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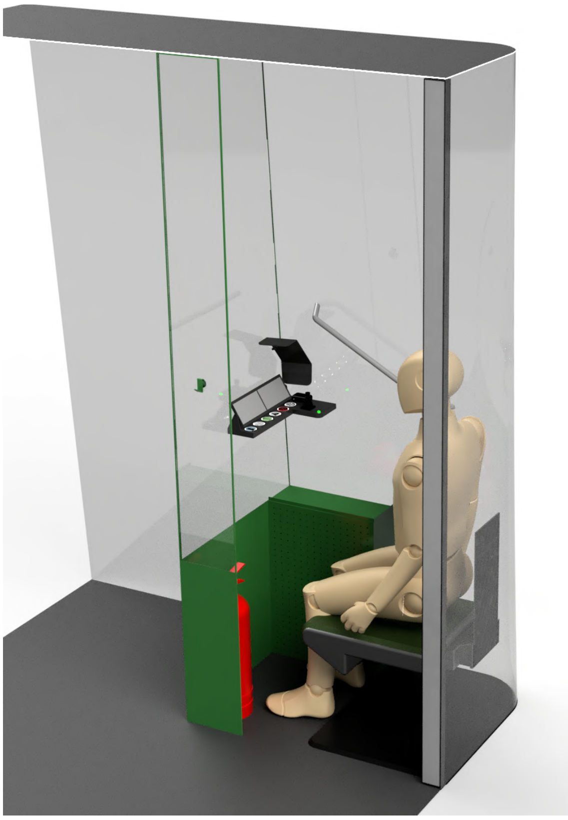

Design of the Ship Officer's Bridge for Autonomous Electric Water Shuttles

A collaborative project between Chalmers University of Technology and CStrider AB

Master's thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

This project is conducted to design an area that ensures the safety and comfort of the ship officer and the passengers on CStrider's boats. The main objective is to provide a concept for the ship officer's bridge that CStrider AB can use as a basis for future development and testing.
The project utilizes an approach that includes multiple steps to achieve said objective. A planning and preparation phase was conducted to frame the project, analyze competitors and identify stakeholders. This research helps identify necessary parameters for the development of the space.
Based on the findings from the previous phases, two concepts emerge from a concept generation and elimination phase that are presented to CStrider. One concept is developed with comfort as the main factor and the other with space-saving as the main factor. An additional concept for the counting system that does not include the space is also presented. After revising said concepts, they are prototyped at actual scale using low-resolution materials in CStrider's workshop. Testing candidates are brought in to the workshop to perform some role playing scenarios where they pretend to be a ship officer as they board passengers, utilize their space, and lastly, deboard the passengers. Feedback is given from the candidates and analyzed.
After the feedback from the conducted tests, a final concept emerges which is a combination between the comfortable concept and the space-saving concept to reach an optimal design. The result includes a space that contains adjustable seating, a standing mat, a dashboard with large buttons with decals and embossed labels as well as adjustable screens, a visor over the dashboard, storage for personal items and lastly, a handle. The space is contained by a front wall that has an L shape which is mainly transparent but opaque up to the height of the locker as well as a paneled emergency door that folds into the corner when not in use. A hook is placed on the outside of the L extension to provide the ship officer the ability to hang wet clothes or accessories. Lastly, an FMEA is performed to identify potential failure modes in the components that the concept consists of.
The outcome from this project can be used as a foundation by CStrider to further develop their optimal ship officer space and recommendations for the future are presented. Recommendations include further steps that CStrider can take to validate the result of the project, as well as recommendations of alterations to the final design to lower the costs if desired.

Keywords: Autonomous boats, product development, user-centered design, ship bridge

Foreword

We feel privileged to have been able to work on this project and would like to express our gratitude to a few key people. To begin, we acknowledge and thank the entire CStrider team for the opportunity to be a part of their product development, and for the responsiveness and support given along the way. Our supervisor, Tobias Husberg, gave us full creative freedom to explore the solution space, while providing invaluable expertise to aid us.

We would also like to thank our supervisor, Lars Almefelt, at Chalmers University of Technology. His detailed feedback and thorough evaluations of our work have been priceless in the effort to produce the best work possible.

Lastly, to every interviewee and test user, we thank them for their time and willingness to provide insightful information that was directly used in our decision-making process.

Katie Richmond, Aya Salih, Gothenburg, June 2024

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

CAD	Computer Aided Design
FMEA	Failure Mode and Effect Analysis
RPN	Risk Priority Number

Contents

1

Introduction

This chapter introduces the foundation of the project. Some company and problem background is given, followed by the project structure. The objectives, limitations, and methodology are discussed.

1.1 Company Background

CStrider AB is a startup company founded in 2023, that has been in the works since 2017[1]. Their company was founded after identifying the issue that cities with major waterways through them heavily underutilize the potential of rivers, bays, and archipelagos, in terms of commuting. For example, although the most efficient method of passenger transportation is over water, Stockholm has less people using boats now compared to a hundred years ago[2]. CStrider identified the need for a modernized, eco-friendly take on waterborne transit that can be utilized in both urban and rural contexts[3].

One of CStrider's visions is to reduce large congestion areas in major waterway cities by running frequent, efficient water shuttles throughout cities. Congestion and traffic in cities with waterways often concentrate around bridges and access points for getting across the water. Traditional ferries hold a lot of passengers, however they do not always circulate quickly, and may not be based out of the most convenient locations. By identifying patterns within traffic routes, CStrider aims to enable the possibility of what they call "virtual bridges" by running shuttles back and forth across the waterway to alleviate the bottleneck found at physical bridges[1].

Their product, shown below in Figure 1.1, is a 3x8 meter boat that will hold 12 passengers and any bikes, baby carriages, or other cargo that they may have. Although the goal is for the vessels to be primarily autonomous, a class VIII ship officer will still be on board for emergency scenarios and passenger ease of mind. The ship officer's bridge space was the focus of this project.

Figure 1.1: Rendering of the conceptualized shuttle in development at CStrider[1].

1.2 Problem Description

The bridge of a ship is the area that the captain typically mans the ship from. This space includes the steering equipment, navigation charts, communication systems, controls, and other features[4]. The complexity and layout change dependent on the size of the vessel, but the basic functions are included regardless of scale, though scaled down on smaller boats[5].

Autonomous driving on boats is implemented in different levels depending on the vessel size and driving context. According to the International Maritime Organization[6], the four degrees of autonomy for vessels are:

i Degree one: manned ship with some automated processes and supported decision making. With some automated operations, and sometimes unsupervised, seafarers are still on board to take control of the vessel.

ii Degree two: a remotely controlled, but manned, vessel. Controlling the vessel is done remotely, but seafarers remain on board to take control of the ship's functions and systems.

iii Degree three: a remotely controlled, unmanned, vessel. No one is on board, and the vessel is controlled remotely.

iv Degree four: a fully autonomous vessel. No one is on board and the ship is capable of its own decision making and process control.

Autopilot features on boats can be used to keep the vessel on a pre-determined course set with the navigation controls[7]. Autopilot technology is also now able to aid in docking the boat, which is often considered one of the most challenging parts of driving boats [8][9].

The bridge, or helm, area of the vessel was the focus of this project. The task was entirely open-ended as this is not an existing product, so the exact nature of the ship

officer's needs and wants was explored. The unknowns varied from details such as dashboard layout, seating options, passenger visibility, and proximity to emergency equipment. The role of the ship officer changes during automated operation, manual operation, emergency mechanical operation, or emergencies such as evacuation and "man overboard" scenarios[1].
Depending on the intended level of autonomy for the CStrider vessels, the requirements of the bridge will vary. Requirements for each level needed to be met, while ensuring that the solution for one level didn't encroach on the needs of another. Finding a solution to balance these needs was one of the challenges for this project.

1.3 Research Questions to be Explored

Unique challenges arise when tackling a problem as open-ended as this one. They present the opportunity for a wide-range of solutions and possibilities, but can also be overwhelming to narrow down to a manageable scope. When tackling such a broad problem it is important to formulate appropriate research questions in order to aid with converging onto a solution that effectively meets the needs of the end-users. Starting broad ensures that no solutions are excluded from the beginning, but narrowing the scope throughout the design process is necessary to manageably tackle the problem. The following questions were explored throughout this research:

- How will the bridge of an autonomous vessel differ from that of a traditional manned bridge?
- How will the needs of the ship officer vary during differing levels of vessel autonomy?
- How will the tasks and responsibilities of the ship officer vary during differing levels of vessel autonomy?
- What bridge design aspects contribute to passengers' sense of safety and comfort? (e.g. open view to the bridge vs. closed wall)
- How can the bridge design be adapted to ensure that safety laws on vessels are followed?

The focus of this project was the experience of the personnel on board and how they interact with the space around them. With that in mind, both physical and cognitive ergonomic theory were considered. Specifically, the Universal Design Principles acted as guidelines for the design decisions that were made. The Universal Design Principles are comprised of the following seven aspects: equitable use, flexibility in use, simple and intuitive, perceptive information, tolerance for error, low physical effort, and size and space for approach and use[10]. These principles were created to aid designers in ensuring that their work is accessible for everyone, regardless of their physical or cognitive capabilities. These principles are often used specifically in accessible design in considering those with disabilities, however the ergonomic theory behind the principles is important for all designers to follow. In considering the ergonomic aspects, the following research questions were be explored:

- How can the comfort of personnel be prioritized without sacrificing safety?
- How can the layout and design of the bridge contribute to ease of use for ship personnel that may not have years of experience?

1.4 Purpose and Objectives

The purpose of this project was to design an office bridge that ensures the safety and comfort of the ship officer and the passengers. This project showcased the methodology involved with narrowing down a broad initial subject, as well as the tools used to evaluate brainstormed ideas.
The objectives for the project were divided into primary and secondary objectives, the former being the prioritized objectives to fulfill and the latter being of lower prioritization. The primary objectives were:

- Provide a concept that facilitates safe boat operation practices
- Adapt the bridge design to accommodate the different levels of autonomy

The secondary objectives were:

- Identify and design for the ship officers different roles during the varying operational modes and emergency scenarios
- Consider sustainability aspects in the design and aim to reduce environmental impact
- Demonstrate the feasibility of the final bridge design through relevant testing methods

1.5 Scope

The scope of the project included the functions and layout of the space, but not necessarily to full detail. The navigation and steering controls, for example, were discussed in terms of their operational requirements (e.g. ergonomic, intuitive, level of complexity), but were not designed from scratch. Rather, their placement in the space and the functions they must fulfill were explored.

1.6 Limitations

Prototyping was done at actual scale, but using low-resolution materials due to budget limitations and expectations from CStrider. In order to stay time-, and budget-efficient, CStrider will not physically produce a detailed prototype until after this project concludes. Due to the low-fidelity prototypes, some exact functionality needed to be sacrificed, but were discussed with the test-users for their feedback. Nevertheless, there was a limitation to the amount of design iterations that could be done to receive feedback from users due to the time limit of the project, which was 20 weeks.

1.7 Assumptions

Expanding CStrider's reach is a priority for the future, however initial launching is projected for Sweden, specifically Gothenburg. Therefore, any weather considerations were based on Gothenburg's climate. With that being said, the future

expansion efforts were kept in mind and design decisions were avoided that may be an issue in other locations.
Although CStrider has planned for a variety of possible use-cases after launching, two in particular were the main focus of this project. First was that of the vessels being a part of public transportation. As such, any functionality or requirements that come with being a part of public transit were based on information received from Gothenburg's Västtrafik operators. The second use-case was that of the "virtual bridge" concept. Consideration were taken for the fact that the vessels may be in operation 24/7 which led to extra concern regarding functionality such as cabin lighting, or personnel comfort.
As the use-case that was focused on was that of urban transport, it can be assumed that the vessels are always relatively close to the shore, and that they are not alone on the water. This is particularly relevant when considering emergency situation circumstances.

1.8 Methodology

The overview of methodologies used throughout this project are presented in this section and visualised in Figure 1.2. The methods and activities presented in the diagram are based on *Product Design and Development* [11]. The bullet points in black are methods or tools, and the bullet points in red are activities. The project was divided into multiple phases, the first one being the planning phase. A planning report was made to establish the scope and key activities of the project, as well as creating a general time plan for the semester ahead. The second phase was project preparation which includes activities such as competitors analysis and requirement specification to collect and define information to use as a basis for the upcoming phases. The third phase was concept development and elimination which includes methods like brainstorming and utilizing a morphological matrix to create and combine separate ideas to whole concepts, and Pugh matrices to eliminate certain concepts. After this phase, two concepts remained and they were modelled in CAD. The fourth phase comprised of prototyping and testing which includes rapid prototyping and the prototypes that emerged from that were tested and updated. The fifth phase includes detailed design which is a final updated design which is visualized in a refined CAD model. The sixth and last phase is validations and ramp-up which includes recommendations for future development as well as reflection on the final concept.
The overarching philosophies that lay behind this project are those of lean product development and frugal engineering. Frugal Engineering is the ideology of creating quality products that consume fewer resources and at a lower cost [12]. Start-up companies such as CStrider do not typically have the capital and financial security of larger, established companies and their success often hinges on their ability to make money-saving decisions[13]. Frugal engineering and lean development are intertwined, sharing principles such as prioritizing user needs and maximizing value with minimal resources[14]. The principles of lean product development are to be as efficient as possible, reducing any waste in the design process such that time, money, and physical resources are used as effectively as possible. At the core of this philos-

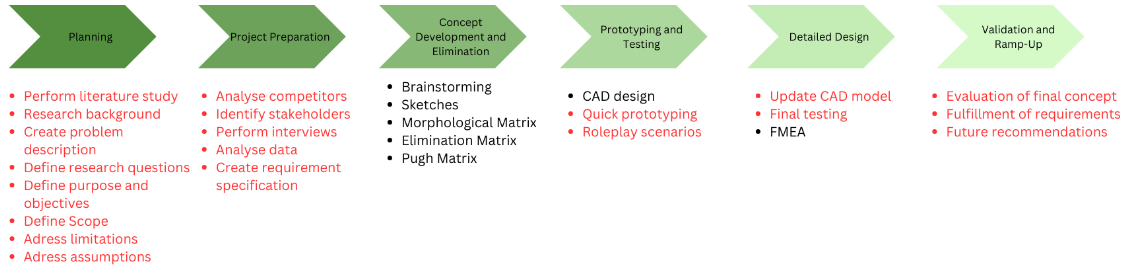


Figure 1.2: Diagram of design process with key activities and methods of the project.

ophy is the notion of testing to *learn* rather than testing to *validate*. The traditional long-form development process includes designing, building, and then testing to validate while a lean approach begins with testing to learn, and then designing, and building effectively the first time with this strong knowledge base[15]. Equipping yourself with as much information as possible on the front-end of the process reduces risk of failure once time and money has been put into building something. Considering both the discrete time frame of this project, as well as the money-saving goal of CStrider, these intertwined philosophies were present throughout this project.

1.9 Reading Guide

The remainder of this report consists of 7 chapters. The next chapter details the first phase of the product development process, Project Preparation. A brief competitor analysis is discussed, followed by a description of data collection and conducted interviews. Lastly, the requirement specification is laid out and leads into the next chapter.
Chapter three relays the Design Process, beginning with a description of the concept generation. Next, the concept evaluation procedure is detailed including a discussion on each of the matrices used.
Chapter four, Prototyping & Testing, explains how the prototypes of the proposed concepts were developed and what the resulted in. It is followed by a description of the testing of the prototypes, as well as what insights were gathered from the tests.
Moving on to chapter five, Final Concept, the decided proposed concept is presented. All decisions around the concept are explained in detail. The result of a Failure Mode and Effect Analysis is presented as well as a evaluation on if the requirements presented in chapter two are fulfilled.
Chapter six, the Discussion, is where all reflections and speculations throughout the project are discussed. It consists of speculative "what if?" questions, what worked great and what didn't, as well as unforeseen challenges.
Chapter seven is the final concluding chapter of the whole report. The main findings and takeaways are summarized in this chapter. It provides a perspective on the success of the project, and future recommendations for the company are made.

2

Project Preparation: Data Collection and Defining Needs

In this chapter all of the ground work was laid out for beginning the design process. The current market landscape was assessed, stakeholders were identified, and competitive advantage was discussed. Interviews were conducted with participants with a wide array of expertise. Using all of the acquired knowledge, a requirements list was created.

2.1 Exploration of Current Nordic Autonomous Vessel Landscape

Research on the current market landscape for autonomous water vessels was performed in order to get an idea of this project's potential impact on CStrider's offerings. Competitor analysis is critical for good strategic planning. It involves a thorough evaluation of a company's competition, both directly and indirectly, as well as new or future competitors. Analyzing competitors' tactics entails using a wide variety of information accessible about their operations in marketplaces and their relationships with customers [16]. In this case, some of the other autonomous vessels in operation were found to not be competitors because they are university collaborations rather than for-profit companies. With that being said, the analysis of their specific offerings still proved to be helpful in determining CStrider's competitive advantages. The three most relevant actors are briefly described below, and the findings were used to discuss CStrider's unique positioning in the market.

2.1.1 Case 1: Callboats

Callboats is a company based in Helsinki, Finland that operates electric autonomous water shuttles. They have different models of various sizes and the biggest one accommodates up to 110 people. The boats are fully automated meaning that customers can call and pay for a ride through their app, and operators can supervise the boats through their Remote Control Center. The autonomous capabilities use sensors to avoid obstacles and navigate along a course, though due to legal regulations one human crew member is still onboard. Solar panels on the roof aid in minimizing the eco-footprint of the shuttles. The first commercial operation started in 2020 and has multiple different routes with Helsinki as a base[17]. A rendering of the CAT 10 L model can be seen below in Figure 2.1.

Figure 2.1: Rendering of Model CAT 10 L from Callboats[17].

2.1.2 Case 2: MF Estelle

Operating over Riddarfjärden in Stockholm is MF Estelle, making a six minute journey across the water[18]. The vessel is owned by Norwegian Shipping Company Torghatten, and uses anti-collision technology developed by Zeabuz, an affiliate company of Torhgatten. The idea for autonomous urban ferries was started at the Norwegian University of Science and Technology in Trondheim, Norway. After the first prototypes were launched in 2017, their success prompted the founding of Zeabuz in 2019 and Torghatten later became a shareholder[19]. Today, Zeabuz is supplier for various levels of automation technology to enable a boat's self-driving capabilities[20].

Similarly to Callboats, a human crew member is on board and solar panels on the roof aid in the charging process, though there are a couple of breaks during the day for charging via cable. The end-goal of operation includes four departures per side per hour for 15 hours a day. Tickets are purchased directly on board the boats and are not included under regular public transit tickets. MF Estelle can be seen below in Figure 2.2.

Figure 2.2: MF Estelle, a Torghatten-owned vessel on the water in Stockholm[18].

