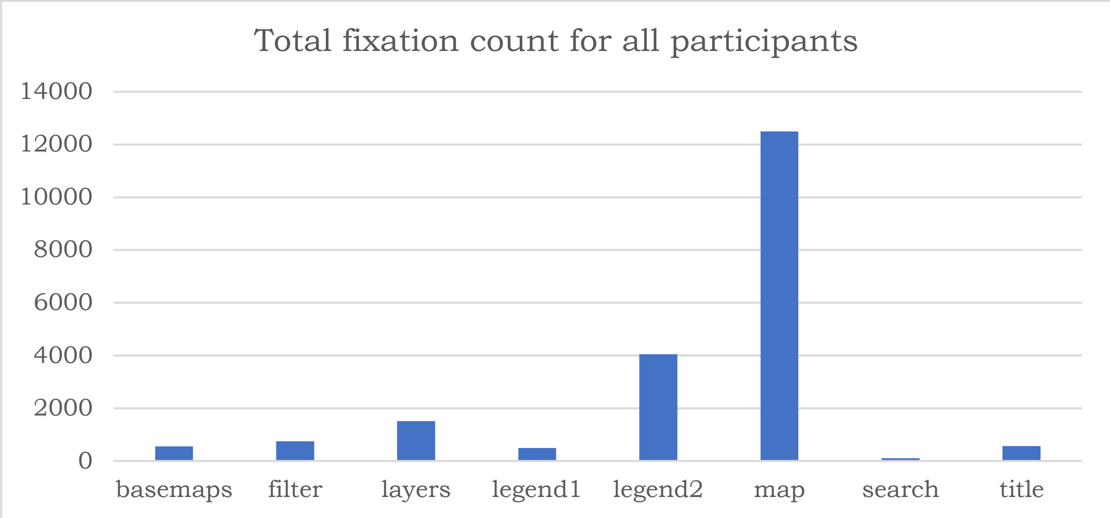

Figure 15 Total fixation count per AOI for all participants

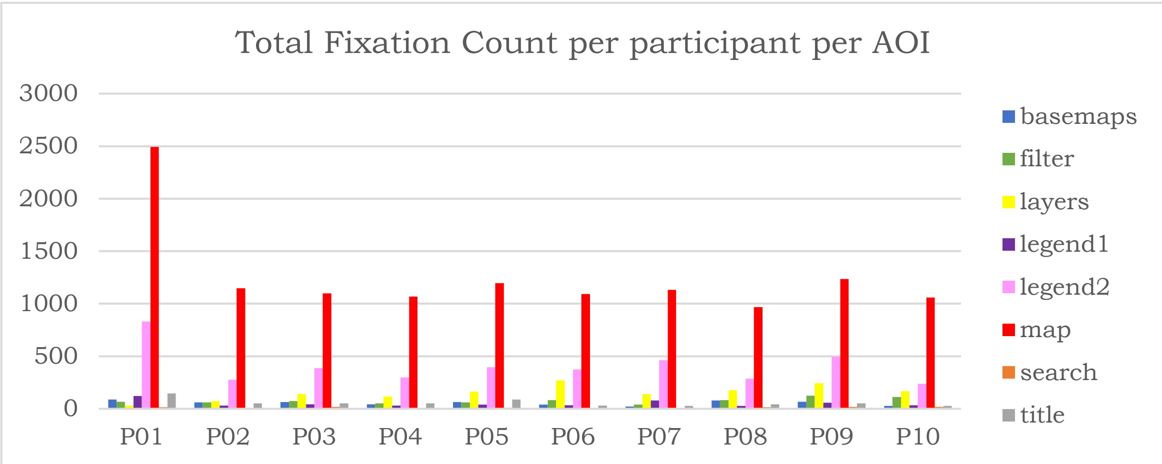

Figure 16 Total fixation count per participant per AOI

From the total fixation count, the overall view shows that most of the respondents spent the largest proportion of time in the map view, with a similar amount of time on the map element, while respondent P01 spent a significantly higher amount of time than the other participants.

A further evaluation of respondent P01's scan path, and heatmap (showing fixation count), in Figure 17 revealed that the respondent spent a large amount of time scanning almost every parish to identify the one with the lowest population density. It can similarly be noted from the total fixation time that this respondent spent more time on legend2 than the other respondents.

