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A SOOP Dashboard: Communicating Real-Time Ocean Data to Non-Expert Users

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Foreword

This thesis was written in collaboration with SOOP (Shaping an Ocean of Possibilities) under GEOMAR - Helmholtz Centre for Ocean Research Kiel. I would like to express my sincere gratitude to Dr. Esther Rickert, Myriam Dutzi, Marco Banzhaf, and Dr. Toste Tanhua from SOOP for their time, valuable input and support of this project.

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Abstract

This thesis explores how real-time ocean data can be communicated to non-expert users in marinas and coastal communities through a digital dashboard interface. The work is conducted in collaboration with SOOP (Shaping an Ocean of Possibilities), a European initiative focused on enhancing ocean observation and public access to environmental data. Despite the development of a network of low-cost sensors for the collection of coastal ocean data by SOOP, there is currently no public-facing platform to present this information in a usable format.

To address this gap, the project follows the Human-Centred Design framework, as outlined in ISO 9241-210, and is guided by two research questions: (1) identifying user requirements for a dashboard that communicates scientific ocean data to coastal communities and non-expert audiences, and (2) translating those requirements into a usable and accessible prototype. Methods included semi-structured interviews, thematic analysis, competitive review, low-fidelity prototyping, and usability testing.

The findings resulted in a dashboard prototype grounded in real user needs and informed by established design principles and dashboard patterns. The second iteration of the prototype addressed usability issues identified in the initial version and incorporated features such as tabbed navigation, contextual alerts, and interactive data previews. This thesis presents a practical design solution and illustrates how user-centred approaches can be applied to develop accessible interfaces for communicating ocean data to coastal communities.

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1 Introduction

It is estimated that the ocean covers approximately 70.8 percent of the Earth's surface (Pidwirny, 2006; UNEP, 2021). This vital ecosystem plays a crucial role in the regulation of global climate and temperature, in addition to the supply of livelihoods to millions of people, particularly those residing in coastal communities (Gattuso et al., 2015; United Nations, 2015). The ocean serves as the foundation of the Blue Economy, contributing with critical resources such as food, marine transport, telecommunications, oil and gas, low-carbon energy, and coastal tourism (Gattuso et al., 2015; OECD, 2016; UNEP, 2024; United Nations, 2015).

However, the triple planetary crisis of pollution, biodiversity loss and climate change, in addition to the pressures caused by intensive human activities and over-exploitation of resources, has a considerable effect on coastal areas and the marine environment (European Commission, 2021; UNEP, 2023). Despite the considerable advancement of ocean observation technologies in recent decades, the oceans continue to be widely undermonitored (IOC-UNESCO, 2024; Tanhua et al., 2023; UNESCO-IOC, 2023). This emphasises the urgent need to enhance public awareness of ocean science and its societal relevance, thus promoting greater support for ongoing monitoring initiatives to manage and protect marine ecosystems (IOC-UNESCO, 2024; Seys et al., 2022). Raising awareness of ocean science is not merely a communication goal of Marine Science Communication, defined by the European Marine Board as "any activity that translates and shares Ocean scientific knowledge with the wider public and with specific target audiences" (Seys et al., 2022, p.9). It is a recognised strategic priority, supported by initiatives such as the United Nations Ocean Decade and the European Union Mission: Restore our Ocean and Waters by 2030 (Seys et al., 2022).

Several initiatives in Europe communicate ocean science, such as the European Marine Observation and Data Network (EMODnet), Copernicus Marine Environment Monitoring Service (CMEMS), or JPI Oceans. The organisations aim to harmonise and share ocean data among range of stakeholders, including policymakers, researchers, and increasingly, the general public (CMEMS, n.d.; EMODnet, n.d.; JPI Oceans, n.d.; Reißmann, 2025). However, these platforms target predominantly expert audiences or citizens with some degree of scientific knowledge.

With the increasing availability of ocean data, there is a growing need for the ocean scientific knowledge and data to be openly communicated in ways that are understandable, easily accessible, and engaging with diverse range of stakeholders including the public (Reißmann, 2025; Trice et al., 2021). The innovation platform Shaping an Ocean Of Possibilities (SOOP) addresses the need for data and revolutionises the collection of ocean data by involving a diverse range of stakeholders that bridges science, industry, and society (SOOP, 2025a).

SOOP is a recently established initiative under the German research centre Geomar, that aims to support sustainable ocean observation and data delivery from non-scientific maritime infrastructure. It does this by developing user-friendly measurement systems and sensors that collect ocean and atmospheric parameters, which are key for climate action, marine resource management, and biodiversity protection. Due to the nature of the standardised sensors, the observations can be carried out by non-scientific actors, as the sensors produce high-quality and comparable data. Currently, SOOP is establishing partnerships with stakeholders across four focus areas: (1) sailing yachts and leisure boats, (2) empowering ocean observing in the global south, (3) cruise ships as ocean data collectors, and (4) marinas and coastal communities, the fourth one being SOOP's priority at the moment (SOOP, 2024b, 2025a).

The aim of the use case of marinas and coastal communities is to establish a comprehensive coastal monitoring network and collect insights into coastal ecosystems. The collection of real-time environmental and climate data facilitates a rapid response to changes or the implementation of preventive measures. SOOP's technologies can accommodate a variety of data requirements of marinas and coastal communities through optimised services for marinas as well as collaborations and partnerships. Furthermore, SOOP is keen to prioritise the development of information digital platforms to raise awareness and provide more information about coastal protection to coastal residents. The digital platform could inform the users about background information or to provide interactive maps and real-time data. However, due to the neweness of the SOOP platform, such digital platform is yet to be established. Consequently, there is no possibility to present the data collected by SOOP's sensors to the relevant stakeholders, including the coastal public (SOOP, 2024a).

1.1 Research Focus

The goal of this thesis is to support SOOP's ambition to communicate real-time marine environmental data to the public through a digital platform. The focus is on designing a dashboard prototype that is accessible and usable for non-expert users in coastal communities, such as sailors and marina users, enabling broader accessibility and engagement with ocean data. The design process is guided by the principles of Human-Centered Design framework, with methods applied iteratively to identify user needs, define requirements, and develop and evaluate design solution.

These considerations lead me to define the following problem statement:

> How can marine environmental data be effectively communicated through a digital platform to support public understanding and engagement with coastal data?

To explore this problem, the thesis is structured around two research questions:

1.1.1 Research Question 1

What are the user requirements for a dashboard that communicates scientific ocean data to coastal communities and non-expert audiences?

This question seeks to understand the needs, preferences, and contexts of use for potential users of the SOOP dashboard. It aims to identify the types of information users want, how they expect to access it, and under what conditions they engage with ocean data. Understanding these user requirements provides the foundation for user-centred design.

1.1.2 Research Question 2

How can user requirements be translated into a dashboard design that improves the accessibility and usability of real-time ocean data?

The second question focuses on how the insights from user research can be used to inform interface design in form of a dashboard. This includes exploring how structural layout, dashboard design patterns, and visual representation of data can be informed by user needs to support usability and engagement with ocean data.

To answer these questions, the thesis follows the four core activities of the Human-Centred Design process, as summarised in Figure 1 and detailed in Section 5, to ensure the solution meets user needs.

2 SOOP

SOOP is an innovation platform that bridges science, industry, and civil society in the efforts of promoting climate protection awareness through more ocean observation and technologies (Möller & Voynova, 2025; SOOP, 2025a; Tanhua et al., 2023). It is collaboratively operated by three leading German Helmholtz Centres, the GEOMAR Helmholtz Centre for Ocean Research Kiel, the Alfred Wegener Institute for Polar and Marine Research (AWI), and the Helmholtz Centre Hereon (SOOP, 2024b, 2025a; Tanhua et al., 2023).

By developing standardised, cost-effective and user-friendly measurement systems and a powerful data platform for the collection, provision, and use of ocean data (AWI, n.d.; GEOMAR, n.d.; SOOP, 2025a), SOOP aims “to reduce the cost of measurement technology and increase accessibility for all committed ocean enthusiasts and blue economy companies” (SOOP, 2025a). This simplification of ocean observation enables non-scientific participants, such as sailors, to carry out ocean observations on non-scientific vessels by deploying new modular instruments and sensors for collecting oceanographic and climate-relevant data (Möller, n.d.; SOOP, 2025a; Tanhua et al., 2023). The parameters measured by SOOP include both oceanic and atmospheric variables. In the water, key parameters are carbon dioxide, environmental DNA (eDNA), microplastics, oxygen, zooplankton, salinity, and temperature, while atmospheric measurements cover aerosols, carbon dioxide, carbon monoxide, sulfur dioxide, methane, and nitrogen dioxide (SOOP, 2025b).

The data collaboratively collected on different types of platforms and by various stakeholders are available on the O2A Data Flow Framework portal (Koppe et al., 2015; Reißmann, 2025). Here, the metadata from items such as vessels, sensor packages or sensors and the parameters they collect are registered. A time series database serves as the central hub where raw data is stored with metadata, allowing visualisation systems to retrieve information in formats like GeoJSON or CSV (Lorenz et al., 2024; Reißmann, 2025).

The published data consistently meet standardised quality requirements, as sensor performance can vary, ensuring transparency and usability for further analysis (Reißmann, 2025). This includes ocean modelling simulations for assessing ocean health, developing early warning systems as well as utilisation in weather and climate forecasting, disaster risk reduction, and ocean productivity assessments (GEOMAR, 2023; Möller, n.d.; Möller & Voynova, 2025; Tanhua et al., 2023). BELUGA Navigator[1] is a visualisation system used to display real-time data from SOOP for outreach campaigns, for example during Boris Herrmann's participation in The Ocean Race, by integrating data with storytelling elements. However, the system requires certain level of domain knowledge and is not tailored to non-expert users (Leibold, Diller, Reißmann, & Faber, 2023).

This thesis focuses specifically on the use case of marinas and coastal communities. The goal of this use case is to make real-time ocean data accessible to local stakeholders, such as sailors, marina users and coastal communities in the immediate vitnicity of the marinas, to support environmental awareness, local decision-making, and safety. While SOOP has developed the sensor infrastructure for collecting data, no user-facing platform currently exists to present this data in an accessible way. Recently, SOOP partnered with the TransEurope Marinas network to expand its sensor coverage across member countries, including France, Italy, Croatia, Portugal, the United Kingdom, Germany, and Denmark. The growing network highlights the need for a unified platform to communicate the collected data to end users. This thesis addresses that need by designing a dashboard prototype tailored to non-expert users in those coastal areas (SOOP, 2024a, 2025a).

3 Literature Review

The following section outlines the approach used to search for and review relevant literature for this thesis. It discusses strategies for effective science communication aimed at public audiences, followed by dashboard as a form of visual communication, including data visualisation and data storytelling in dashboards. Additionally, information behaviour was explored with focus on users,

[1] BELUGA Navigator: https://beluga.geomar.de/

their goals, context, and search modes to understand how users get affected in information exploration and understanding of contexts.

The following section outlines the approach used to search for and review relevant literature for this thesis. It presents key studies on information behaviour and the four dimensions of the search experience, followed by an overview of data visualisation approaches, including data storytelling and a specific focus on dashboards as a form of visual communication. Finally, it discusses strategies for effective science communication aimed at public audiences.

3.1 Literature Search Process

In order to obtain an overview of the key existing literature, theories and current knowledge regarding information behaviour, data visualisation, and science communication approaches, I conducted a narrative literature review (Bryman et al., 2021h; Cronin et al., 2008). A comprehensive search was ensured by employing a variety of search methods and databases throughout the literature exploration.

Due to the large number of electronic databases available, it is imperative to identify those that are relevant to the research topic (Cronin et al., 2008). In my particular instance, the search was executed using a number of databases, including ACM Digital Library, IEEE Xplore, Google Scholar, Primo and ScienceDirect. The ACM Digital Library is an online repository of academic publications specialising in the field of computer science. Similarly, IEEE Xplore and ScienceDirect offer extensive access to scientific and technical research, while Google Scholar and Primo are broad databases covering a wide range of multidisciplinary content. Combining multiple databases allowed me to identify articles from additional disciplines not necessarily related to information technology, as I also aim to gain understanding of science communication with focus on marine environment.

To collect literature relevant to my thesis, the problem statement and research questions were deconstructed in order to identify concepts and key words that could be used for the search. I formed combinations of various keywords, with consideration given to both American and British spelling. These were then connected by Boolean operators, including `AND`, `OR` and `NOT`, to form search strings (Bryman et al., 2021h; Cronin et al., 2008). For example, while searching for information on dashboards that visualise real-time data to non-expert audiences, I started with the following query `("dashboard" AND "real-time data" AND ("non-expert" OR "public" OR "novice")`. Following the initial search, I added `AND NOT ("car" OR "health")` to achieve more refined results, as many of them focused on car or health dashboards. My approach to the search had an iterative nature, as I refined the search strings after reviewing the initial results to gather more relevant sources.

Another search strategy that has been employed in the literature search is citation pearl growing, whereby one can identify other suitable terms in already found documents to retrieve new documents (Rowley & Slack, 2004; Schlosser et al., 2006). Once having relevant articles in place, by reviewing their citations to find other relevant articles I went backward, but also searched for articles that had cited it, going forward (Webster & Watson, 2002). When evaluating the found literature, except for topic relevance, I also considered other aspects such as the site type, and prioritised sources that are peer reviewed (Bryman et al., 2021h).

3.2 Science Communication

Effective science communication involves translating scientific knowledge into accessible terms and establishing trusted two-way communication channels (Fischhoff, 2019). It requires both subject matter experts who know the subject communicated as well as social, behavioural and communication scientists who should collaborate in order to communicate the knowledge, facts, and information while ensuring the attractiveness of the message (Fischhoff, 2019; Seys et al., 2022). It is generally accepted, that non-expert audiences acquire the majority of their scientific information through mass media (Dahlstrom, 2014). However, other proven accessible means of communication should also be considered, such as quality visuals, storytelling, infographics and other tools (Seys et al., 2022). Despite the prevalence of negative connotations surrounding narrative formats such as storytelling within the scientific community due to its persuasive nature, Dahlstrom (2014) proposes a contrary view, advocating for their continued consideration. This perspective is further endorsed by the marine science community, acknowledging storytelling as a valuable tool in scientific communication (Seys et al., 2022). To ensure ethical science communication, the narrative should focus on minimising harm to consumers, avoiding manipulation, respecting privacy, and ensuring informed consent (Dahlstrom & Ho, 2012; Volk & Schäfer, 2024).

Despite the considerable impact of the ocean on both the climate and the population, due to its remoteness, the marine environment remains invisible and overlooked by humans. Seys et al. (2022) argue that raising awareness of ocean science can inspire responsible behaviour within society and promote a more profound understanding of its importance. That is also the purpose of marine science communication, defined by the European Marine Board as "any activity that translates and shares ocean scientific knowledge with the wider public and with specific target audiences" (Seys et al., 2022, p.9). Marine science communication is part of the wider field of science communication, which refers to the use of skills, media, activities, and dialogue aiming to raise public awareness and interest, as well as to increase understanding and engagement with scientific topics and issues, particularly between scientists, mediators, and non-expert audiences (Burns et al., 2003; Seys et al., 2022).

The primary challenge that marine science communicators face is to make the invisible the marine environment visible and to communicate the outcomes, findings and opportunities of ocean research to the society (Seys et al., 2022). To achieve this objective, European Marine Board has issued a list of recommendations that could support the development of a more ocean-literate and sustainable society through ocean science communication (Seys et al., 2022). Among others, the most relevant to this thesis is the call for development of communication platform or database to share expertise and resources, while communicating "under the umbrella of the Ocean Decade and of the EU Mission: Restore our Ocean and waters by 2030" (Seys et al., 2022, p.7). Moreover, Ocean Decade (2024) articulated ocean-related priorities into ten challenges. This thesis aim to contribute to five of these challenges. Through the design of ocean digital representation (Challenge 8), it can support community resilience to ocean and coastal risks (Challenge 6) by informing coastal communities of real-time data through sustainable expansion of ocean observing systems (Challenge 7). This, in turn, increases knowledge by providing access to data and information (Challenge 9) and ultimately restoring humanity's relationship with the ocean (Challenge 10) (Ocean Decade, 2024).

3.3 Dashboard Design

Dashboards, which originate in vehicle dashboards, have become a widely adopted format for communication and data visualisation of complex datasets in a condensed, recently also interactive, and often real-time format (Kitchin et al., 2015; Sarikaya et al., 2019). As more and more real-time data is collected, the prevalence of publicly accessible interactive visualisations through dashboards is rising, as is the interest and involvement of citizens (Kitchin et al., 2015).

According to Few (2006), "a dashboard is a visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance"(p.26). Meanwhile Pettit and Leao (2017) define dashboard from a graphic user interface perspective "which comprise a combination of information and geographical visualization [sic] methods for creating metrics, benchmarks, and indicators to assist in monitoring and decision-making" (p.255), underscoring the relevance of dashboards in communicating geospatial data through public-facing marine data platforms.

Dashboards are developed and used in a wide range of application domains, from commercial enterprises to public service and non-profit organisations, to support data-driven decision-making (Bach et al., 2022; Sarikaya et al., 2019). The most common components of the dashboard interface are charts, graphs, diagrams, and maps (Kitchin et al., 2015; Nasir et al., 2024). Despite their ubiquity and potential impact, dashboards remain relatively under-explored in research, being subject to ongoing discussions about key principles and rather variable design guidelines (Bach et al., 2022; Matheus, Janssen, & Maheshwari, 2020; Nasir et al., 2024; Qu & Hullman, 2018; Sarikaya et al., 2019).

In order to communicate effectively with target audiences through dashboards, it is necessary to consider the varying levels of data literacy and domain expertise among users and avoid information overload (Bach et al., 2022). Sarikaya et al. (2019) highlight the importance of tailoring dashboards to specific purposes, audiences, and data semantics, moving beyond generic, one-size-fits-all tools that cannot cater to the diverse user needs and goals. In addition, Sarikaya et al. (2019) present three levels of visualisation literacy (low, medium or high) that is required when considering the use of visualisation techniques of different complexities to the target audiences. Typically, novice and casual users possess low visualisation literacy, while experts or frequent users are expected to have a high data and visualisation literacy (Bach et al., 2022; Sarikaya et al., 2019).

Novice or casual users benefit from more guidance and less information, which can include clear layouts, minimal interaction, and single-value or aggregated data (Bach et al., 2022), visualised in basic chart types such as bar and line charts (Sarikaya et al., 2019). Adding a temporal context of data from the past or comparison can also improve the comprehensibility of the dashboard (Bach et al., 2022). Clear presentation of information through a simple, yet more message-heavy dashboard makes it easily accessible and understandable, even for public without specialised knowledge (Bach et al., 2022; Matheus et al., 2020). On the other hand, expert or frequent users need more data and bespoke features, which could include scatterplots, heatmaps, treemaps, network visualisations and other custom visualisations, forming more "self-serving" dashboards (Bach et al., 2022; Sarikaya et al., 2019).

In the context of ocean data for the general public and coastal communities, dashboards can play a crucial role in communicating real-time sensor data to raise awareness and promote informed decision-making (Sarikaya et al., 2019). By visualising key parameters related to geospatial data measured in water and atmosphere, dashboards can stimulate citizen engagement in environmental issues, supporting transparency and accountability (Matheus et al., 2020; Sarikaya et al., 2019). The engagement may be further enhanced by modification of the dashboard features by the users to adapt to their requirements through customisation, personalisation or adaptation (Vázquez-Ingelmo et al., 2019).

3.3.1 Data Visualisation in Dashboards Data visualisation is a multidisciplinary field closely related to information visualisation that transforms complex data into visual formats that are easier to interpret and engage with, while encouraging art-science collaborations (Almeida, 2023; A. Duarte et al., 2023; Wells, 2022; Wilke, 2019; Zdanovic et al., 2022). This is particularly relevant in the context of multifaceted environmental data, where visualisations through maps, graphs, diagrams, or interactive dashboards can play a critical role in science communication, decision-making and enable non-expert audiences to understand and engage with scientific data (Almeida, 2023; Aparicio & Costa, 2015; A. Duarte et al., 2023; Kehrer & Hauser, 2013; Kendall-Bar et al., 2024).

Data visualisation is a flexible tool that can be utilised to achieve different goals across various applications, from practical pragmatic goals to more complex reflective goals (Almeida, 2023; Ynnerman et al., 2018). As described by Knaflic

(2015), goals can be separated into two types of visualisations, exploratory and explanatory. Exploratory visualisations are designed to facilitate data-driven discovery by enabling users to interact with complex and multifaceted data to uncover patterns or insights, often for internal or analytical use. In contrast, explanatory visualisations synthesise the explored data into specific information with the aim to communicate the key findings to a general audience, adapting the visualisation language to their understanding (Almeida, 2023; Knaflic, 2015; Ynnerman et al., 2018).

Both categories are not rigid and can be combined, such as dashborads as a good example of exploratory visualisation can be reframed and adapted to communicate to non-expert audience (Almeida, 2023). In science communication, the convergence of exploratory and explanatory visualisation represents a significant paradigm shift (Ynnerman et al., 2018). Ynnerman et al. (2018) combine exploration and explanation to coin the term "exploranation". Exploranation uses the same data and methods for both experts and the public, leveraging "advanced visualization [sic] methodologies to communicate results effectively, enriching the exploration process and accommodating diverse levels of prior knowledge" (Ynnerman et al., 2018, p.13).

By basing science communication directly on real, large-scale scientific data, exploranation ensures that the general public interacts with the same information as researchers through simplified interfaces with limited interaction (Ynnerman et al., 2018). This approach can be well applied into communication of marine science, where there is often a disconnect between scientific knowledge and public understanding (Wells, 2022). Together, the findings suggest that dashboards should be designed not only to present data, but also to foster public interpretation and engagement—blending exploration and explanation through adaptive, iterative visual strategies. The findings of Ynnerman et al. (2018) and Wells (2022) indicate that dashboards should be designed with a view to not only presenting data, but also fostering public interpretation and engagement.

3.3.2 Data Storytelling With an increasing amount of complex data, other approaches complementing traditional data visualisation techniques are needed, such as data storytelling. This approach as an emerging visualisation paradigm enables the aggregation of data by using numbers to tell a story (Zdanovic et al., 2022). Communicating science through scientific storytelling can be used to share knowledge, engage and motivate audiences or influence attitudes or behaviours towards science (Dahlstrom & Scheufele, 2018). Savoie (2020) adds that "without story, science can fail to connect in a meaningful way. It is the narrative that provides science with its power" (p.1).

Yet, the majority of visualisation tools available focus on exploratory and analytical visualisations, thereby leaving the task of uncovering the story to the users themselves (Segel & Heer, 2010; Zdanovic et al., 2022). In the systematic review of 58 narrative visualisation designs, Segel and Heer (2010) divide features into three types of visualisation: (1) genre, (2) visual narrative tactics, and (3) narrative structure tactics. Furthermore, the paper discusses author-driven and reader-driven approaches to visualisation, proposing three types of storytelling approaches: (1)the martini glass structure prioritising the author-driven approach, (2) the drill-down story prioritising the reader-driven and (3) the interactive slideshow combining both approaches (Boy, Detienne, & Fekete, 2015; Segel & Heer, 2010; Zdanovic et al., 2022). These two approaches can be applied in the context of dashboards, in which author-driven storytelling is typical for curated dashboards, while reader-driven storytelling for data collection dashboards, further explored in detail in Section 8.1 (Bach et al., 2022).

To understand how narrative structures work, it is important to distinguish between "story" and "narrative". While the terms are frequently used interchangeably, *story* refers to all events in a narrative communicated directly to the audience, whereas *narrative* is the process of telling and shaping those events (Bach et al., 2018; Branston & Stafford, 2010a, 2010b). A story consists of an individual or combination of several narrative patterns (Bach et al., 2018). Bach et al. (2018) suggest five narrative patterns that serve as a basis for data-driven storytelling designs relying on data visualisation. The framework distributes patterns for data-driven stories presented in interactive environments into five major pattern groups: argumentation (1), flow (2), framing the narrative (3), empathy and emotion (4), and engagement (5). Across the major five pattern groups, 18 core patterns are distributed, such as comparison, gradual reveal, or make-a-guess. Each of these serves different communicative goals (Bach et al., 2018).