2.1.3 Case 3: GreenHopper

In collaboration with the maritime industry, Technical University of Denmark(DTU) has developed the GreenHopper autonomous harbor bus[21]. This catamaran ferry is Denmark's first emission-free and driverless vessel[22]. The vessel operates across the Limfjord in the Port of Aalborg[23]. The vessels are driverless, but not uncrewed, and carry 24 passengers. Control of the boat is handled remotely from a control room where one operator is responsible for several routes at once[22].

DTU claims that the most difficult part of the autonomous driving algorithm was accounting for pleasure crafts or people in the water, as these do not show up on traditional ship radar. Such objects aren't always aware of the right-of-way shipping rules, thus making them unpredictable and dangerous[22]. This highlights the importance of maintaining awareness of autonomous vessels, despite their complex and developed algorithms. Figure 2.3 displays the GreenHopper vessel on the water.

Figure 2.3: GreenHopper, Denmark's first autonomous harbor bus prototype[22].

2.1.4 Stakeholder Identification

There are a variety of different actors that could be impacted by this product. Firstly, commuters and residents in cities with traversable waterways would benefit from the addition of a new method of navigating throughout the city. Making the city more accessible to its residents through both connectedness and reduced traffic congestion can improve quality of life for people as they spend less time en route[24].

CStrider says that the vessels are being developed with long-range capabilities in mind[1]. This means that for those owning and operating the vessels, the frequency that the boat batteries will need to be charged is reduced. This could alleviate the challenge of planning routes and schedules when knowing charging won't be a huge issue.

Agencies in charge of public transit for cities would purchase these vessels to add to the city's transportation fleets. For these purchases the agencies would be interested in things like cost, passenger capacity, and pollution impact.

The pollution and general environmental impact of the vessels is one of the main marketing points from CStrider's development efforts. As stated, public transit agencies are invested in this aspect, as well as environmental agencies, and city boards. Reduced pollution in cities also increases the quality of life for residents through promoting healthier air quality[25]. City boards and municipality stakeholders have a vested interest in the environmental impact because sustainability is a determinant of city reputation[26] and plays a role in many laws that cities need to adhere to.

2.1.5 Product positioning: Competitive Advantage

CStrider holds a competitive advantage in key areas for different groups. They prioritize sustainability, aiming to minimize their carbon footprint which could be appealing for the municipalities that the vessels will operate in. Furthermore, they stand out in terms of operational cost efficiency which ensures a competitive edge for the shipping company. The required capital investment for implementing their vessels could potentially be lower than other solutions.
CStrider provides smaller vessels and they are inherently more economical. Commercial boats are often times built based on existing infrastructure and replacing larger boats could incur higher coasts, rather than just implementing the smaller vessels.
Smaller vessels do not only contribute to cost savings but they allow for faster delivery, which is crucial to ensure having a advantage against other competitors.
This project's contribution to CStrider's offering revolves around the integration of the ship officer on board. This project is about ensuring that they are not an afterthought, present only for legal reasons, but rather an active part in passengers having a smooth and enjoyable journey.

2.2 Data collection: Interviews

Interviews were held with different stakeholders and representatives from various fields to gather insights and information about both the product and the environment it will be used in. The interviews were semi-structured which means that a set of questions was prepared but the conversation was free to flow. Semi-structured interviews are great to answer "why" questions since it allows the interview to be flexible and the questions are not as detailed as in a structured interview [27]. These interviews were held with passengers of varying ages, multiple experienced boat captains as well as the CEO of CStrider. This was done to gather information from as many different stakeholders as possible to get a well-rounded perception of what stakeholders would appreciate in a captain's bridge. Interview questions can be found under Appendix A

2.2.1 Interviews with Passengers of Different ages

Semi-structured interviews were held with passengers of different age groups to get an understanding of passengers opinions regarding autonomous water-shuttles, their views on safety onboard and their preferences when riding a ferry today. The different age groups were chosen to see if there is a noticeable difference in opinions based on their ages, if older passengers were generally more against autonomous vessels than younger passengers, how their definitions of safety may differ etc. The age groups are 20-40, 40-60 & 60+.
10 passengers, 4 women and 6 men, above the age of 60 were interviewed on the ferry Älvsnabben going from Lilla Bommen to Klippan in Gothenburg which is shown in Figure 2.4. For the younger age groups, interviews were held informally with personal contacts..

- 20-40: This group demonstrated a unanimous confidence in the self-driving technology, but desire having no contact with personnel onboard. Personnel should be there to take over driving if necessary, but even in an emergency scenario interviewees felt comfortable getting themselves out through signage alone. One interviewee commented that their desired level of activity from the personnel depends on the length of the journey. For a short commuting trip during rush hour no interaction is desired, but on a longer journey perhaps out to the archipelago then being greeted and having a higher level of interaction could be appreciated.
- 40-60: This group also expressed a unanimous confidence in the self-driving technology. One interviewee recalled an experience of taking a water shuttle in London where the captain drove recklessly and damaged the vessel, causing all passengers to to get off and transfer to a different boat. The interviewee said that self-driving capabilities would have been an advantage in this scenario to avoid the recklessness of bad drivers. That being said, this age group also unanimously agreed that the physical presence of someone on board to take over if necessary raised their comfort levels.
  When asked about the level of engagement that they desired out of the employee on board, they expressed indifference and had no expectations either way. In emergency situations however, they expected employees to take charge and direct passengers towards safety.
- 60+: When asked about their opinions on autonomous vessels, the majority of them had a positive attitude to the idea. However 40% of them expressed that they would be okay with it only if there was at least one staff member on board. This is because it would increase their feeling of safety to have staff on board in cause something happens or to check tickets. The majority of them expressed that they would like autonomous vessels because they would operate in the river where there aren't any big waves and the short travel distance between the stations. Their opinions would differ if the water-shuttles were to operate out at sea where there are bigger obstacles like waves and further distance to nearest dock. 30% of the interviewees expressed concern regarding how the water-shuttle would react to other manually driven boats in the river who may be driven recklessly, which further emphasized their need of having staff members on board to take over in case something happens.
  When asked about if they have ever reflected on the captain's role in cases of emergency, the majority of them said that they would look for them for communication. They do not have the opinion that the captain's role is to help them all to safety but rather communicate what to do in that scenario. Other than that, they do not reflect on the captain's role and their absence would not affect their trip in any way.

Figure 2.4: Älvsnabben 4, operates between Lilla Bommen and Klippan in Gothenburg[28].

2.2.2 Experienced Vehicle Operators

This section includes all interviews with the "experts" which are experienced vehicle operators. This includes three boat captains with differing credentials and job titles as well as a tram driver.

2.2.2.1 Interview with Taxi Boat Captain

An interview with the CEO and captain of Hönö Båtturer, Bosse Johansson, was conducted to gather information about his experiences as a captain, his view on passenger safety etc. He has the classification ship officer class VII and 17 years of experience, 10 of them as the CEO and captain of Hönö Båtturer. Figure 2.5 shows the *Belle-Amie* in action.

The captain had a positive attitude towards autonomous water-shuttles and he thinks that they would be safer than manually driven water-shuttles. He referenced an accident in Gothenburg where two boats collided due to miscommunication between the captains which and he thinks that there would be less cases like that if more boats were automated. He mentioned that he has set routines that he performs either once before the first passengers of the day board or every time new passengers board, multiple times a day. So when asked about his duties he said that operating the water-shuttle is only a small part and that most of his duties regard the water-shuttle itself or the safety and comfort of the passengers.

He has felt overwhelmed as the only staff on board a few times due to children

Figure 2.5: Bosse's boat the Belle-Amie giving a tour on the water[29].

running around or passengers who are drunk. However he has never feared for his own safety, which he credits to his extensive experience as a captain, but rather the experience for the rest of the passengers. He however expressed concerns about the possible safety issues for both the passengers and the staff on autonomous water-shuttles that are meant for public transport since that is a different experience compared to his service that you actively have to book.

When asked about his opinions on the captains bridge on not only his boat but other boats he has operated as well, he mentioned that he is satisfied with the control panel and the components available on most boats. He therefor does not necessarily see the need in trying to further develop that aspect of a captains bridge but rather on elevating the social experience for both the staff and the passengers. He appreciates the connection he has with his passengers and views that as the highlight of his job, which passengers have expressed to him as well.

2.2.2.2 Interview with Car Ferry Captain

An interview was held with a boat captain on car ferry M/S Gullbritt between Lilla Varholmen and Hönö in Gothenburg. M/S Gullbritt can be seen in Figure 2.6. Dan Börjesson's time at sea accumulates to 18 years as a matros and 16 years as a commander.

He expressed enthusiasm to the idea of autonomous boats with the reasoning that it

Figure 2.6: M/S Gullbritt car ferry on the water[30].

could increase safety due to them always following the rules. Captains on manually driven boats can ignore the rules and captains on bigger boats might feel superior and feel that they should have precedence. Like Bosse, he mentioned that the majority of accidents today with autonomous vehicles are due to human factors and that automated boats could reduce those types of accidents.

His tasks besides steering are to check on the machinery, empty trash and make sure that everything needed in the passenger areas are there. There is not a lot of steering involved so his main tasks revolve around the overall experience on the boat.

When asked about his opinions on having a closed off area for the captain he expressed that it could be great not only for the captains physical safety, but for living in a post-covid world as well. It could be nice to have the option to be around passengers at times but have your own space nevertheless.

He appreciates big windows so he can look around from multiple sides which increases his feeling of safety. Otherwise regarding the comfort level, he mentioned that he appreciates having a chair that he can pull out of the space when it is not in use as he prefers to stand up, but it is nice to have the option to sit as well. The dashboards are mirrored on either side of the pulpit so that he can comfortably look ahead regardless of which direction the boat is going. The position of the hands on the joysticks are comfortable as well and his experience in his captains bridge is overall positive. Figure 2.7 shows the bridge of M/S Gullbritt.

Figure 2.7: The bridge of M/S Gullbritt showcasing the large windows as well as the mirrored dashboards.

2.2.2.3 Interview with CEO of CStrider

The CEO of CStrider, Tobias Husberg has 14 years of licensed boating experience and has the documentation for a class VIII ship officer. He was interviewed for both his role as the CEO as well as his role as a boater.

One of the main concerns expressed was how the vessels will be limited to only 12 passengers once they have been transitioned to full autonomy and no personnel on board. While the scope of this project was limited to designing with an employee on board, the issue of counting passengers was still relevant and became a main focus for the development ahead. Since the boats are electric there is no need for routine checks of machinery that personnel needs to do as with traditional boats, which frees up their time for other activities. This is an advantage that can be utilised to increase the social awareness and contact with the passengers to make sure that everything is running smoothly instead of having to take time away for routine checks.

When asked about his preferences as a captain, he mentioned that it is important to have free sight in and around the boat as well as intuitive controls, especially in a case of emergency when the personnel might have to take over the steering.

2.2.2.4 Interview with Tram Driver

In addition to boat-related interviews, other public transit vehicle operators were contacted for their perspective. Tommy Viljestig has 30 years of experience as a

tram driver in Gothenburg.
Tommy feels a greater sense of safety in being able to close the door to his cabin from the rest of the passengers, however having only one door makes him uncomfortable as a violent passenger could easily block his only exit. The windows are able to be climbed through, but it is not convenient and would only be done in an absolute emergency. Being able to keep an eye on passenger behavior also contributes to Tommy's sense of safety.
The physical design and layout of the driver's cabin in the tram plays a large role in the quality of the driver's workday. The dashboard has buttons clustered by their functionality, and their proximity to the driver's hands is based on their frequency of use. Buttons used constantly are close, while those used once per day may be a longer reach away. For driving at night, there are three levels of button brightness that drivers can choose, as well backlighting on the panel in order to reduce strain on the eyes. The seats are completely adjustable and an ergonomist is part of the tram driver educational process, teaching them how to properly set up the chair for optimal comfort and reduction of pain for long shifts of sitting. Figure 2.8 shows the dashboard on the M33 tram which is the newest tram model used in Gothenburg.

Figure 2.8: The driver's dashboard of Gothenburg's M33 trams, the newest model of tram in circulation[31].

2.2.3 Interviews with Amateur Vehicle Operators

This group includes two participants who do not professionally operate any boats but have multiple years of experience. They were interviewed with the point of view of being potential ship officers of this boat as well as their preferences as amateur operators.

Two interviews were held with amateur, licensed boat drivers under the age of 30. Carl Troiza, aged 24, has had his Level 2 Powerboat license (up to 10 meters) for 5 years, but has been driving boats with his family since he was 10. When asked about the things that he looks for in order to feel most safe and comfortable while driving a boat he answered that visibility was of the utmost importance, as well as being able to move unobstructed up and down the boat. Especially when operating the boat by himself, having everything close at hand and being able to get outside of the cabin quickly is critical. He notices ergonomic luxuries such as intuitively placed handles, swiveling chairs, and visibility from either standing or seated positions. These aspects are things that set apart a vessel for him, a wow-factor of sorts. He claims that his current boat lacks ergonomic thought at times such as the door to the cabin opening into a seat such that someone sitting there would be hit by it.

One aspect that makes him feel safest is familiarity with his route. Having done the same route repeatedly gives him a greater sense of confidence in his awareness of the water conditions, but does not cause any decrease in alertness because there's still always a need for vigilance when on the water.

Carl stated that the ability to close himself off from a potential threat could be nice, however he would primarily opt for an open floor plan as not to impede his mobility. He also said that with the only door at the back of the boat, as well as the gangway, having personnel stationed at the back of the boat would be ideal for convenience. The size of the boat itself is small enough that he is confident that there would be no unforeseen challenges with needing to drive from the back.

In regards to automated driving, Carl expressed confidence in the safety of aspects, but would prefer if manual takeover was very simple. In the event that manual takeover would be necessary, needing to press a bunch of buttons to override would cause additional stress. He also suggested that the automation system could have different modes of driving dependent on weather conditions, such that personnel could choose how the boat drives in order to increase passenger comfort based on real-time experience in the boat.

Samuel Stüber, aged 28, has had his International Certification for Operators of Pleasure Craft for 5 years and primarily operates sailboats. Many of Samuel's responses echoed those of Carl's, particularly regarding the importance of visibility, the preference of using analog instruments and eyesight rather than digital technologies, and opinions regarding personal safety from passengers. When asked about what he looks for and notices onboard a new boat, he mentioned the maintenance and conditions of not only the exterior and interior of the boat, but the tools on board as well. He says that well-cared for equipment is a sign of a responsible operator and gives him a sense of safety in confidence as a passenger.

2.2.4 Summary and Categorization of Interviews

To summarize, most participants regardless of role or age group, had the same opinions on multiple points. To get a better overview of the most important points to consider for the upcoming concept generation, a chart and a table were made.

The chart in Figure 2.9 shows the analysis from the interviews conducted with the potential passengers. The most important points are highlighted like their attitude towards autonomous boats, physically having a ship officer on board as well as how big of a role the ship officer has on said boat. One thing to consider is that there were 12 participants in the youngest category, 6 in the middle and 10 in the oldest. So even if it seems that the results vary a lot between age groups, the percentage difference is not as high within each group.

All age groups had an overall positive attitude towards autonomous boats where all the participants in the two first age groups had a unanimous opinion, and 80% of the participants in the oldest age groups as well. All age groups had similar opinions about preferring a manned autonomous vessel as well as thinking that a ship officer's role was crucial during a boat ride. Overall, there were not many differing opinions across the age groups and there is a general positive outlook on future autonomous boats.

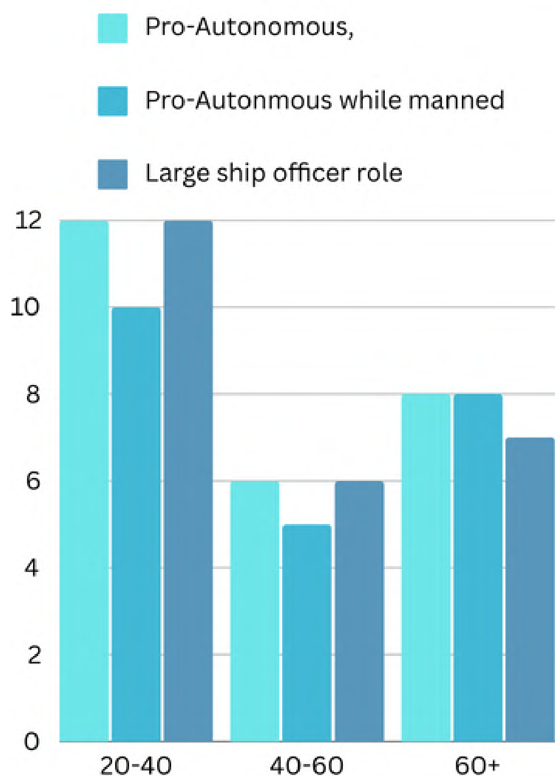


Figure 2.9: Data analysis from interviews depicting people that were pro autonomous driving, pro autonomous *with* someone on board, and those that believed the ship officer should play a large role.

Table 2.1 shows the most important and most mentioned comments regarding safety and ergonomics from the experts. The safety category includes safety when operating the boat, safety from passengers, and safety of the equipment. The ergonomics category includes the experience when using the ship officer's space as well as having easy access to the exit.

Safety	Ergonomics
Visibility in and around the boat	Proximity to exit
Option to screen-off	Adjustable and comfortable seating
No passenger access to ship officer's space	User-friendly interface

Table 2.1: Key takeaways from interviews showing most important aspects.

2.2.5 Specification of Safety and Ergonomic Requirements

With the help of the information gathered from the interviews, existing solutions and the company, a requirements specification was put together. The requirements were divided up into safety and ergonomics to get a better understanding of which category each requirement should belong to. Safety was a top priority and by doing this, the requirements under the safety category naturally received more focus and attention when it was time to brainstorm ideas. In this case, safety did not necessarily only include the personal safety of the ship officer, rather general items related to how to safely operate a boat. The requirements for each category are presented under Tables 2.2 and 2.3. For each category, the groupings are explicit, unfulfilled and latent needs. Explicit needs are simple for the user to express and are the most important to fulfill to receive a basic, satisfactory solution. Unfulfilled needs are not found in current solutions but are greatly appreciated. Latent needs are hard for users to express but create a positive effect if found in a solution [11]. All future references to these types of needs have been renamed as primary, secondary, and tertiary matching up to explicit, unfulfilled, and latent respectively. This was done to clarify the prioritization order for each category of needs.