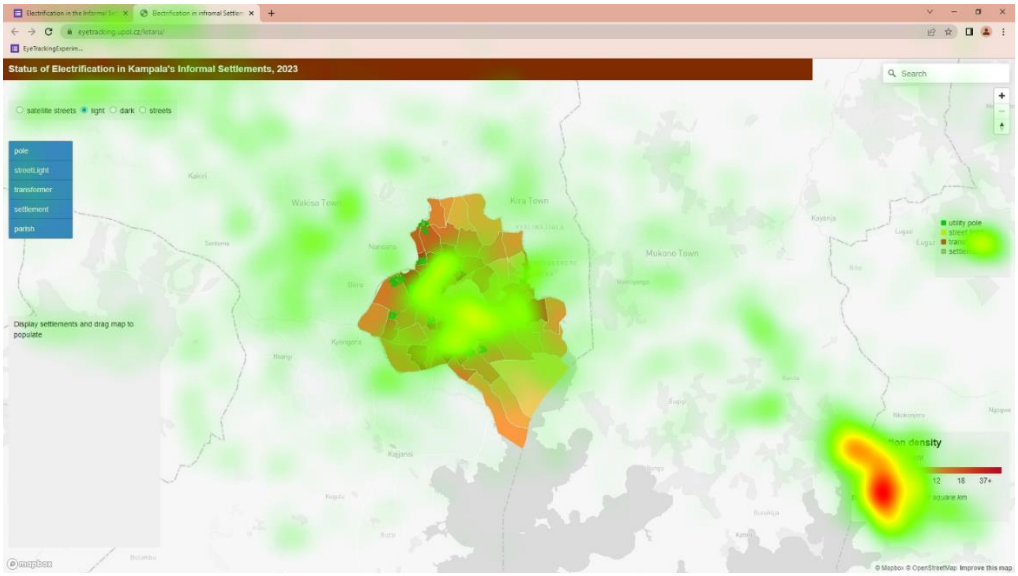

Figure 17 Heatmap P01 showing the largest fixation on legend2 and the map

Time to the first fixation

The time to the first fixation metric provides information on the noticeability of different elements of the web map (Table 7). By rearranging this metric, it is possible to evaluate the overall order in which individuals notice different elements of the map. The map was generally noticed early, while the search button was noticed later in the experiment.

Table 7 Participant time to first fixation in AOIs

Participant	basemaps	filter	layers	legend1	legend2	map	search	title
P01	1.30	14.03	37.50	2.00	29.43	0.00	40.18	23.95
P02	1.25	50.89	47.30	49.53	9.57	0.00	344.16	0.54
P03	4.60	25.49	1.46	2.91	2.20	0.17	88.04	18.15
P04	19.00	72.87	23.76	27.01	0.00	0.97	75.65	1.46
P05	4.47	66.80	2.36	3.25	3.51	0.15	80.10	9.47
P06	0.00	42.64	15.03	223.00	9.90	1.66	580.81	18.48
P07	181.16	5.12	12.58	29.45	7.39	0.00	31.87	3.07
P08	10.45	1.76	3.80	11.35	11.94	3.01	11.70	10.05
P09	6.63	22.85	12.44	0.00	5.00	1.06	5.66	6.85
P10	1.60	11.68	22.75	0.50	2.18	0.00	89.57	6.90
Avg	23.05	31.41	17.90	34.90	8.11	0.70	134.77	9.89

Evaluation of the outliers provides extra insights into the problems with the map. For instance, user P07 first fixated on the basemap switcher at 181 seconds. This was much later than the first fixations in the other map elements and could point to the un-noticeability of the map element because, in the end, this participant was not able to change the use of the basemap switcher. However, a different situation is observed with participant P10 whose first fixation on the basemap switcher was early at 1.6 seconds, but the participant still was not able to switch the basemap. At the end of the experiment, P07 and P10 stated that they did not know the word basemap, so even with an explanation, they did not know what to expect or how to switch them.