Building on these ideas, Zdanovic et al. (2022) propose a complementary framework of data storytelling principles that are grouped into three overarching levels: (1) the *phases* are indicative of the thematic focus, (2) *principles* encompass the individual steps that must be followed to reach the final visualisation, and finally (3) *concrete actions* provide further elaboration on these principles when applicable. Zdanovic et al. (2022) applied this framework to investigate the hypothesis that data storytelling visualisation can enhance the ability to recall information as opposed to the traditional data visualisations. Although the result does not show a significant difference in the visualisation approach and the recall, there is an indication that adding narrative elements increases the cognitive load and makes them more difficult to decode (Heer & Bostock, 2010; Zdanovic et al., 2022). This is supported by the study by Nyhan and Reifler (2019), indicating that data presented in graphs is more easily comprehensible and more effective at correcting misperceptions than tabular or textual formats (Ingraham, 2018).

In contrast to findings by Zdanovic et al. (2022) and Nyhan and Reifler (2019), Dahlstrom (2014), Dahlstrom (2021) and Savoie (2020) believe that narratives and storytelling are an integral part of science communication, if incorporated carefully to avoid scientific misinformation. In the context of dashboards that communicate environmental marine data, the adoption of narrative design patterns in a proportionate manner can ensure that data is not only accessible but also meaningful and actionable, thereby bridging the gap between scientific knowledge and public understanding.

3.4 Information Behaviour

Understanding how users seek and interact with information is the foundation for the effective design of communication tools for scientific data. Over time, many theories and models emerged in the research field of information behaviour (Wilson, 1999). In the context of this thesis, I explore the dimensions of information seeking behaviour and information search behaviour including the context and search modes as subsets of information behaviour (Russell-Rose & Tate, 2013d; Wilson, 1999). Wilson (1999) defines information behaviour as "activities a person may engage in when identifying his or her own needs for information, searching for such information in any way, and using or transferring that information" (p.249). It is particularly relevant to dashboard design as non-expert users can have information needs to find and understand context-specific data with varying levels of context knowledge and interpretation ability (Matheus et al., 2020).

Differences in user opinions are deeply rooted in the underlying assumptions corresponding to dimensions that help us understand information seeking behaviour. In the conceptual framework for search and discovery, Russell-Rose and Tate (2013d) defined the four dimensions of search experience as the users, their goals, the context, and search modes. In order to gain understanding of the user, it is necessary to investigate the human characteristics such as (1) the type of user and their level of knowledge and expertise (Section 3.4.1) as well as (2) their goals. Users can be influenced by different types of wider (3) contexts (Section 3.4.2, such as physical context of using mobile device while travelling, as well as intangible social context that can affect the user while at home. The final fourth dimension is the users' (4) search mode (Section 3.4.3, which is defined by understanding the overall task and completing the user goals through a set of activities (Russell-Rose & Tate, 2013d). In the framework, Russell-Rose and Tate (2013d) utilise insights from cognitive psychology to comprehend how users approach the complex task of search and how to apply the findings for designing more user-friendly and efficient search interfaces.

3.4.1 The Users Expertise can be divided into two categories, domain and technical expertise, and presence of both is the most valuable for the users. It influences the way people seek information and draws the line between expert and non-expert users (Russell-Rose & Tate, 2013b). According to Jenkins et al. (2003), there are four types of users: double experts, domain expert/technical novices, domain novice/technical experts, and double novices.

Double novices, lacking proficiency in both areas, tend to struggle with information seeking. They tend to frequently reformulate their queries while looking at fewer pages, retreat to the search page, and spend more time on task than experts. Providing a list of related searches or breadcrumbs in the design can aid their search process and navigation. Conversely, double experts take the depth-first approach leading them directly to their destination. They employ advanced syntax and filters to quickly locate relevant content. The hybrid users, possessing expertise in either the domain or technical dimension but not both, exhibit a mix of characteristics. Domain expert/technical novices enter effective queries, evaluate pages timely and effectively but lack the technical expertise for in-depth exploration. On the other hand, domain novice/technical experts confidentially use advanced query formatting techniques but struggle to evaluate relevant content (Hölscher & Strube, 2000; Russell-Rose & Tate, 2013b).

Dual coding theory suggests that information is best learnt when presented in both verbal and visual modalities, as in the brain they are stored in different formats (Mayer & Sims, 1994; Paivio, 1979). In alignment with this theory, the framework for designing with visual overviews and previews combine both sensory modalities to improve the learning process, where “overviews and previews are graphic or textual representations of information abstracted from primary information objects” (Greene et al., 2000, p.380). For instance, effective immersive data visualisations created by distilling complex raw data into visual overviews such as composite maps, transform the information into easily digestible form, for example through a dashboard. Incorporating preview functionality can enable users to inspect the results in more detail (Greene et al., 2000; Riding & Sadler-Smith, 1992; Russell-Rose & Tate, 2013b). The combination of the domain and technical expertise together with the verbal–visual modalities underscores the diversity of target audience to be considered when identifying users, gaining understanding of them and designing with their needs in mind (Russell-Rose & Tate, 2013b).

3.4.2 The Role of Context Context is a crucial element in designing effective information systems, especially when visualising environmental data for public use. It shapes the search experience and facilitates a shared understanding between the user and the system (Russell-Rose & Tate, 2013a). Schilit et al. (1994) define context as “where you are, who you are with, and what resources are nearby” (p. 85). The definition of context can be challenging and it varies, however, there is a consensus “that context is a user-oriented phenomenon that is focused more on users’ immediate surroundings than on their inner state” (Russell-Rose & Tate, 2013a, p.48). Myrhaug and Göker (2003) describe five key components of context as (1) users’ tasks, (2) spatiotemporal attributes such as time or location, (3) personal characteristics, (4) social environment, and (5) environmental factors including temperature, light or accessed information resources. Due to the ambiguity in search queries, such as differentiating between ”Java” as a programming language, an island, or coffee, demonstrates why understanding the user’s current context and surroundings from the foundation of search experience when creating interfaces (Russell-Rose & Tate, 2013a).

3.4.3 Modes of Search and Discovery It is important to note that search behaviour does not necessarily have to be informational. Challenging traditional information seeking theories, Russell-Rose and Tate (2013c) present a model consisting of nine search modes that are utilised to achieve the user's information objectives. It encompasses a more diverse set of behaviours related to information interaction and use, and extends the scope of information seeking to broader concepts of discovery-oriented problem solving applicable to any user or context.

The first is (1) locate mode, in which the user finds a specific and potentially also already known item. The user then (2) verifies that an item meets objective criteria, such as confirming accuracy. (3) Monitor describes keeping track of the status of the item for management purposes. (4) Compare allows the user to identify similarities and differences between multiple items, while (5) comprehend refers to interpreting patterns in data to gain independent insights and build understanding. (6) Evaluate involves the user making subjective judgments about the value of an item in relation to a specific goal. In (7) explore mode, the user engages in open-ended and often opportunistic browsing to discover new knowledge. (8) Analyse focuses on exploring data for patterns and relationships. Finally, in (9) synthesise mode, the user combines various inputs to create a new or composite output (Russell-Rose et al., 2014; Russell-Rose & Tate, 2013c). The modes reflect Marchionini's taxonomy of search activities, which comprises three top-level categories. (1) Lookup modes include locate, verify, and monitor, (2) learn modes with compare, comprehend, and evaluate, and finally (3) investigate modes explore, analyse, synthesise (Marchionini, 2006; Russell-Rose et al., 2014; Russell-Rose & Tate, 2013c).

The search modes form patterns, typically consisting of chains with two to three sequential modes. In addition to mode chains for enterprise described by Russell-Rose, Lamantia, and Burrell (2011) and Russell-Rose and Tate (2013c), which are not relevant to this thesis, Russell-Rose et al. (2014) added patterns used for site search. The most common sequences characterising site search are insight-driven search (explore, analyse, comprehend), representing "an exploratory search for insight or knowledge to resolve an explicit information need" (Russell-Rose et al., 2014, p.8), opportunistic search (explore, locate, evaluate) being less exploratory and potential discovery by coincidence, and qualified search (locate, verify) a goal-directed search with required instant validation (Russell-Rose et al., 2014). Russell-Rose et al. (2011) mention combining monitoring and synthesis mode as a whole screen pattern, which is particularly relevant for dashboard design when "presenting a collection of metrics which in aggregate provide the status of independent processes, groups, or progress versus goal" (p.3).

Understanding the different information-seeking behaviours users exhibit when engaging with environmental data can inform the design of dashboard features that effectively support their goals. These behaviours have direct implications for the design of dashboards, which features and functionalities should be available at particular system locations, how they should be designed for user interaction, and what design cues can guide users toward the most relevant data views or actions (Russell-Rose et al., 2014; Russell-Rose & Tate, 2013c).

4 Framework

In selecting a design research framework to guide the research of this thesis, three widely recognised user-oriented design paradigms were considered: Participatory Design, Design Thinking, and Human-Centred Design. While all three frameworks adopt an iterative, user-centred orientation, they differ in stakeholder participation, epistemological assumptions, and intended practical applications (Bryman et al., 2021g; E. Sanders & Stappers, 2008; L. Sanders, 2008).

Participatory Design, stemming from the research-led Scandinavian tradition, is also referred to as co-design. It is a collaborative approach to design that actively engages end users throughout the entire design process and decision making, ensuring that the final product reflects their real-world needs and expectations (Interaction Design Foundation - IxDF, 2023; E. Sanders & Stappers, 2008; L. Sanders, 2008). The framework is rooted in interpretivist and critical-ideological paradigms, where reality is constructed through social interactions. It emphasises the importance of interaction between researchers and users in fostering an understanding of the users' experiences. The concept of understanding is based on Max Weber's idea of *Verstehen* as a perspective within interpretivism (Bryman et al., 2021g; E. F. Duarte & Baranauskas, 2016; Goldkuhl, 2012).

Design Thinking is a framework originating from system thinking and business strategy, often applied to solve complex wicked problems or ill-defined challenges and generate innovative solutions. It is a non-linear iterative process that follows five core stages: empathise, define, ideate, prototype, and test (Interaction Design Foundation - IxDF, 2016). Resonating with pragmatist philosophy, John Dewey sees design as a form of inquiry that transforms uncertain situations through iterative experimentation. Pragmatist concepts not only enrich the theoretical discourse on design but also offer practical guidance by helping designers understand and orchestrate the design process in concrete projects (Dalsgaard, 2014; Goldkuhl, 2012).

Human-Centred Design (HCD) is a structured iterative design approach that focuses on understanding the needs, behaviours, and experiences of users, with the goal of producing solutions that are beneficial to users and tailored to their unique challenges and desires (Interaction Design Foundation - IxDF, 2021). While HCD also reflects pragmatic patterns, the dominant paradigm is postpositivism. Although the researcher and the user are not completely independent of each other, the aim is to be as objective as possible through systematic inquiry and validation. Rather than acting as co-creators in the design process, as in the case of interpretivism, users primarily act as sources of information for design decisions (E. F. Duarte & Baranauskas, 2016; Pickard, 2018).

As outlined in the preceding paragraphs, the key distinctions in the three frameworks lay in their scope, philosophical orientation, and degree of user involvement. Participatory design requires a much deeper level of user involvement and collaboration throughout the design process and decision-making than was feasible for this project. Design Thinking is best suited to the early stages of ideation, offering a broad approach to solving large-scale problems and generating innovative solutions. In contrast, the objective of this thesis is not to explore broad systemic change, but to develop a focused, usable digital tool tailored to support non-expert users in accessing and understanding real-time coastal environmental data. The HCD was selected as the framework for this thesis because it offers a structured process that enables designers to implement user's perspective throughout the design process without requiring full co-design, while catering to its narrower scope. The aim is to create an interactive system that is both useful and usable and based on validated user needs (Interaction Design Foundation - IxDF, 2016, 2021, 2023; ISO, 2010).

4.1 Human-Centred Design

ISO (2010) defines HCD as an "approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" (p.2). Usability, described by ISO (2010) as an "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (p. 3), is critical to make the interactive system successful (Maguire, 2001). Benefits of making system usable, among others, are increased productivity, reduced user errors, training time and human support, improved user acceptance or enhanced company reputation (Maguire, 2001).

In order to create dashboard as a usable system that enables the users to find and interact with marine and coastal data, it is fundamental to meet technical, functional and user requirements (Maguire, 2001). Additionally, adopting HCD approach to dashboard design and development can provide significant economic, social, and functional benefits. It also improves quality of the system and user experience, enhance accessibility and contribute to sustainability objectives (ISO, 2010). Consequently, employing a HCD framework allows for incorporation of the user's perspective into the process to ensure the dashboard is tailored to real user needs and supports meaningful interaction with environmental data (Maguire, 2001).

A framework of HCD, as set out in the international standard for ergonomics of human–system interaction 9241-210:2010, part *human-centred design for interactive systems* indicates that the HCD shall adopt a set of principles, based on which "(1) the design is based upon an explicit understanding of users, tasks and environments, (2) users are involved throughout design and development, (3) the design is driven and refined by user-centred evaluation, (4) the process is iterative, (5) the design addresses the whole user experience and (6) the design team includes multidisciplinary skills and perspectives" (ISO, 2010, pp. 5-8).

HCD consists of five phases, commencing with the planning phase of the HCD process in which a project plan is defined and shall be revisited throughout the project. Once the initial plan is set, four interdependent HCD activities follow: "(1) understanding and specifying the context of use, (2) specifying the user requirements, (3) producing design solutions, and (4) evaluating the design" (ISO, 2010, pp. 10-19). Iteratively following these activities results into a designed solution that meets user requirements (ISO, 2010).

5 Method

As indicated in Section 4.1, this thesis follows the HCD framework as defined by ISO (2010). After an initial planning phase, the project proceeded through the four core HCD activities, using methods that support each activity (Maguire, 2001). Understanding and specifying the context of use is described in Section 6, specifying user requirements in Section 5.3.1, producing design solutions 5.4, and evaluating the design in Section 5.5. These phases were applied iteratively, allowing the process to evolve as new insights are gained. Figure 1 outlines the methods applied within each phase of the HCD process. The following subsections describe the general methodological approach applied within each HCD activity, while the specific results of each phase and their iteration are presented in Sections 6 to 11.

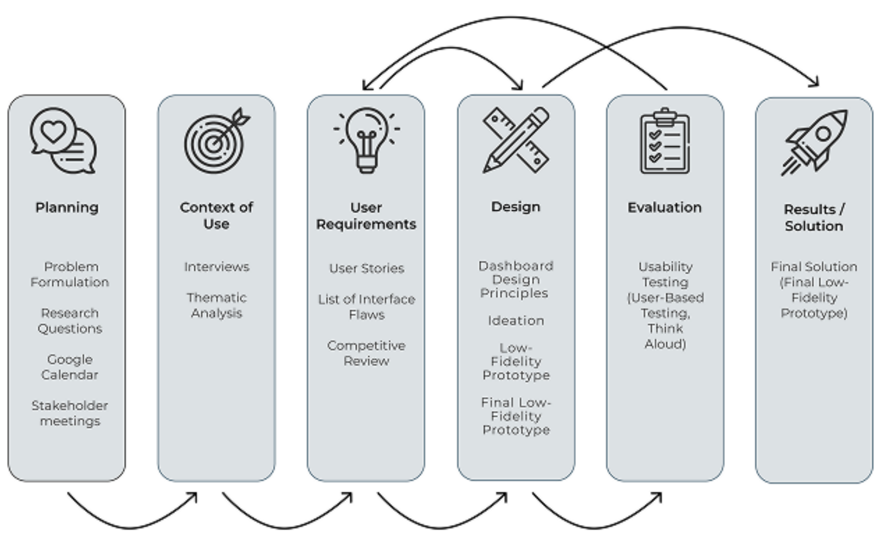

Fig. 1. Overview of methods used in each phase of HCD phases, including arrows visualising iterations, adapted from ISO (2010).

5.1 Planning

It is essential to plan and integrate the HCD process across all phases of the product lifecycle in order to ensure the success of the final system (ISO, 2010). In this thesis, the planning phase involved the formulation of the problem statement, defining and refining the research questions, and alignment of the project scope with the strategic goals of SOOP and GEOMAR.

The preliminary meeting was held with Dr. Toste Tanhua, a chemical oceanographer at GEOMAR and the coordinator of the SOOP. Subsequent series of scoping and alignment meetings were held with key stakeholders from GEOMAR, including Dr. Esther Rickert, a specialist in Transfer and Innovation Management, and Myriam Dutzi, a specialist in Innovation Management and Communication. Furthermore, meetings were also conducted with the data scientist Sylvia Reißmann, and the student worker specialising in data science, Marco Banzhaf. As part of the planning phase, I joined the GEOMAR headquarters in Kiel, Germany for a 2-day visit, which gave me the opportunity to meet Esther and Marco in person and further clarify and refine the scope of the dashboard design solution.

To plan and coordinate activities necessary for this thesis throughout the HCD process, a personal calendar was developed in Google Sheets to track progress and manage tasks. This was complemented by Google Calendar, which was used to maintain the thesis writing timeline.

5.2 Context of Use

The goal of the first HCD phase is to understand who the users are, what their goals and behaviours involve, and under what conditions the dashboard will be used. To specify the context of use, the requirements were gathered through semi-structured interviews (Section 5.2.2), and thematic analysis of the interview data followed (Section 5.2.3).

5.2.1 Requirement Gathering Requirements can be gathered using a variety of qualitative and quantitative research methods, such as surveys, focus groups, interviews, or usability tests (further described in Section 5.5) (Bryman et al., 2021d; Goodman & Kuniavsky, 2012a). Interviews can provide valuable insight into the stakeholders' routines, the anticipated interaction with the system, and gain understanding of any challenges or difficulties with the existing systems (Sommerville, 2010). Focus groups are designed to facilitate participant interaction and group dynamics and generate multiple levels of data. However, they are also prone to being negatively affected by problematic reticent or dominant speakers, and participants can be potentially influenced by the opinions of other group members (Bryman et al., 2021e). Survey methods, including structured interviews or questionnaires, offer a structured approach to qualitative research with rigid rules, gathering data through precisely set closed-ended questions and an identical structure for effective aggregation for analysis, limiting the option for open-ended questions (Bryman et al., 2021a, 2021i). Unlike focus groups or surveys, qualitative individual interviews allow the researcher to employ open-ended questions, to gain an understanding of how the interviewees think and feel about the investigated issues, or what they see as important and relevant (Bryman et al., 2021c).

5.2.2 Interviews Interviewing is the most widely used method in qualitative research, with the two main forms being unstructured and semi-structured interviews (Bryman et al., 2021c). Due to the nature of this thesis with a clearly defined research focus, conducting semi-structured interviews is opted for as the preferred method to understand the context of use in Section 6. In semi-structured interviews, the interviewer follows an interview guide with predefined topic areas and questions to ensure comparability in the analysis. Nevertheless, the interviewer should be able to rearrange the order of the questions throughout the interview, adapting to the flow of the conversation and responses of the interviewees. To ensure an effective interviewing process and the collection of rich data, it is essential that the interviewer is a good listener who is flexible and non-judgmental (Bryman et al., 2021c).

Using purposive sampling as a non-probability sampling approach in this research ensures the collection of information from participants who are rich in information, thus facilitating the elicitation of comprehensive insights from the research area. Specifically, criterion sampling, a form of purposive sampling, enables the researcher to select participants based on an initial set of criteria that each participant must fulfil. The maximum variation sampling strategy aims to identify both unique and shared features of the participants across a range of contexts. Combining these two purposive sampling types is beneficial in terms of the sample representativeness, to identify similarities, but also to identify which type of data is most critical for the users to inform the dashboard (Bryman et al., 2021b).

5.2.3 Thematic Analysis Qualitative research can produce large quantities of detailed and comprehensive data. To identify the main findings and make them actionable, it is necessary to analyse the data, a process which is not always straightforward (Bryman et al., 2021f; Rosala, 2022). Thematic analysis is a widely used method that offers a flexible approach to analysing qualitative data. The method does not inform the data collection and the analysis is conducted only after the data collection has been completed. It is used to identify, analyse and interpret patterns, also called themes, within qualitative data, providing both detailed description and broader insight into the research topic. A theme can be viewed from a variety of perspectives, however, Bryman et al. (2021f) summarise that, in general, a theme is a category of interest that relates to the research focus, it builds on the identified codes in transcripts and provides a theoretical understanding of the data contributing to the research focus.

However, due to its adaptable nature, it is essential for the the researcher to be aware that the selection of suitable aspects of data may potentially paralyse their decision-making process due to the large volume of information. Nonetheless, thematic analysis is recognised as a valuable method for summarising key features of the data, highlighting both similarities and differences between them, and generating insights that were not previously anticipated (Braun & Clarke, 2006). Braun and Clarke (2006) define the general method of thematic analysis as an iterative six-stage process, that include (1) familiarisation with the data by reviewing and transcribing the interviews, (2) generating the emergent characteristics of data through initial coding, (3) identifying potential themes from emergent codes, (4) review of themes and search for potential sub-themes, (5) defining and describing the characteristics of the theme. Following these steps leads to the final data analysis in order to (6) produce the analysis report. This report follows the thematic analysis framework in order to identify themes and patterns in the qualitative data collected through interviews, as described in Section 6.2.

5.3 Requirement Specification and Analysis

In this HCD phase, the user needs identified in the context of use were specified into user requirements. The formulation of user stories (Section 5.3.2) is a structured way to express functionality expectations, while a competitive review of related platforms as described Section 5.3.3 can help to identify interface features and patterns relevant to the future dashboard design.

5.3.1 User Requirements Requirement engineering process consists of three key activities: “(1) discovering requirements by interacting with stakeholders (elicitation and analysis), (2) converting these requirements into a standard form (specification), and (3) checking that the requirements actually define the system that the customer wants (validation)” (Sommerville, 2010, p. 111). The method of requirement elicitation through interviews is described in Section 5.2.1 and analysis in Section 5.2.3.

Requirements define what a system should enable users to achieve. According to ISO/IEC/IEEE 2476 (2017), these are capabilities necessary to meet user goals and contractual specifications. Requirements not only reflect the user needs but also the needs of broader organisational, governmental, and industry standards. In an ideal case, requirements should describe what a system should do rather than how, independently of design (Aurum & Wohlin, 2005). Requirements can be described on varying levels. Sommerville (2010) separates them into user and system requirements. User requirements are high-level statements, while system requirements describe detailed system functions (Sommerville, 2010). Additional two types of requirements that can share similarities with user and system requirements, are functional and non-functional requirements. Unlike functional requirements that describe what the system should do, non-functional requirements focus on how it should perform as a whole under various constraints. Non-functional requirements can be further classified into three levels: (1) product,

(2) organisational and (3) external or project requirements (Aurum & Wohlin, 2005; Sommerville, 2010).

Requirements specification is the second activity of the requirement engineering process. The process involves documenting both user and system requirements (Sommerville, 2010). From a human-centred design perspective, this also includes explicitly defining user requirements with consideration for the specific context of use and the system's business objectives (ISO, 2010). The specified user and system requirements can be documented in various ways, such as in a requirements document, as natural language sentences or as user stories (Sommerville, 2010).

5.3.2 User Stories User stories are concise, specific, and user- or customer-oriented descriptions of desired system functionality that guide agile development processes. They are typically written on small cards or sticky notes focusing on a specific feature that delivers value to the user (Cohn, 2004b; Domingo, 2021; Sillitt & Succi, 2005). A user story consists of three components, a brief written description, ongoing conversations between stakeholders and developers, and acceptance tests to confirm implementation (Cohn, 2004b; Jeffries, 2001). Those components can be translated into a simple format in which user stories are written "As a [user role], I want [goal], so that [benefit]", capturing who the user is, what they want to do, and the value they gain from it (Domingo, 2021).

User stories can be organised by scope into subsequent categories of themes, epics, and individual stories. A further detail can be added to user stories through acceptance criteria or creating smaller sub-stories. User-story mapping is an effective method to maintain an overview of categorised stories (Cohn, 2004c; Kaley, 2021). In line with human-centred design principles, user stories help integrate user perspectives into agile workflows. This ensures that the focus remains on user needs rather than internal processes, with the aim of delivering a system that meets those needs (Cohn, 2004b; ISO, 2010).