For the safety needs, the most important were the primary needs which include high visibility, sense of safety, and awareness of amount of passengers. High visibility is important to allow the personnel to not only be aware of what is happening on the boat, but around it as well, to see if there are obstacles in the water or such. Sense of safety for personnel entails that personnel should feel safe as the sole operator at all hours of the day in their space if there ever occurs a situation where passengers are acting disorderly. Manual driving capabilities allow manual driving in case of an emergency, Lastly, awareness of amount of passengers is of upmost importance since there is a strict cutoff at 12 passengers and the boat is not allowed to leave the dock if there are any more passengers on board. The secondary needs would facilitate a positive experience for the personnel and have high importance, for example it is important that the personnel are able to communicate effectively with the passengers and provide a sense of safety for the passengers.

Primary needs	**Secondary needs**	**Tertiary needs**
Exists high visibility in and around the boat	Space instills a sense of safety for passengers	Exists a clear distinction between notifications for critical situations
Space instills a sense of safety for personnel from disorderly passengers	Space keeps personnel alert	
Manual driving capability	Permits ability to communicate with passengers	
Space assists personnel in awareness of number of passengers on board at all times		

Table 2.2: Safety requirements categorized by need.

For the ergonomics needs, the primary needs were that the personnel has easy access to exit as they will need to go out and count the amount of passengers at each stop. The space needs to promote comfort for the personnel as they will spend significant amount of hours there in the long run and will need a space they appreciate. The secondary needs included points that would create an easier and seamless experience for the personnel, such as an unobstructive layout, and strategically placed tools. Lastly, the tertiary needs included things like having ergonomically placed joysticks to promote comfort when they need to be used and an intuitive interface which again would facilitate the experience for the personnel and is appreciated but not necessary.

Primary needs	**Secondary needs**	**Tertiary needs**
Personnel has easy access to exit	Enables personnel to quickly change direction	Ergonomically placed joysticks
Space promotes comfort for personnel	Has unobstructive layout	Has intuitive interface
	Strategically placed tools/gears	

Table 2.3: Ergonomics requirements categorized by need.

3

Concept Development Process of the Ship Officer's Bridge

The design process refers to the creative and systematic approach of generating, iterating and evaluating ideas to develop a new solution. This process is divided into two steps concept generation and concept evaluation which are presented in this chapter and follows the method of [11].

3.1 Concept Generation

Concept generation was also divided into two steps beginning with breaking down the subsystems and then generating ideas.

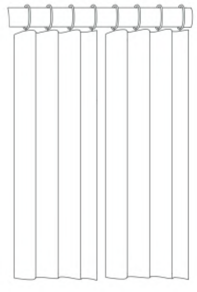
3.1.1 Subsystem Breakdown for Brainstorming

To start off the brainstorming of ideas, the ship officer's space was divided into so called subsystems to be able to better categorize what is needed to be conceptualized. The categories of subsystems are shown and explained in Table 3.1 below. The categories were decided based on the information collected from the interviews and discussions with the supervisor at CStrider.

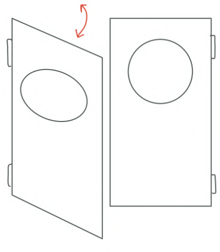
Screening off mechanism	Any type of divisions between the personnel and the passengers to ensure the personnel's safety in case of disorderly behavior from passengers.
Seating	Provide seating, preferably seating that is adjustable and movable.
Anti hijacking	Ensure that passengers do not have unauthorized access to the dashboard or joystick.
Dashboard placement	What the dashboard and equipment is attached to.
Counting	Ways to facilitate the counting of passengers boarding the boat and help the personnel ensure that no more than the maximum amount of passengers are allowed on the boat.

Table 3.1: Categories for brainstorming. Each category represents a crucial component for the final concept to provide a safe and comfortable solution.

After establishing the subsystems, multiple ideas for each category were brainstormed. Some examples for each category are shown in the figures below. Figure 3.1 shows the screening off mechanisms curtain and swinging door to separate the area between the personnel and the passengers. Figure 3.2 shows examples of seating to ensure comfort and adjustability.



(a) Example of a curtain.



(b) Example of a swinging door.

Figure 3.1: Sketches of potential screening-off mechanisms.

(a) "Lollipop" chair. **(b)** Chair with leaning area

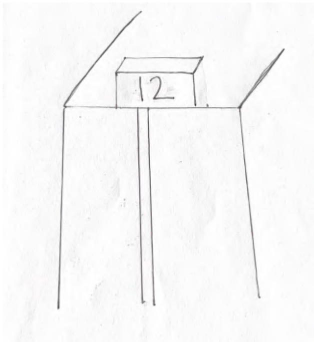
Figure 3.2: Seating examples.

Figure 3.3 shows examples of anti hijack systems. The "buffet" covers the control panel from above, ensuring that no one can reach anything except when standing in front of the control panel. The "trap door" hides the control panel when it is not in use, for example when the personnel is not in their designated area and perhaps helping passengers board the boat.

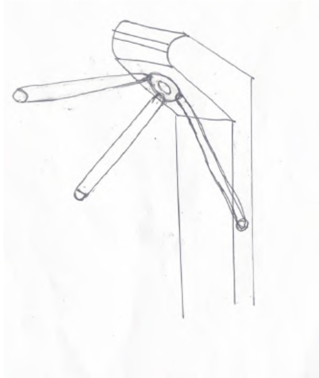
(a) "Buffet" cover **(b)** "Trap door" solution

Figure 3.3: Anti-hijacking examples.

Figure 3.4 shows examples that helps the personnel to stop people from boarding after the maximum amount of passengers has been reached. The digital countdown is connected to the physical clicker that the personnel has and it informs the passengers of how many available spots are left. The turnstile is also set to not allow more people to pass through when the maximum amount of people have been reached.



(a) Screen displaying countdown.



(b) Turnstile barrier for entry.

Figure 3.4: Counting mechanism examples.

3.2 Concept Evaluation

To evaluate the generated concepts, several matrices were done to systematically choose the most fitting concepts.

3.2.1 Morphological Matrices to Create Combinations

In order to assemble a plethora of combinations from the different subsystem ideas, morphological matrices were created. The rows of the matrices represented the different subsystems, while the columns were organized by desirable factors or priorities. The counting subsystem was excluded from the categories of the morphological matrices as its function and positioning will be separate from the personnel's pulpit within the boat. Evaluation for this subsystem's ideas was performed separately and will be discussed later.
The focuses that were created for the columns were:

- Personnel's physical comfort
- Saving space with a minimal floor footprint
- User-friendliness
- Mobility and ease to get in and out of the pulpit area

In order to maximize the number of combinations under these areas, two matrices were created; one for the best guessed solution and one for second-best. This yielded 8 combinations, and then two more were created for the best-guessed "overall" solutions that attempted to prioritize all of the desires at once.
A "reference" column was also created to be used later in the Pugh matrices. This reference solution was formulated to represent a basic, average solution that doesn't fulfill any particular desire, but ultimately gets the job done. This solution consisted of:

- A stationary chair
- A non-adjustable desk
- A regular door
- No separate anti-hijacking solution, personnel would just always close and lock the door when leaving

With these ten solutions, plus the reference, this step was completed. Figures 3.5, 3.6 and 3.7 display the solution combinations that were developed.

Subsystem	Physical Comfort	Space Saving	User-friendly	Mobility
Seating	Ergonomic adjustable seat (as seen in trams)	no chair	Bolted swivelchair	standing mat + leaning
Dashboard (Layout)	Pull in & out desk	Portable tablet	Regular desk	wall embedded
Screen-off	Train door	Curtain	saloon/swinging doors	Sliding door
Anti-hijacking	Buffé cover	stage trap door	flip over	two-panel window
Concept	1	2	3	4

Figure 3.5: First morphological matrix with the viewed best options for each category combined. The columns represent the four most important categories that a solution should fulfill and the rows represent the components for each category.

Subsystem	Physical Comfort	Space Saving	User-friendly	Mobility (getting in and out easily)
Seating	sitting/leaning combo chair	tram flip down seat	yoga ball	lollipop
Dashboard (Layout)	adjustable standing desk	wall embedded	pull in & out	slanted
Screen-off	curtains	folding screen	sliding	saloon door
Anti-hijacking	flip over	two-panel window	screen-off solution (spårvagn)	stage trap door
Concept	5	6	7	8

Figure 3.6: Second morphological matrix with the viewed second best options for each category combined. The columns represent the four most important categories that a solution should fulfill and the rows represent the components for each category.

guessed best (KT)	guessed best (AS)
standing/leanin g combo chair	lollipop
adjustable standing desk	adjustable (height + pull out?)
folding screen	slide
stage trap door	buffe

Figure 3.7: The guessed best combinations from the team members. These combinations are solely assumptions and added to have personal opinions a part of the concept generation.

3.2.2 Removing Concepts with Elimination Matrix

After the morphological matrix is done and the final amount of concepts emerged, an elimination matrix was performed. This was to ensure that only the concepts that are deemed fit according to set criterion are passed through to the next stage. Each concept is evaluated through each criterion and only the concepts that receive a majority of + go through and the concepts that receive a majority of - are eliminated. After the matrix was performed, four out of ten concepts go through to the next stage. See Figure 3.8 for the full elimination matrix.

Done By: Aya & Katie						Created: 2024-03-18	
						Modifiad: 2023-03-18	
Solution						+ Yes	+ Keep solution
						- No	**- Eliminate solution**
						? Information is missing	? Search(more) information
						Comments	**Decision**
	Enables captain to quickly change direction	Space instills a sense of safety for personnel	Does not obstruct high visibility in the boat	Space promotes comfort for personnel	Easy to get in and out		
1	-	+	+	+	-	Ergonomic chair not reasonable	-
2	+	-	-	-	+	Not comfy + curtain not reasonable	-
3	+	+	-	-	+	uncomfy bc always closed & normal desk + bolte	-
4	+	+	+	?	+	Good combo, investigate seating	+
5	+	-	-	+	+	Good combo, curtains suck	-
6	+	+	?	-	+	visibility of folds needs investigating, wall + flip dc	-
7	+	-	+	-	+	not convenient to not get to choose open/closed	-
8	+	+	-	?	+	explore if people are claustrophobic	+
9	+	+	?	+	+	visibility of folds needs investigating	+
10	+	+	+	+	+	lollipop back support unknown	+

Figure 3.8: Elimination matrix with the concepts moving on to the next stage marked in red. Each concept has comments to why it was chosen as + or -, highlighting their points to investigate for the + and their weaknesses for the -.

3.2.3 Performing Pugh Matrices to determine Best Scoring Concepts

With the remaining concepts, multiple Pugh matrices were performed. This is to find the concepts that perform the best against not only a set of criteria but also each other. This is done through several iterations where one concept is decided as a reference concept and all the other ones are compared against it. If one concept is assumed to perform better than the reference concept, it receives a + and if it is assumed to perform worse, it receives a -. If there are uncertainties, it receives a 0. The goals is that one or a select few perform exceptionally well compared to the rest and can move on to the next stage [11].
The first one used a pre-defined "basic" concept as a reference, which is defined in the subsection 3.2.1 and the four concepts are compared to that. This was done to see how well the concepts perform against the most simple combinations and to see if there is potential in the more developed concepts. All concepts performed relatively the same with only concept 8 receiving a slightly better score, see Figure 3.9 for the first Pugh matrix.

Criterion	Alternative				
	Our	Con. 4	Con. 8	Con. 9	Con.10
Adaptable for multiple body types	Reference	+	+	+	+
Minimally occupies floor space		+	+	0	0
Comfort for personnel		0	+	+	+
Ease of maintenance		-	-	-	-
Cost estimation		-	-	-	-
SUM +		2	3	2	2
SUM 0		0	0	1	1
SUM -		2	2	2	2
Net value		0	1	0	0
Ranking					
Futher development					

Figure 3.9: First Pugh matrix with the concept used as a reference in the next matrix marked in red.

For the second matrix, the concept used as a reference is the one who got the highest score in the first matrix, concept 8, to see how well the concepts compare against that and if the scores differ significantly from the first matrix. The results showed that concept 4 still scored relatively well and scored the highest in this matrix. Concept 9 performed the worst and will be used as a reference for the third matrix to see how well the other concepts perform against it. See Figure 3.10 for the second Pugh matrix.
The same procedure was done for the third matrix, only this time concept 9 was used as a reference because it performed the worst in the previous matrices. After reviewing the results, it was decided that concept 4 moves on to be further developed as it has been consistently well ranked through the matrices. One last matrix was

Criterion	Alternative			
	Con.8	Con.4	Con. 9	Con. 10
Adaptable for multiple body types	Reference	-	0	+
Minimally occupies floor space		+	-	-
Comfort for personnel		-	+	+
Ease of maintenance		+	-	-
Cost estimation		+	-	-
		3	1	2
SUM 0		0	1	0
SUM -		2	3	3
Net value		1	−2	−1
Ranking				
Futher development				

Figure 3.10: Second Pugh matrix with the concept used as a reference in the next matrix marked in red.

performed using concept 10 as a reference as it was the second best performing concept after concept 4. The remaining two concepts, concept 8 and 9, did not receive better scores than the reference concept, concept 10, which led to the decision of further developing concept 10 as well. See Figures 3.11 and 3.12 for the last two performed matrices.

Criterion	Alternative			
	Con 9	Con. 4	Con. 8	Con.10
Adaptable for multiple body types	Reference	0	-	0
Minimally occupies floor space		+	+	0
Comfort for personnel		-	-	0
Ease of maintenance		+	+	+
Cost estimation		+	+	0
SUM +		3	3	1
SUM 0		1	0	4
SUM -		1	2	
Net value		2	1	1
Ranking				
Futher development		+		

Figure 3.11: Third Pugh matrix with the concept used as a reference in the next matrix marked in red.

Criterion	Alternative		
	Con.10	Con.8	Con. 9
Adaptable for multiple body types	Reference	-	0
Minimally occupies floor space		+	0
Comfort for personnel		-	0
Ease of maintenance		0	-
Cost estimation		-	0
SUM +		1	
SUM 0		1	4
SUM -		3	1
Net value		−2	−1
Ranking			
Futher development			

Figure 3.12: Fourth and last Pugh matrix with the concept used as a reference in the next matrix marked in red.

3.2.4 Concept Development of Counting System

As previously mentioned, the counting subsystem was evaluated separately. First, evaluation criteria was decided upon. Similarly to the criteria of the personnel's pulpit, the counting solution would also need to be accessible to a variety of body types, as well as those with wheelchairs, bikes, or strollers. Next, the system needed to be reliable and accurate under a variety of cases; for example, recognizing that a baby in a stroller counts as a passenger. An additional factor was that of passengers receiving some kind of external cue from the boat itself once the max number of passengers has been reached. It is predicted that this will help take some of the pressure off of the personnel for being the one responsible for turning people away, as there would be evidence from the boat itself that it cannot handle more people onboard.

At first, the ideas were going to be put into a Pugh matrix for evaluation, but on initial assessment of the idea list it was immediately evident that only a few ideas would fulfill our requirements. The full list of all proposed ideas are listed under Appendix B.

- Turnstiles aren't adaptable to different body types, strollers, or bikes
- Sensors at the entrance wouldn't be able to tell if there were children in strollers or in someone's arms
- Doors automatically closing after twelve passengers poses a safety risk

From there, four solutions remained that fulfilled all the criteria. One of the proposed ideas was that of booking your place in the public transit app, however it was felt that this posed additional issues. Although this solution may work well for booking a longer journey, for the virtual bridge use case where boats will be continuously circulating through, finding the specific boat that you booked may be confusing or burdensome. Secondly, this solution would rely on the infrastructure of an external app, while the scope of this project pertains to CStrider and their particular vessels, so any counting solutions should be contained to the boat itself.

The remaining ideas all revolved around the idea of personnel holding a remote clicker counter that would be connected to the boat such that when twelve passengers was reached a cue would go off on the boat itself. The ideas for cues were:

- Lights at the entrance that turn from red to green
- A voice that announces that capacity has been reached
- A displayed countdown for how many more passengers are allowed on

When discussing the merits of each idea, it was realized that a combination of all three would result in the most accessible solution possible. Both auditory and visual cues provide information regardless of eyesight or hearing levels, while lights and numbers cross any potential language barriers. The simple image shown below in Figure 3.13 summarizes the idea in action.

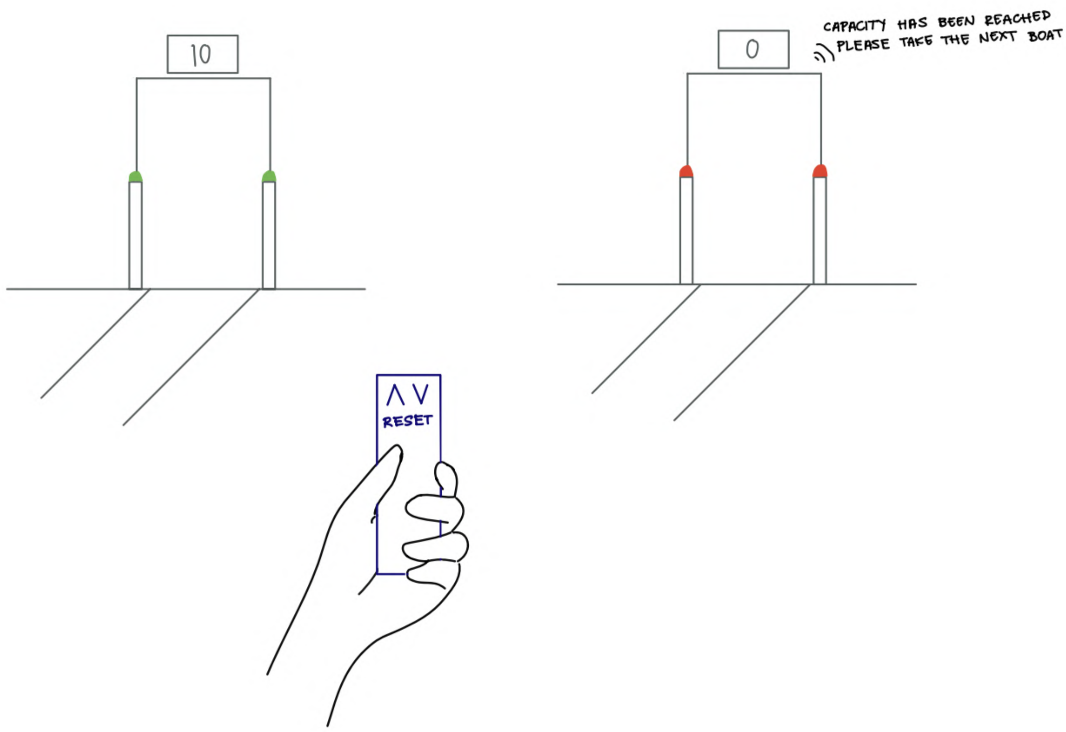


Figure 3.13: Sketch of the "counting" ideas all together. Lights that are green when passengers are allowed to board that turn red when the maximum capacity has been reached, which is also displayed through a countdown system. This is connected to a physical clicker that the ship officer controls. Simultaneously, a voice from the speakers will tell the remaining passengers that they can not board.