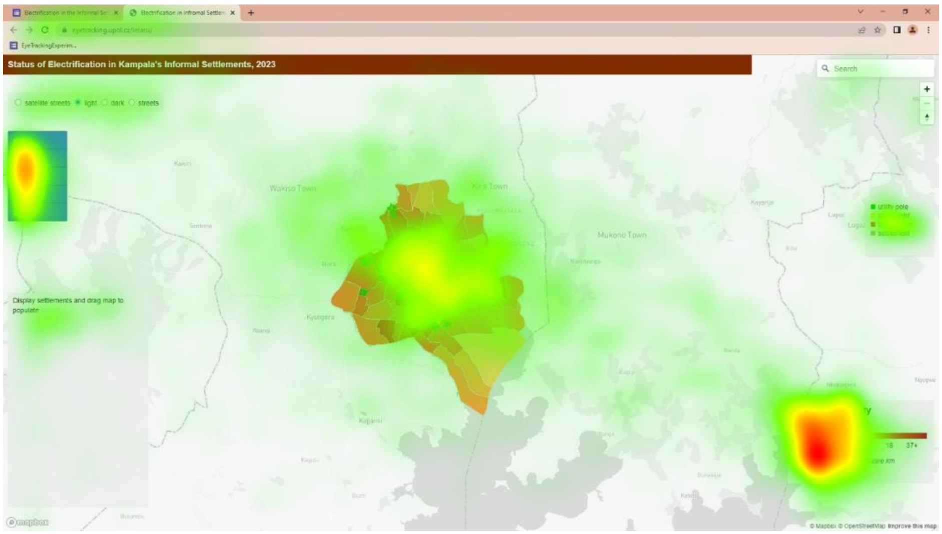

Figure 18 Attention heatmap for all participants

An evaluation of the sequence chart plots provides information on the way in which the participants interacted with the map elements while responding to the tasks. Figure 19 Sequence chart highlighting fixations on the basemap AOI shows the sequence chart highlighting the fixations on the basemap. The task to change the basemap was at the beginning of the experiment. It can be noted from the sequence chart in Figure 19 that 70% of the respondents had many continuous fixations on the basemap switcher at the beginning of the experiment. P01 and P07 noticed the basemap switcher later in the experiment, while P10 had no successive fixations on the basemap switcher throughout the experiment.

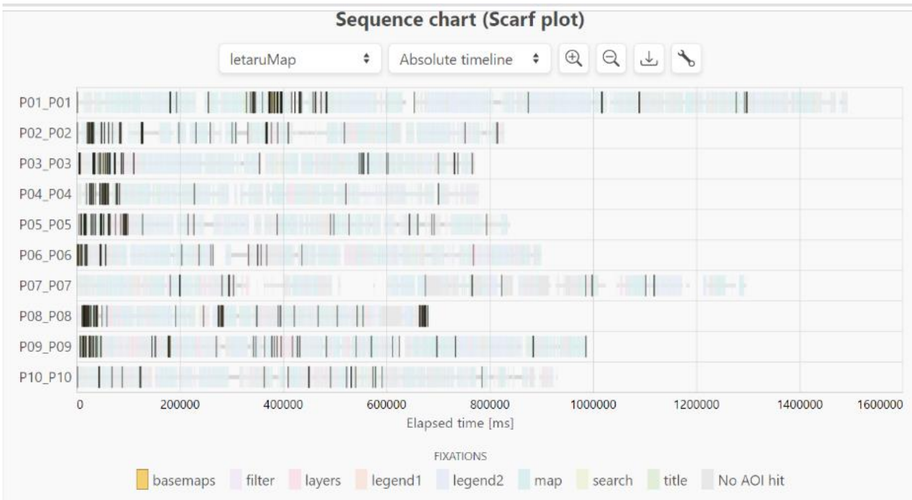

Figure 19 Sequence chart highlighting fixations on the basemap AOI

6.6 Insights from the Eye-tracking Experiment

The eye-tracking experiment identified the same problems as the remote usability assessments. In addition to the identified problems, the experiment was able to explain the reason for the problems.

For the respondents who were not able to change the basemap, the eye-tracking experiment highlighted that the respondent presented two scenarios. One in which the respondent saw the basemap switcher but did not associate it with the given task, and one where the respondent did not see the basemap switcher within the timeframe of the task. This means that the basemap switcher is neither visible nor intuitive to its use.

The respondent who was not able to switch the layers on and off had fixations on the layer switcher but did not associate the layer switcher with its purpose. The layer switcher may, therefore, not be intuitive and communicate its purpose.

Errors in reading the population density legend were attributed to the fact that some participants did not read the entire legend, while others read it but did not comprehend what it meant. This was identified by the fact that the respondents returned to the legend multiple times before entering their responses. Repeated returns to an AOI can indicate the ineffectiveness of a tool.

7 RESULTS

This chapter presents a summary of the results achieved during the research.