5.3.3 Competitive Reviews In HCD, specifying user requirements involves not only direct input from users, but also evaluation of existing or competitive systems to gain understanding of how similar systems meet the needs of their users (Maguire, 2001). The process of competitive evaluation consists of the identification of competitors, the definition of aspects to be compared, and the actual comparison, which results in recommendations for action (Goodman & Kuniavsky, 2012c). Goodman and Kuniavsky (2012c) define three types of competitors, tier one, tier two, and niche competitors. Tier one competitors are direct competitors who share common target audience and offer products that are either identical or highly comparable, such as systems communicating real-time marine or environmental data from local stations to the public. Tier two competitors are defined as indirect competitors with focus on marine or environmental data, but not specifically tailored to station-based or marina-focused real-time use. Niche competitors are directly competing with specific aspect of the product, but not the system as a whole, which could be communicating some real-time data as part of its functionality or providing weather alerts.

Competitive usability evaluations aim to identify how competitors' designs meet user needs, while uncovering any potential usability problems that should be avoided (Maguire, 2001; Neusesser, 2024). They are typically performed on two to four sites belonging to direct, indirect, or niche competitors. Two methods to conduct competitive usability evaluations are competitive reviews and competitive testing. During competitive testing, a usability test is performed on existing design and the designs of the competitors. As there is currently no existing design for SOOP's dashboard, this method is not possible to apply in this thesis. In contrast, competitive reviews adopt a flexible approach to analysis that can focus on features or entire sites, evaluating strengths, weaknesses, trends, patterns, and differences (Neusesser, 2024). Competitive reviews support objective decision making, reduce risks, and make value-driven improvements that benefit the users through learning from others. The ultimate goal of the competitive review findings is to advise the ideation process as well as inform and improve the future design (Maguire, 2001; Neusesser, 2024).

5.4 Design

The third activity in the HCD process involves producing design solutions based on specified user requirements (ISO, 2010). To generate ideas, methods such as ideation, sketching or prototyping are used, described below in Section 5.4.1.

5.4.1 Prototyping To evaluate ideas and solutions, prototyping is a widely recognised, effective and useful way to examine design problems and reflect on them (Houde & Hill, 1997; Sharp et al., 2019). Sharp et al. (2019) describe a prototype as "one manifestation of a design that allows stakeholders to interact with it and to explore its suitability. It is limited in that a prototype will usually emphasize one set of product characteristics and de-emphasize others" (p. 422). The most commonly used purposes of using prototyping in design are (1) refinement, (2) communication, (3) exploration and (4) active learning (Camburn et al., 2017).

This thesis utilises explorative prototyping through ideation and generation of concepts with the purpose of creating a new solution. An approach typically used in explorative prototyping is parallel prototyping. During parallel prototyping, designs are created in parallel, allowing designers to compare different perspectives and options concurrently, ultimately leading to more diverse concepts and ideas (Camburn et al., 2017; Stickdorn et al., 2018). In addition, another key technique employed is iterative prototyping, which involves repeatedly testing and refining a prototype to progressively achieve user requirements. The number of iterations is chosen by the design team, guided by balancing the cost of each test against the value of anticipated improvement in design performance

(Stickdorn et al., 2018). Warfel (2009) points out that the fundamental value of iterative prototyping is the generative prototyping process that produces a multitude of innovative ideas. This leads to a reduction of misinterpretation, a savings of time, effort, and money, as well as a creation of rapid feedback that reduces risk.

Prototypes can be produced in many forms, from paper-based storyboard, cardboard mock-up or video simulations to a complex piece of software or hardware (Sharp et al., 2019). While they may vary in resolution and fidelity, it must be acknowledged that "the degree of visual and behavioral [sic] refinement of a prototype does not necessarily correspond to the solidity of the design, or to a particular stage in the process" (Houde & Hill, 1997, p. 3). A common and economic practice is to start with low-fidelity prototypes, such as on paper or cardboard with limited functionality, because it is affordable, easy to make, and quick to develop and modify. This makes low-fidelity particularly suitable for early stages of development, for example, for exploring alternative ideas, concepts, and designs. In contrast to low-fidelity prototypes, high-fidelity prototypes are designed with almost complete functionality, interactivity, look and feel as the final product (Sharp et al., 2019; Stickdorn et al., 2018). However, Stickdorn et al. (2018) add that the distinction between low and high fidelity is more complex. The fidelity levels such as look, feel, details, content, or information structure can vary or be combined in a single prototype to accommodate the purpose of the prototype.

In explorative prototyping, the first low-fidelity method often used is sketching. The sketching of an interface design utilises hand-drawing of basic elements such as icons, boxes, or figures. To visually show a user's process, a series of sketches can be turned into a storyboard (Sharp et al., 2019; Stickdorn et al., 2018). Sketching is used in this thesis as a first step in the low-fidelity prototyping as it is a flexible, quick, and inexpensive way to generate ideas that serve as a basis for further refined prototyping.

5.5 Evaluation

Usability evaluation of prototypes against user requirements is a key activity to ensure user requirements are being met, while it also provides valuable insights that can be used to refine designs (Maguire, 2001). The objective of usability testing is "to improve the quality of an interface by finding flaws-areas of the interface that need improvement" (Lazar et al., 2017, p.264). As stated by Lazar et al. (2017), an interface flaw refers to any element, feature, or widget within the interface that may be confusing, misleading, or otherwise not functioning optimally. Usability testing as a method is a form of "structured interviews focused on specific features in an interface prototype" (Goodman & Kuniavsky, 2012a, p.273), the function of which is to guide the definition and implementation of functionality. Thus, the efficacy of this method is maximised when employed in the early to middle stages of development, particularly for the evaluation of ideas and designs to ensure that the changes can be implemented (Goodman &

Kuniavsky, 2012a). This is also the time when the usability test was used in this thesis to test a low-fidelity prototype, as further described in Section 9.

5.5.1 Usability Testing There are three types of usability evaluation, (1) user-based testing, (2) automated testing, and (3) expert-based testing. However, the majority of usability tests are user-based (Lazar et al., 2017). User-based testing involves evaluating a system by having representative users perform typical tasks, helping to identify usability issues. In this thesis, the focus is on testing preliminary design concepts to identify and fix usability problems and understand how users perceive different components to improve the interface (Lazar et al., 2017; Maguire, 2001). Additionally, low-fidelity prototypes make it easier for users to give honest feedback and criticism, since the unfinished appearance of the prototype indicates that changes are still welcome (Lazar et al., 2017). Therefore, usability evaluation used in this thesis is exploratory, also described as formative testing, combined with comparison testing, in which designs are evaluated against another. As opposed to formative testing, summative testing is conducted only on high-fidelity prototypes to derive metric data (Goodman & Kuniavsky, 2012a; Lazar et al., 2017; Maguire, 2001).

A four-step process has been determined to facilitate the preparation for conducting usability testing: (1) recruiting suitable participants, (2) choosing features to be tested, (3) creating tasks that are representative of typical user activities while focusing on a single feature, and (4) writing a script or discussion guide (Goodman & Kuniavsky, 2012a). There is no simple answer to determine the right number of users in usability testing (Goodman & Kuniavsky, 2012a; Lazar et al., 2017). A study by Nielsen and Landauer (1993) suggest three to five users should provide sufficient cost/benefit ratio, and Lazar et al. (2017) claim that five users can discover 80% of the usability issues of the interface. However, this depends on the size of a project, but also the number of tasks tested and how many flaws might exist, which is often unknown. Lewis (2006) argue that testing should continue until the rate at which new issues are discovered begins to decline, which can vary depending on the context and objectives to identify problems. Concluding from the discussion, the focus of usability testing should be to identify and rectify the most critical issues within the constraints of time, budget, and participant availability, rather than aiming to uncover every possible flaw (Lazar et al., 2017).

To make sense of the collected data and uncovered interface flaws during the usability test, the results are typically summarised into a prioritised list of flaws, highlighting the most important flaws to be fixed (Goodman & Kuniavsky, 2012a; Lazar et al., 2017). Processing the results take place in three steps: (1) collecting observations, (2) organising observations, and (3) extracting trends into individual flaws (Goodman & Kuniavsky, 2012a). Each identified flaw should contain information about the problem, the usability test data, assigned flaw priority, suggested way of fixing as well as estimated fixing time (Lazar et al., 2017).

6 First Iteration – Context Of Use

Understanding and defining the context of use is the first activity in the human-centred design process. Gathering of requirements in sufficient detail forms the basis for identifying user needs, tasks, and environment conditions in which the system will be used (ISO, 2010). This section presents the first iteration of the context of use, based on the qualitative data gathered through semi-structured interviews in Section 6.1 followed by thematic analysis of the results in Section 6.2. The findings serve to inform user requirements and guide design decisions in later stages of the thesis.

6.1 Interviews

To explore how users engage with marine environmental data and identify their related behaviours, needs, and challenges, semi-structured interviews were conducted with a diverse group of participants involved in coastal and marine activities. Participants were recruited through purposive sampling method. An interview guide was developed and followed throughout the interviews to maintain consistency and support comparability of the data in the thematic analysis. The interviews focused on the context in which participants access environmental information, the tools they currently use for this purpose, and their expectations regarding real-time marine data.

6.1.1 Participant Recruiting & Sampling In order to conduct interviews, it is first necessary to recruit suitable participants. This process involves finding, inviting and scheduling interviews with the right people (Goodman & Kuniavsky, 2012d). The target group of SOOP and its future digital platform, as described in Section **??**, are coastal communities and people with connection to marinas, such as sailors, fishermen or swimmers. Therefore, the ideal participant profile is defined as an adult who is diverse in age and irrespective of gender, and who actively engages in coastal and maritime activities, including but not limited to sailing, swimming, fishing, and residing in coastal areas. Reflecting the SOOP's strategic growth initiative, which involves the expansion of operations from Germany to marinas in various European countries, including the United Kingdom, Denmark, France, Portugal, Italy, Croatia and Greece, it is advantageous of the participants to be of international background with experience from marinas in these countries. Furthermore, they are regular internet users who are capable of interacting with digital tools.

A purposive sampling method was employed to select participants who met the criteria set in the desired participant profile in line with the research focus (Bryman et al., 2021b; Goodman & Kuniavsky, 2012d). In purposive sampling, the researchers aim to "ensure that there is a good deal of variety in the resulting sample so that sample members differ from each other in terms of key characteristics" (Bryman et al., 2021b, p. 378). In context of this thesis, variations in key characteristics are predominately considered as the diverse experience from marinas in countries specified above. Moreover, it was ensured these individuals were from diverse age groups, genders, nationalities and sea-related activities.

The interviews were conducted with 7 participants, of whom 4 were males and 3 were females. The age of the interviewees ranged from 31 to 67, with an average age of 50.14. The participants were purposively selected as they have varying international background and experience with marinas and sailing in the English Channel, Baltic Sea, North Sea, Mediterranean Sea and the Atlantic. Full overview of the interview participants including age, gender, nationality, sailing places and coastal activities is mapped in Table 1.

Table 1. Overview of interview participants.

ID	**Age**	**Gender**	**Nationality**	**Sailing Places**	**Coastal Activities**
P1	52	Male	Czech	Croatia, Greece	Sailing for 25 years since 1999
P2	41	Female	Finnish	Baltic Sea, North Sea, English Channel and the Caribbean	Sailing for 21 years, fishing, swimming, coastal living
P3	66	Male	Danish	Around the world, English Isles, France, Norway, Portugal, Mediterranean, Denmark	Sailing for over 50 years, participated in 4 Paralympic Games
P4	55	Male	Italian	Around the world, Mediterranean, Baltic Sea	Sailing for 34 years since 1991, fishing, diving, swimming, working in a shipyard
P5	31	Female	Danish	Baltic Sea, Indonesia	Sailing for 10 years, swimming, winter bathing, paddle boarding, kayaking
P6	67	Male	German	Around the world, Mediterranean, Sardinia, Baltic Sea	Sailing since 6 years old, working as a marina building planner
P7	39	Female	French	Portugal to Sweden, Canary Islands to Fiji crossing the Atlantic Ocean and the Pacific Ocean, French Polynesia	Sailing since childhood, snorkelling, paddling, and kayaking

6.1.2 Interview Guide To maintain consistency through the interviewing process, an interview guide was developed. The questions were formulated in such way to guide towards answering the first research question, while ensuring that they do not become overly specific or leading. The guide was divided into two main focus areas. Firstly, information-seeking patterns and understanding environmental information. Secondly, needs and expectations for digital coastal tools.

The first part focused on understanding how users engage with already existing environmental or meteorological data, how and in which situations they do so, and what challenges they encounter. The questions asked in this segment included following "When you spend time at the coast, do you ever look for information about the environment (like water, air, or biodiversity conditions)? Tell me about that.". This question could be followed by a further question: "If so, have you encountered any challenges (in accessing them)?". Specifying question could follow, for example "Can you describe a recent situation where having this information/data would have helped you or influenced your actions".

The second part focuses on user preferences related to existing digital tools that communicate environmental data and common visual formats within this target group. It also covers understanding their data needs in and around marinas and how to stay informed when conditions change. The questions asked in this segment included the following "What types of local data do you find most useful or interesting to you when at the marina? (e.g., water temperature, air quality, water turbidity, sea level, biodiversity indicators, CO_2, pH, eDNA, air quality)" or "If you were looking at these data, is there anything that would help you understand what is happening?". Another question is for example "When you are at the coast or marina, would you find it helpful to be informed if environmental conditions change? Why or why not?".

The interview guide initiates the conversation with introducing questions, such as asking participants about their connection to marinas or water and what activities they usually do there. Follow-up and probing questions were used to encourage elaboration, such as asking when and how they check conditions like wind or water temperature, or what digital tools they rely on. Specifying questions helped uncover specific behaviours, for instance asking participants to describe situations where having environmental data influenced their sailing or mooring decisions. Interpreting questions further explored user preferences for visual formats and features that could support their decision-making, such as comparing real-time versus forecast data. Overall the interview guide was designed in a way that supports the semi-structured approach. This makes it possible to ask questions in different order to maintain the interview flow or customise the questions to the interviewees' responses (Bryman et al., 2021c). The full interview guide is accessible in the Miro board[2] and in the Appendix B.

[2] Miro board: https://miro.com/app/board/uXjVIt_QGKQ=/?share_link_id=302688091978

6.1.3 Conducting the Interviews To create a more relaxed environment, interviews were conducted individually between the researcher and the participant. Four interviews took place online through Zoom video call, two interviews took place in person, one of them being on the participant's boat, and one interview took place through a WhatsApp call. The duration of the interviews varied between 30 minutes and 60 minutes, with an average length of 50.1 minutes. To ensure compliance with General Data Protection Regulation (GDPR), participant anonymity was maintained throughout the research. Even though demographic data including age, gender, and nationality were collected, personally identifiable details such as names were intentionally excluded and substituted with participant identification (ID) number, as can be seen in Table 1.

All interviews were recorded, which allowed for transcription. The transcription process was facilitated by user research software, specifically the Dovetail system. Afterwards, the interview data and quotes were transferred into individual sticky notes in a Miro board to prepare them for analysis.

6.2 Thematic Analysis

To understand how sailors and members of coastal communities engage with and interpret environmental data, a thematic analysis was conducted on qualitative data collected through the interviews described in Section 6.1. Following a thorough examination of the transcribed interview data, the thematic analysis framework was employed, as introduced in Section 5.2.3, using a Miro board.

Thematic analysis approach was used to identify emergent patterns in the data through coding. Interview transcriptions were fragmented into individual sticky notes, each labelled with the participant ID and question number for better tracking of the results. Should any participant's statement stand out, the sticky note was marked with green for biggest delights, red for biggest pains, and dark yellow for what is considered as important information. In addition, a yellow star was placed on sticky notes with information particularly relevant to the research focus. Several iterations of the review process led to the identification of further sub-themes and refinement of the themes to ensure their alignment and contribution to the research focus of this thesis. The complete results of the the thematic analysis, as visualised in Figure 2, are available in the Miro board[3].

The analysis focuses on user experiences, expectations, and challenges when interacting with marine data information and related decision-making processes. Seven key themes, each containing multiple sub-themes, were identified to gain a deeper understanding of context of use of marine, coastal, and environmental data. The themes are (1) User Context, (2) Planning and Preparation Habits, (3) (Real-Time) Data Availability and Accessibility, (4) Dashboard and Data Needs, (5) Data Presentation and Visual Preferences, (6) Notifications and Alerts,

[3] Miro board: https://miro.com/app/board/uXjVIt_QGKQ=/?share_link_id=302688091978

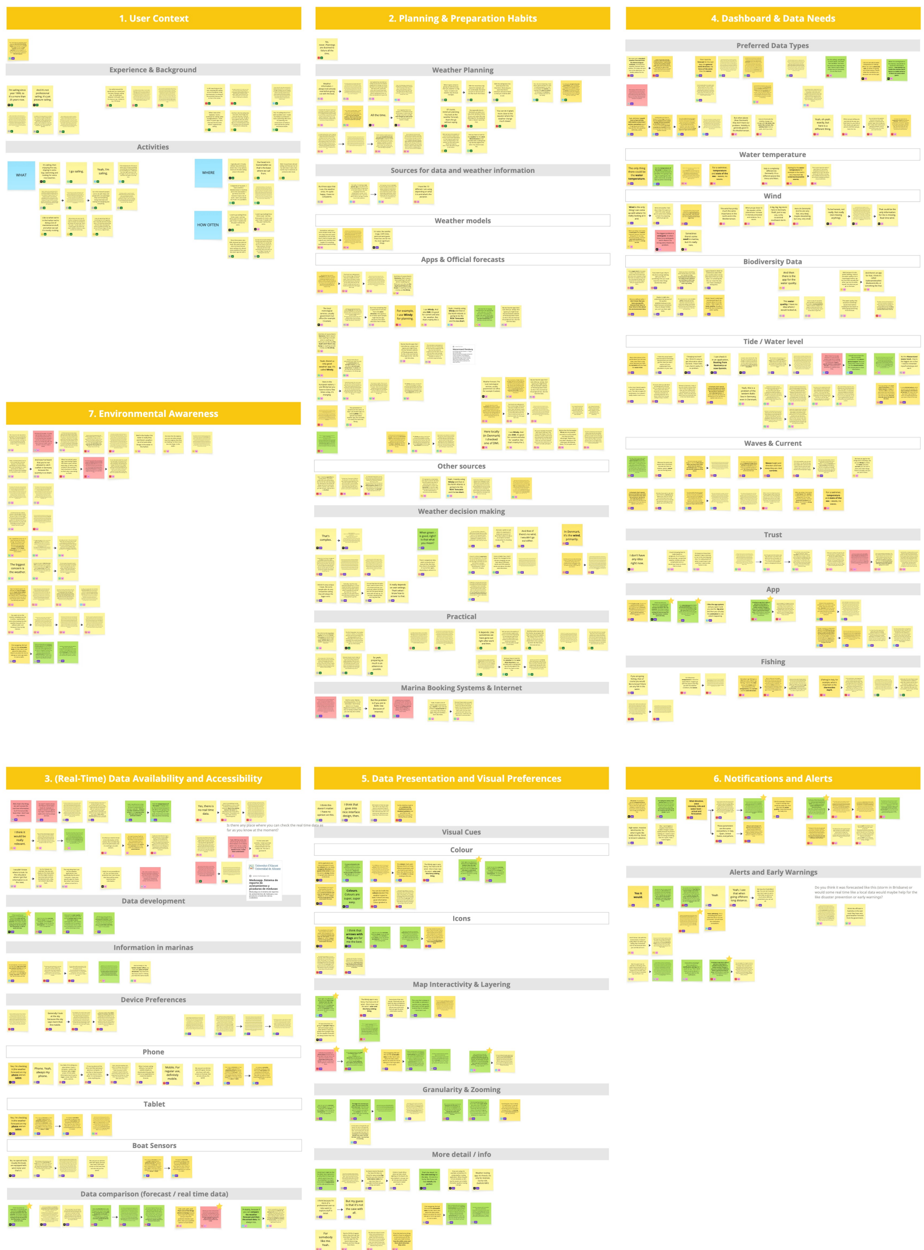

Fig. 2. Visual representation of thematic analysis in the Miro board. Green sticky notes marks biggest delights, red biggest pains, and dark yellow important information.

and lastly, (7) Environmental Awareness. Every theme contains several subthemes, which will be delved into and explained in detail in the upcoming paragraphs.

6.2.1 User Context This theme explores participants' levels of experience, the background, motivations, and typical activities at sea. As a highly experienced skipper, P3 reflected on their extensive sailing background: "I've sailed around the world and I've cruised and I've been Olympic sailing also, so anything in between" (P3). In contrast, P1 described their leisure approach to sailing: "It's sailing, then enjoying the sea, staying in some bay, swimming and looking for some nice beaches" (P1). Other participants expressed concerns stemming from living in coastal areas that are vulnerable to changing weather patterns and high water levels due to increasing storm activity. As a coastal resident, P2 explained:

> "Well, I live on the coast. My window is up towards the sea. So in Flensburg, it is high water. It is something happening not so often, but when it happens it bothers a lot every day. Cannot get out of the house anymore if the water comes too high. And obviously the damage that can do on the coastal areas" (P2).

The participants have varying degrees of involvement in sailing, fishing, water sports and other coastal activities, across different seas and climates, including the Baltic and North Sea (P2, P3, P4, P5, P6, P7), Mediterranean (P1, P3, P4, P6), Caribbean (P2, P3, P4, P6, P7) but also other areas around the world (P3, P4, P6), including very remote areas (P3).

The diversity in interviewees' profiles suggests a wide range of expectations for coastal and ocean data, with some requiring precise, advanced data for own interpretation, and others relying on intuitive cues or basic user-friendly summaries and interfaces. For example, P6 groups sailors specifically into three types of sailors; young people focusing on racing would benefit from very localised data close to the marina (P2), while older people with a lot of experience and expertise in weather data comprehension prefer to understand the data from a bigger perspective (P3, P4, P6, P7). People using charter boats, who account according to P6 to 80 percent of the sailors, have little experience and are interested in as much relevant information as possible, on top of weather forecasts (P1). That could include include specifying which applications are the most accurate and communicate the data in accessible and understandable way.

Overall motivations for activities on the water are pleasure, relaxation and connection with nature, as well as social or family activities. For example, P3 describes sailing as deeply personal and even therapeutic, offering a sense of freedom and harmony.

6.2.2 Planning and Preparation Habits This theme reflects how participants approach planning and preparation for activities on or around water, what sources they use and how environmental data support or interrupt their decision-making. All participants agree that weather is the most important factor for any water-related activity, that they check “all the time”(P1). In terms of planning an activity, interviewees typically begin inspections of the forecasts as soon as these are made available, typically ten days in advance (P3, P5, P7). The intensity of the checking increases towards the desired date, as the forecasts become more accurate (P1, P2, P3, P5, P7), the most important being the conditions on the actual day and time of departure assessed in person (P1, P2, P5). When in the marina, “I’m checking weather and I’m thinking about the wind, how is blowing in the marina and how it will affect me and the boat to get out of the marina” (P1). However, the ability to plan also depends heavily on the location of the activity. While in Denmark or Croatia the weather can change on a very short notice (P1, P3, P4), closer to the equator the weather changes much slower and it is therefore possible to plan more in advance (P4).

To get information about weather, they speak with their neighbours, marina managers or seek knowledge from locals (P1, P3, P6, P7). In addition to that, majority of the participants also obtain the information from various applications and online services that they use for different purposes, the most mentioned being the application Windy.com (P1, P2, P4, P5, P6, P7). Besides Windy.com, applications such as PredictWind (P3), MeteoBlue (P1), WindFinder (P6) or Boating from Navionics (P1, P5, P6, P7) are mentioned for weather data access.

In addition to the above-mentioned applications that provide global data, the users tend to seek information from local authorities and government-run services depending on the location of the activity. This could be Environmental Modelling and Monitoring Laboratory for Sustainable Development (LaMMA) for Italy (P4, P6), YR.no as a collaboration between Norwegian Broadcasting Corporation (NRK) and the Norwegian Meteorological institute (MET) (P2, P3), official weather reports from Germany’s National Meteorological Service DWD (P6) or Croatian Meteorological and Hydrological Service (DHMZ) (P1), while in Denmark the Danish Meteorological Institute (DMI) is popular (P3, P4, P5).

Finally, the planning habits depends largely not only on the weather, forecasts and real-time conditions, but also on the confidence, experience, length of the activity, boat, as well as type of the crew and security (P1, P3, P5, P6).