3.2.5 Proposed Concepts for Future Development

Along with the solution for the counting system, two concepts were chosen from the Pugh matrices to go into further development.
The first alternative consists of the following:

- A thick standing mat as well as a leaning cushion on the wall
- A sliding door mechanism for closing the pulpit
- The dashboard will be embedded flat into the front wall of the pulpit
- Above the dashboard the front wall will be paneled such that personnel can choose whether to have it open or closed

This solution was developed with the aspects of easy mobility in mind and can be seen sketched in Figure 3.14.

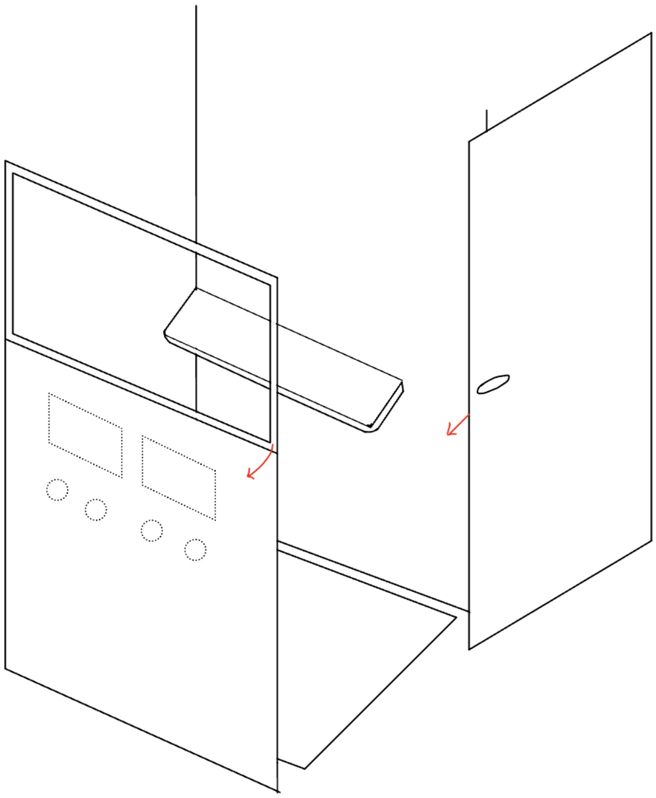


Figure 3.14: A sketch depicting the first proposed alternative.

The second proposed concept contains the following:

- The flip and swivel, "lollipop", seat
- An adjustable desk that can be both raised/lowered or pulled forward/backward
- The folding panel screen door
- The buffet cover for dashboard protection

Figure 3.15 shows the alternative compiled all together.

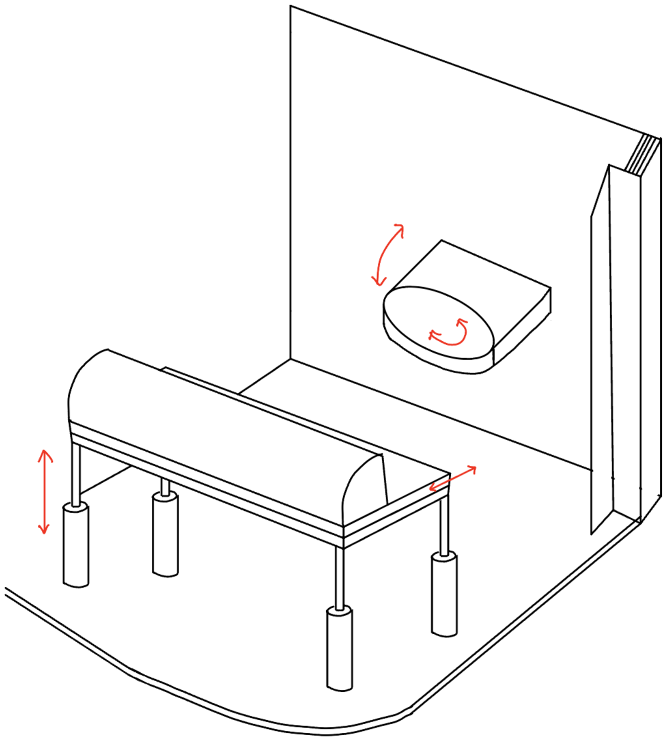


Figure 3.15: A sketch depicting the second proposed alternative.

This concept was one of the hypothesized "ideal" solutions as it attempts to equally prioritize comfort, easy mobility, and a minimal floor footprint. The paneled folding door is inspired by security grates commonly found in commercial store fronts for protecting the entrance outside of working hours. An example image can be seen in Figure 3.16.

Figure 3.16: A paneled security door in place at a bank after hours [32]

The proposed dashboard layout would be the same for both concepts, and is sketched in Figure 3.17.

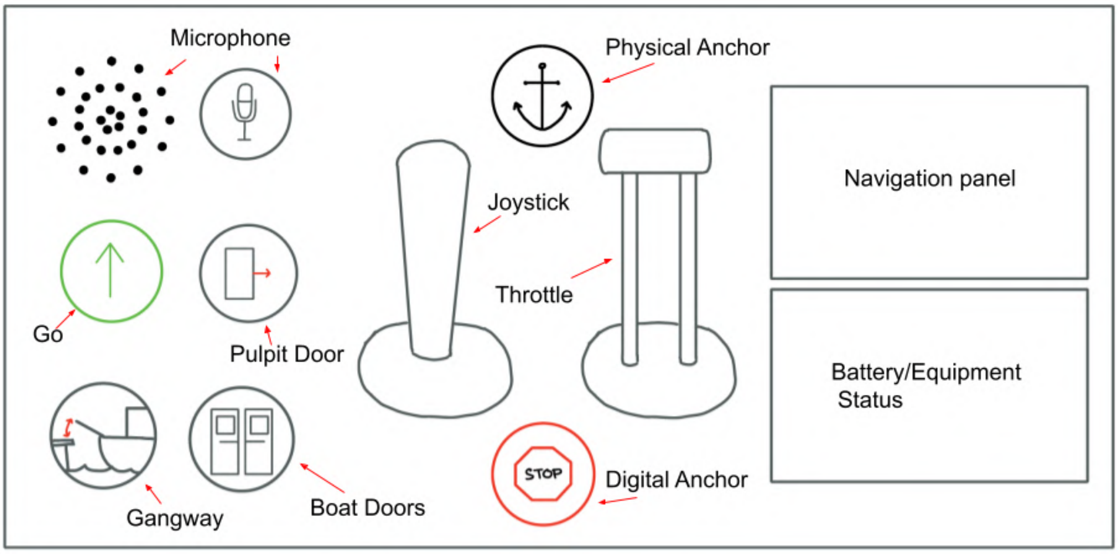


Figure 3.17: Sketch of the proposed dashboard layout

3.3 Initial Feedback on Proposed Concepts

After proposing the ideas to the CStrider CEO, Tobias Husberg, feedback was received that led to some immediate design changes. For the first concept, any sort of electronics that could fail for the safety door were immediately nixed. It could be catastrophic if the door were to jam and the personnel be trapped in their pulpit. Although the focus of the first concept was saving space, Tobias felt that the comfort of personnel was still a high priority and that having the dashboard flat on the front wall sacrificed ergonomics too much. He did like that the wall could theoretically be made to fold out of the way, thus creating even more of an open concept. For the dashboard, he liked the things that had been included, but wished for the layout to be reconsidered for better ergonomics. For example, with one hand on the throttle and joystick, screen visibility would be impaired if they were to the right. With the need for wrist support, buttons shouldn't be placed where they may accidentally be pushed.

With this feedback, the first concept was almost entirely redone, and aspects of the second concept were changed in order to try out a wide variety of the generated concepts. The new first concept consisted of:

- A thick standing mat as well as a leaning cushion on the wall that can be height-adjusted
- A paneled folding screen that can be closed all the way around the corner, like a shower curtain rail
- The dashboard will be mounted to the side wall and can be swung out perpendicular for usage

- The buffet cover concept will swing up and down to cover the entire wall-mounted part when not in use

The second concept remained mostly the same, with two changes:

- The flip and swivel, "lollipop", seat
- An adjustable desk that can be both raised/lowered or pulled forward/backward
- A front wall to the pulpit where the top is a window that can be opened or closed
- The folding panel screen door up until the front wall
- The buffet cover for dashboard protection

The new concepts differ in such a way that the dashboard layout will be unique to each of them. These concepts were created in CAD for better visualization and will be further discussed in the next section.

3.4 Concepts to be Prototyped

After the final two concepts have been revised and updated, they were designed in CAD using Catia V5 and Autodesk Fusion. The components of each concept were put into an assembly replicating the actual available space as closely as possible to get a a feel for how every component will fit together. The proper materials were assigned to each component as well to make the models more realistic. See Figures 3.18 and 3.19 for the preliminary CAD models of the concepts, as well as Figure 3.20 for the counting mechanisms.

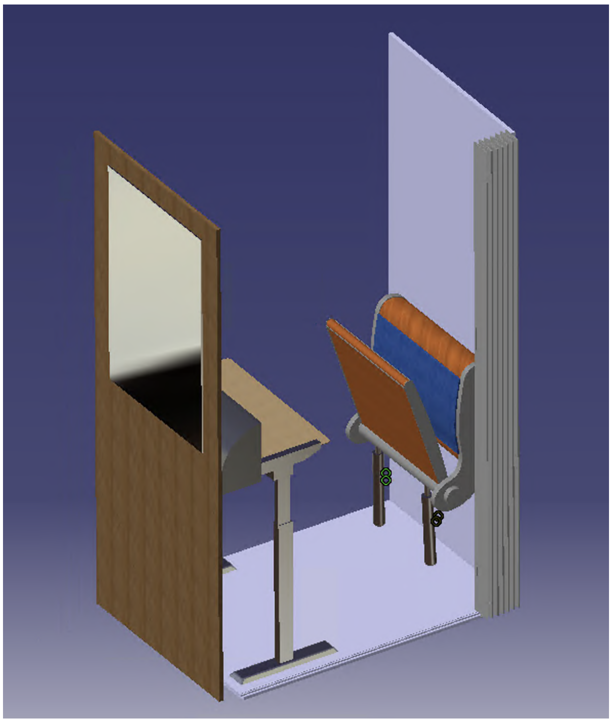


Figure 3.18: CAD model of the "comfortable" concept.

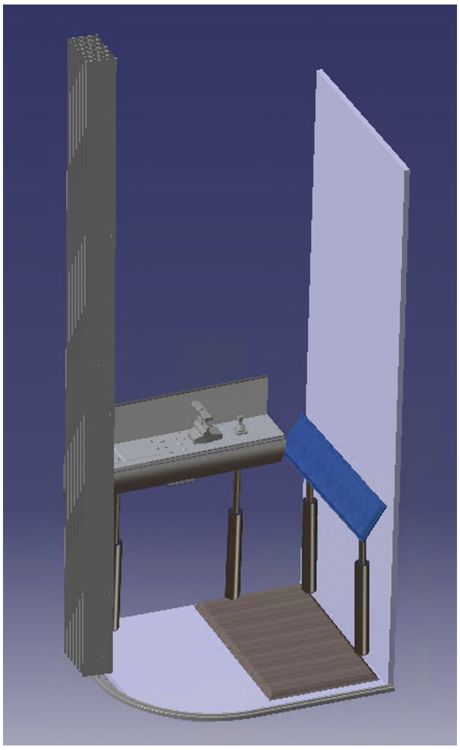


Figure 3.19: CAD model of "space-saving" concept.

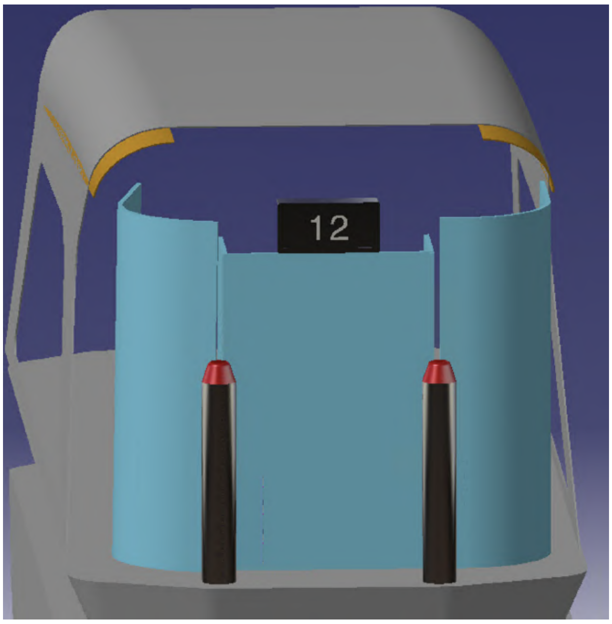


Figure 3.20: CAD model of the counting system with lights and countdown for the indication when maximum amount of passengers has been reached.

The physical prototyping and testing of these concepts will be further discussed in the next chapter.

4

Prototyping & Testing of Concepts

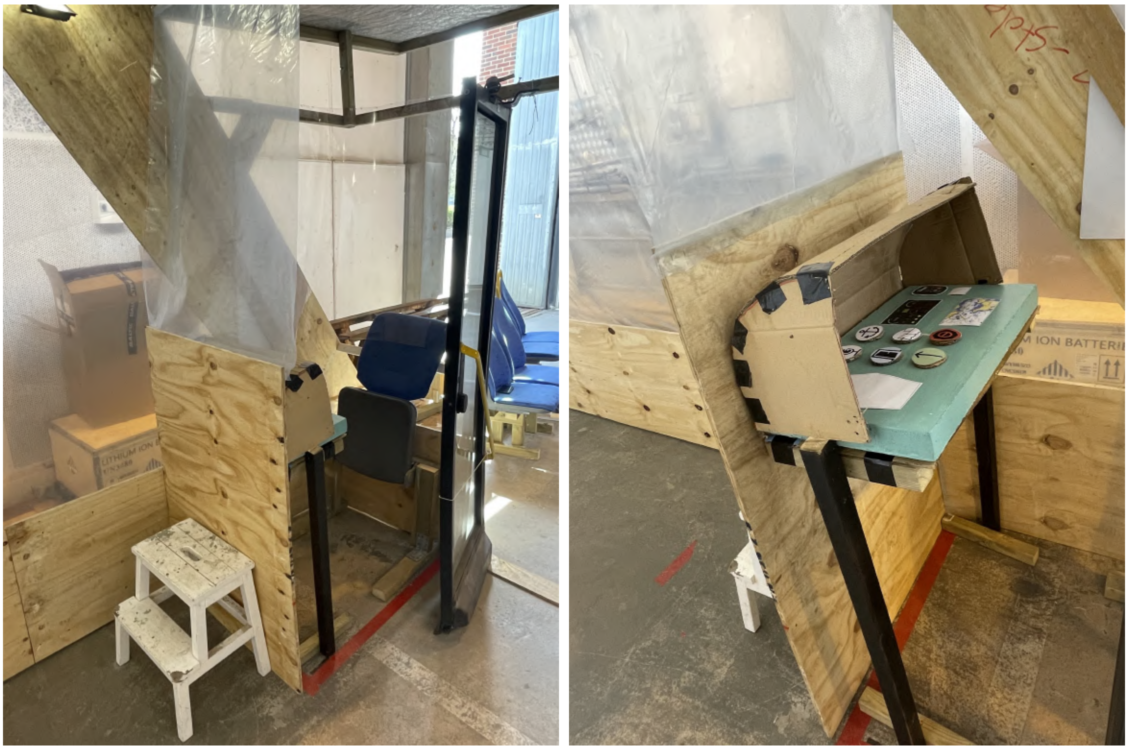
This chapter describes the prototyping process of the concepts as well as the testing and feedback given on the physical prototypes.

4.1 Building the Prototypes

A frugal engineering approach was taken during the prototyping process in order to reduce the cost of production for our final concept. The CStrider workshop had a selection of materials and fasteners available for use, and additional purchases were avoided as much as possible. Consuming fewer resources is also tied into the sustainability of the product, which is one of the key values and selling points for CStrider, therefore making the frugal engineering approach even more appealing. This led to certain building choices that would simply simulate the desired function, rather than being an exact mockup. Both concepts were built using a combination of cardboard, wood, and polystyrene foam. The emergency doors of both concepts were not built, due to budget and time restrictions. Recreating the sketch with the given materials was not feasible, but test users were shown images and asked about their opinions on it.

The "comfort" solution can be seen in Figure 4.1. This consisted of the fixed buffet cover over the regular desk, a front wall with openable window, and a flip-down seat.

The "space-saving" solution can be seen in Figure 4.2, depicting the wall-mounted dashboard and leaning pad.



(a) View of front wall and foldable chair. **(b)** Buffet cover shielding dashboard.

Figure 4.1: Two angles of the comfort concept's pulpit.

(a) Buffet cover pulled closed over the wall-mounted, space-saving solution. **(b)** Dashboard folded out for usage of the space-saving solution.

Figure 4.2: The space-saving prototype shown closed and in-use.

A close-up view of the dashboards for each concept can be seen in Figures 4.3 & 4.4.

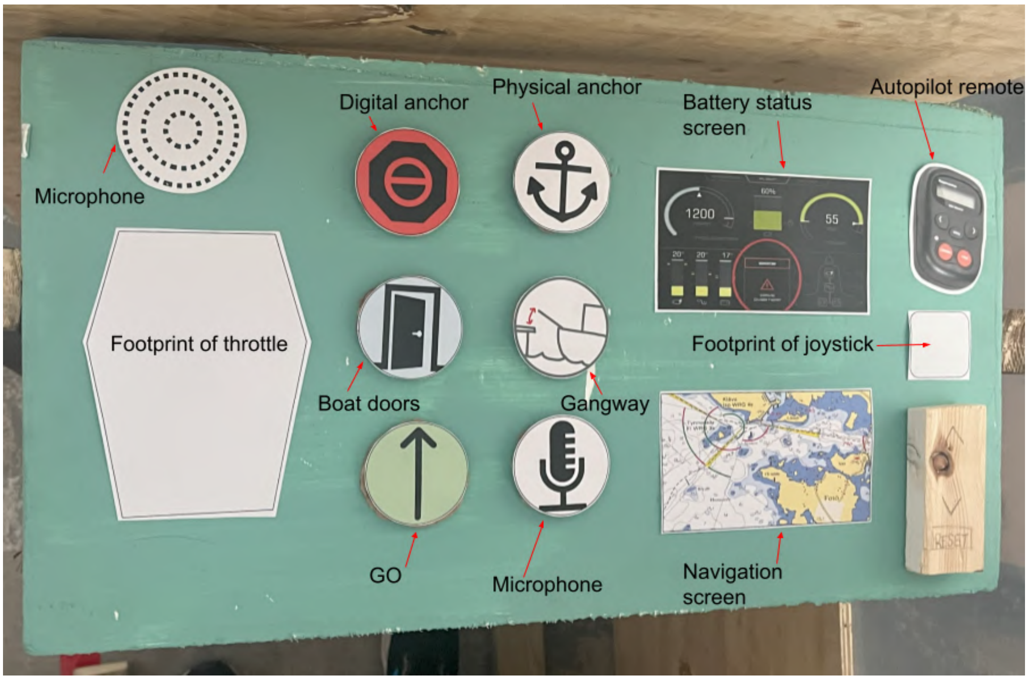


Figure 4.3: Dashboard explanation of the "comfort" solution.