7.1 Evaluation of existing maps

The Esri suite of software and tools is predominantly used for web mapping in the energy sector of Uganda. The different companies and government departments apply it in the form of story maps, web maps, and web applications that are used to show the status of infrastructure. These tools are also used to show plans for future development. One company, UEGCL, does not use the Esri products but rather represents the infrastructure using an i-frame. At the time of completing this research, umeme did not have any officially published web map. They use engineering drawings created in desktop GIS software and presented in printed or softcopy pdf format.

The five interviewed engineers from umeme welcomed the idea of using a web map to present and access information on electricity infrastructure in the informal settlements of Kampala. They provided insight into the design of the web map, such as the need for multiple basemaps and the fact that the colours used to represent the infrastructure were not strict if an appropriate legend was attached.

7.2 Web map design

The web map presenting access to electricity infrastructure in the informal settlements of Kampala was designed with MapBox GL JS. The web map uses electricity infrastructure data collected under the Spotlight Kampala project, hosted as vector tiles in MapBox studio. The electricity infrastructure includes utility poles, with the number of prepaid and other connections, streetlights, and transformers. The web map also shows Kampala parish population density, from UBOS, using the choropleth method.

The web map features the following functionality: a basemap switcher, layer switcher, data filter, search button, and two legends. The web map interactions include zoom, pan, pop-ups, hover capabilities, side windows, dynamic symbology, and labels implemented at different zoom levels. This web map was presented as stimuli for the usability evaluation.

7.3 User assessment with remote methods

Remote user assessment was performed using a combination of targeted tasks delivered through a questionnaire, screen recording, and interviews. A total of 57 students from Makerere University, Uganda, four electrical engineers, and one GIS specialist from umeme participated in the user assessment.

Using the rate at which participants can arrive at the correct answer, it was observed that reading the population density legend was among the most problematic areas. This was accompanied by determining the number of transformers and their colour, the size of point data, and labels.

Through video observation, it was determined that some respondents did not associate the graduating colours with population density and therefore performed a more inefficient search for the parishes with the lowest and highest population density. It was also determined that some wrong answers were a result of typing errors, insufficient zooming in, or not reading the questions carefully.

From the interviews, it was determined that the electrical engineers prefer the satellite or streets basemap. This is because the satellite image can be used for orientation and planning for infrastructure development based on what exists on the ground. The street basemap is also important because much of the electricity infrastructure follows the road network.

Whereas the remote assessments could identify many challenges with the web map, these methods could not provide information on why some participants could not change the basemap, switch layers, or why reading the population density legend was a challenge.

7.4 User assessment with eye-tracking

Two scenarios were observed, one where the respondent did not notice the basemap switcher and another where the respondent noticed the basemap switcher but did not recognize its intended use.

Respondents did not read the entire legend, and some of those that read it had to return to it a couple of times before deciding on the response to write.

Insufficient zooming-in was the reason for counting the wrong number of transformers. It was also observed to be the reason for the selection of the wrong parish with the lowest population density, as the respondent did not notice that there were two parishes next to each other in the same population density class.

Respondents did not use the filter, therefore, spent more time searching for settlements by hovering over each settlement. It was not determined if the instructions were too complicated, but it was noted that all the respondents noticed the filter at least once during the experiment.

90% of the participants preferred to use the mouse for zooming in and out, while one respondent used double-clicking or the zoom tool.

As the geocoding tool uses the MapBox database, some of the local names are not available; therefore, many of the respondents who used the search tool selected the wrong place with a similar name, leading to the map getting lost. As no home button was implemented, the respondents either searched for Kampala or used the pan tool to get back to the correct area.

7.5 Final web map design improvements

After evaluating the findings from the usability assessment, the following improvements to the web map were implemented to improve the user experience:

- Larger size for the point data.
- Larger font size for both the feature and tool labels.
- The colour of the transformers was changed.
- The legend of the population density was changed.
- The basemap and layer switchers were labelled.
- Home button implemented.

8 DISCUSSION

During the execution of this research, a mixed remote and in-person usability assessment was conducted using both quantitative and qualitative techniques. The implications of the decisions and approaches to this assessment need to be discussed, along with the challenges and limitations of the product.

The web map was designed using MapBox GL JS. Whereas the library promises to produce highly interactive web maps, the implementation of the functionality was somewhat difficult and problematic. For instance, implementing the basemap switcher triggered several problems. In the beginning, when the switcher was used, the data was not reloaded. When this was corrected, the entire map and dataset were reloaded, and the layer switcher was reset regardless of whether the data was loaded or not. This is problematic if the user decides to change the basemap after turning some layers off.