6.2.3 (Real-Time) Data Availability and Accessibility Exploring how participants access and interact with environmental data and potentially real-time data led to a third theme of Accessibility and (Real-Time) Data Availability. It unveils the interviewees’ need for data as well as locally accurate real-time measurements and how they prefer to access them.

All participants primarily use smartphones and some of them also tablets (P1, P6, P7) or computer (P3). They access data in many different forms through variety of applications and online resources, often simultaneously (see theme 2), or directly in the marinas, where often local data such as wind direction is shown on large screens (P4, P6, P7). However, not all marinas do that (P7) and it is predominantly available only in South of Europe, as P4 points out:

> "In Italy, Spain, France, in Mediterranean it is very normal in a marina to have a screen with a weather forecast. [...] The more advanced marinas have an external touchscreen" (P4).

Yet, the data can be very fragmented and the users have to use multiple information points, websites or applications to check and compare their data (P2, P7), which can be time-consuming (P1). Additionally, the data are mostly predicted, based on global or local models. Due to the nature of predicted data, they tend to have a lower accuracy in local areas as they do not reflect the reality (P1, P7). P7 explains this issue:

> "Usually when you have on Windy.com or those bigger forecasts, it's not adapted to the coastal changes and the mountains or the effect of land and so on. [...] the models they are too big to see what exactly the small current is over there. [...] But sometimes I have to go to a specific website or ask the local if the tidal current is the good one because usually people don't agree with the models." (P7).

Some real-time measurements are already available for example on the DMI, but as P3 points out:

> "[...] all of it as far as I know is shore based, so it's inland, which is for me as a sailor, not really interesting. To matter to me, I need them underwater. It is the same with currents. I mean you have some very few current measurements, but not really a lot. The rest is guesswork." (P3).

Typically, sailors can access real-time data and measurements such as wind speed and direction, sea temperature, or pressure from various sensors and instruments with which their boats are equipped (P1, P7). The issue lies in the absence of documentation of these data, which can only be accessed at a specific given time and only when the boat is actually in operation. P2 recognises this as a problem and illustrates a scenario in which they would benefit from real-time data rather than from data that have been predicted and can therefore be inaccurate:

> "Well, that is the thing, we can't access the real time information. When being out with the boat, I think everything that is critical we have on board, this wind direction and wind speed and this kind of stuff. But that's not something we have when, when the boat is in the marina. Because we cannot send that information from the boat to our phones. [...] So if I am not on the boat, then I do not see my meters. So now if I need to know the wasser stand (water level), for example, in order to loosen or tighten my ropes, I would have to walk to the marina and go and see" (P2).

Even though participants agree that access to real-time data would be highly beneficial to them, the real-time data is not available or they do not know where to look for it (P1, P2, P3, P4, P5, P7). Furthermore, P3 points out that "there is an enormous lack of continuous collection of data" (P3).

The desire to compare real-time with forecasted data and came up frequently, emphasizing that understanding the past development of the data is equally important as the actual measure point to create more qualified opinion (P1, P3, P5, P7). As this information is missing from most of the public websites and applications (P3), P1 suggests that:

> "If there would be any application or something, that would follow what was the forecast and what's the real situation. And simply compare these two parameters and you could go for last six hours for this information. It will be quick and easy" (P1).

Having a comparison of various models from the past and the future to the actually recorded data in real-time could aid the users to identify which prediction model to follow as currently they have to perform this task manually, often resulting in a large spreadsheet or calculations (P1, P2, P3, P7). To access and compare real-time data with forecasts, the users prefer a format of an application (P1, P3, P4, P5, P7), specifically articulated by P1:

> "If there would be any application [...], that would follow what was the forecast and what's the real situation. And simply compare these two parameters and you could go for last six hours for this information. It will be quick and easy" (P1).

6.2.4 Dashboard and Data Needs In order to inform the dashboard, this theme captures what types of data users find essential for their activities, and the specific scenarios in which data is applied. In addition to general information that is widely available such as wind direction and wind speed, data that have considerable effect on coastal activities and sailing are water temperature, tide or water level, waves, current, as well as biodiversity data.

For sailing, wind strength and direction, and especially wind gusts (P1), is obviously the most important parameter, regardless of location (P1, P4, P5, P6). Additionally, as a leisure sailor who does not know the local conditions, P1 notes that:

> "It would be fine if you could have a net of information about real time wind. [...] When I'm coming back to the marina, I would like to know the information before – how windy it is inside the marina and if there is a stable wind or if there are some wind gusts" (P1).

Despite the fact that storms are known to increase in intensity, power, and violence towards closer proximity to the equator, storms that do hit regions such as Denmark or Germany can be small in size, yet very fast, deep and devastating (P2, P3, P6). A sudden decrease in atmospheric pressure can predict local thunderstorms, which have become increasingly prevalent in the Mediterranean region, extending beyond the conventional thunderstorm season, pose a significant threat to inexperienced sailors (P4, P6). Accurate and local water temperature can help identify weather changes such as fog or storms (P3, P4, P7), which is especially relevant in the Mediterranean (P4), but not so important in the north such as the Baltic Sea (P4).

Although waves are not much of an issue in shallow waters such as in Denmark, they can be very dangerous and deal-breaking in other areas such as Spain, Portugal, West France, Western Great Britain or Norway (P3, P5, P6):

> "As soon as you go outside Skagen or into the other places where you have more rocky bend, then the waves is everything to you. The wave size and the steepness of the waves. [...] There in those wavy areas you really would like to see the waves in real time because it could make or break that you can go into a specific harbour. [...] I mean, the waves are 80% of what makes up your decision." (P3).

Similarly, tides that have an effect on water level and currents are not very relevant in the Baltic Sea, Italy, Croatia, and other closed areas (P1, P3, P4), except in extreme weather conditions (P2, P6). In contrast, on the west coast of Denmark, British Isles, USA, or other places with coastline open to the ocean, the subject of tides is a perpetual topic of conversation as they are crucial when entering or exiting harbours. The predictability of tidal currents is generally high and their availability in the forecast is sufficient (P1, P7), yet detecting the presence of local variations in the current is challenging due to the grid size of the forecasting models (P3, P7):

> "And I know that when I'll be in the Faroe Island, I know that the current is really, really strong around the islands. So this info is accessible only on the website that is just for this area" (P7).

Biodiversity data, and water quality in particular, are very relevant to swimmers, who also appreciate the knowledge of water temperature and state of the waves (P2, P3, P4, P5). For fishing, important parameters are water temperature, weather conditions including waves, current, tide and in Italy, thermocline depth (P2, P4). While salinity or water DNA could help detect what kind of fish is in the water (P2, P4).

6.2.5 Data Presentation and Visual Preferences This theme uncovers how users interact with current systems and how they understand data through visual representation, to ensure the future dashboard is usable. For part of the participants, the visual aspect of the current applications used for data acquisition, including the importance of effective interface design, is essential for the comprehension of frequently complex data (P1, P2, P5, P7). This is particularly relevant when the motivation is to gain an overview before delving deeper to explore the nuances. In contrast, highly experienced sailors do not have a preference and, while they enjoy the effective visual representation of data, they are also capable of decoding complex data themselves (P3, P4, P6).

The utilisation of colour is the most significant aspect, as P1 notes: "Colours. Colours are super, super easy". Colours ensure the data is easily understandable at a glance when comparing various types of data, such as wind strength or wind direction (P1, P3, P4, P7). P7 provided a more detailed explanation of the process:

> "Yeah, the Windy app is perfect for that [...] if it's green, I can go. [...] If it's starting to get orange or red, I will stay back or maybe look more precisely to understand how it's going to evolve and if there's a chance that maybe in the coming days it's going to pass or not. [...] I can see the coming days, and it's green, it's orange, it's easy to understand" (P7).

In addition to the colour, the use of arrows or lines is essential for a visual representation of the wind direction. Nevertheless, some interviewees (P1, P3, P4) have expressed concerns about the potential implications for interface usability when designed for a more generic audience, where the standardised visualisation of wind strength as a line with barbs is being compromised:

> "So to swap standard information for easier or more user friendly – there is no user friendly, it is more unfriendly. [...] I mean, it doesn't take much to understand this. It is also a matter of how to explain to people how it works" (P4).

They question whether this simplification actually makes it more usable. Even for those who do not sail frequently, such as P1, the barbs provide a straightforward method to instantly determine the strength of the wind.

Often referencing the Windy.com application, participants enjoy to have a map included in the interface as it helps them to obtain information from the location they are planning to go to (P2, P4, P5, P7):

> "This cross that is always in the middle, so wherever I put this cross, it gives the information of that specific location, then in numbers. I think that's cool" (P2).

Many different types of data can be relevant to different types of users. However, it is not always possible to select particular data types to be shown in the map together as a layer. The data then become incomparable, or the interface becomes over-cluttered (P4, P7). P4 wishes to have:

> "[...] the possibility of choose layers because one of the problem that we have on all electronic interfaces is the cluttering of data on the screen. You don't understand what is going on. There is too much. So you need to be able to have toggle on and off different layers. [...] So you can isolate, you can concentrate on the data that you're looking at and not be distracted by a mountain of other things [...] And then you can

> set maybe two layers together and work with that. So you need to be complete of the full range, but the possibility to use layers" (P4).

And P7 adds that on the map, they "would love to have like everything on top of it if I have access to all the layers, the waves, the current, the ice, the weather, the pressure, the low pressure, the wind and so on" (P7). P5 wish for a solution that is customisable and shows data relevant personally to them:

> "Like a really simple app where there's not a lot of information, but just like the information that I want. So maybe an app where I can click off the things that I want to see, and then other people, they can click off what they want to see, but I don't need to see like all the information that I'm not really interested in." (P5).

In the context of sailing, for instance, a range of data granularity is necessary. The ability to zoom in and out on the map is also crucial in order to gain more complex overview. However, as the departure time approaches, the necessity for greater levels of detail increases, and the need for very specific and real-time data rises (P3, P7):

> "The bigger the overview you want, the more visual is the best way to go. Then when you start zooming in, then at one point in time you, you want to see numbers. [...] I want to see a figure saying 2.5 instead of some colour showing me that it's anything between two and four. But that's because of the experience I have and my ability to read these data that I want the actual detailed figure. But you come a long way with visualisation" (P3).

The level of detail necessary depends on the level of experience, but also the type of activity the data is being used for (P1, P2, P3). For example, in sailing races close to the shore, local and very accurate data are crucial as "you need to know how the shifts come and from which direction they come" (P3). In contrast, P2 expressed the need for actionable recommendations in order to determine whether action is needed on particular type of data rather than specific details – "I don't care about the data unless there's an action for me to take go or not to go swim or not to swim [. . .] green is good for me" (P2). However, this is even more important in regard to communicating complicated data, such as biodiversity data regarding quality of water: "give me a CO2 level of the water, I have no idea what to do with that, what does that mean? [...] some kind of explanation on the side would be nice" (P2).

6.2.6 Notifications and Alerts A recurrent theme that has emerged throughout all the interviews is the absence of a system to provide alerts, notifications, or early warnings in the event of unexpected weather changes, such as storms or water quality, regardless of the location (P1, P2, P3, P4, P5). While in some places, local subscription to SMS information service is available, a more universal and optimised solution is missing (P4). The interviewees note that for boat owners, real-time data from the harbours is particularly crucial for disaster prevention (P2, P4):

> "I think it's very important as a boat owner [...] the real time data. [...] Especially in the winter time if you keep the boat in the water. If there is a storm here, there is a surge, the water may actually go up [...] the mooring just go out of the stick or just the boat start to hang, the front line are too short and then it start to pull and something can break. And with a wind surge, tide has done disasters in the past in some harbours here" (P4).

For boat owners, the most critical data from marinas are tides, water level, wind direction and wind strength, both in real time and forecasted (P1, P2, P3, P4). It is possible to issue a pre-warning for the possibility of squalls, based on the water surface temperature and barometric pressure (P4). Additionally, swimmers would appreciate information about changes in water quality (P2, P5).

From currently existing solutions, the PredictWind application offers the possibility of personalising a warning for parameters that are deemed acceptable, such as wind not stronger than 10 metres per second. This can be used in offshore long-distance sailing, but for inshore coastal sailing, this information is not accurate enough (P3). Drawing from past experiences of encountering disastrous storms or unexpected squalls in various locations worldwide (P3, P4, P6), P4 proposes:

> "Creating an app that is able to give you a warning of a possible incoming storm or sudden weather change in your area, localised, definitely will be a great, great thing to have" (P4).

The implementation of a notification system and weather warnings from the marina has the potential to reduce user concerns, eliminate the need for frequent personal visits to the harbour, particularly during the winter months, and ultimately ensure enhanced preparedness should the forecast and real development of weather conditions differ (P2, P4, P5, P6, P7). While the notification should explain what the weather change means, the information should remain concise. For example, it could take the form of a pop-up message on a mobile device (P4, P5). In general, users seek clear contextual warnings for weather changes and disturbances.

6.2.7 Environmental Awareness Even though environmental data does not have a direct effect on the performance of water-related activities, participants are well aware and concerned about changes in water and marine life. The specific changes influence not only sailors, but also all commercial fishing and coastal countries (P3).

A significant decline in environmental conditions, species availability, the number of species and the number of fish has been observed by P2, P3, and P4 in comparison to several years ago. In contrast, there is a significant increase in the quantity of medusas, which makes it challenging for swimmers to access the sea (P2). In addition, the extensive presence of blue algae in Finland makes the sea dangerous to swim in (P2). In the Baltic Sea, P3, P4, and P6 observed that the yellow algae have spread extensively and now cover the seabed for the majority of the year. This phenomenon has been observed to result in the death of seabed fauna and animals living on the seabed, including shrimps, fish or crabs (P3, P4, P6). In French Polynesia, P7 notices majority of the corals are white and dead, as opposed to the colours they have experienced when diving ten to twenty years ago.

The seawater in the Baltic Sea is considered dirty (P2), and especially in the harbours (P5). P4 attributes this to the extensive use of chemicals and human waste, rather than to an increase in sea temperature. P5 adds that supporting environment-friendly antifouling for the boats and making it more affordable could be a valuable contribution of the sailors to enhance the health of the oceans. In contrast, P6 hypothesise that the alterations they have been observing over the past 12 years are due to rising water temperatures. This phenomenon is also considered as a contributing factor to increasingly extreme weather patterns, including storms and hurricanes, as well as the low and high pressure system changes in the Atlantic Ocean (P3).

Thematic analysis of the interview data provided valuable insights into how different users engage with marine environmental information, revealing key behaviours, challenges, and expectations. Seven core themes were found by identifying recurring patterns across users' experiences. These findings form the foundation for translating qualitative insights into user roles and user stories as user requirements that inform the design and functionality of the dashboard in a way that reflects the user needs.

7 First Iteration – User Requirements

Specifying user requirements is a central activity in the human-centred design process, as it transforms user needs and contextual insights into concrete system expectations (ISO, 2010). The following section presents the first iteration of these user requirements, derived from the interviews and thematic analysis outlined in the previous Section 6, as well as insights from a competitive review of comparable websites and dashboards in Section 7.2. This phase of the HCD process addressed the first research question by identifying user requirements for a dashboard that communicates scientific ocean data to coastal communities and non-expert audiences.

In line with ISO (2010) guidelines, requirements were formulated with reference to the intended context of use, user needs and the goals they aim to achieve. Rather than describing how features should be implemented, this phase focuses on what the system must enable users to do. The output of this process is in the form of user stories, which describe functional expectations and design priorities through the perspective of defined user roles.

7.1 User Stories

User stories were developed based on the findings from the thematic analysis of interview data (Section 6.2), supplemented by relevant findings in the literature review on user behaviour (Section 3.4.1) and dashboard interaction design (Section 3.3). The iterative process involved the identification of user needs, their roles and goals, as well as gained benefits, informed by the sources above. To ensure human-centred approach to the user stories, they should not be written from a single user perspective. Therefore, prior to the process of user story writing, it was necessary to identify types of users and group them into user roles (Cohn, 2004a).

The insights acquired were then synthesised into user stories, which express the functionality users expect from the system in a concise, user-centred format. Stories with similar intent or addressing related functionalities were grouped and, where appropriate, structured into higher-level epics, encompassing multiple related stories. The full set of user stories was subsequently organised into overarching themes, helping to systematically structure the design requirements. To maintain consistency with the earlier research stages, the collaborative platform Miro[4] was used to facilitate the organisation, refinement, and visual mapping of user stories, epics, and themes, as illustrated in Figure 3.

7.1.1 User Roles As outlined in Sections 3.4 and 3.3, the research findings concerning users' information-seeking behaviours and needs were utilised to identify three distinct user roles: casual user, user and experienced user. Drawing from the Interviews (Section 6.1) and Thematic Analysis (Section 6.2), five further user roles were identified: pleasure sailor, experienced skipper, marina user, coastal recreational user, coastal community member and environmental advocate.

The user roles casual user, user and experienced user are employed for more general epics and user stories, applicable to the majority of other user roles. The user roles of pleasure sailor, experienced skipper and marina users are defined by their experience in sailing, for which they also utilise the weather data. These individuals are likely to be involved in marinas, and may even be boat owners. The sailing-related user roles can be often interdependent as well as overlapping in many cases. To illustrate, experienced skippers are likely to be boat owners who, therefore, also make use of marinas. In contrast to sailing activities of the three user roles, the coastal recreational user performs a variety of other water-based sports, including swimming, fishing and paddling. The coastal community member is defined as a person who lives on the coast and is directly affected by the coastal environment, including high tides. An environmental advocate is defined as an individual who is interested in environmental issues and the related parameters. The key characteristics and needs are described in detail in Figure 4.

[4] Miro board: https://miro.com/app/board/uXjVIt_QGKQ=/?share_link_id=302688091978

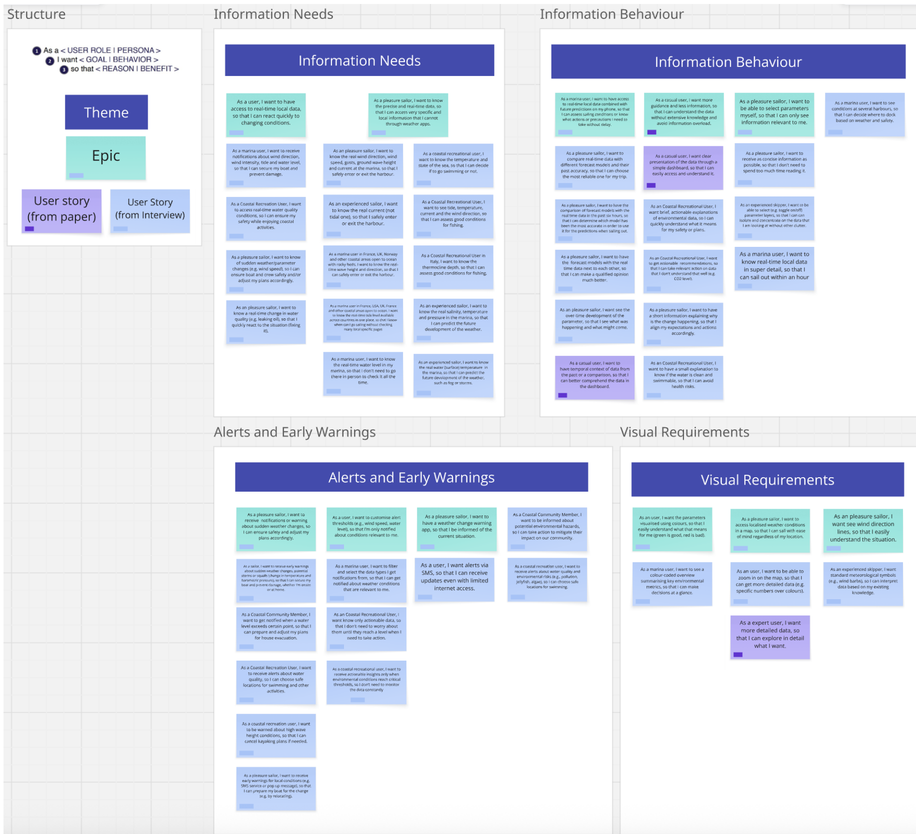

Fig. 3. Visual mapping of themes, epics and user stories in the Miro board.

7.1.2 Themes Four overarching themes were identified during the organisation of the user stories: (1) information needs, (2) information behaviour, (3) alerts and early warnings, and (4) visual requirements. The first theme, information needs, focuses on the types of information different user roles need in various situations and it contains two epics:

> As a user, I want to have access to real-time local data, so that I can react quickly to changing conditions.

> As a pleasure sailor, I want to know the precise and real-time data, so that I can access very specific and local information that I cannot through weather apps.

The user stories contained within the first epic focus on parameters required for changing weather conditions. Conversely, the second epic comprises user stories that emphasise parameters for which accessibility of real-time local data would

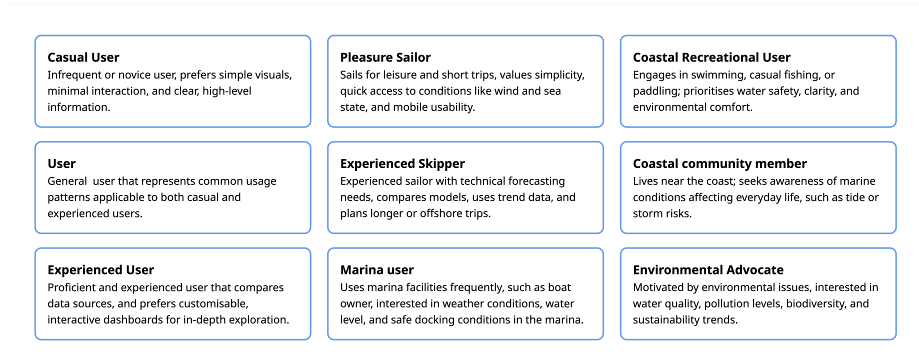

Fig. 4. User roles from the Miro board including key characteristics and user needs.

be very useful, particularly in and around marinas that are not currently covered by standard weather forecasting applications, such as:

> As an pleasure sailor, I want to know the real wind direction, wind speed, gusts, ground wave height and current at the marina, so that I safely enter or exit the harbour.

> As a coastal recreational user, I want to see tide, temperature, current and the wind direction, so that I can assess good conditions for fishing.

The second theme, information behaviour, consists of three epics related to the utilisation or combination of information for the benefit of the user:

> As a marina user, I want to have access to real-time local data combined with future predictions on my phone, so that I can assess sailing conditions or know what actions or precautions I need to take without delay.

> As a casual user, I want more guidance and less information, so that I can understand the data without extensive knowledge and avoid information overload.

> As a pleasure sailor, I want to be able to select parameters myself, so that I can only see information relevant to me.

The user stories contained within these epics delve deeper into the exploration of the significance of the context of the data, the combination of real-time data with forecasts, the development over time, and the amount of information or detail required, as well as personalisation through the ability to filter and select parameters to the user's needs, such as:

> As a pleasure sailor, I want to have the comparison of forecast models with the real time data in the past six hours, so that I can determine

> which model has been the most accurate in order to use it for the predictions when sailing out.
>
> As a pleasure sailor, I want to have a short information explaining why is the change happening, so that I align my expectations and actions accordingly.
>
> As a marina user, I want to know real-time local data in super detail, so that I can sail out within an hour.

Additionally, one user story without an epic under the information behaviour theme is:

> As a marina user, I want to see conditions at several harbours, so that I can decide where to dock based on weather and safety.

The third theme revolves around the concept of alerts and early warnings, which was prevalent yet missing topic that emerged during the interviews and thematic analysis. The three epics under this theme are:

> As a pleasure sailor, I want to receive notifications or warning about sudden weather changes, so I can ensure safety and adjust my plans accordingly.
>
> As a user, I want to customise alert thresholds (e.g., wind speed, water level), so that I'm only notified about conditions relevant to me.
>
> As a pleasure sailor, I want to have a weather change warning app, so that I be informed of the current situation.

Many parameters that are currently collected by SOOP could be highly beneficial to users when they exceed certain thresholds as they can be potentially dangerous. For that reasons, the user stories cover the need for early warnings allowing for more reaction time, as well as customising said threshold as it can differ by user. The examples of individual user stories under these epics are as follows:

> As a coastal community member, I want to get notified when a water level exceeds certain point, so that I can prepare and adjust my plans for house evacuation.
>
> As a marina user, I want to filter and select the data types I get notifications from, so that I can get notified about weather conditions that are relevant to me.
>
> As a user, I want alerts via SMS, so that I can receive updates even with limited internet access.