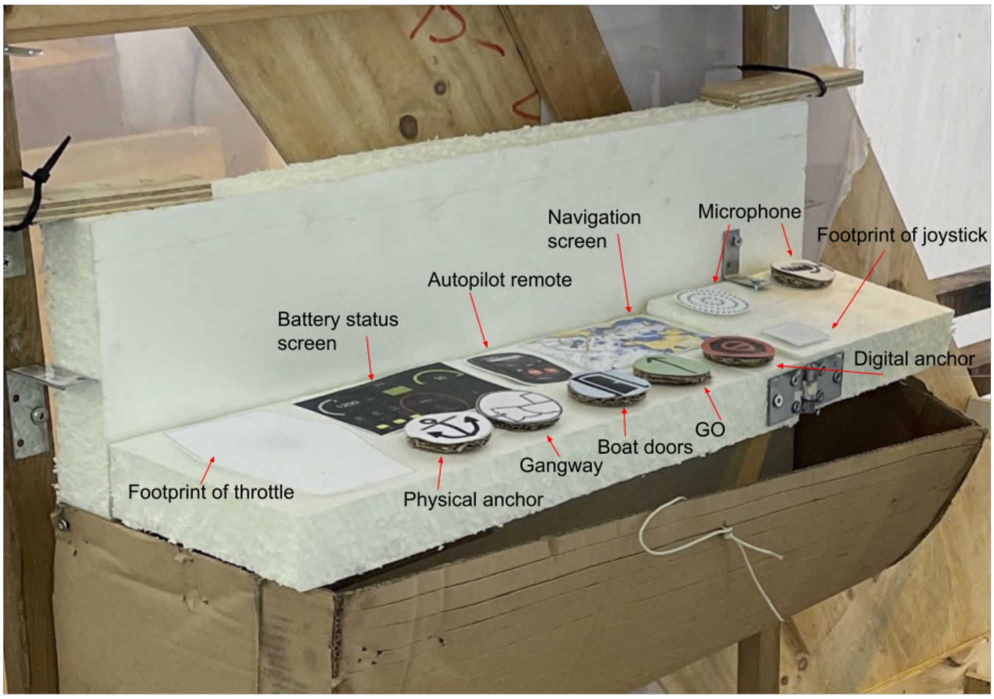


Figure 4.4: Dashboard explanation of the "space-saving" solution.

4.2 Testing & Feedback on Prototypes

Four candidates participated in the testings that were arranged in the CStrider workshop where the prototypes were developed. All four candidates are between the ages of 24-29 and were chosen due to the fact that CStrider sees the potential operators in the future as young people, particularly students who may work on their boats part time. The two interviewed amateur vehicle operators Carl Troiza and Samuel Stüber were brought in to test the prototypes. Being two people with boating experience as well as being familiar with this project made them suitable as testing candidates. The other two candidates, Gustav Fjellheim Eriksson and Evelina Stridsberg, are both design master's students, the former studying industrial design engineering and the latter studying interaction design. Their expertise was deemed valuable from their design and ergonomics backgrounds, and their lack of boating experience offered a fresh perspective. It was important to have different points of view gender-wise, as men and women may view their situational safety differently. For this reason, a female test-user is included for the physical prototypes, and additional women that could not make it to the test site were shown the CAD models.

The tests were arranged as a role play where each of them would take a turn acting as the operator and play out a scenario. The scenario included boarding passengers, going in to the designated ship officer's space, pretending to manually drive the boat in case of emergency and lastly, deboard passengers. Feedback was given on these pre-defined questions:

- How seamless was the experience?
- How intuitive were the buttons in terms of placement and function?
- How physically comfortable was the space?
- Would the space feel safe in case of disturbing passengers?
- What would you change about the space to enhance your experience?

All candidates role played for each concept and after feedback was given on them, they got to give suggestions on things they would change. A third role play was then made with these changed in mind to compare the experience. For future references, the "comfortable" concept will be referred to as concept 1 and the "space-saving" concept will be referred to as concept 2.

4.2.1 Feedback on Counting System from Amateur Vehicle Operators

Starting from boarding of the passengers, feedback was given that the counter should count down from 12 instead of counting up from 0 like demonstrated because passengers will not know that 12 is the maximum people allowed. See Figure 4.5 for setup of the cues for the countdown and light. Both Troiza and Stüber liked all three cues for counting as they thought that it would make it easier for passengers to understand that there is a limit and when that limit is reached, rather than the operator having to explain it to individuals at every stop and increasing the risk for unnecessary arguments. Some comments were raised about the physical clicker, they would like it to be attached to them in some way to not risk losing it and that it should be able to lock the door as well. Troiza who would prefer a more host like role would like for the clicker to be a microphone as well so he can communicate with the passengers at all times, while Stüber who would prefer a more passive role as an operator did not think it would be necessary to have that feature.

Figure 4.5: Setup of the counting indicators: countdown screen and lights to alert passengers when maximum capacity is reached.

4.2.2 Feedback on Concept 1 from Amateur Vehicle Operators

Moving into the actual ship officer's space, both of them expressed that they would want the back wall to be the officer's exit instead of using the main doors. This could serve both as an emergency exit, or as a strategic exit to avoid potential passenger crowding near the main doors during boarding and deboarding. Having to do crowd control and squeeze through passengers to get out first could become bothersome in the long run. See Figure 4.6 for test scenario 1.
They both raised the questions if the buffet cover and front wall are both necessary to prevent people from touching the equipment. They would prefer to only have the front wall as the cover is making it harder to use the buttons. A suggestion was made that instead of having the cover, the front wall could instead be in an L

shape to block people from being able to reach the equipment from all sides while simultaneously freeing up the desk space.
Since the space is so limited, they did not think it is necessary for the desk to be able to move forwards and backwards and instead only have a height adjustment. They did enjoy the flipping chair and liked that it does not take up unnecessary space when not used.
Troiza expressed that he would prefer to have a handle on the wall or the desk to hold on to in case there are strong winds and Stüber agreed. To increase the comfort in cases when the joystick needs to be used, they would prefer some sort of padding for the wrist.

Figure 4.6: Amateur vehicle operator test candidates discussing concept 1.

4.2.3 Feedback on Concept 2 from Amateur Vehicle Operators

Both their initial comments were that they liked the openness of this concept more, it did not feel as cramped as concept 1. They did however not prefer the leaning seat and would prefer to have the flipping chair in this concept as well. Their main concern with this concept were that passengers may not understand that it is the ship officer's space due to its openness and may put their things there, for example

bikes or strollers. For the same reason they both did not feel as safe in case of disorderly passengers with this concept and expressed that they feel more exposed with the door being fully open and in a worst case scenario, they would not have the time to close the door. They would prefer to have the same front wall as the last concept to increase the sense of safety as well as communication to passengers that this is the captain's space. See Figure 4.7 for test scenario 2.
Regarding the desk itself, they preferred the "buffet" cover for this concept as it is not in the way when using the equipment and thought it was easy to use. An ideas was expressed that instead of having a physical barrier to hinder passengers from touching the equipment, a digital lock can be implemented. This way it is only the operator that has access to control the buttons and the risk of unauthorized access is limited.
They would like to utilise the space underneath the desk and would like some sort of locker to place personal items in and space for a fire extinguisher to have it close by.

Figure 4.7: Test user standing in the designated ship officer's space.

4.2.4 Feedback on Counting System from Design Students

Both Eriksson and Stridsberg appreciated the multiple cues regarding the counting system and referred to multi-modal information as something they would want to have as ship officers. They shared the same opinions as Troiza and Stüber regarding the clicker, that it should have added functions like locking the door or raising the gangway to make it more useful. They would also want it attached to them as they anticipated that there is a high risk of losing it if not.

4.2.5 Feedback on Concept 1 from Design Students

Both Eriksson and Stridsberg raised questions about the front wall perhaps being too tall, they expressed concerns about the visibility in front of them while seated. They did appreciate the fact that there is a wall to screen off between them and the passengers but would either want it completely or majority of it see through. Regarding the door, Eriksson had some initial comments about it being unnecessary but liked the idea of it more when it was explained that it is only meant to be locked during emergencies. However, it was not a top priority of his to have a door as it minimized the space. Stridsberg however saw the door as a top priority and would want to be able to lock herself in to increase her safety. It was important for her for the door to not be completely see through and without any holes to reduce the possibility of disorderly passengers to reach her.
They both liked the idea of a symbolic screen off for the dashboard but would also prefer to have a digital lock to fully secure the dashboard from unauthorized access. Regarding the adjustable features for the desk, they both wanted height adjustability and Eriksson would like the ability to tilt the screens as he anticipated that glare could be an issue for the screens in sunny conditions. He would prefer to have that feature rather than the ability to adjust the desk forwards and backwards.
Like Troiza and Stüber they would like to utilize the space underneath the desk to store their personal belongings and would like some features that are not necessary but preferable, like a cup holder or a hook to hang their jackets.

4.2.6 Feedback on Concept 2 from Design Students

They really liked the visibility and space in this concept a lot more but did not like the fact that they were fully exposed to the passengers when the door is open. This concept did not indicate to the passengers that the space is off limit, like Troiza and Stüber mentioned, and Stridsberg raised concerns about not having enough time to close and lock the door if needed and therefor not feeling safe. They would both prefer a seat with more options, like a foldable seat that also combines a leaning pad for when they would prefer to stand.

4.3 Primary Takeaways From Testing Feedback

After analysing the feedback given from the tests, these were the primary takeaways and features that were taken into consideration for the final concept:

- Although the fully open concept offers great mobility, some sort of barrier indicating that this is "personnel only space" is desired.
- Space for personal items such as somewhere to hang a jacket, store a backpack, or place a beverage would be appreciated.

- Users could not see themselves closing the buffet cover every time they had to go outside to count, they would rather have a digital lock that only they have access to.
- The clicker should be more than just that, add some features so it facilitates their experience.
- The desk and seat should be adjustable and have multiple options, however not necessarily in a horizontal direction.

5

Final Proposed Concept of Ship Officer's Bridge

Utilizing the feedback from testing, a variety of design changes were made. The new proposed concept is a combination of features from the two prototyped concepts, as well as some new additions and alterations.

5.1 Final Proposed Design

The concept's features have been broken up into the pulpit and the counting system and are quickly summarized below, but will be further discussed and shown later. The pulpit consists of the following features:

- A front wall that is primarily transparent, but opaque up to the height of the personal items locker to provide some privacy. The previous idea of having the ability to open the window was removed. The wall was also expended into an L shape for a visual cue that the space is not for passengers.
- Personal item storage is provided with a locker placed along the side wall under the dashboard, a cup holder mounted on the wall next to the seat, and a hook on the extended L portion of the wall facing the outside of the pulpit.
- A paneled emergency door folds into the corner when not needed, but can be deployed by pulling on the handle. The handle is also the latch, which hooks onto a pin on the inside of the wall's L extension.
- The ability to adjust the desk itself was removed, opting instead for it being fully fixed to the front wall. However, the screens are able to be tilted up and down. The buttons are large and backlit with decals and embossed labels for easy identification. The brightness of the screens and button backlights are adjustable.
- A handle mounted to the side wall can be grabbed for stability in choppy waters.
- A visor fixed on the front wall above the dashboard will act as a guard against the glare of the sun. It swivels and folds for maximized adjustability.
- The throttle is now integrated into the joystick, thus minimizing the space needed on the actual desk for two separate entities.
- The seat allows for height adjustability as well as provides the possibility to lean against the folded up seat when standing.
- A standing mat is in place to relieve some pressure from the body when standing and add comfort.

The following CAD images were created for this project using a combination of Autodesk Fusion and CATIA v5, although it should be noted that a few of the props were taken from the open source library of GrabCAD: the fire extinguisher[33], backpack[34], hat[35], and mannequin[36]. The engineering drawings for each component of the model can be found in Appendix C. Figure 5.1 gives a summarizing view of the personnel pulpit that will be described in more detail below.

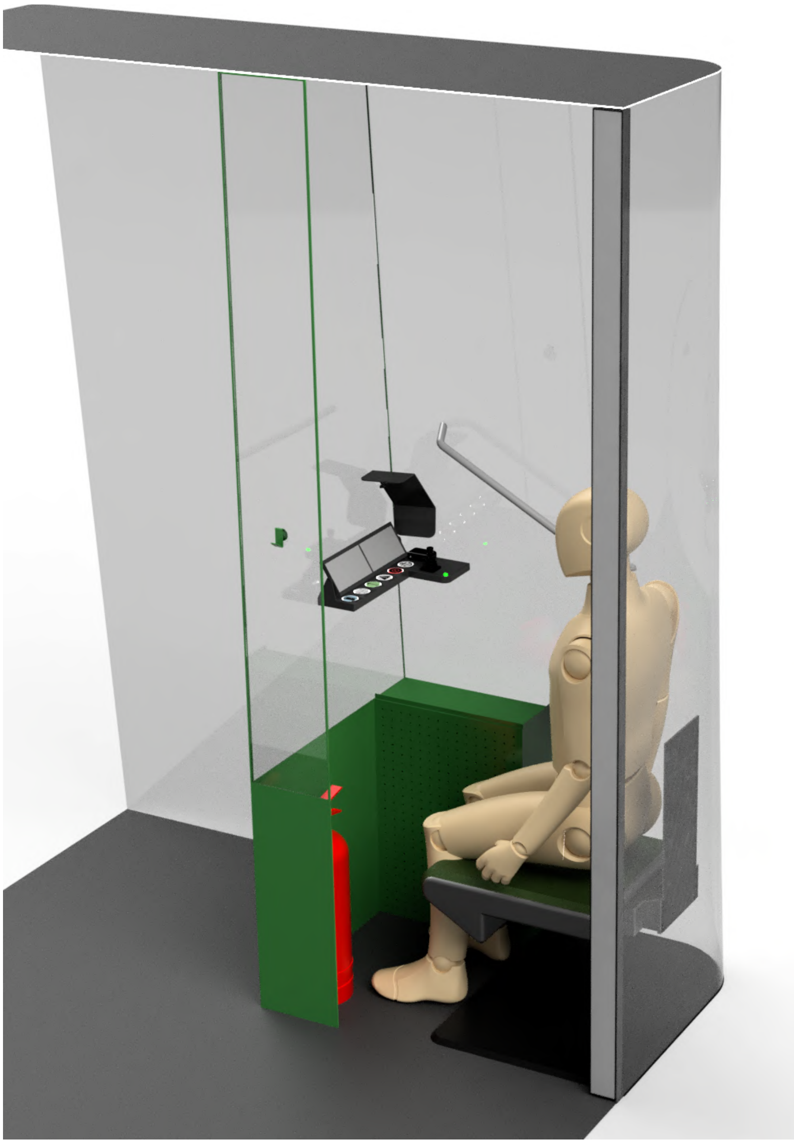


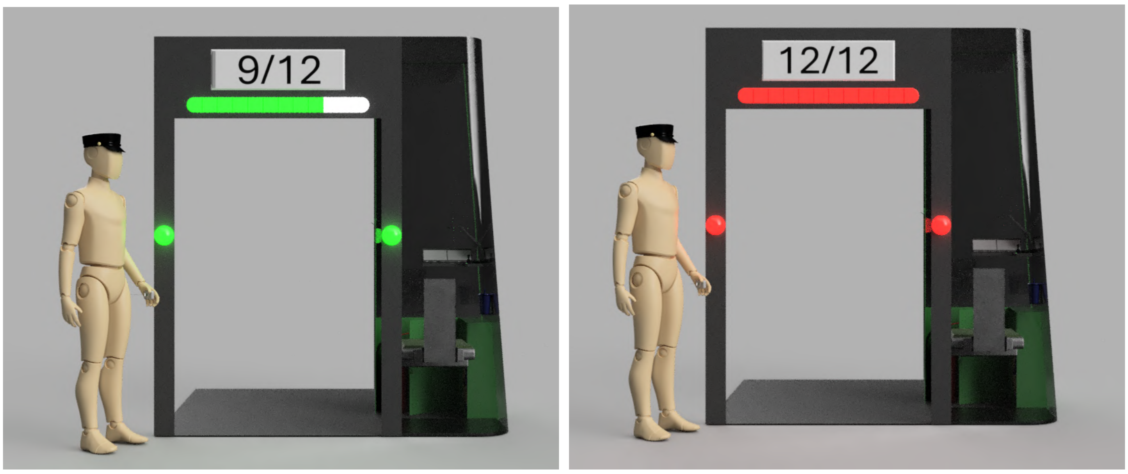
Figure 5.1: The personnel pulpit equipped with a variety of features to enhance personnel experience on board.

The counting system consists of the features below:

- A remote attached to a retractable lanyard acts as the digital key for the dashboard. It is equipped with arrow buttons that connect to the counting screen and lights, as well as microphone, door, and gangway buttons.
- A screen above the outside of the door displays how many passengers are on board as a fraction, for example "9/12".

- A progress bar directly underneath the screen provides a visual representation of 9/12, lighting up in green, but turning red when capacity is reached.
- Lights that turn from green to red will also be placed on each side of the door at halfway height to provide an indication for those at lower eye level.
- At full capacity, a speaker will audibly announce that capacity has been reached.

Figures 5.2 a and b depict the counting setup for passengers boarding and full capacity having been reached.



(a) Counting setup for nine out of twelve passengers on board.

(b) Counting setup for reaching full capacity.

Figure 5.2: Renderings of the counting system in-progress and at maximum passenger limit.

5.1.1 Dashboard Description

Testers did not like the idea of having to physically close something to protect the controls every time they left the pulpit, whether that be sliding down the buffet cover or pulling a rope across the entryway. That being said, they agreed that some precaution was necessary to prevent tampering, and the idea of a digital lock/key was suggested. Therefore, the dashboard only works when personnel is in close proximity. This idea was implemented, with a small indicator light placed near the joystick to determine whether the control panel is "live" or not.

According to the interview with the tram driver, large buttons with clear decals are preferable. This was implemented with 4 cm wide buttons and graphic symbols. Embossed labels were added under the buttons so that they are identifiable should someone learning the controls need a reminder, or should the decals fade over time. Buttons were kept to a minimum to reduce cognitive load, as a cluttered interface with too many buttons can be overwhelming and increase stress[37]. Placement of buttons was also based on expected usage. The included buttons and their functions are as follows:

- DOOR: opens and closes the door to the boat.