In total, the remote assessment consisted of 63 participants. Sixty of the participants performed an unmoderated remote assessment, while the three electrical engineers performed a moderated remote assessment. There is no strict number of participants, but for a formative study, this number depends on the number of problems and the probability of their occurrence for each participant. Geisen and Bergstrom, (2017) suggest a minimum of 5 participants where a staged usability assessment is performed.

The low number of electrical engineers involved in the usability assessment was due to the difficulty in recruiting them and the fact that Ugandans prefer personal to digital interaction. However, this was compensated for with the extensive interview sessions.

One challenge with the remote assessment method is the limited control over the environment in which the participants perform the given tasks. In the case of this research, whereas the person who was analysing the data was in Czechia, the respondents were in Uganda. To reduce the negative impacts of the chosen method, the evaluation was conducted with three groups of students at different times and was conducted under the supervision of a lecturer.

Screen recording also provided useful insights into what the participants were doing during the execution of the tasks. It was noted when there were long pauses with no activity between tasks.

Another challenge was the issue of a power blackout during the first evaluation. This blackout meant that some participants could have lost some of their progress. It was not determined how many people lost their work or had to repeat, and an evaluation of the blackout's impact on the results was not performed. However, it should also be noted that since the respondents were entering their responses into a Google form that stored their progress, the students may not have repeated the exercise.

The eye-tracking experiment consisted of 11 respondents, of which one was left out because of insufficient data collected and poor calibration. This number was more than sufficient as the number of required respondents in relation to the number and occurrence of problems was eight.

Since the research took on a mixed approach to usability data collection, there was also a mixed approach to the analysis of the data. The rate of correct responses was applied to both the remote assessment and eye-tracking experiment outputs.

The experiment was designed in such a way that the stimuli were presented as a webpage that was accessible on the respondent's monitor, and the responses were entered into the form and displayed on the monitor. One video was therefore recorded for the entire experiment, with no events or way to determine when the tasks began or ended.

The number of fixations and time to the first fixation per AOI were calculated for the entire stimuli. However, even though it is possible to perform an evaluation of the fixation count and time to first fixation per task, this was not done because of the limitation in terms of time and the nature of the experiment design.

9 CONCLUSION

The aim of the thesis was to create a web map depicting the access to electricity utility infrastructure in the informal settlements of Kampala and to perform the user experience with the developed web map. To achieve this goal, the thesis was divided into three sub-goals as described below:

The **first sub-goal** was to develop the electricity utility infrastructure distribution web map for Kampala. To do this, it was necessary to establish the desired functionality of the web map. This was achieved by evaluating the existing web maps in the energy sector of Uganda, evaluating engineering drawings from umeme, and conducting interviews with selected engineers at umeme.

The web map was developed with MapBox GL JS, using electricity infrastructure data collected under the Spotlight Kampala project and available on OSM. The functioning web map with interactivity via pop-ups, hover effects, filters, and zooming, including the GUI windows and native functionality, was published for usability assessment.

The **second sub-goal** was to perform a usability assessment to determine any problems with using the developed web map. This was done using a mixed approach with both qualitative and quantitative analysis of subjective and objective feedback. Both the remote and in-person (eye-tracking) usability assessments identified the same challenges. However, the eye-tracking experiment provided further insights into why some participants were not able to change the basemap and why the population density legend was problematic to use.

From the usability assessment, possible improvements to the interface design, functionality, and representation of features were determined by evaluating the identified challenges and taking into consideration subjective feedback.

In conclusion, a functioning web map was developed using MapBox GL JS, and a usability assessment was performed using a combination of remote and eye-tracking (in-person) methods. The complementary nature of the selected usability assessment methods was observed, with both methods able to identify all the problems, but eye-tracking was able to give further insight into why some problems occurred.

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ATTACHMENTS

LIST OF ATTACHMENTS

The chapter is not numbered. Provide a complete numbered list of bound and free attachments.