In relation to the environmental conditions, two standalone user stories are listed under the third theme:

> As a coastal community member, I want to be informed about potential environmental hazards, so I can take action to mitigate their impact on our community.

> As a coastal recreation user, I want to receive alerts about water quality and environmental risks (e.g., pollution, jellyfish, algae), so I can choose safe locations for swimming.

The fourth and final theme addresses visual requirements of users, which are frequently informed by their positive experiences with existing applications, predominantly in the domain of weather forecasting. Three epics were identified, focusing on colour-coding data, map and standardised icons:

> As an user, I want the parameters visualised using colours, so that I easily understand what that means for me (green is good, red is bad).

> As a pleasure sailor, I want to access localised weather conditions in a map, so that I can sail with ease of mind regardless of my location.

> As an pleasure sailor, I want see wind direction lines, so that I easily understand the situation.

Use of colour dominates in making the interface more accessible and understandable, but also being able to zoom in to get more detailed information. Highlighted especially by experienced skippers is the need for standardised meteorological symbols. Examples of the user stories are:

> As a expert user, I want more detailed data, so that I can explore in detail what I want.

> As an experienced skipper, I want standard meteorological symbols (e.g., wind barbs), so I can interpret data based on my existing knowledge.

Through the development of these user stories, a wide range of user needs, roles, and interaction preferences were defined. By combining insights from literature and interviews with thematic analysis, the stories capture user requirements that will inform the future human-centred design in Section 8.

7.2 Competitive Review

As part of the requirement elicitation, a competitive review was conducted to examine how similar websites and dashboards present real-time data and identify features that could further inform the ideation and design process (Maguire, 2001). In accordance with recommendation by Neusesser (2024), described in detail in Section 5.3.3, three websites providing ocean-related real-time data were selected for the review. Additionally, drawing from findings in thematic analysis in Section 6.2, applications and websites mentioned by the participants were screened. However, these are not subject to this review, as the objective was to identify the most relevant applications and websites, thus avoiding a costly and exhaustive analysis (Neusesser, 2024).

The review process and the choice of features and functionalities for comparison were guided by epics and user stories identified in Section 7.1. The selection for comparison consists of a map view, a preview on the map, and communication of more detailed information regarding the station data, including plotted data development over time. Miro board[5] was used for the execution of the competitive review. Screenshots of relevant interface sections were collected from selected competitor websites and grouped under corresponding epics and user stories within the Miro board. Based on finding is Section 6.2 and as described in Section 8.3, the design aims to follow a mobile-first and responsive approach. Therefore, all screenshots were taken on a mobile device. The analysis involved annotating key interface elements using a colour-coded system, with a legend describing the identified functionalities and design features. An example of this method, focusing on the analysis of map functionalities, is presented in Figure 5.

7.2.1 Competitors As outlined in Section 5.3.3, competitors can be divided into three types, tier one, tier two and niche competitors (Goodman & Kuniavsky, 2012b). While numerous initiatives offer real-time marine data, many are designed for scientific audiences and lack user-friendly interfaces, such as portal Data.shom.fr from the French Naval Hydrographic and Oceanographic Service, or GEOMAR's Beluga Navigator, described in Section 2. Among tier two competitors, Windy.com was the one mentioned by all participants in Interviews (see Section 6.1) as the most popular and visually appealing application used around marinas. As a leading platform providing interactive weather forecasting services, it was used as inspiration for capturing current best practices in meteorological data visualisation to the public. Other systems such as Windy.app, which includes customisable alerts, and the Danish Meteorological Institute (DMI), which offers some real-time data visualisation, were screened as niche competitors.

However, the main focus of the competitive review was on three tier one systems that provide access to real-time marine and environmental data. That includes Wind and Water (ViVa) from Swedish Swedish Maritime Administration, SmartBuoy from British Centre for Environment Fisheries and Aquaculture Science, and Tides & Currents from National Oceanic and Atmospheric Administration (NOAA) in the United States of America (USA). ViVa provides real-time weather and oceanographic data from over 150 sensor stations located along the Swedish coast and lakes, designed to support seafarers' safety (ViVa, 2025). SmartBuoy is a system that displays real-time and historical data from deployed buoys, monitoring the marine environment (Cefas, 2025). NOAA offers a comprehensive dashboard that provides access to tide, current, and water level data

[5] Miro board: https://miro.com/app/board/uXjVIt_QGKQ=/?share_link_id=302688091978

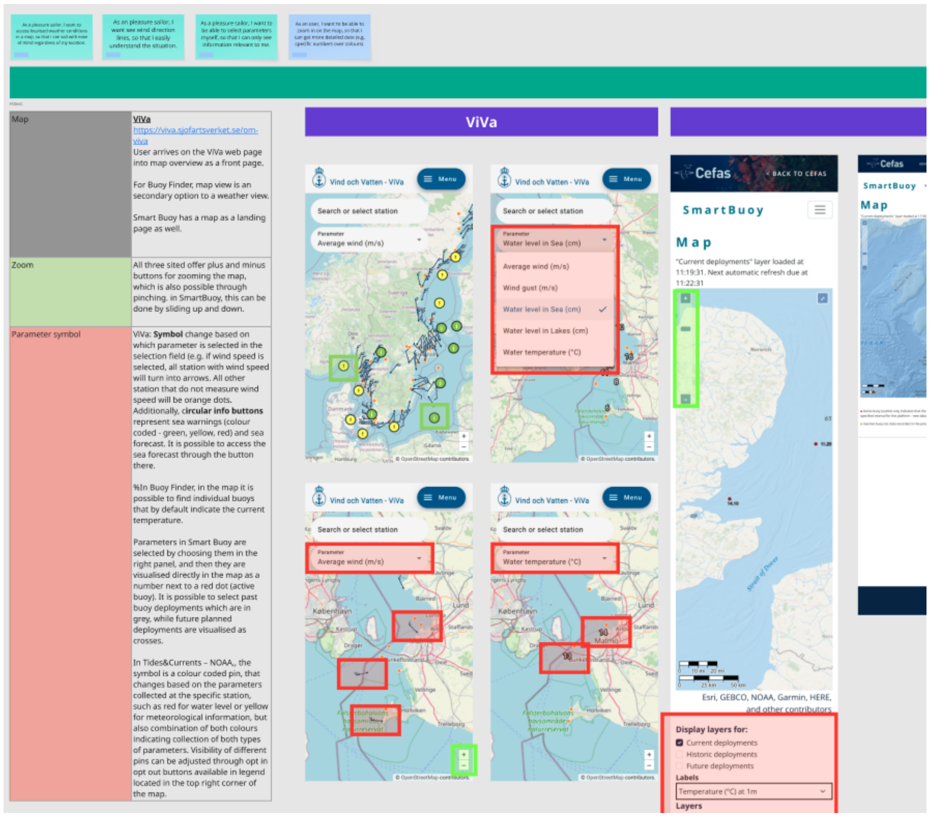

Fig. 5. Example of competitive review process conducted in Miro. Investigated epics and user stories are located at the right top, legend with functionalities in a table on the left and colour-coding system on the screenshots to the right.

from coastal stations in the USA, to support maritime safety and coastal communities' preparedness for flooding caused by extreme weather events (NOAA, n.d.).

7.2.2 Map Map overview is used across all three interfaces, as can be seen in Figure 6. User arrives on the ViVa web page into map overview as a front page. It is possible to zoom in and out through buttons or pinching. SmartBuoy has a map as a landing page as well. All three sites offer plus and minus buttons for zooming the map, which is also possible through pinching. In SmartBuoy, this can be done by sliding up and down.

In terms of parameter or station symbols, in ViVa the symbol change based on which parameter is selected in the selection field. For example, if wind speed is selected, all stations with wind speed will turn into arrows. All other stations that do not measure wind speed will be orange dots, making it less intuitive.

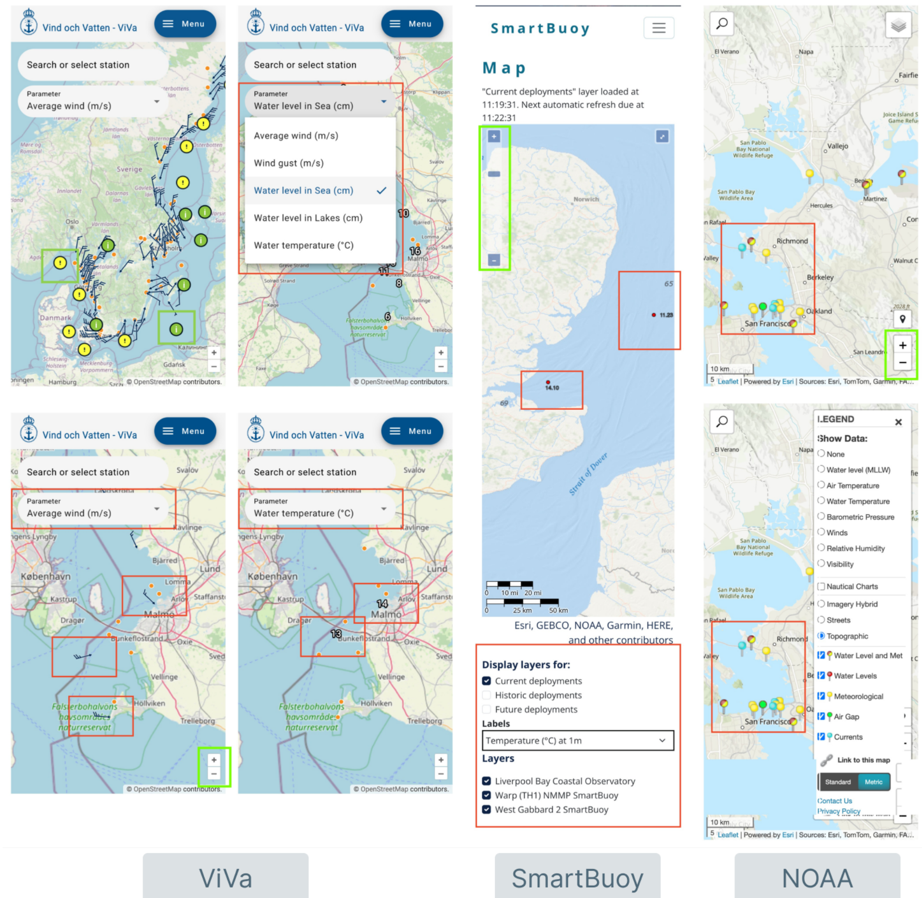

Fig. 6. Map overviews with parameters in ViVa, Smart Buoy and NOAA. Parameters are highlighted in red while zoom options in green.

Additionally, circular info buttons represent colour coded sea warnings and sea forecast, which is possible to access through the button.

Parameters in SmartBuoy are selected by choosing them in the right panel, and afterwards they are visualised directly in the map as a number next to a red dot, indicating an active buoy. It is possible to select past buoy deployments which are in grey, while future planned deployments are visualised as crosses.

In NOAA, the symbol is a colour coded pin, that changes colour based on the parameters collected at the specific station, such as red for water level or yellow for meteorological information, but also combination of both colours indicating collection of both types of parameters. The visibility of different pins can be adjusted through checkboxes available in the legend located in the top right corner of the map.

7.2.3 Data Preview Preview activated on click is integrated in all three assessed interfaces, as depicted in Figure 7. Preview on ViVa is available after clicking on chosen icon, therefore if it is for example wind speed, the preview will only show wind speed data. It is not possible to preview more parameters at once, such as wind speed and water temperature, for that it is necessary to go on the station page.

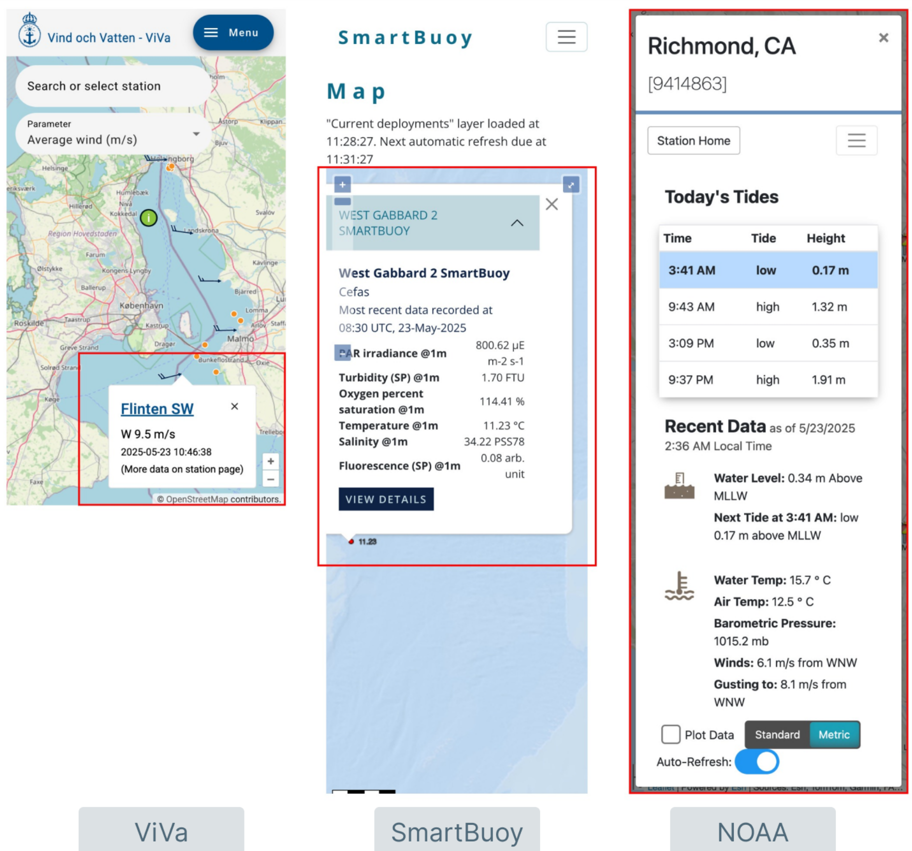

Fig. 7. Station previews on a map, marked in red, for ViVa, SmartBuoy and NOAA.

SmartBuoy offers preview for every station, including brief information on all recorded parameters and time of last update. A station page with more details can be accessed through "view details" button.

NOAA provides very comprehensive preview with a list of measured tides and last recorded data, with possibility to plot the data below by clicking a checkbox “plot data”. Additionally, auto-refresh is automatically selected by an activated toggle button, and it is also possible to choose between metric and standard measurement systems. Aside providing more information about the measuring station in the preview than others, it offers a very similar experience and information otherwise.

7.2.4 Real-Time Data Station Page How competitors approach information shared on station pages is illustrated in Figure 8. The station information on ViVa include station name, exact GPS location, possibility to show the location on the map and add the sation to your favourite stations. SmartBuoy provide information on the buoy and its identification number, link to map localisation as well as GPS location. NOAA provides very detailed information about the station, today’s tides, photos and sensor information.

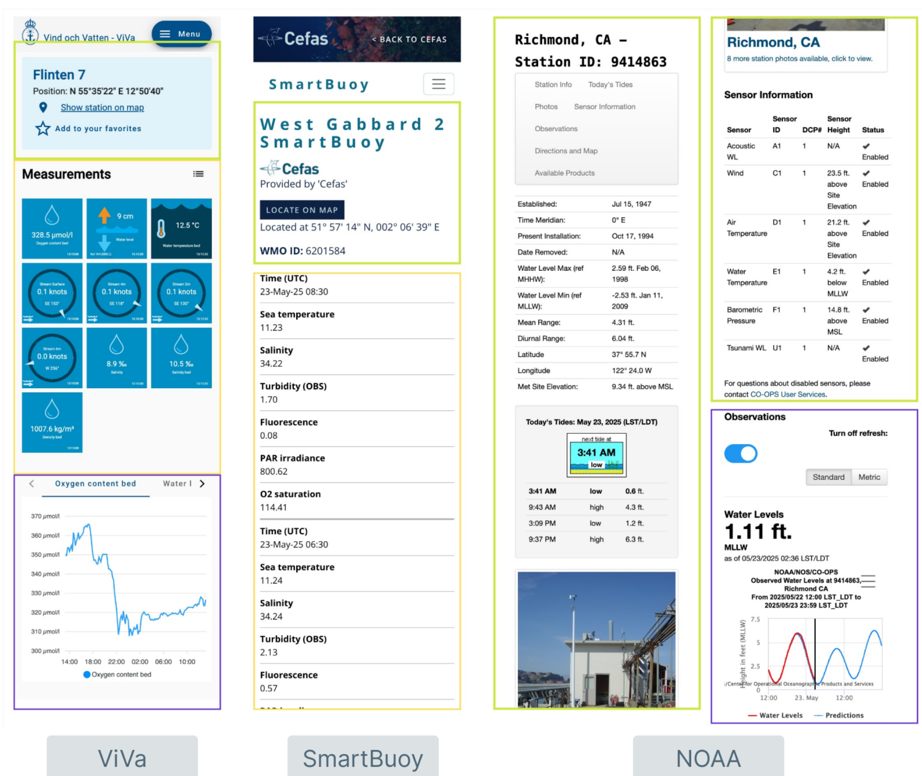

Fig. 8. Station pages for ViVa, SmartBuoy and NOAA. Green highlights station information, yellow measurements and purple plotted data.

On ViVa, measurements can be seen either in a tile-based layout or in tabular list view, while on SmartBuoy, the measurements are only available in a list. On NOAA, data can be only viewed as plots below the station information. On the other hand, ViVa presents data development in plots below the tiles and the plots for different parameters can be navigated through an in-page navigation. SmartBuoy does not offer this option.

8 First Iteration – Design

The design phase in HCD aims to produce design solution that meet user requirements through iterative prototyping (ISO, 2010; Maguire, 2001). The section begins with an overview of the dashboard design principles in Section 8.1, which guided structural and interaction choices, in line with Maguire (2001) recommendation to consult design guidelines early in the process. This is followed by the ideation process in Section 8.2. The first design iteration concludes with the development of a low-fidelity prototype described in Section 8.3, also marking the initial step toward answering the second research question, focusing on how to translate user requirements into a dashboard design.

8.1 Dashboard Design Principles

To inform dashboard design, Bach et al. (2022) present a summary of high-level design guidelines synthesised from numerous case studies, according to which a dashboard

> "should not overwhelm users; should avoid visual clutter; should avoid poor visual design and carefully chose KPIs; should align with existing workflows; should not show too much data; should have both functional features (i.e., what the dashboard can do) and visual features (i.e., how information is presented); should provide consistency, interaction affordances and manage complexity; and should organize [sic] charts symmetrically, group charts by attribute, clearly separate these groups of charts and order charts according to time" (p. 343).

However, as these guidelines predominantly stem from general knowledge on perception, visualisation, and information architecture, more specific guidelines are lacking. Therefore, building on prior dashboard research by Sarikaya et al. (2019), Bach et al. (2022) analysed 144 dashboards and identified eight groups of content and composition dashboard design patterns. Design patterns are reusable solutions to recurring design problems (Bach et al., 2022; E. F. Duarte & Baranauskas, 2016). The patterns that make dashboards unique focus on "abstraction of data, organizing [sic] of a screenspace, grouping of elements, showing relations (hierarchy, grouping, color [sic]), and the use of interaction for exploration, drilldown, navigation, or personalization [sic]" (Bach et al., 2022, p.350).

Additionally, Bach et al. (2022) identify six genres of dashboards within curated and data collection dashboards: (1) static dashboard, (2) analytic dashboards, (3) magazine dashboards, (4) infographic dashboards, (5) repository dashboards, and (6) embedded mini dashboards. In the context of this thesis, data collection dashboards (analytic and repository dashboards) are most relevant due to their focus on communicating large volumes of information or data, while allowing for users to find information according to their needs. As discussed in Section 3.3.2, Segel and Heer (2010) consider data collection dashboards as reader-driven storytelling. Analytic dashboards emphasises data visualisation, enabling for interactivity, exploration, navigation and drilldown, but also utilise parametrisation and tabs that allow for multiple pages while limiting scrolling. In contrast, repository dashboards allow for page overflow and regularly updated data and visualisations, but limit comparison or textual and narrative explanations (Bach et al., 2022).

Overall, the dashboard design process should be grounded in principles that reflect both user needs and the structure and functionality of dashboards. Drawing on the dashboard design patterns and genres described by Bach et al. (2022), the following updated guidelines should inform the design process, in which the designer should (1) consider design tradeoffs, (2) provide visual representation and information for the data, (3) provide meta information, (4) minimise overflow in analytic dashboards to support comparison, (5) emphasise key data and support personalisation, (6) use dashboard patterns relevant to the dashboard types and the audience, (7) use consistent colour scheme, and (8) opt for a layout most suited for the needed widgets, such as table or stratified structure (Bach et al., 2022).

Dashboard design involves navigating a series of tradeoffs between competing parameters such as screenspace, interaction, the number of pages, and the level of abstraction. The designer must make the decison which information not to show and whether the remaining information can be accessible elsewhere. Bach et al. (2022) propose a simplified model to balance these tradeoffs, illustrating that reducing one parameter, for example abstraction, typically necessitates increasing others, for example interaction or number of pages to maintain usability.

However, the tradeoffs can be reduced by using the right design patterns, in which layout is one of the most important considerations. To crate a good dashboard layout and structure, it has to prioritise information, for example by stratification, but it is also necessary to consider possible facets in data, and the tasks that the users perform across these facets, such as comparing the data. Using repetitive elements within components such as a number or trend arrow can help the users to interpret and retrieve information, while table layouts are ideal for similar or repetitive information (Bach et al., 2022) .

Finally, based on existing literature combined with own research and findings, Bach et al. (2022) suggest a four-part design framework for dashboards, that consist of "(1) knowledge in the form of guidelines, annotated examples, and design patterns; (2) tradeoffs that require discussion and decision making; (3) design processes; and (4) tool support" (p.349). This framework provides a structure for guiding both the conceptualisation and iterative development of dashboards, aligning with the HCD process in this thesis. However, what makes a good dashboard depends largely on subjective and domain-specific factors. Combining design knowledge and tradeoffs with user research allow for tailoring dashboard solutions even for complex domains such as communicating oceanographic data to the public.

8.2 Ideation

The first iteration of design commenced with ideation for possible concepts that meet requirements defined through user stories in Section 7.1. The main focus was to generate ideas on visualising and communicating real-time marine data collected through stations located in marinas around Europe and how to get alerted when they reach certain thresholds, through a new digital platform, specifically, a dashboard. As most of the participants indicated in the thematic analysis in Section 6.2 that a mobile phone is the dominant device used around the marina, sketches were created in a phone layout to reflect the actual usage contexts and inform future decisions about responsiveness.

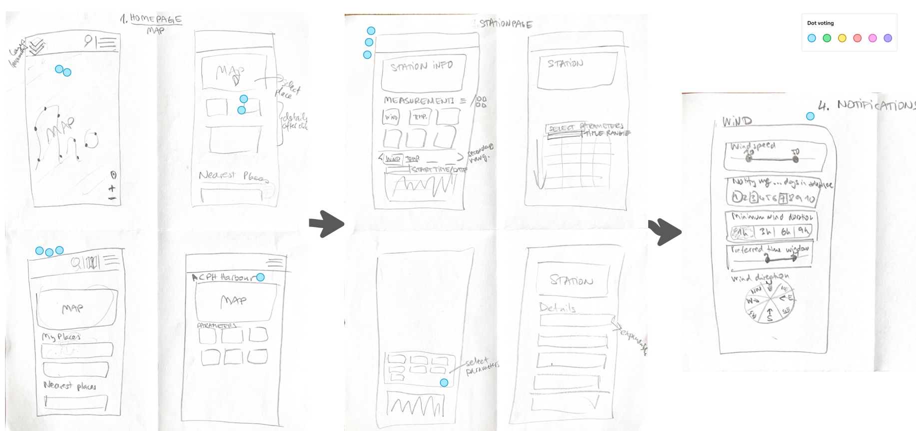

Fig. 9. Variation of sketches from the divergent sketching process, visualising ideas and voting on selected elements.