- GANGWAY: lowers and raises the gangway when docking.

- GO: once the gangway is raised and the doors are closed, this button can be pressed to indicate to the autonomous driving system that the boat is ready to depart.

- ALERT: contacts the traffic center for the public transportation authority that is operating the boat. This is to be used in medical or safety emergencies in conjunction with the microphone located on the employee remote.

- STOP: initiates the "digital" or "GPS" anchor such that the boat keeps itself in one place using minute adjustments from the motors.

- ANCHOR: deploys the physical anchor.

The tram driver also said that for night driving, backlighting behind the buttons was helpful, and the ability to adjust the brightness of these lights and the screens was immensely relieving for strain on the eyes. Therefore, these features were added to this design. Although brightness adjustability was mentioned in the context of nighttime usage, this feature would also be helpful for excessive sunlight which is often the case on the water.

The joystick is an integrated joystick and throttle system such that a separate throttle is not necessary on the dashboard. Not only does this enable the dashboard to be even more compact, one tester with boating experience voiced that this system has less of a learning curve than a two-hand system. As previously discussed, an advantage of the CStrider vessels being kept at a 12 passenger limit is to lower the barrier to entry for working on the vessels as it only requires a class VIII Ship Officer license. Having the boats themselves be easier to learn also contributes to lowering this barrier to entry. A clear space was also left for wrist support when using the joystick and space was cleared for the autopilot system remote which was a requirement from CStrider. Figure 5.3 provides a close-up shot of the dashboard.

Testers wanted to combine the privacy of a wall from the first prototyped concept, with the easy mobility of the second. To do so, the dashboard was made compact, and was mounted in the upper right corner of the pulpit to leave as clear a path as possible from the seat to the exit. Having minimal buttons, one-handed driving capability, and mounting in the corner of the pulpit enables the driver to stand sideways and look backwards as well as depicted in Figure 5.4.

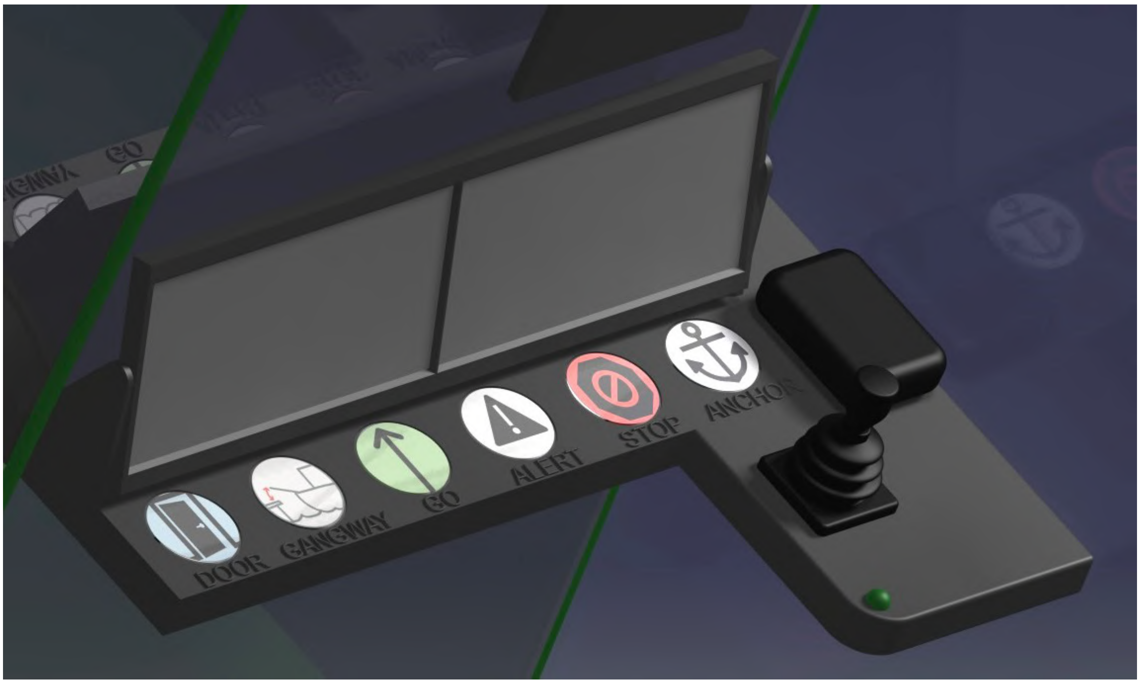


Figure 5.3: A close-up shot of the dashboard, showcasing the compact design, tiltable screens, button decals and embossing, and integrated joystick.

Figure 5.4: Rendering depicting one-handed driving while facing backwards.

Although the prototyped concepts were both height adjustable, and the traditional desk option was also horizontally adjustable, testers felt that they would realistically never utilize those functions in such a small space. Therefore, to minimize cost and complexity, these features were removed. Instead, the dashboard is mounted at a fixed height of 94 cm (37 in). This height was based on Figure 5.5 which shows the elbow height for a 5th percentile female and a 95th percentile male. The height should be accommodating to any employee regardless of height, and it was agreed after discussing with experienced boaters that it is easier to steer if something is a bit too low rather than too high. Therefore, the shorter height was selected. To provide some level of adjustability for users of different heights, the screens are able to be tilted instead to ensure a clear view of their information.

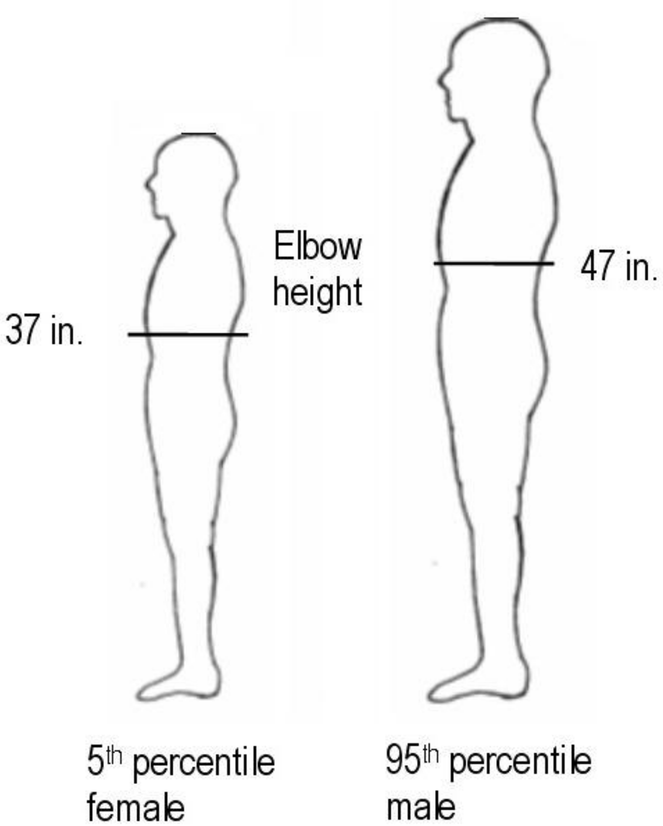


Figure 5.5: Diagram showing the elbow height for a 5th percentile female (37 in= 94 cm) and a 95th percentile male (47 in= 119 cm). [38].

5.1.2 Front Wall Description

Testers said that while the open concept's mobility was great, being entirely left open to passengers made them uncomfortable. They expressed that some sort of barrier gave them a greater sense of professionalism. Many noted that a barrier would also contribute to the ability to periodically mentally relax during one's shift rather than being in constant proximity to customers. Female testers additionally stated that a barrier gave them an increased sense of safety. Although the prototype's wall was an

openable window, testers postulated that they would never actually use this feature and that a fully transparent barrier would not hinder their visibility.
Using this information, a front wall was positioned in our concept one meter from the back wall. The majority of the surface is transparent, from the ceiling to 63.5 cm above the ground, where the rest is opaque. This height corresponds with the height of the locker so that personnel can open the door to the locker without showing passengers their personal items.
As previously mentioned, closing the pulpit every time they left felt cumbersome, and with the installation of the digital lock/key there is now no great risk, but some additional privacy would be nice. Testers suggested that slightly extending the wall into an L shape would be enough of a visual cue to indicate to passengers that the corner space is not to be entered. This also provides the additional benefit of a lesser distance to cover when pulling shut the emergency door. Figure 5.6 shows the front wall and L-extension from floor to ceiling.

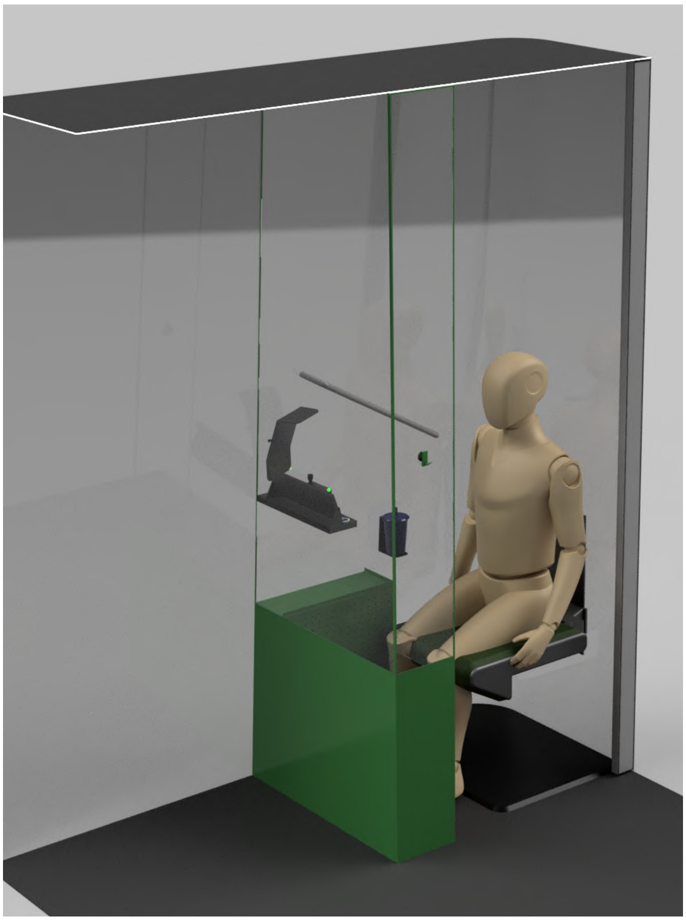
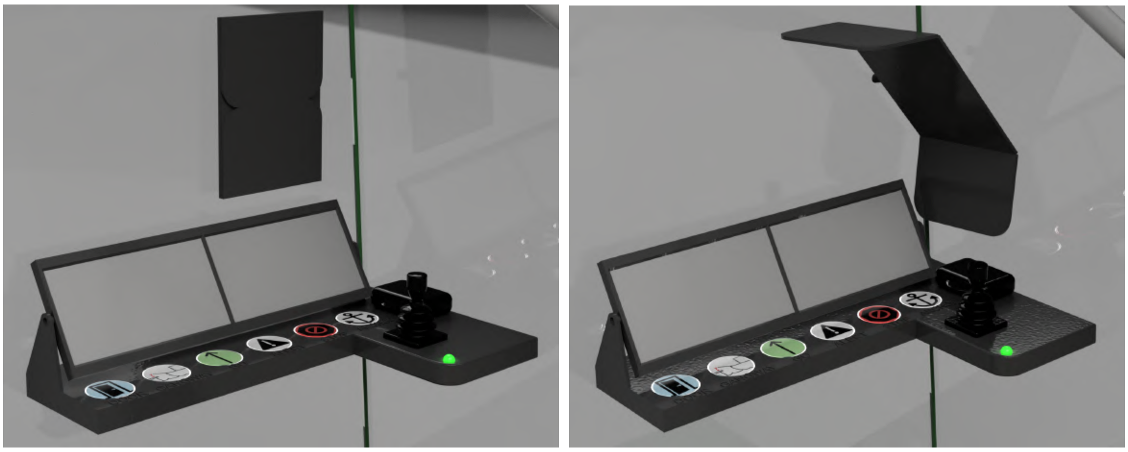


Figure 5.6: The front wall is L-shaped, extends floor to ceiling, and is opaque up until the height of the locker.

Attached to the wall, above the dashboard, is a sun visor. Two flaps fold out to cover more area, but can be folded flat when not in use. The entire thing swivels and tilts for total adjustability against the angle of the sun. Figures 5.7 a and b depict the visor folded away and opened up.



(a) The visor closed and folded flat against the wall to be out of the way.

(b) The visor opened up and in position for blocking the sun.

Figure 5.7: Two views of the sun visor that is attached to the front wall.

5.1.3 Personal Item Storage Description

The prototyped concepts did not take into account personnel's personal items at all, and this was repeatedly addressed by test users. The first remedy was adding a locker placed along the side wall in the corner under the dashboard. The standard backpack size for adults is approximately 48 cm high, 33 cm wide, and 18 cm deep[39]. The locker dimensions aimed to accommodate that and potentially more, while still not taking up too much space, and landed upon: 63.5 cm x 44.5 cm x 20 cm. A ledge was added to the top of the locker such that items placed there, such as a phone, wouldn't slide off.

A cup holder was added to the side wall near the seat. The "arms" of the holder do not meet to make a full circle in order to allow some flex for cups of differing sizes.

A hook was placed on the L extension of the wall, but facing the outside of the pulpit. This was done so that wet umbrellas or jackets wouldn't drip water into the pulpit itself. This also helps to prevent overcrowding of the small space.

The three features can be seen in Figure 5.8.

Figure 5.8: This angle shows a hat hanging on the hook, a cup in the cup holder, and a backpack in the locker with a slight ledge on the top.

5.1.4 Emergency Door Description

The intention behind the emergency door is that it will only be deployed should personnel feel unsafe, thus the door should be folded away a majority of the time. Therefore, a design that could be deployed quickly and securely, but not take up too much space when not in use, was necessary. Testers felt that in the space-saving concept, where the rail for the paneled door would go all the way around the pulpit area, the time to draw the door into place would take far too long if there was a threat in the boat, particularly due to having to pull the door across a bend. In the second concept, where the rail only had to cover a straight line and the front wall provided extra protection, testers felt more comfortable. When performing feedback outreach, male participants expressed less interest in the presence of the emergency door, while female participants felt very strongly about the ability to close themselves off. CStrider supports diversity of potential future employees, so the door was included in the final concept.

As previously mentioned, the inspiration for the original emergency door design came from Figure 3.16. Due to the concerns of deployment time, the idea of using a scissor gate style door was brought up and an example image can be seen in Figure 5.9. Testers were positive to how small it folded up when not in use, but were apprehensive to the open holes and felt it would not give enough of a sense of safety.

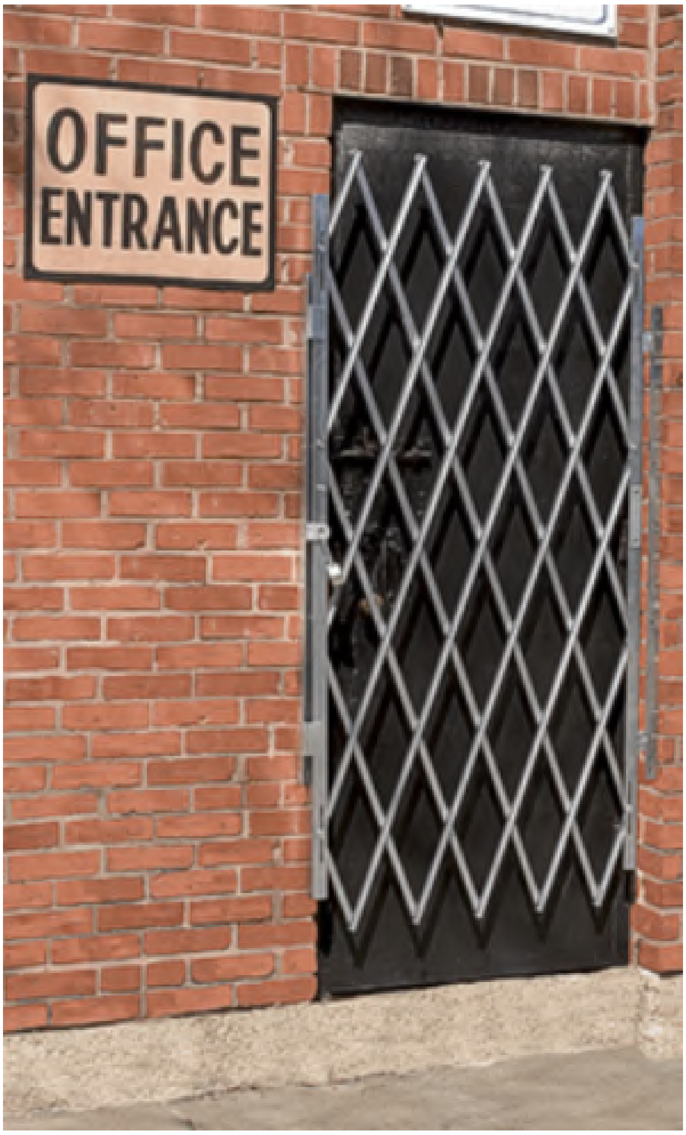
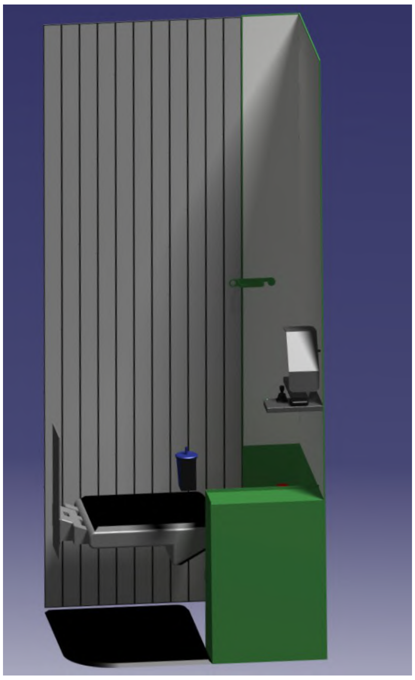
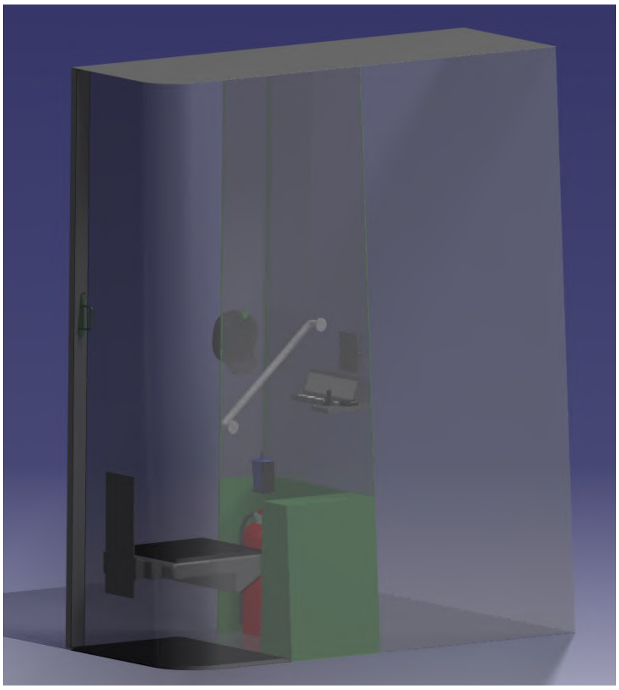


Figure 5.9: A "scissor gate" style steel protective door [40].