Microsoft Teams attachments

Attachment 1	transcripts
Attachment 2	Code
Attachment 3	Results of the questionnaires

Free attachments

Attachment 3	Poster
Attachment 7	Web

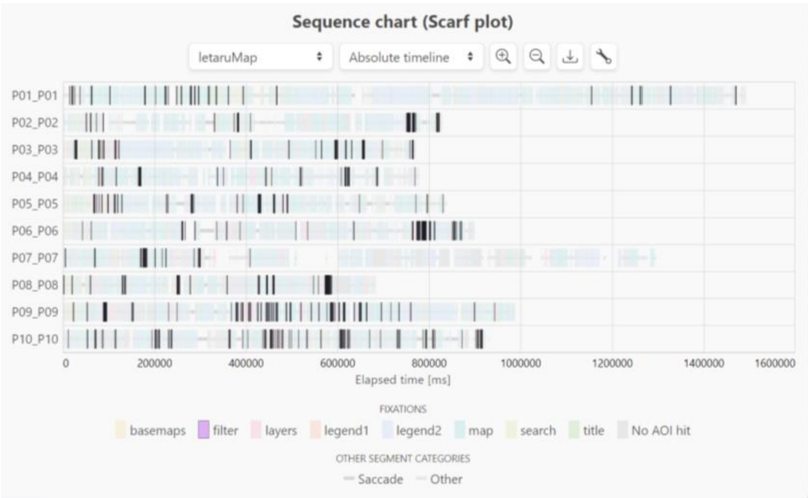
These attachments are stored in the data storage of the eye-tracking laboratory of Dept. of Geoinformatics

Eye-tracking project

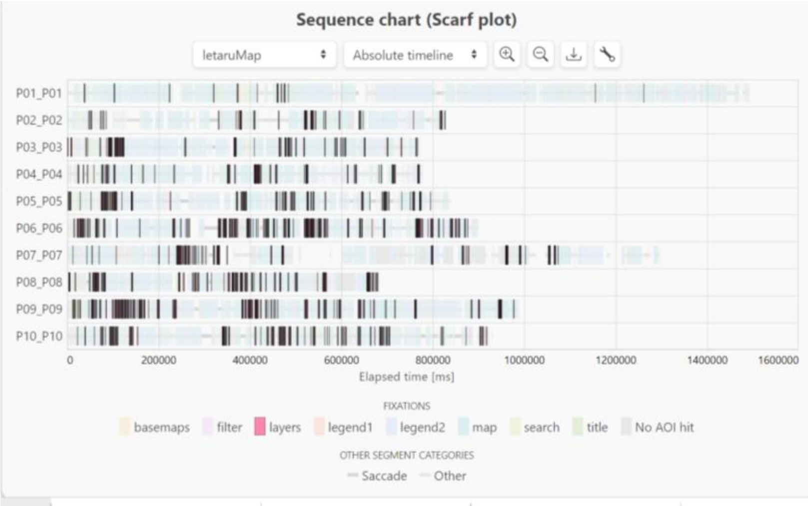
Videos of the remote testing

Negative subjective feedback from the questionnaires and occurrence rate

Negative
transformer ID and scale (3)
Settlement colour (2)
Search to include parish (1)
Spellings and labels (1)
energy consumed instead of population density (1)
text size and colour (1)
streets and roads (1)
size of points (1)
colour transformer (5)
colour utility pole (2)
settlement as points (1)
number of points per polygon (2)
pole ID larger (2)
population density colour (4)
population density, highest to lowest (1)
more data (1)
accurate boundaries (2)