Combining parallel and iterative sketching on paper as a form of prototyping, described in more detail in Section 5.4.1, allowed for exploration of new ideas for the dashboard features following the dashboard design principles outlined in Section 8.1 while utilising design feature findings from the competitive review (Section 7.2). The explorative ideation process took place in two phases. In the

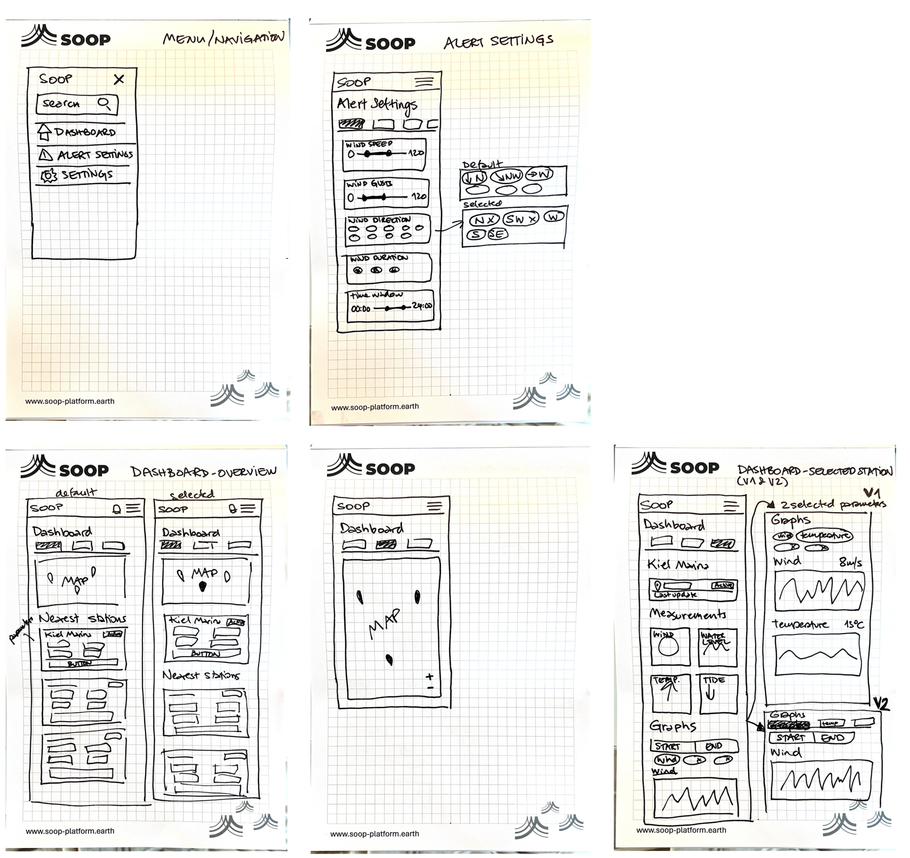

Fig. 10. Concise sketches from the convergent sketching process, visualising a navigation menu, alert settings, dashboard overview, a map view as well as two versions of a station page.

divergent phase, parallel sketching was utilised to generate numerous ideas to get the right design, as can be seen in Figure 9. This includes variation of tiles and boxes of the dashboard homepage, station page and alert settings. Generated ideas were placed on a Miro board[6] and then evaluated using dot voting. In the convergent phase of iterative prototyping, to get the design right, it was further narrowed down into more concise sketches, as visualised in Figure 10 (Camburn et al., 2017; Rojas, 2023). The outcome of this process was the generation of sketches containing a navigation menu, alert settings, a dashboard overview, a map view, as well as two versions of a station page. These served as a basis

[6] Miro board: https://miro.com/app/board/uXjVIt_QGKQ=/?share_link_id=302688091978

for developing a low-fidelity but interactive prototype in Figma in the following Section 8.3.

8.3 Low-Fidelity Prototype

The next step was to create a low-fidelity prototype. To ensure responsive design, a mobile-first approach was adopted for both sketching and prototyping. This decision is supported by findings from the thematic analysis in Section 6.2, in which most participants indicated that a mobile phone is the dominant device used around the marina. The prototype was created in the collaborative interface design tool Figma[7], utilising the sketches produced during the ideation process described in Section 8.2. Designing mobile-first enable scalable and consistent layout across devices, aligning with best practices for responsive design (Interaction Design Foundation - IxDF, 2016).

Concurrently, discussions with SOOP, the main stakeholder, informed the decision to conceptualise the prototype as a web-based application. This was identified as the most feasible and sustainable option to deliver the final solution. Whilst the implementation of the solution is beyond the scope of this project, the prototype was designed with a web-based application context in mind. This reflects both the stakeholder's lack of resources for the development and maintenance of a native application, as well as GEOMAR's existing technical infrastructure, where web platforms are already used in similar initiatives (Dutzi & Rickert, 2025).

While the prototype is designed with low fidelity in this early stage of development, in alignment with Stickdorn et al. (2018), it contains elements of a high-fidelity prototype, such as already added details and placeholders instead of plain boxes, as well as interactivity for better testing. As already indicated in Figure 10, the ideation of the station page and data visualisation in a plot resulted in two versions, which shall be further tested by users in the upcoming phase of HCD. That is due to two contradicting user stories, where one group of users wishes to only see the data selected and relevant to them, while the other wishes to easily compare various data in one place to gain better context.

> As a pleasure sailor, I want to be able to select parameters myself, so that I can only see information relevant to me.
>
> As a casual user, I want to have temporal context of data from the past or a comparison, so that I can better comprehend the data in the dashboard.

Both versions of the prototype contain five main pages navigation menu, alert settings, a dashboard overview, a map view, and a station page, however, the station page differs in versions A and B.

[7] Low-fidelity prototype in Figma: https://www.figma.com/design/n79fe3SPCJS7fmPu5nnfnU/Master-s-Thesis-%E2%80%93-SOOP?node-id=3102-1758&t=ORbJhT8Fcfw5N6RX-1

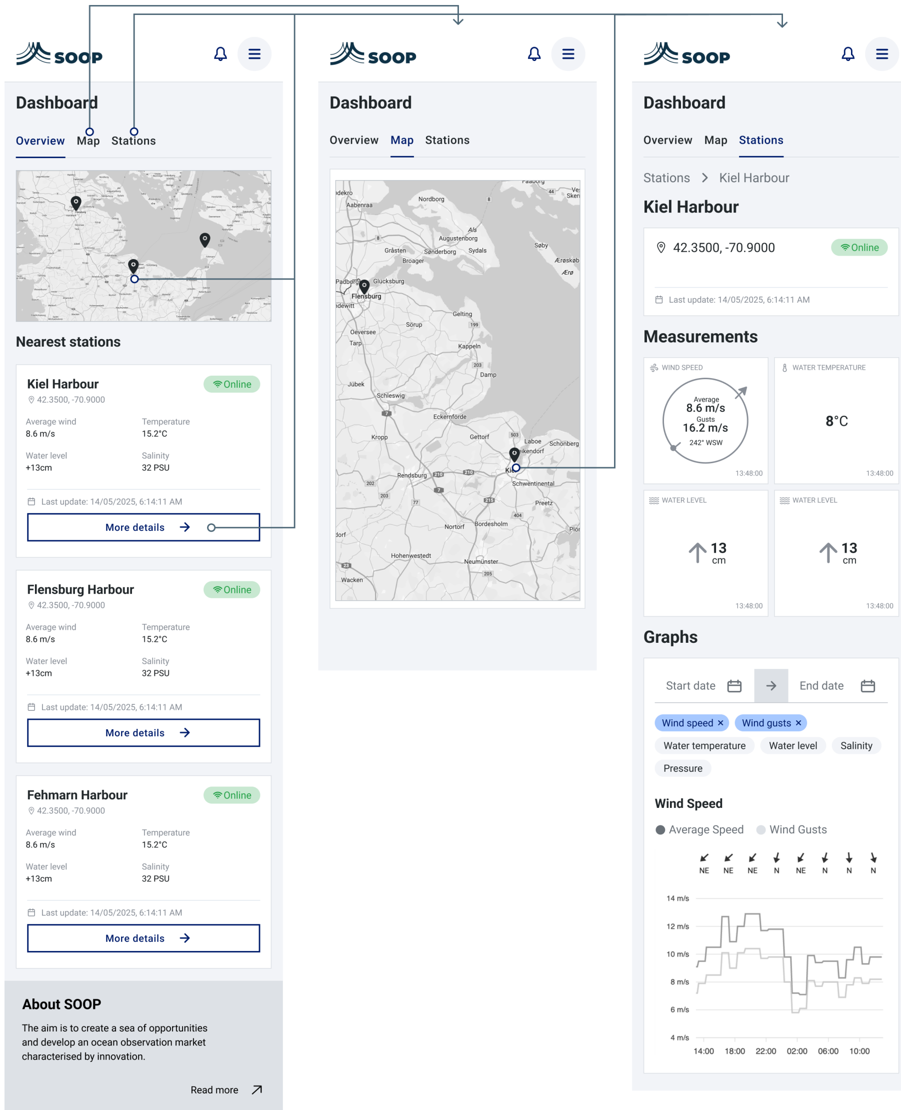

Fig. 11. Multiple-page dashboard of the first low-fidelity prototype consisting of overview, map and station pages.

8.3.1 Dashboard The multiple-page dashboard consists of three pages: an overview, a map and stations. These pages are accessible via the secondary navigation menu, as shown in Figure 11 (Bach et al., 2022). The overview provides all important information at a glance, including a smaller version of a map with pinned available stations, as well as cards with key information from nearby harbours and marinas. A map that covers almost the entire screen gives users the freedom to explore all the available stations. Lastly, the station page communicates basic marina and station information, detailed measurements collected by the station, as well as plots that allow for following the data development over time.

Version A presents a more exploratory interaction pattern combined with drill-down, where users can choose parameters to be visualised in plots by selecting dismissible chips, after which the plots appear below each other. This provides users with the desired context and options for comparison across data types in one place, however, there is a potential for visual clutter and cognitive load, particularly for casual users. Version B provides a cleaner look using in-page navigation to separate data types, where users can navigate and click between plot views. The simpler structure prioritises clarity over customisation, which may hinder the possibility of comparing more plots at once, but reduce overload Bach et al. (2022). The comparison of station page versions A and B can be seen in Figure 12.

8.3.2 Alert Settings Outside of the main dashboard, accessible through a hamburger menu, are alert settings. Here, users are able to set and configure alerts for individual parameters according to customised thresholds and settings. On an example parameter of wind, as visualised in Figure 13, the interface includes sliders for setting wind speed and gust limits, chips for selecting wind directions and minimum wind duration, and a time range selector to define preferred alert windows.

9 First Iteration – Evaluation

User-centred evaluation is an essential phase of the HCD process, and is used to test early designs against the specified user requirements and identify areas for improvement ISO (2010). The evaluation of the low-fidelity prototype described in Section 8.3 was performed in form of usability tests with five participants from the target user group. This section presents the usability test process in Section 9.1, how they were conducted (Section 9.2), and the evaluation results described in Section 9.3, which provided critical input for refining the prototype in the second design iteration.

9.1 Usability Testing

The low-fidelity prototype outlined in Section 8.3 was tested to identify usability issues. User-based testing was selected as the most suitable type of usability

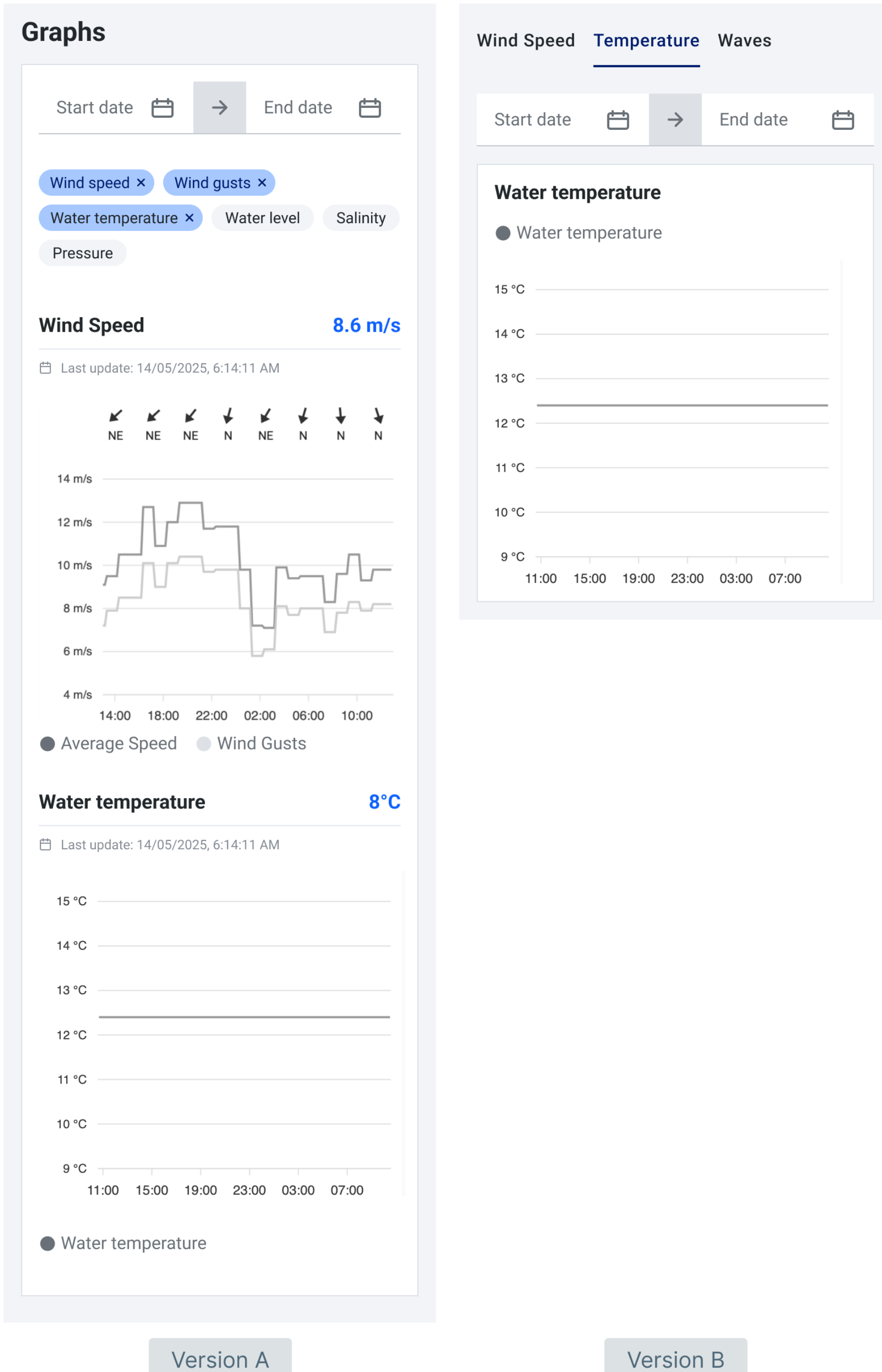

Fig. 12. Interaction variances of data visualisations between Versions A and B.

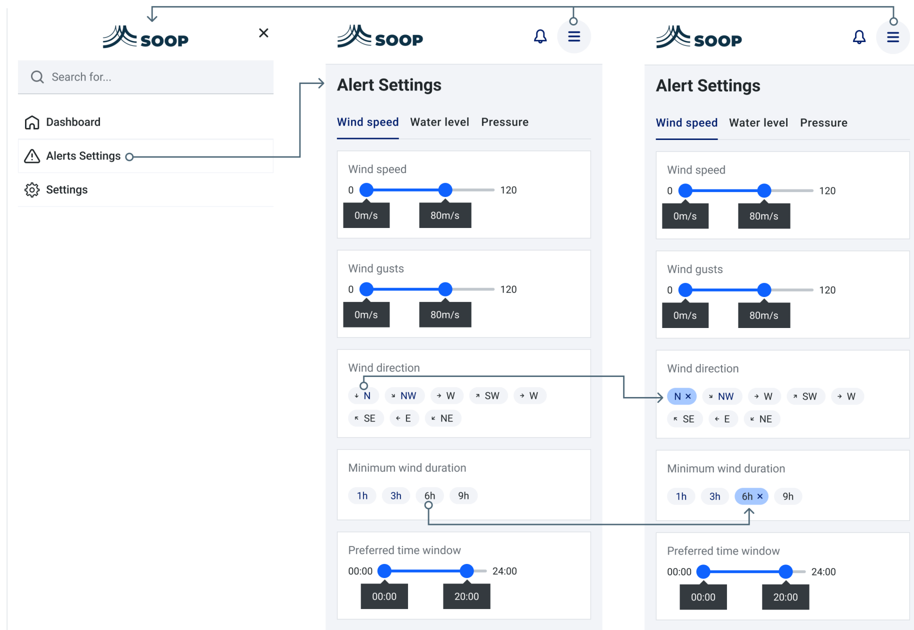

Fig. 13. Low-fidelity prototype of the alert settings.

testing for this thesis, as it focuses on users, which aligns with the HCD approach. Following the four-step process to prepare the usability test proposed by Goodman and Kuniavsky (2012a) described in Section 5.5.1, the initial step involves the recruitment of suitable participants who are representative of the target group.

The low-fidelity prototype can be considered a rather simple test with limited number of features. Therefore, this thesis adopts the recommendation of five users by Nielsen and Landauer (1993), who should identify the most significant usability issues at optimal cost-to-benefit ratios. Furthermore, the same purposive sampling method used for the interviews (see Section 6.1.1) was employed to select the right evaluators within the target group defined in Section 6.1.1. Five participants were recruited for the usability test, all of whom were male. The age of the evaluators ranged from 23 to 66, with an average age of 38.2. The nationalities of participants included two Italians, and one individual each from France, Denmark and Poland, with a background in sailing or other coastal activities, in addition to their familiarity with marinas across Europe.

In order to conduct the usability evaluation, the second step is to select features that are to be tested (Goodman & Kuniavsky, 2012a). The low-fidelity prototype (Section 8.3) focuses primarily on real-time data visualisation in a dashboard and the configuration of alerts, which are therefore also the features to be tested in this evaluation. In the third step of the process, tasks representative of typical user activities are created. Goodman and Kuniavsky (2012a) states that tasks should be reasonable, described in terms of end goals, specific, doable, in a realistic sequence, domain neutral, and have a reasonable length. Applying these principles to this thesis, three tasks were created for version A of the low-fidelity prototype. As version B differs mainly in terms of navigation on the station page, only one of these tasks was repeated when testing the second version. The tasks are described in more detail in Section 9.3 of the test evaluation.

The fourth step in this process is the creation of a script or discussion guide. The evaluation structure followed a list of instructions, consisting of an introduction, a preliminary interview, evaluation instructions, tasks during which probing questions may be asked, and a wrap-up (Goodman & Kuniavsky, 2012a). Due to the nature of the test objectives in exploratory evaluation, a set of open-ended questions was asked during the wrap-up after the tasks were completed to hear the participants' reactions to the prototype versions and their final thoughts (Dumais, Jeffries, Russell, Tang, & Teevan, 2014; Goodman & Kuniavsky, 2012a). The usability test discussion guide available in the Miro board[8] and in the Appendix C.

9.2 Conducting the Usability Test

Moderated approach to testing was selected to carry out the test, as opposed to automated. This allows the moderator to ask questions during the evaluation and monitor the evaluator's reactions (Goodman & Kuniavsky, 2012a). The test should take place in a setting and contexts in which people typically use the product (Goodman & Kuniavsky, 2012a). Four of the tests were conducted online with participants attending from their homes (one of whom lives on a boat), and one test was conducted in person at the marina. This aligns with the context of use identified in the thematic analysis in Section 6.2, where participants indicated that they mostly use the applications to access relevant information while at home or directly at the marina. As the low-fidelity prototype is designed with mobile-first approach, the tests were conducted on mobile devices to allow for the intended interaction. During the online tests, participants were required to join scheduled meetings with their mobile devices. The software used for the tests was Microsoft Teams as it allows for real-time sharing of screen and audio. The participants then completed tasks in the Figma prototype while thinking aloud. During the audio-enabled screen sharing session, the moderator could ask additional probing questions.

[8] Miro board: https://miro.com/app/board/uXjVIt_QGKQ=/?share_link_id=302688091978

9.3 Evaluation of the Usability Test

The usability evaluation is structured according to the three tasks for version A[9], and one task for version B[10] of the low-fidelity prototype. After completing each version, participants were asked a set of evaluative questions. To conclude the session, summarising questions were asked to gather feedback on both versions and wrap-up. The three-stage process, as articulated in Section 5.5.1, was utilised to evaluate the usability tests conducted. To collect observations, the video recordings were uploaded to Dovetail for transcriptions. The observations, including relevant quotations, were then arranged in a Miro board[11] under the respective tasks, evaluations, and wrap-up. Additional subsequent categories emerged within, such as marina information or plot issues. Grouped observations were afterwards categorised in singular flaws, resulting into a prioritised list of flaws in Section 10.

9.3.1 Task 1 The first task aimed at exploring whether and how users can navigate from the overview page to the station page and locate desired temperature data in a plot, as the access to the plot differed in versions A and B:

> "Imagine you want to know what is the development of the water temperature in a plot in Kiel harbour. Try to navigate to the place where you can find this."

To finish the first task, the users had to arrive at a plot of water temperature, located at the bottom of the station page. In version A, that is done by selecting a dismissible chips and the plots appear below each other, while in version B the users can navigate between plots using in-page navigation. The difference can be seen in Figure 12.

Once landing at the station page in version A, four out of five users (UT1, UT2, UT4, and UT5) attempted to access the temperature plot by clicking on the temperature tile under the measurements. UT4 said that "one thing is to see what it is now and the next is what is the development. So again here I would like to be able to tap that one and get the graph". While all users located the dismissible chips and found the water temperature plot afterwards, UT1,

[9] Version A of the interactive low-fidelity prototype in Figma: https://www.figma.com/proto/n79fe3SPCJS7fmPu5nnfnU/Master-s-Thesis-%E2%80%93-SOOP?node-id=3110-2819&t=iHF7z3d7ApNtQZxw-1&scaling=scale-down&content-scaling=fixed&page-id=3102%3A1758&starting-point-node-id=3110%3A2819&show-proto-sidebar=1

[10] Version B of the interactive low-fidelity prototype in Figma: https://www.figma.com/proto/n79fe3SPCJS7fmPu5nnfnU/Master-s-Thesis-%E2%80%93-SOOP?node-id=3131-35195&t=tc92HF6kTFVwPvAc-1&scaling=scale-down&content-scaling=fixed&page-id=3102%3A1758&starting-point-node-id=3131%3A35195&show-proto-sidebar=1

[11] https://miro.com/app/board/uXjVIt_QGKQ=/?share_link_id=302688091978

UT3, and UT5 did not expect the plot to appear below the currently visualised plot, as UT3 pointed out: "it is not so intuitive to scroll down to see the water temperature". UT1 added, that by using dismissible chips for selecting variables, they expect them to appear and disappear within one plot and would prefer all variables in one plot, and UT5 shares the same opinion. In contrast, UT4 preferred the plots below each other as it allows for better comparison of data: "that is nice because sometimes when you pick one, then you lose the other one".

In version B, locating the plot appeared to be much smoother process and the in-page navigation is preferred by all users in comparison to version A with dismissible chips. Once at the in-page navigation, UT3 expressed their relief: "Ah, it is better! It is really more intuitive completely". While UT5 does not see much of a difference to version A, UT4 prefers version A as they can see the plots below each other to understand what they are looking at. However, UT4 admits "it would be more understandable for the user if you change between them, because otherwise you could get confused what you are looking at if you have everything on top of each other".

9.3.2 Task 2 The aim of the second task was to let users locate a place where they can set up parameter-relevant alerts:

> "You want to get alerted when the wind speed exceed specific limit for a specified duration of time so that you can go to the marina and secure your boat. Navigate to the place where you can do that."

To complete the second task, users were required to navigate to the alert configuration page to set up an alert for the wind, which could be accessed via the hamburger menu, present on all pages. However, it is important to note that the first task concluded on the station page, and thus, all users initiated the second task from this location.