As such, a combination of the two ideas was developed. The new door utilizes solid panels, but is mounted to the wall the same way the scissor gate is, rather than along the rails as is seen in the original security grate idea. With a gap between the door and the floor/ceiling, there will be no friction which should aid in quick deployment. The panels fold up out of the way along the back wall next to the seat, and then the handle can be pulled to straighten the panels out. Figures 5.10 a and b show the door deployed and folded up.
Once fully pulled out, the handle rotates down and hooks onto a pin on the inside of the L-extension to lock the door. Figure 5.11 provides a close-up view of the handle mechanism.



(a) The emergency door deployed, closing off the pulpit.



(b) The emergency door folded up to the left of the seat, the handle ready to be pulled.

Figure 5.10: The emergency door component of the final concept.

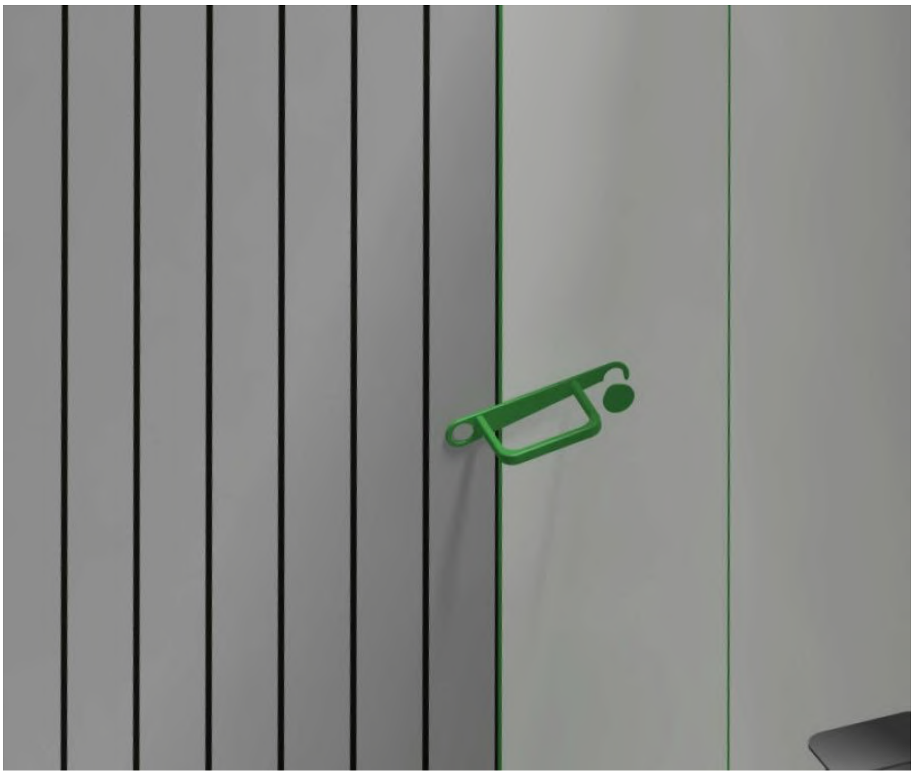
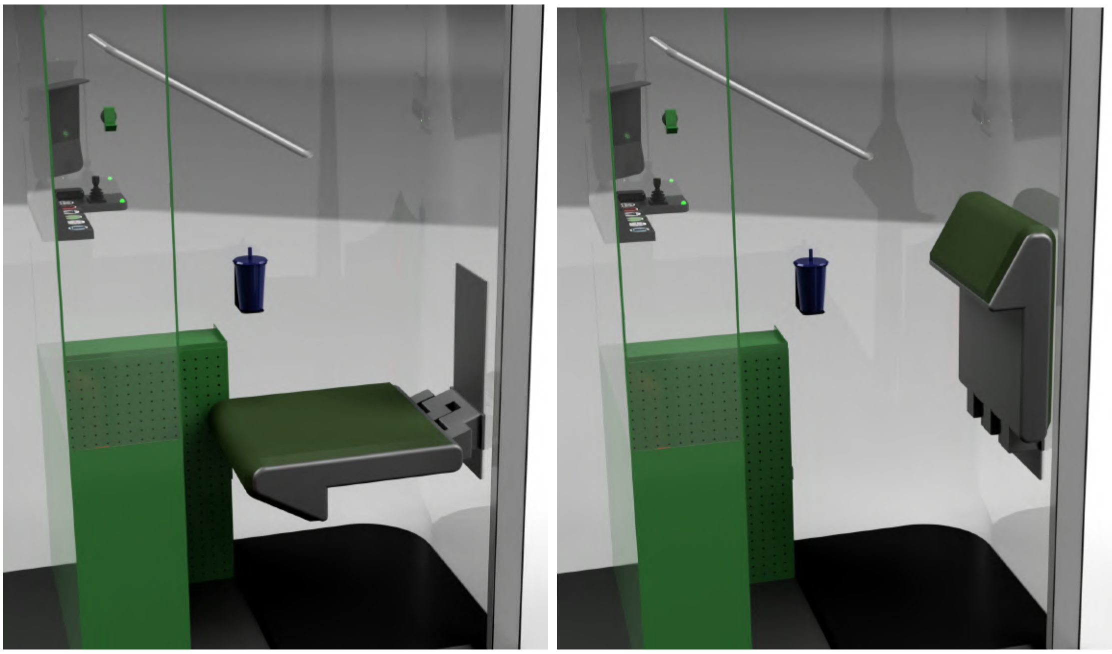


Figure 5.11: The latch to the door is integrated with a handle, to be pulled and rotated down onto a pin coming out of the wall to lock.

5.1.5 Seating Description

Testers were unanimous in their opinion that having a plethora of options is a great contributor to comfort when working a long shift. Standing, leaning, and sitting were therefore all incorporated into this design.
For optimal comfort while standing, an ergonomic standing mat covers the distance from the back wall to the ledge of the dashboard. A handle has also been placed on the side wall to grab onto should the boat rock and extra stability is needed.
The seat itself is a nod back to one of the original brainstormed ideas, the chair with leaning area shown in Figure 3.2 b. The seat itself is a regular flip-down chair, but when folded up, the backside reveals an angled leaning pad to rest against. Figure 5.12 shows the ergonomic standing mat, the handle on the wall for stability, and the height-adjustable flip-down seat that doubles as a leaning pad.



(a) This angle depicts the seat, wall handle, and standing mat.

(b) The seat folded up reveals the leaning pad on the underside.

Figure 5.12: The pulpit offers a variety of components that contribute to comfort when standing, sitting, or leaning.

Due to the decision to fix the dashboard at a set height, the seat being height-adjustable was necessary, especially when considering that leaning may occur at a different height than sitting. For the adjustability mechanism, inspiration was taken from wall-mounted shower seats that can be found in elderly residences or hospitals, as shown in Figure 5.13.
To determine both the best height placement on the wall, as well as the necessary adjustment range, the anthropometry diagrams shown below in Figure 5.14 were consulted. Using this information, the bottom of the mounting plate will be fastened 48 cm high and will proceed up to 94 cm. This range should accommodate the comfortable seating height of an average woman, to the comfortable leaning height

Figure 5.13: An example of a wall-mounted shower seat whose height can be adjusted without the use of tools [41].

of an average man, thus encapsulating everything in between as well.

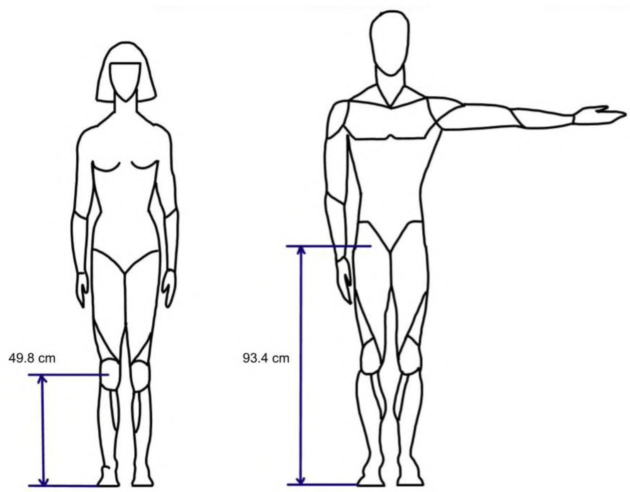


Figure 5.14: An anthropometric diagram depicting the knee-height of a woman and hip-height of a man [42].

5.1.6 Remote Description

Testers responded positively to the remote during testing, but had numerous suggestions for improvement. Firstly, they were nervous that it could easily be dropped or lost, so to combat this the remote will come attached to a badge reel, as seen in the example in Figure 5.15.

Figure 5.15: An example of a retractable badge reel, typically used for an ID card and fastened to one's belt or breast pocket [43]

Next, they requested that a few of the most used buttons from the dashboard be added alongside the counter buttons. The door and gangway buttons were added such that personnel can leave the pulpit and stand ready at the doors prior to pushing the buttons. By having personnel closer to the doors, they will be able to maintain better control of passengers for safe and orderly boarding or deboarding.

Lastly, the microphone was moved from the dashboard to just the remote for both dashboard space-saving, and convenience purposes. Should personnel need to contact the traffic center, they would be able to press the button on the dashboard and then retain contact when they leave the pulpit if they need to attend to a passenger's medical emergency. A rendering of the remote can be seen in Figure 5.16.

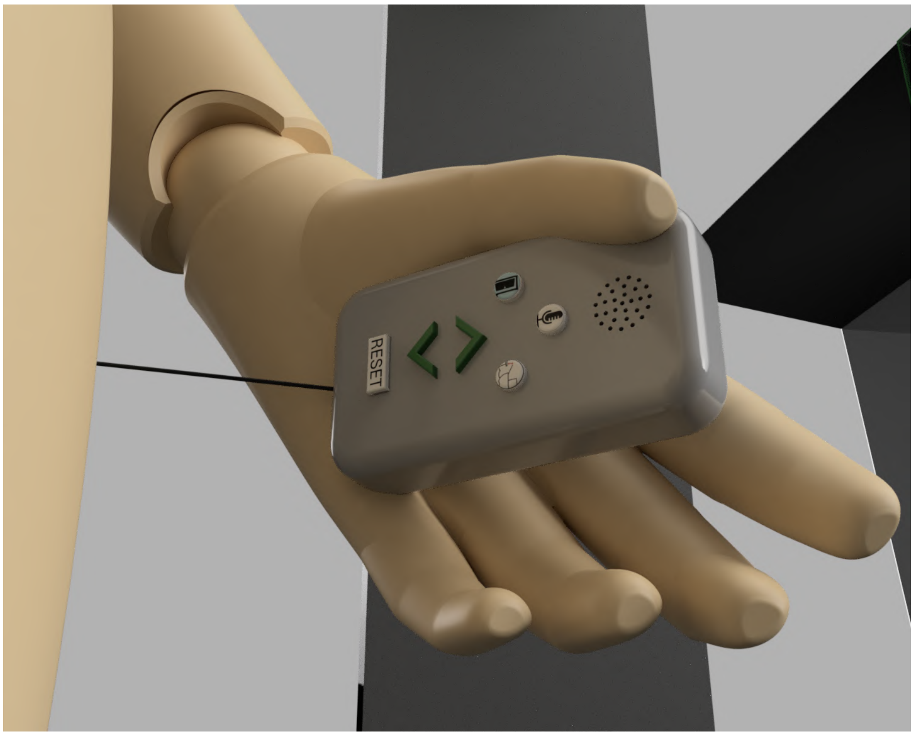


Figure 5.16: Rendering depicting the remote for the final proposed concept.

5.1.7 Counting Indicator Descriptions

Testers were primarily pleased with the prototyped counting system, though they had a few suggestions. The first was that displaying only one number on the screen made it unclear as to whether it was counting down or up. Thus, the singular number was replaced with a fraction representation of how many passengers are on board, for example "9/12" instead of just "9". To make it even clearer that this means "nine people are already on board" rather than "there are nine remaining spots", a status bar is present for a graphical representation of the boat's capacity. Once capacity has been reached, the status bar, as well as the lights on either side of the door turn from green to red. A loudspeaker will then call out, "Capacity has been reached, please wait for the next vessel". The lights on either side of the door are placed halfway up the height of the entryway in order to provide an indicator at a lower eye-level. For those in wheelchairs, or elderly people that may have mobility issues, an indicator should be provided at a level more natural to their usual body posture. Having both visual and auditory cues makes the system more accessible to those that may be hard of hearing or visually impaired, as well as for someone that may not speak the language emanating from the loudspeaker.

5.2 Performing a Failure Mode and Effect Analysis on Final Concept

One of the original objectives stated for this project was to consider the sustainability of the developed product. To do so, a Failure Mode and Effect Analysis (FMEA) was performed. An FMEA is a risk analysis tool used to identify potential failure modes when developing a new product or process[44]. The identified failure modes are prioritized and used to develop maintenance procedures as a preventative measure[45]. Maintenance plans are a crucial tool for companies to ensure the longevity of their products, which aids in saving money and increasing the return on investment[46]. Supporting the longevity of products is also one way that companies can promote sustainable practices by encouraging the reduction of waste production. This ties into the premise of a circular economy, a system where materials never become waste by keeping them in circulation through various actions[47]. In the circular economy framework presented by the Ellen MacArthur foundation, maintenance is the cycle closest to the user, meaning that it is the most accessible solution at hand[48]. Figure 5.17 shows the butterfly diagram, a visual representation of the circular economy and how maintenance fits into it. The FMEA presented below will contribute to the CStrider maintenance plan for their future vessels, thus aligning with their mission towards sustainable product development.

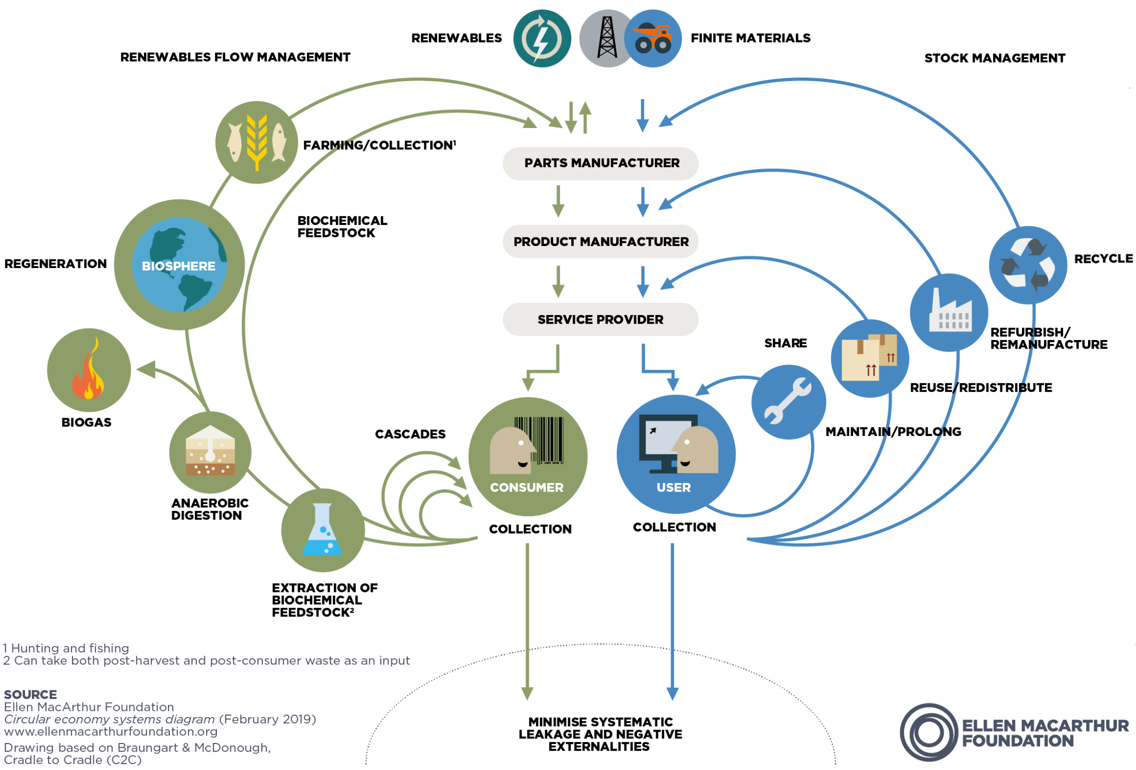


Figure 5.17: The butterfly diagram of the circular economy developed by the Ellen MacArthur Foundation [49].

Performing an FMEA consists of seven steps. First, a product is broken down into its base components and potential failure modes for each are identified[50]. The component breakdown for the pulpit was: Seat, Personal Item Storage, Dashboard, Door, Visor, Front Wall, Remote, and Counting Setup. Next, the cause and effect of each failure mode is listed[50]. The next three categories are Severity, Occurrence, and Detection and a numerical value is assigned to each of them. "Severity" describes the seriousness of the potential failure mode and "Occurrence" describes the likelihood that failure will happen[51]. "Detection" describes the likelihood that the problem will be discovered before the effect of failure is discovered[50]. Ratings are assigned such that a higher number implies a higher level of risk[51]. Therefore, for "Severity" and "Occurrence", a high number means high severity/likelihood. However, for "Detection" a high number means a lower chance of detection because that poses a greater risk. The ranking scale for these categories is not a fixed rule, the same scale should be used for all three columns as not to potentially skew the final results. It has also been proven that non-consecutive scales are more useful than consecutive ones because it allows for more distinction between the levels which makes them easier to place[50]. For this analysis, a 1,3,5,7,10 scale was used. Lastly, the Risk Priority Number(RPN) is calculated by multiplying Severity x Occurrence x Detection[51]. The RPN is used to prioritize potential faults and the procedures for addressing them[45].