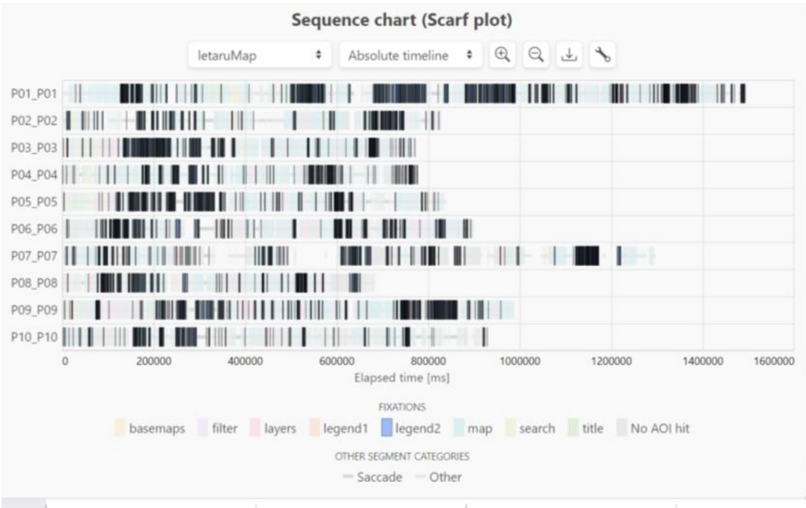


Fixations on the filter

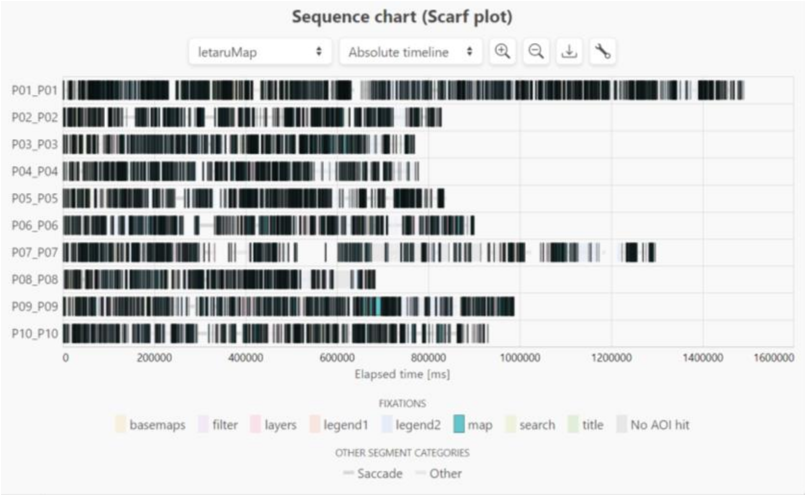


Fixations on the layer switcher

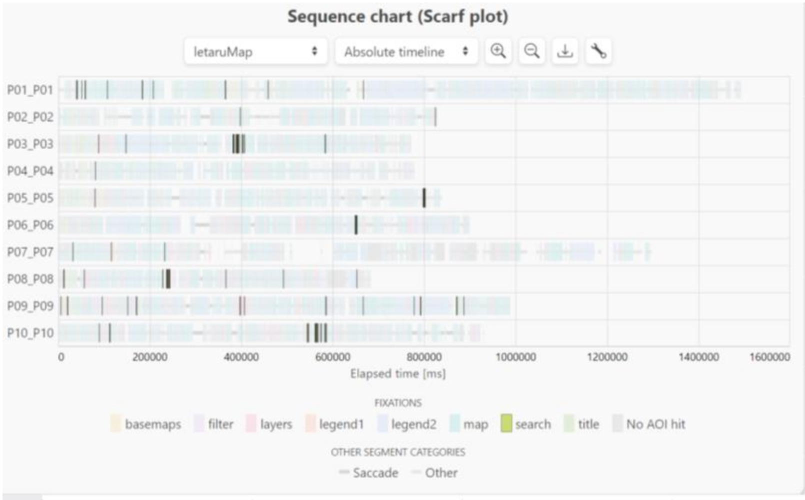
Fixations on the legend1



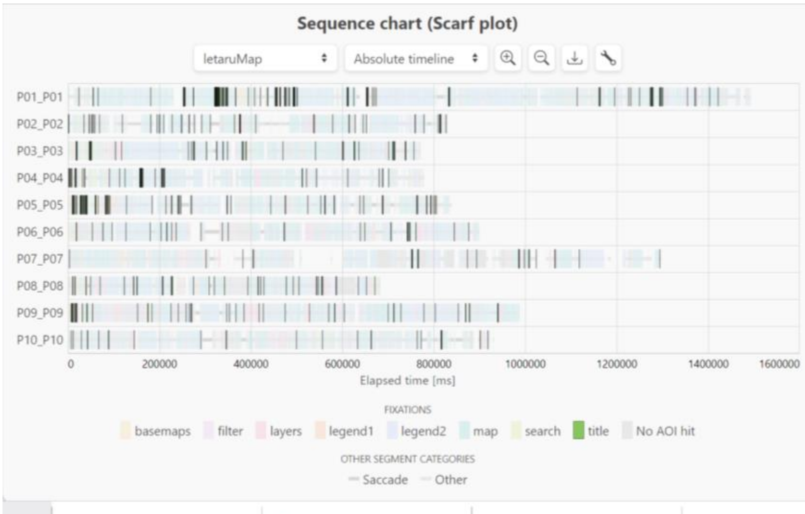
Fixations on legend2



Fixations on the map



Fixations on the search widget



Fixations on the title