As a first step, UT2, UT3, and UT5 expected to be able to set up an alert in the wind plot or the measurement tile: "I would try to click on wind speed and get information into that, including an alert" (UT2). UT3 added "So if I have the wind like this, maybe, you know, like on the right of graph, maybe set an alarm, like to just have it written. Set an alarm. Something in this page". In contrast, UT1 and UT4 anticipated that the alert settings would be located under the bell icon for notifications: "ah, there is a bell up at the top that will be an alarm setting, I guess" (UT4). After some exploration of the prototype, four users landed on the alert setting page, however, UT1, UT2, and UT3 noted that the access through the hamburger menu is not intuitive.

When configuring the alert parameters, UT5 brought to attention that it does not indicate whether an alert is already set up or not: "I want a confirm button, because I am not sure whether the app is processing something. There will be something that shows up when I click. [...] How do I know that I already have the alert set up?". Additionally, UT1 and UT5 wished to configure the alerts for a specific location relevant to them, rather than general settings. Overall, four users managed to locate the alert setting page, while UT2 failed on the second task.

9.3.3 Task 3 The third task focused on general exploration of the interface and on assessing whether users access station data through textual information or a map interface:

> "Try to explore data from other stations, not only Kiel marina, think aloud what you expect to see and if you encounter some limitations."

This task is of an explorative nature, and therefore has no exact success criteria. The focus was rather to observe users' behaviour, to understand how they navigated the interface when searching for information, and to verify the usability of the implemented user stories. It has become apparent that a map is a very popular option to do this exploration. UT1, UT3 and UT4 enjoy zooming in and out the map to roam around to get desired overview and more details on stations they are interested in. In the map preview on the overview page, UT5 mentions "I like the function on the overview where you click on the map and below it shows you the station, I don't want to scroll".

An expected functionality that has not been prototyped but expressed by UT3 is that the list of harbours below the map preview on the overview page would dynamically change based on the stations currently visible in the map preview. Drawing from their user experiences with other systems, UT1 would like to access more information directly in the map after tapping the pin: "I would expect a small pop up around the spot with some info, like some tool tips," and UT3 adds a suggestion for an indication of which stations are available, online or functioning by the colour of the pin.

9.3.4 Evaluation and Wrap-Up To evaluate versions A and B of the prototype, participants were asked three questions aimed at understanding their overall impression of the interface, the ease of navigation and whether they were missing any information:

> "What was your impression of the interface and the screens you just saw?"

> "How easy was it for you to navigate through, particularly the station page and the plot?"

> "Was there any information you expected to see on the screen that was not included?"

At the very end of the usability tests after both versions had been tested, two questions were asked to wrap-up and conclude the session:

> "Which version did you prefer?"

> "How easy to understand the measurement details and plot navigation?"

In terms of likeability of the prototype and its content, the participants emphasised they enjoy to see the development of the parameters (UT1, UT4) as well as the possibility to see more parameters in a single plot such as wind and wind gusts (UT1, UT4). They further appreciated the incorporation of a green tag to indicate whether the availability of the station (UT2, UT3, UT4), and a precise timestamps when the data were recorded (UT2, UT4). UT5 liked the map preview function on the overview page, where selecting a point in the map displays more information below the map without the need for scrolling. Furthermore, the participants liked the possibility to select the start and end time of the visualised data (UT4, UT5). UT2 highlighted the list of stations below the map preview on the overview page that provides an overview of the most important information.

Upon landing on the interfacte, UT5 expressed a concern that it takes a few seconds to realise what the interface is actually about, not realising it is about real-time data at first. UT1 expressed a wish for more guidance and help how to use the interface that would enable them to feel as safe as possible:

> "For example, a water level is too high. Like if I can see that like 13 centimeters for this harbour is like is it actually dangerous or is it just fine. [...] so it tells you what the data mean. Maybe on the site it is like green or red and maybe on the side there is like an alert sign or there is like a thumbs up or something. So I can at least compare and have an understanding of what the number means."

A lot of feedback was gathered about the box containing station and marina information at the top of the station page, as this elicited a considerable degree of interest and engagement from participants. Alongside the real-time conditions in the marinas, the participants also expressed a desire for more comprehensive information about each marina, highlighting two main categories of missing content: information about accessing marina and practical details.

In terms of marina accessibility from the sea, participants requested contextual data that would help assess whether the marina is safe and navigable under specific conditions. For example, UT2 and UT5 noted the importance of understanding whether a marina is protected from dominant wind and current directions, and whether there are limitations based on tidal or water level changes. UT5 elaborated, "so, for example, that you cannot really enter this marina in these hours because, you know, the water level is too low or something". UT2 further emphasized the need for technical specifications such as draft clearance and beam limitations, explaining that "if you combine information with the water level and the tide and your clearance, then you know if you can get in or not". They also mentioned the significance of knowing how wind conditions behave inside the harbour, as well as having access to a harbour map indicating depth zones and berth sizes.

In addition to access-related information, participants emphasised the value of practical marina details. UT1 and UT4 noted that the GPS coordinate currently displayed is not particularly useful for regular users and are more suited for scientific purposes. Instead, they recommended integrating contact information for the harbour master, Google Maps links, and details about the harbour office, including its location and opening hours. UT4 also suggested adding links to national or local weather authorities for further forecasts as a complement to the real-time data. Including the country name to avoid confusion between similarly named marinas in different countries was also suggested (UT4). UT2 proposed providing an overview of available facilities such as fuel stations, water access, and bathrooms. Ideally this overview would be displayed on an interactive map. Moreover, they noted that showing berth availability, nightly prices based on boat length, and even linking to a booking form would represent “the holy grail” (UT2) of marina information.

Overall, the users expressed preference to minimise unnecessary scrolling within the interface. UT2 specifically noted redundancy between the information presented on the overview page and the measurements section of the station page, as well as the need to scroll to access the plots, and suggested streamlining the interface to show detailed content directly on the station page. In terms of data visualisation, UT3 and UT4 recommend improvements to the plots. Using the water level plot as an example, they proposed integrating historical real-time data, forecasted values, and tidal information within a single visual representation to enhance interpretability. Despite these suggestions for improvement, participants generally found the prototype intuitive and easy to navigate (UT2, UT3), with UT2 describing it as solid in its simplicity.

10 Second Iteration – User Requirements

As part of the iterative HCD process, the second iteration of user requirements was conducted. During this iteration, new requirements were created based on the insights gathered from usability testing of the low-fidelity prototype (ISO, 2010). The results are summarised into a prioritised list of interface flaws to further refine the prototype with new user requirements.

10.1 Prioritised Interface Flaws

During the usability tests, all five participants expressed a clear preference for the navigation structure presented in version B[12]. Additionally, four out of five participants were not satisfied with the necessity to scroll to see more plots.

[12] Version B of the interactive low-fidelity prototype in Figma: https://www.figma.com/proto/n79fe3SPCJS7fmPu5nnfnU/Master-s-Thesis-%E2%80%93-SOOP?node-id=3131-35195&t=tc92HF6kTFVwPvAc-1&scaling=scale-down&content-scaling=fixed&page-id=3102%3A1758&starting-point-node-id=3131%3A35195&show-proto-sidebar=1

Based on this feedback, the in-page navigation from version B was selected to substitute the dismissive chip option to select plots in the version A.

To support this iteration, a structured list of prioritised interface flaws was developed based on observations and feedback collected during the usability tests. The list contains issues that users experienced while completing the tasks, such as difficulties in navigating to alert settings, interaction problems on the station page, or redundant content. All issues and user expectations were first mapped in Miro board[13] and further refined into a structured table containing 14 interface flaws.

The prioritisation of these flaws was guided by Jakob Nielsen's severity ratings for usability problems. The rating evaluates severity of the issues based on their frequency, impact, and persistence (Nielsen, 1994). Accordingly, two factors were used to assess each flaw, the number of participants affected (frequency) and the severity of the flaw's impact on the user interaction, ranging from cosmetic to minor and major usability problems. Based on the frequency and severity criteria, a priority level was identified for each issue ranging from high to medium and low. The priority level indicates the urgency with which the flaws should be addressed in future design iterations. The final prioritised list of interface flaws is presented in Table 2.

11 Second Iteration – Design

The second design iteration builds on findings from the usability evaluation and addresses the prioritised interface flaws in order to result in the final low-fidelity prototype. As part of the HCD process, this phase involved refining the prototype to better meet user requirements, directly contributing to answering the second research question. Section 11.1 outlines the ideation process that informed design refinement, while Section 11.2 introduces the updated and final low-fidelity prototype.

11.1 Ideation

The ideation process for the second iteration was grounded in the prioritised list of interface flaws (Table 2) identified through the usability evaluation (Section 9.3). Using Figma[14] as the workspace, interface flaws were mapped to their corresponding pages within the prototype. The flaws were colour-coded by priority, red for high, yellow for medium, and green for low. An visual example of the process can be seen in Figure 14. Ideation began with high-priority issues and progressed through medium to low-priority ones. For each flaw, solution ideas

[13] Miro board: https://miro.com/app/board/uXjVIt_QGKQ=/?share_link_id=302688091978

[14] Ideation in Figma: https://www.figma.com/design/n79fe3SPCJS7fmPu5nnfnU/Master-s-Thesis-%E2%80%93-SOOP?node-id=3287-14550&t=ORbJhT8Fcfw5N6RX-1

Table 2. Overview of identified usability flaws with frequency, severity and priority.

Interface Flaw	**Frequency**	**Severity**	**Priority**
Non-clickable parameter tiles (expected plot interaction)	4	Major	High
Unintuitive access to alert settings via burger menu	3	Major	High
Unexpected redirection from map pins to station page without preview	2	Minor	Medium
Scrolling required to access multiple plots	4	Major	High
Redundancy between overview and station page data content	1	Minor	Medium
Missing date in timestamp and unnecessary seconds	1	Cosmetic problem	Low
Alert settings not clearly linked to plot or parameter tiles	3	Major	High
Lack of confirmation or feedback after setting alerts	1	Major	High
Unclear interface for setting range-based alerts	1	Minor	Medium
Desire for station-specific alert customisation	2	Minor	Medium
Lack of zoom targeting and visual interactivity on map	1	Minor	Low
Missing visual indicators of station status on map pins	1	Cosmetic problem	Low
Lack of onboarding or contextual guidance	2	Major	Medium
Missing unit preferences (metric/imperial)	1	Cosmetic problem	Low

were written down and design alternatives were created utilising design inspiration from open-source design libraries such as dribbble.com as well as findings from the competitive review (Section 7.2). This approach allowed for rapid iteration and visual exploration of solutions to first resolve the most critical usability problems. The decisions resulting from this ideation process informed the improvements to the first prototype, which are then reflected in the updated final low-fidelity prototype, described in detail in the following Section 11.2.

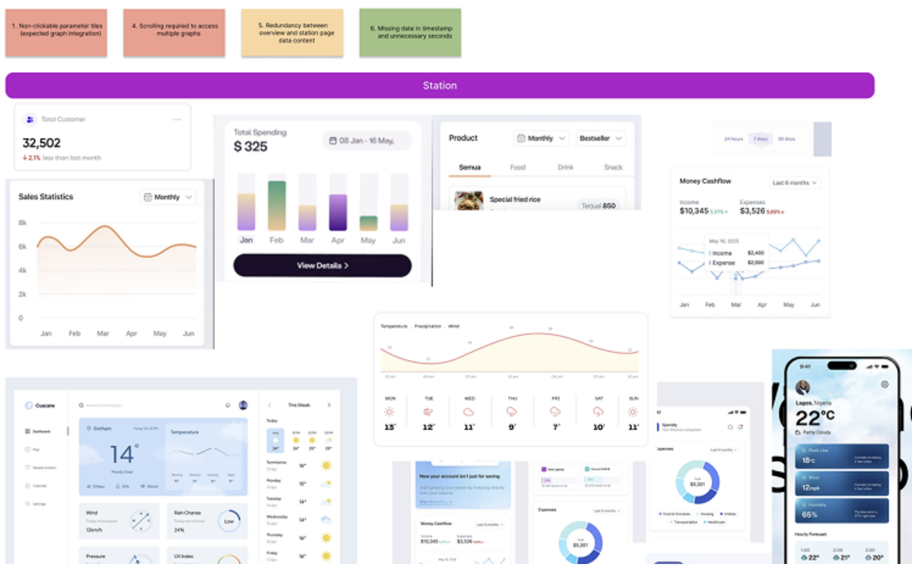

Fig. 14. Example of the ideation process for the station page improvements. Relevant prioritised interface flaws are located in the top left corner, red marking high, orange medium and green low priority.

11.2 Final Low-Fidelity Prototype

The final low-fidelity prototype of the SOOP dashboard builds upon insights from earlier research, including thematic analysis (Section 6.2), competitive review (Section 7.2) and usability testing (Section 9.3), to iteratively refine the first low-fidelity prototype based on identified user needs and interface flaws. The final prototype integrates these findings across four main interface areas, (1) the overview, (2) map, (3) station, and (4) alert settings pages. Each page was redesigned to address the interface flaws identified during usability testing (Table 2) and to align with the dashboard design principles outlined in Sections

3.3 and 8.1. The prototype can be accessed in the Figma file[15] and explored in an interactive prototype[16].

The guidelines set by Bach et al. (2022) served as a theoretical foundation for guiding structural decisions, interaction logic, and layout strategies, helping to ensure that the dashboard supports both exploration and monitoring tasks typical in environmental data platforms. The following sections describe each part of the final prototype, the patterns they reflect, and the specific interface flaws they resolve.

The SOOP dashboard can be characterised as a hybrid data collection interface that combines design patterns from both analytic and repository dashboard genres, as defined by Bach et al. (2022). From the analytic dashboard genre, it adopts complete visualisations of data development and integrates interactive elements that support user-driven exploration. From the repository dashboard genre, the SOOP dashboard incorporates page overflow where necessary, such as on the overview and station pages. This is in contrast to screenfit, which is used in analytic dashboards, and, for example, on the map page. While the overflow page structure can complicate the comparison of charts, a challenge also raised by UT1, UT2, UT3, and UT5 in the usability test, a tabbed in-page navigation structure was introduced in this iteration on the station page (Section 11.2.3) to mitigate this issue and enhance comparison. Additionally, in alignment with the repository dashboard patterns, the dashboard displays meta information including the last update timestamp across the dashboard and continually updated data visualisations. To complement complete data visualisation patterns from the analytic dashboard, simplified indicators such as trend-arrows are used to aggregate data and accommodate varying levels of data and visual literacy (Bach et al., 2022; Sarikaya et al., 2019).

The dashboard is composed of multiple pages, with tabbed navigation serving as the primary navigation within the interface. It follows a hierarchical page structure, enabling users to drill down to more details, for example, from the overview page or preview on a map to a specific station page. The widgets are arranged in a stratified layout, however, this is not as readily apparent in the prototype due to the mobile-first approach adopted in the design process. The header includes a notifications icon and a burger menu. In the first low-fidelity prototype, the burger menu was used to access alerts, however, this was removed following usability testing (Section 9.3). As a result, the burger menu currently has no assigned function and is considered out of scope for this iteration. It

[15] Final low-fidelity prototype in Figma: https://www.figma.com/design/n79fe3SPCJS7fmPu5nnfnU/Master-s-Thesis-%E2%80%93-SOOP?node-id=3368-21043&t=ORbJhT8Fcfw5N6RX-1

[16] Final interactive low-fidelity prototype in Figma: https://www.figma.com/proto/n79fe3SPCJS7fmPu5nnfnU/Master-s-Thesis-%E2%80%93-SOOP?node-id=3368-21137&t=KyLrpyXYEbOBJSKO-1&scaling=scale-down&content-scaling=fixed&page-id=3287%3A7759&starting-point-node-id=3368%3A21137

may be repurposed in future versions to support settings or personalisation features.

11.2.1 Overview Page The overview page, as can be seen in Figure 15, was refined to include a dismissible informational banner below the in-page navigation, offering a brief contextual introduction for first-time users. This feature addresses the the interface flaw "lack of onboarding or contextual guidance" by clearly stating the purpose of the dashboard, which is providing real-time local marine data. In addition, a short section about the SOOP platform is located at the bottom of the page. Description of what the dashboard is showing supports narrative framing through lightweight storytelling components, when communicating the data.

Further, the page contains an interactive map preview showing location pins with sensor stations. Even though the prototype is low-fidelity, semantic traffic light colour scheme was applied to indicate the availability or non-availability of the sensors. Below the map, users can see nearest stations based on the current map preview, which change dynamically with adjusting the preview. While this functionality is not available in the low-fidelity prototype, it is designed with the intention to do so, supporting the expectations of UT3. The nearest station component contains parameter highlights that are measured at the specific station, availability of the station, last update meta data as well as option for more details, leading to the station page (Section 11.2.3).

11.2.2 Map Page The map page was redesigned to introduce a pop-up preview when selecting a station pin, resolving the flaw "unexpected redirection from map pins to the station page without preview". This enhancement, visible in Figure 16, provides users with detail-on-demand interaction, which supports user control by offering previews before deeper navigation, in this case to the station page (Bach et al., 2022). The pop-up preview contains the same information as the station component used in the overview page, leading to the station page when the more details button is clicked.

Following the same pattern as in the preview map on the overview page, visual distinction between online and unavailable stations has been made through colour-coded icons, addressing the flaw "missing visual indicators of station status on map pins". Although real-time map interactivity, such as zoom-level-dependent filtering, is not implemented due to the nature of the low-fidelity prototype, this functionality is expected in the future in line with exploration strategy. To suggest interactive zoom functionality, plus and minus icons were added to the map interface, resolving the flaw "lack of zoom targeting and visual interactivity on map". On mobile devices, this interaction would typically be supported through native gestures such as pinch-to-zoom.

11.2.3 Station Page Multiple major usability flaws were identified on the station page in the first iteration, which therefore underwent multiple refine-

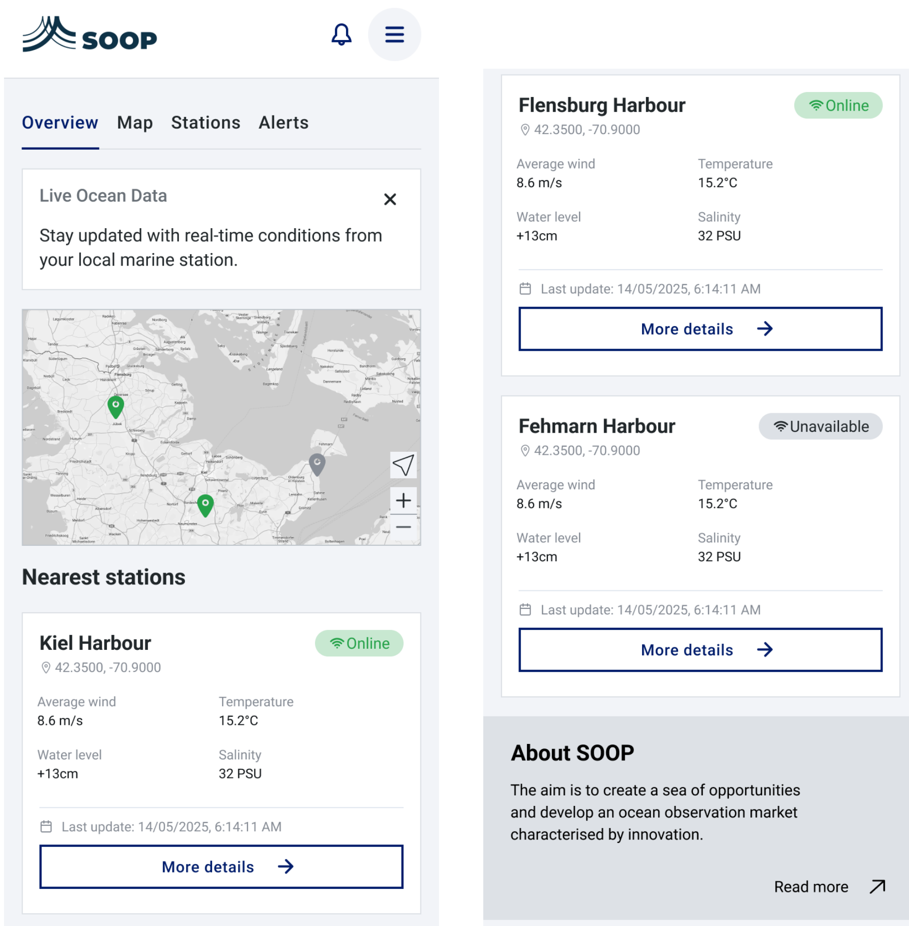

Fig. 15. Final prototype of the overview page with a dismissible informational banner.

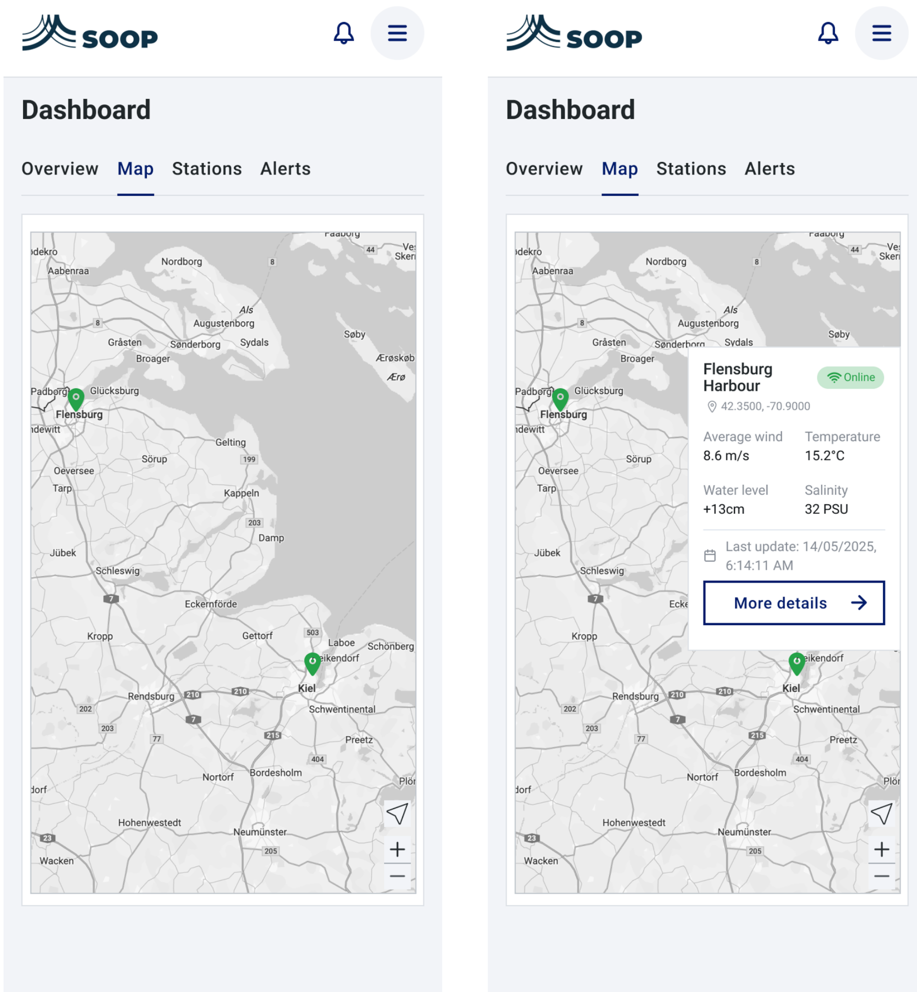

Fig. 16. Final prototype of the map page with a pop-up.

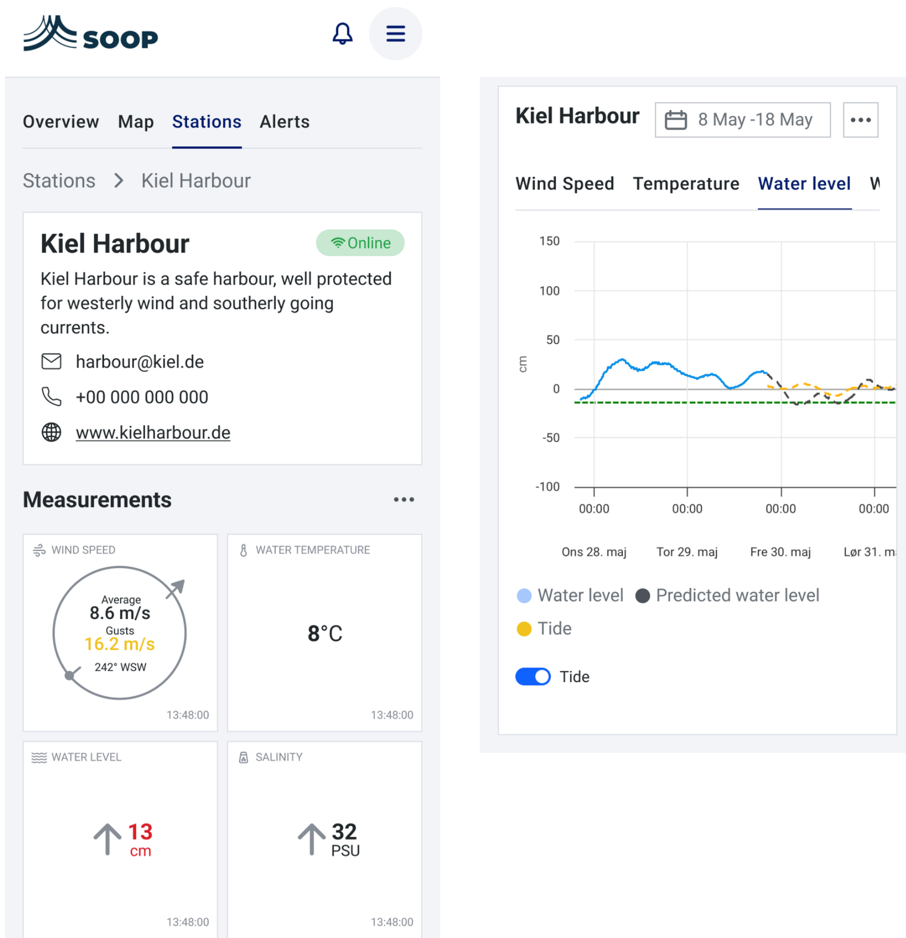

Fig. 17. Final prototype of the station page with added marina details and improved navigation.

ments. The final version of the station page after the second iteration can be seen in Figure 17. Parameter tiles such as wind speed and water temperature are now clickable and linked to the respective charts below, resolving the flaw “non-clickable parameter tiles”, in line with navigation through links and detailed data exploration (Bach et al., 2022). The time format inside of the tiles was simplified by removing seconds and adding full timestamps including a date, as indicated in the flaw “missing date in timestamp and unnecessary seconds”. Colour-coding shall be used in high-fidelity prototype to indicate when the parameters reach thresholds higher than usual to provide context to inexperienced users, tapping into the flaw of “lack of onboarding or contextual guidance”.

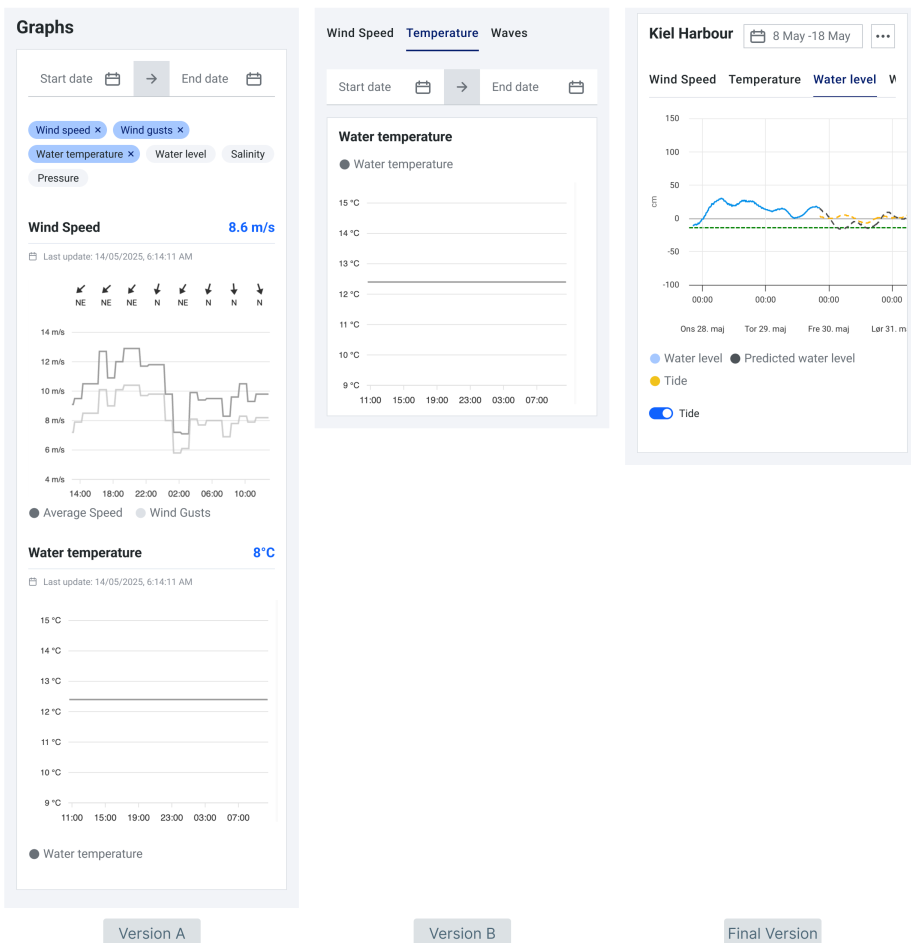

Fig. 18. Comparison of version A, B and the final prototype of the in-page navigation and data visualisation on the station page.

In addition, the data visualisation area was redesigned. Version A from the first low fidelity prototype (Section 8.3) was discarded and substituted with version B. This adaptation addressed the flaw “scrolling required to access multiple plots”. The in-page navigation from version B was adapted into a final component version, using tabs for different parameters such as wind speed, temperature and water level. The comparison of the final version with versions A and B is available in Figure 18. Now this widget also includes selective time range for the visualised data in which users can configure a filtered time frame (parametrisation), as well as overflow menu to access and set alerts for each parameter individually, answering the flaw “alert settings not clearly linked to plot or parameter tiles”. Moreover, on the example of water level parameter, the chart visualises the past measured water level, forecasted water level in gray, optionally combined with tide activated through a toggle button, as expressed in usability test by UT2, UT3, and UT4.

Not particularly an interface flaw, but UT1, UT2, UT4, and UT5 have indicated a significant demand for additional information regarding the marina in which the sensor station is located. Therefore, the most desired information was added to the top widget, including the best harbour approach conditions from the sea and contact details for the marina.

11.2.4 Alert Settings Pages Alerts, as a subject to Task 2 in the usability test, was the most unsuccessful task in the test and therefore many changes had to be made. The updated alert setting process is visualised in Figure 19. Firstly, due to the demand indicated by the participants, access to alert settings was made more intuitive by creating a new alerts tab and integrating it directly into the main dashboard navigation bar, replacing the previously unintuitive access via the burger menu, identified as a flaw. Alerts can be also accessed through the station page (Section 11.2.3).

Second, the interface now contain a confirmation button to provide confirmation after alerts are set, resolving the previously reported flaw “lack of confirmation or feedback after setting alerts”. To set an alert, users can now select location and parameter for the alert, added in response to the flaw “desire for station-specific alert customisation”. This redesign reflects parametrisation and personalisation patterns. For example, when setting a parameter alert for wind, users can select the wind speed and gust threshold, as well as the preferred time window for receiving alerts and notifications, using double-dot sliders. Furthermore, users can select the desired wind direction and minimum wind duration at the indicated threshold strength before receiving an alert, using chips. Once an alert has been set up, it will appear under active alerts, where the users can edit the settings using the settings icon, further allowing for setting another alert and alert deletion as well.

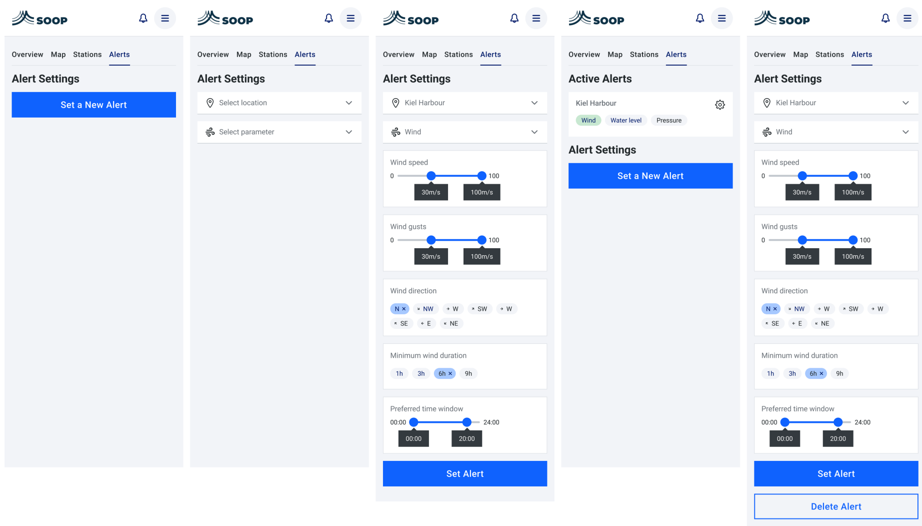

Fig. 19. Process of setting alerts in the final prototype.

12 Results

The outcome of this thesis is the final improved low-fidelity, yet interactive prototype of the SOOP dashboard, presented in the previous Section 11.2. This prototype was developed by following the HCD process iteratively, building on user insights gained from interviews and usability testing with non-expert users. The final low-fidelity prototype that meets user requirements is therefore the result and solution of the HCD process (ISO, 2010).

This section presents the answers to the two research questions raised at the beginning of the project, focusing on the user requirements for a dashboard and translation of those into the final low-fidelity prototype.

12.1 Research Question 1

What are the user requirements for a dashboard that communicates scientific ocean data to coastal communities and non-expert audiences?

To answer the first research question, user requirements were identified through two iterations of multiple HCD process phases that directly involved the users. In the first iteration, semi-structured interviews were conducted with seven participants representative of the target audience, including sailors, marina users, and coastal community members (see Section 6.1). Drawing from the thematic analysis of the interviews, the findings were then synthesised into user stories, described in Section 7.1. Section 7 provides a detailed description of the first iteration on user requirements, specified through user stories that informed the first version of the low-fidelity prototype in Section 8.3.

To refine the initial set of user requirements, usability testing was conducted on the first prototype with five participants representative of the target audience (see Section 9.3). Additional user requirements emerged during the second iteration of user requirement specification, which were summarised in a structured list of 14 prioritised interface flaws, as detailed in Table 2. These flaws served as new requirements for the second iteration of the design, which resulted in the final low-fidelity version of the prototype. The combination of user stories and the prioritised list of interface flaws defined the user requirements for the SOOP dashboard, which communicates scientific ocean data to non-expert audiences, thereby answering the first research question.

12.2 Research Question 2

How can user requirements be translated into a dashboard design that improves the accessibility and usability of real-time ocean data?

In order to answer the second research question, user requirements informed the design decisions made during two iterations of the HCD process design phases, with the aim of creating a dashboard prototype. The first low-fidelity prototype (see Section 8.3) focused on the core functionalities identified through the user stories, applied to an overview page, a map view, a station page with real-time data, and alert settings. The design layout was created with the results of competitive review and the dashboard design principles in mind. Version A[17] and version B[18] of the first prototype were evaluated through five user-based usability tests, described in Section 9.3. The tests revealed multiple interface flaws, including unintuitive navigation, lack of confirmation after setting alerts, and difficulties accessing plots. Prioritised list of said interface flaws was used to inform a second design iteration.

The final low-fidelity prototype, as can be viewed if Figma[19] and detailed in Section 11.2, addressed the identified usability issues and incorporated features such as interactive parameter tiles to support drill-down exploration, tabbed

[17] Version A of the interactive low-fidelity prototype in Figma: https://www.figma.com/proto/n79fe3SPCJS7fmPu5nnfnU/Master-s-Thesis-%E2%80%93-SOOP?node-id=3110-2819&t=iHF7z3d7ApNtQZxw-1&scaling=scale-down&content-scaling=fixed&page-id=3102%3A1758&starting-point-node-id=3110%3A2819&show-proto-sidebar=1

[18] Version B of the interactive low-fidelity prototype in Figma: https://www.figma.com/proto/n79fe3SPCJS7fmPu5nnfnU/Master-s-Thesis-%E2%80%93-SOOP?node-id=3131-35195&t=tc92HF6kTFVwPvAc-1&scaling=scale-down&content-scaling=fixed&page-id=3102%3A1758&starting-point-node-id=3131%3A35195&show-proto-sidebar=1

[19] Final interactive low-fidelity prototype in Figma: https://www.figma.com/proto/n79fe3SPCJS7fmPu5nnfnU/Master-s-Thesis-%E2%80%93-SOOP?node-id=3368-21137&t=KyLrpyXYEbOBJSKO-1&scaling=scale-down&content-scaling=fixed&page-id=3287%3A7759&starting-point-node-id=3368%3A21137

navigation to reduce scrolling, contextual alert settings with confirmation feedback, and improved map interaction. The dashboard structure now reflects a hybrid of analytic and repository dashboard genres, supporting both real-time data monitoring and user-driven exploration. The final low-fidelity prototype result demonstrates how a dashboard design grounded in user research and guided by design patterns can lead to a more accessible and usable dashboard interface for communicating real-time ocean data to the public, thereby answering the second research question.

13 Discussion

This thesis addressed the following problem statement:

> How can marine environmental data be effectively communicated through a digital platform to support public understanding and engagement with coastal data?

While SOOP already supports the development of a coastal monitoring network and collects real-time environmental data, no platform currently exists to present this data to the public, including sailors, marina users, and other members of coastal communities. Two research questions were formulated based on the problem statement with the purpose of conducting research to address the identified gap and to support public understanding and engagement with local coastal data. The first question focuses on defining user requirements for a dashboard that communicates ocean data. The second question investigates how to translate these requirements into a dashboard design that is accessible to a non-expert audience. The research followed the iterative HCD process, guided by the principles of ISO 9241-210, to identify user needs that inform the final design solution.

Following an initial project planning phase, the context of use was explored by conducting semi-structured interviews, which were then analysed by thematic analysis. User roles were then identified, requirements specified and further refined through usability testing, which identified interface flaws that were used to drive the second design iteration. This process uncovered varying user needs and contexts based on different types of user segmented into user roles and how these users complete the identified needs through search modes. The theoretical foundation for this lies in the search and discovery framework with four dimensions of search experience defined by Russell-Rose and Tate (2013c), consisting of users, their goals, the context, search mode and associated models within those dimensions. Furthermore, a connection can be drawn between the four types of users in information seeking presented by Jenkins et al. (2003), and the novice–expert distinction by Sarikaya et al. (2019) and Bach et al. (2022). This distinction suggests that the user's data visualisation literacy, domain experience, and context influence the information retrieval process and the way the data are explored in order to be understood. Information behaviour and the need to find and understand context-specific data with varying levels of context knowledge and ability to interpret data emphasised by Matheus et al. (2020) is also supported here, as many participants described differences in how they use such data depending on whether they are at home planning or at a marina preparing to leave.

To accommodate these contextual variations, the dashboard developed during two iterations of the design phase reflects the principles of *exploranation* coined by Ynnerman et al. (2018) that bridges expert and non-expert understanding of the scientific data. Design decisions were grounded in dashboard genres and design patterns identified by (Bach et al., 2022), according to which the SOOP dashboard follows a hierarchical page structure that allows for drilling down to more details (Bach et al., 2022). The prototype combines elements of both analytic and repository dashboards, providing time series visualisations for exploration while maintaining updated data and simplified visual cues for broader accessibility. The application of design patterns such as parameterisation, tabbed navigation, and metadata display helped address several usability issues identified in the usability test and created a solution tailored to the users' needs. However, some tradeoffs were inevitable. While tabbed navigation and overflow structures improved data access and comparison, they may also increase interface complexity and limit overview at glance, especially on mobile screens or for less experienced users.

Overall, the thesis proposes a dashboard solution as a way to communicate scientific data to the public and enhance understanding and engagement with the marine environmental data. The prototype serves as a first step toward establishing SOOP's future digital platform grounded in user research, ready for further development.

13.1 Implications

The outcome of this thesis have several implications both for dashboard design, public engagement with scientific data, and environmental resilience. The prototype proves that extensive marine environmental data that are often scattered across complex platforms designed for scientists and expert users can be translated into a clear, accessible format tailored to non-expert users. In doing so, it contributes to SOOP's mission of enabling more open and equitable access to ocean data and supports its broader efforts to address the triple planetary crisis of climate change, biodiversity loss, and pollution.

Due to communication of real-time data, the dashboard has the potential to support actionable decision making in vulnerable coastal areas. In the interviews, several participants described increasingly unpredictable weather patterns, such as out-of-season and unpredictable storms that can rapidly change sea conditions. In this context, the purpose of the dashboard extends beyond informing users to potentially enhancing safety and disaster preparedness, for example, in case of unexpected storms by helping sailors make safe and timely decisions about their boats or alerting coastal inhabitants of rising sea water levels. In this sense, the collection and communication of oceanographic and climate-relevant data not only contribute to ocean modelling simulations such as weather and climate forecasting, but also directly support the daily lives and safety of those affected by environmental change.

In terms of design implications, the use of dashboard genres and patterns from Bach et al. (2022) provided a practical framework for effective and streamlined dashboard design to communicate real-time scientific data. The combination of analytic and repository dashboard genres offers a hybrid data collection dashboard type for similar platforms seeking to support both deeper exploration and quick overviews. Finally, by grounding design decisions in user feedback and dashboard guidelines, it presents how HCD methods can be effectively applied in the domain of ocean and environmental data communication.

13.2 Limitations

Several limitations of this thesis should be acknowledged in terms of terminology used, research and design choices as well as time constraints.

13.2.1 Terminology and Data The terminology used throughout the thesis, such as environmental, marine, ocean, and coastal data, was applied interchangeably to reflect the range of SOOP's data collection. However, this prototype focuses primarily on nearshore data collected in marinas relevant to coastal communities, including atmospheric and water parameters. Data processing and technical aspects of backend integration were outside the scope of the project.

13.2.2 Research Limitation The user research conducted in this thesis focused exclusively on one of SOOP's four use cases, the coastal communities, with a particular emphasis on sailors and marinas. Although the participants were selected from multiple European countries that reflect SOOP's expansion plans, the sample size was relatively small, and some coastal community members could be underrepresented. Additional perspectives from casual charter sailors, swimmers, fishers, and marina operators in the relevant countries would be valuable due to their relevance to SOOP's target audiences.

The competitive review included three direct competitors, however, all were national initiatives, and no pan-European platform equivalent to SOOP was identified. Although such system may exist, they have not been uncovered in this review.

Additionally, due to the lack of publicly available research on dashboards or data visualisation for science communication of ocean or related data, no comparable systems were included in the literature review. While this may represent a gap, it also highlights the novelty of this project. Instead of directly evaluating existing dashboards, the design was informed by established dashboard guidelines and best practices, particularly those outlined by Bach et al. (2022), who summarised previous dashboard research and added analysis of a wide range of dashboards across domains.

13.2.3 Prototype Limitation The prototype created in this project is a low-fidelity design with selected high-fidelity elements. It is clickable and includes realistic content, but does not yet reflect the final user interface design that includes visual identity of SOOP. The purpose of the prototype was to test core functionality and user experience. Although the prototype establishes a basis for a future system, it is important to note that it is a design concept, rather than a final user interface.

13.2.4 Time Limitation Time was a main limiting factor in this thesis, particularly in relation to design iterations and evaluations. With a longer timeframe, further usability testing and refinement could have been conducted to strengthen the prototype as well as to transform it into a high-fidelity prototype. More time would also have allowed for additional design iterations and broader testing, together with designing fully responsive prototype versions for desktop and tablet use based on the mobile-first approach presented in this thesis.

While SOOP was actively engaged in the planning phase, time constraints did not allow for more extensive stakeholder involvement during the design phase to carry out more collaborative design activities, such as co-design workshops. Additionally, analysing the volume of qualitative data such workshops produce would have required more time and resources than were available. As a result, the design process focused primarily on user-based input rather than a co-design approach.

13.3 Future Work

Several areas for future work emerged throughout the HCD process. Future work could focus on further HCD iterations that would lead to developing a high-fidelity, fully interactive version of the prototype. In addition to user-based testing, expert evaluations could provide more insights into technical feasibility and viability of the system, to prepare the solution for development.

Additional input and alignment with SOOP and other stakeholders, including the harbour authorities, has the potential to inform the interface design, as well as strategic aspects and new features such as monetisation models, subscription-based features, or admin views for managing marina-specific data. These additions would allow the dashboard to evolve into a scalable platform that serves both public users and SOOP's business partners.

Future studies could involve larger participant pools to cater for all four SOOP use cases, incorporating not only qualitative but also quantitative methods such as surveys distributed through the SOOP network across countries and user groups. Due to the international aspirations of SOOP, future iterations could explore multilingual support, responsive layouts for larger screens, user-configurable dashboards to cater for varying data needs across countries and user roles. Furthermore, the inclusion of storytelling or educational components to further enhance public engagement with ocean and environmental data.

14 Conclusion

The aim of this thesis is to investigate how marine environmental data can be effectively communicated through a digital platform to support public understanding and engagement with coastal data. In response to this problem, two research questions were defined. The first research question focused on identifying user requirements for a dashboard that communicates scientific ocean data to coastal communities and non-expert audiences. The second examined how those requirements could be translated into a usable and accessible dashboard prototype.

To answer these questions, the project followed the HCD framework. The solution that has been designed in order to meet the requirements of the users is a functional prototype. This was achieved through a structured yet iterative process involving interviews, thematic analysis, competitive review, prototyping, and usability testing. The first iteration revealed key insights into user needs, goals, and contexts of use, which were synthesised into user stories that informed the first low-fidelity prototype. Usability testing of the initial prototype uncovered interface flaws, which were then prioritised and addressed in a second design iteration, resulting in a refined final low-fidelity prototype.

The final prototype implements important design patterns for dashboards, including interactive plots, in-page navigation, contextual alerts, and real-time data previews. It supports different modes of user interaction, ranging from exploration to monitoring, and accommodates various levels of visual and data literacy. The outcome demonstrates how design decisions guided by user input and established dashboard design principles can improve the accessibility and usability of ocean data for non-expert audiences.

In conclusion, this thesis provides a concrete and research-based design solution that addresses the current lack of a public-facing platform for SOOP's real-time ocean data observations. It demonstrates how HCD methods can be effectively applied to support the user-centred design of environmental data platforms. The prototype presented here serves as a foundation for further development and implementation of SOOP's future digital interface.

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List of Appendices

Appendix A: Literature Approval

Appendix B: Interview Transcripts and Audio Recordings

Appendix C: Usability Testing Transcripts and Video Recordings

Note: The appendices B and C are submitted as a separate attachement titled "Appendices – Master's Thesis".

A Literature Approval

28/05/2025, 10:00 Email - Aneta Bejsakova - Outlook

Outlook

Re: Literature Approval for Master Thesis

From Florian Maximilian Meier <fmeier@ikp.aau.dk>
Date Wed 28/05/2025 09:52
To Aneta Bejsakova <abejsa23@student.aau.dk>

Dear Aneta
Your literature list is hereby approved. Please attach this approval along the submission of your thesis.
Best,
Florian

Dr. Florian Meier
Department of Communication & Psychology, Aalborg University Copenhagen
A.C. Meyers Vænge 15 | 2450 Copenhagen SV, Denmark | Room: 3.006
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On 28 May 2025, at 07:28, Aneta Bejsakova <abejsa23@student.aau.dk> wrote:

Dear Florian,

Please kindly see the attached literature for your approval.

Kind regards,
Aneta Bejsakova
<Bejsakova_Literature approval.xlsx>

https://outlook.office.com/mail/inbox/id/AAQkAGFiMjcwMmVhLTk3NjgtNDMyNS04M2E4LTY5MDA0ZTg2NjhmZQAQAO1lsZ5viPBJh0trPOoaQAk%3D 1/1

B Interview Transcripts and Audio Recordings

The Appendix B is submitted as part of a separate attachement titled "Appendices – Master's Thesis". It contains:

- Interview Guide
- Interview Transcripts
- Interview Video Recordings

C Usability Testing Transcripts and Video Recordings

The Appendix C is submitted as part of a separate attachement titled "Appendices – Master's Thesis". It contains:

- Discussion Guide
- Usability Testing Transcripts
- Usability Testing Video Recordings