For the performance of this analysis, a couple of assumptions were made. First, the assumption was made that effects were based on the first occurrence of the failure, not the effects of operating the vessel with a malfunctioning component for a long period of time. Next, the conditions for usage of the emergency door were that of the personnel feeling uncomfortable and distressed, but not facing an active threat. An active threat would have changed the potential effects of failure. Figures 5.18 and 5.19 show the full analysis.

Based on the RPN results from the analysis, the top three greatest risks all occur around the emergency door. The greatest risk was found to be the inability to close the door and protect oneself from a potential threat due to the panels not unfolding, while the second highest was the same effect from the handle breaking off. Third was the opposite effect of being locked inside the pulpit and unable to close the doors from jamming hinges. Although this had a higher severity than not getting the door closed, it was postulated that it was less likely to occur and would be more easily detected because it was assumed that should the door be unable to open, there would have been some trouble closing it too. Using this information, a future maintenance plan should include regular inspection of the emergency door hinge and panel integrity.

Tied for third at 210 was the cup holder breaking because depending on the conditions of breakage, liquid could splatter onto the dashboard and damage the control panel, or if the liquid is hot personnel could be burned. All others fall below the 200 mark, with the next value jumping down to 150. A maintenance plan would ideally look beyond just the RPN, because certain failure modes were deemed catastrophic with no chance of prior detection, though their likelihood of occurring was so low that the RPN did not become very high. That being said, items with catastrophic outcome would ideally be regularly checked despite low occurrence probability as an extra safety precaution.

Failure Mode	Effect of Failure	Cause of Failure	Severity	Occurence	Detection	RPN
Seat:						
Seat breaking off hinge	Risk of hurting yourself (falling)	Weight capacity reached causing high torque at the joint	7	3	7	147
Height adjustment jamming	Less comfortable experience	Excessive weight leading to misalignment of the mechanism	3	3	1	9
Standing mat curling up	Risk of hurting yourself (tripping)	Repeated kicking of the edge	7	7	3	147
Personal item storage:						
Cupholder breaking	-Liquid spillage damages equipment -Hot liquid burns personnel	- Forcefully knocking into it - Sun damage weakening material	7	3	10	210
Locker lock jamming	Inability to reach personal items	Rust from humidity	1	1	1	1
Dashboard:						
Button backlight goes out	-Reduced visibility -Risk of pressing wrong button	-Technical problem -Compromised moisture sealing	3	1	10	30
Dashboard comes off wall	-Damage control panel -Injury to personnel	Too much force placed at the edge	7	3	5	105
Decals on buttons fade	Not being able to identify correct button, press wrong one	-Sun damage -Worn away from finger friction	3	5	1	15
Screen tilting mechanism fails	Less comfortable experience (bending back and neck to see)	-Not enough lubricant -Stripped screws from wear & tear	3	1	3	9
Digital lock fails to connect to remote	Not accessing the controls, lose control over boat	Technical problem	10	1	10	100
Door:						
Door jamming (cannot close)	Left vulnerable to disorderly passengers	Inadequately lubricated hinges	7	5	10	350
Door jamming (cannot open)	Locking yourself in (safety hazard)	Inadequately lubricated hinges	10	3	7	210
Handle comes off	The inability to lock yourself in(safety hazard)	Forceful handling	5	5	9	225
Panels detach from each other	The inability to lock yourself in(safety hazard)	Hinges break apart (rust or general wear & tear)	7	1	5	35
Latch breaking off wall	The inability to lock yourself in(safety hazard)	Pulling on handle with excessive force without lifting off of latch	5	1	10	50

Figure 5.18: The first page of the Failure Mode and Effect Analysis depicting the seat, personal item storage, dashboard, and door component categories.

Failure Mode	Effect of Failure	Cause of Failure	Severity	Occurence	Detection	RPN
Visor:						
Snaps off wall	Less comfortable experience	-Forceful handling -Sun damage weakens material	5	3	10	150
Side flap snaps off	Less comfortable experience	-Forceful handling -Sun damage weakens material	1	1	10	10
Front wall:						
Window cracking	Reduced visibility	-Material defect -Excessive vibrations -Hit with excessive force	1	1	3	3
Hook breaking	-Liquid from wet items dripping in the pulpit -Tripping hazard if items are instead placed on floor	Weight capacity reached	3	1	10	30
Remote:						
Lanyard snapping off	Losing the remote	Applying too much tension	10	1	10	100
Decals on buttons fade	Not being able to identify correct button, press wrong one	- Sun damage - Worn away from finger friction	1	5	1	5
Digital key fails to connect dashboard	Inability to access controls, lose control over boat	Technical problem	10	1	10	100
Counter buttons fail to connect to boat	Confused passengers, stress on personnel	Technical problem	3	1	10	30
Counting setup:						
Lights go out	Less informed passengers, stress on personnel	Technical problem	1	1	10	10
Screen goes out	Less informed passengers, stress on personnel	Technical problem	1	1	10	10
Speaker not working	Less informed passengers, stress on personnel	Technical problem	1	1	10	10
Lights fail to update	Confused passengers	Technical problem (lag in system)	3	3	10	90
Screen fails to update	Confused passengers	Technical problem (lag in system)	3	3	10	90

Figure 5.19: The second page of the Failure Mode and Effect Analysis depicting the visor, front wall, remote, and counting setup component categories.

5.3 Requirement Fulfillment of Proposed Final Concept

After the final concept has been decided, it was time to compare it to the requirement specification and see which requirements were fulfilled and which were not. The two categories presented are the safety and the ergonomics requirements.

5.3.1 Safety Requirement Fulfillment of Proposed Final Concept

For the primary safety requirements, the most important ones, all of them are deemed to be satisfactorily fulfilled thought at varying levels. These requirements and their fulfillment statuses are presented in Table 5.1. The first requirement is fulfilled but there is some room for improvements. Thanks to the translucent wall in front of the operator, there exists high visibility in the boat so they can have clear vision of their passengers. However, there are not any additional measures taken like mirrors or cameras to improve their vision even more, they are solely relying on their eyesight. Thanks to the boat's design with the big windows, their visibility around the boat is deemed to be high as well but again, there are no added features like cameras to be able to see what is in the water. The concept of cameras was brought up during the interviews phase, however no participants were particularly excited over the thought of relying on technology too much. As such, the operator has good visibility in and around the boat, but it could potentially be improved.
The space do instill a sense of safety for personnel due to the emergency door being in place, as well as the front wall. This was highly appreciated by the test participants and they all agreed that they would not feel as safe without these features included. Manual driving capabilities are present, as the joystick was taken into account when designing the dashboard and it has a designated spot which is easily accessible. The space in it self does not assist the personnel in awareness of number of passengers, however the measures added outside through the lights, countdown and speakers do assist the personnel and therefor fulfill the requirement. By having the personnel leave their space to count each time with the help of these measures, it keeps them alert between stations which is a requirement in the next category.

Primary needs	**Fulfilled?**
Exists high visibility in and around the boat	Yes
Space instills a sense of safety for personnel from disorderly passengers	Yes
Manual driving capability	Yes
Space assists personnel in awareness of number of passengers on board at all times	Yes

Table 5.1: Primary safety requirements fulfillment statuses.

All the secondary requirements are deemed to be fulfilled as well and are presented in Table 5.2. Thanks to the ship officers designated space that is somewhat see through, the passengers know where the nearest help is at all times. By going out and greeting passengers as they count them, passengers can feel safe knowing that there is a helping hand, perhaps for elderly passengers and therefor instill a sense of safety for them. The ship officer is also kept alert through the act of getting up and out to count passengers at each stop. This could additionally heighten passengers' sense of safety knowing that the ship officer is not distracted in the pulpit causing them to be nonreactive should something happen. With that being said, more testing would either prove or disprove this point as these are speculated results. By integrating a microphone to the remote, the ship officer has the ability to communicate with their passengers at all times which is the last requirement for the secondary category.

Secondary needs	**Fulfilled?**
Space instills a sense of safety for passengers	Yes
Space keeps personnel alert	Yes
Permits ability to communicate with passengers	Yes

Table 5.2: Secondary safety requirements completion statuses.

The last category, tertiary needs, is presented in Table 5.3 and only consists of one need. This was not fulfilled as the proposed solution does not take any distinction between notifications into account. This is due to the need being of low priority, hence it being a tertiary need, and the focus was instead placed on the more important needs.

Tertiary needs	**Fulfilled?**
Exists a clear distinction between notifications for critical situations	No

Table 5.3: Tertiary safety requirement fulfillment statuses.

5.3.2 Ergonomics Requirement Fulfillment of Proposed Final Concept

The primary ergonomics needs are both fulfilled as well and presented in the Table 5.4. By placing the ship officer's space to the back of the boat, closest to the exist, it facilitates their job when they go out to count to not have to go through the entire boat every time. In addition, they can also always have their eyes on the dock by being close to the exit and therefor possibly heightening the passengers sense of safety by knowing that they are always nearby to help passengers board etc. The space promotes comfort for personnel as the added features were designed with comfort in mind. By allowing comfortable standing, seating and leaning options, the ship officer can choose what they find most comfortable in that particular moment.

The dashboard is placed on an intentional height to be as comfortable as possible for the most amount of heights as possible. The joystick is placed in a way so there is some support on the wrist when used and therefor a relief for the operator when needing to use the joystick.

Primary needs	**Fulfilled?**
Personnel has easy access to exit	Yes
Space promotes comfort for personnel	Yes

Table 5.4: Primary ergonomics requirements fulfillment statuses.

The secondary ergonomics needs are presented in Table 5.5. The ship officer can quickly change direction due to the throttle and joystick being integrated into one so they can drive one handed as they turn their heads for visibility. The dashboard is also placed partly on the right wall which allows more space for them to turn around when needed. The layout requirement is deemed to be fulfilled since it has a minimal amount of objects on the ground to prevent obstruction, however there has not been adequate enough testing to evaluate how true it is. No tools or gears are placed in the space so that requirement is deemed to be unfulfilled. There was a trade-off between saving space and adding features and it was decided that necessary tools can be placed outside the boat and that the only emergency tool the officer needs to be able to instantly reach is a fire extinguisher, which is available in the space.

Secondary needs	**Fulfilled?**
Enables captain to quickly change direction	Yes
Has unobstructive layout	Yes
Strategically placed tools/gears	No

Table 5.5: Secondary ergonomics requirements completion statuses.

The last category, the tertiary needs of the ergonomic category is presented in Table 5.6. The joystick is not deemed to be ergonomically placed as the placement was not based on any particular ergonomic factors thus leaving the first requirement unfulfilled. The interface is however deemed to be intuitive as the amount of buttons were kept to a minimal and there is both text and decals for the buttons to know exactly what they do.

Tertiary needs	**Fulfilled?**
Ergonomically placed joysticks	No
Has intuitive interface	Yes

Table 5.6: Tertiary ergonomics requirements fulfillment statuses.

6
Discussion

This chapter will serve as a reflection on the entirety of the project. This will include consideration on both the process that was used, as well as the final proposed product. A critical approach will be taken to investigate what went well and what could have been improved, as well as a speculative look into a few "what if?" questions.

6.1 Discussion of the Assigned Task

One of the discussed research questions with CStrider is what the ship officer's tasks will be since the vessel is meant to be self-driving during all normal operation. This was something that was brought up early in the project and a focus for the team during the project preparation stage. Because of that, interview questions were adapted to ask the boat captain's and personnel what their tasks were when they are not operating the boat and the majority of the answers were regarding checking machinery for leakage, if they need maintenance etc. It was quickly realised that the tasks for the personnel on a traditional manually driven boat will differ drastically on a fully autonomous boat. The focus was then shifted to the passengers to investigate if they could possibly need or want anything that can fall under the ship officers tasks. When the results showed that passengers are not dependent on the ship officer and would actually rather be left alone, the decision to solely focus on the physical space was made. One aspect to that decision is that there simply was not enough time to do more outreach and investigate further what tasks could be relevant. Different priorities of the research questions would possibly lead to different results. One thing to note is that even though the possible tasks were not a focus, they were still relevant throughout the development of the final concepts. For example, the decision to make the counting so interactive was due to the fact that it could add to the tasks of the ship officer. The microphone was also an added feature for the officers who prefer to have a more host-like role and interact with their passengers throughout the journey. So even though the decision of specific tasks was not a focus of the project, a compromise was still found.

6.2 Discussion of the Project Preparation

For the project preparation, it was a conscious choice to interview boat captains with not only different experience levels and classifications but also who operate their vessels under different contexts. For example, Bosse Johansson operates his taxi boat for leisure purposes acting as a guide on different routes whereas Dan

Börjesson operates his car ferry in a strictly professional role across more or less the same routes. This gave the project a more nuanced view on ship officers' priorities, tasks, and preferences when operating their specific boat. Interviewing the tram driver, Tommy Viljestig, was also extremely helpful as he had differing preferences and opinions than the boat captains and his feedback was greatly referenced and used in the development of the dashboard. Overall, the performed interviews gave great knowledge and more importantly, differing experiences which resulted in a more well-rounded base for the concept development phase. With that said, performing more interviews would have provided a larger sample size to provide data representative of a larger population.

During the project preparation, discussions were had regarding how to verify the final result and how well it fulfills the requirements. It was quickly realized that most requirements would have more qualitative verifications than quantitative and it was a struggle to define them in more ways than just "testing". For example, how do you verify if a space is comfortable if not for extensive testing? It was decided that the verification methods would be revised when a final concept emerged to be able to better decide how to verify the fulfillment of requirements. However, it was still a struggle to define valuable verification methods and the time was unfortunately not there.

As a result of that, a discussion was had on what could have been done to better verify qualitative results. What would the results have been if, for example, a survey was made to convert qualitative data to quantitative by asking the test candidates to rank their experiences on a numerical scale? That is an important point that could give stronger evidence to the fulfillment of requirements.

6.3 Discussion of Concept Generation

The concept generation resulted in many different combinations in the morphological matrices thanks to the amount of brainstormed ideas from the start. The usage of morphological matrices was also a conscious decision as many combinations were desired and the fact that the project was done by two people could potentially limit the amount of produced ideas. It was also decided that the combinations would not be randomly produced but rather have a "best" and "second best" ranking to try and produce intentional combinations with potential.

For the first Pugh matrix, all concepts were compared to a "basic" concept which was essentially our own combination of the most basic components. Even though this was done to try and have the most simple combination as a neutral starting point, it raises the question if the results would have been different if another combination would have been chosen. An ultimate reference would have been an already existing standardised concept to limit any potential bias.

As mentioned, there were many different combinations for the space that were evaluated multiple times which was not the case for the counting ideas. There were not enough valuable ideas with potential that could fill out their own matrix so the final solution ended up being a combination of multiple different ideas. The combined ideas definitely had potential to be great but would the result differ more if more ideas were produced? Or if they were evaluated through matrices as well?

The combinations were however appreciated not only by the team but also CStrider and the testing candidates so they were deemed to be good enough to not need any additional ideas.

6.4 Discussion of the Prototypes

When deciding how prototyping should be performed, there was a discussion regarding the merits of full-scale, low-resolution prototypes versus 3D-printing highly detailed scale models. A full-scale model typically provides a better feeling and is helpful in immersing oneself in the role of the user, but the lack of detail in the limited materials resulted in leaving quite a bit up to the imagination. A 3D-printed model would provide high-definition visuals, but would make it very difficult to gauge whether the allotted clearance is enough or if things are actually quite uncomfortable etc. Therefore, full-scale prototypes were built and this proved to be an excellent choice as it meant that test users were able to role play being an employee rather than just discuss what they think of a 3D model.
Due to the time constraint of the project, a second iteration of physical prototypes was not done. Instead, a new CAD model was created with the feedback from test users and then feedback was given on renderings from this model which served as the second iteration. As was just mentioned, feedback tends to be richer when it comes from being able to physically interact with a product. One positive note that served as a half iteration of sorts, was that test users were asked to mix and match components from the two proposed concept to create their optimal solution. This provided excellent feedback, and enabled test users to get creative.

6.5 Discussion of the Testing Procedure

One aspect of the testing procedure for this project that could have been better is the diversity of the test users. In general, more test users would have provided a better sample size, and thus more representative data. All testers fell between the ages of 24 and 29. On the one hand, this is a representative age group for potential future employees, but at the same time the an older group may have had differing needs. For example, an older person may care more about the comfort of the space as working long shifts becomes harder on the body with age. The test group was also primarily male, which did affect the results regarding personnel safety on board. One thing that was represented well in the test users was the level of boating experience. Some testers were licensed, while others were not which was important because the intended future employee is not necessarily someone with many years of prior experience.
Looking back at the testing phase of this project bears a few possibilities for speculation. Although keeping the prototyping process short and cheap was necessary to adhere to the schedule and budget of this project, it did mean that aesthetic sacrifices were made. Would having higher resolution prototypes enable test users to imagine real-life usage better? And would any new views potentially change the feedback that was given? Test users were explained the concept alongside the

prototypes in an attempt to fill in any gaps where the prototypes fell short in conveying the design intent, though one can wonder how potential misinterpretations or different imaginations affected the feedback.
One such component that was explained rather than demonstrated was that of the emergency door. Under time and material constraints, building the wall was foregone and was instead shown on the ground where its path was. This meant test users had to just give a general opinion on whether they could see themselves wanting a barrier between themselves and the passengers. As previously mentioned, male testers were ambivalent to its presence while female testers were adamantly for the idea.

6.6 Discussion of the Results

When reflecting on the design choices made in the final result, it can be seen that a democratic decision was not made in regards to the emergency door. Although the majority of test users did not care about the presence of the door, further inspection revealed that it was all male feedback. All feedback from women pointed to the inclusion of a safety door, so to ignore this desire simply based on the fact that they were a minority group in our testing sample size did not feel inclusive. CStrider has mentioned their desire to accommodate a diverse employee-base, so it felt important not to only integrate feedback from young men.
The financial implications of the design components of the final proposed results were not prioritized. The design choices were made entirely based on data and feedback from tests and interviews, which yielded the best possible result, but not necessarily the cheapest. Different design choices potentially would have been made had a designated budget or range been assigned. During the design process, certain areas were identified where cuts to the design could be made without sacrificing functionality. For example, in the counting system setup, having just the number screen alone could get the job done, but would sacrifice certain ergonomic features such as visual + audible indicators and indicators at different eye-levels. Further examples will be discussed in subchapter 7.2 of this report.
A challenge of this project that was mentioned earlier in this report was that of compromising the differing needs of varying levels of autonomy. One approach that could potentially have alleviated this issue is modular design. The requirements and feedback received varied depending on the use-case being discussed. For example, operating the vessel in the middle of the night, versus as a tour guide, versus during rush-hour traffic all had differing needs. Had modular designs been developed there could have been different vessel layouts for different use-cases.

7
Conclusion

7.1 Concluding Remarks

The purpose of the project was to design an office bridge that ensures the safety and comfort of the ship officer and the passengers. By understanding CStrider's needs and being responsive to valuable feedback, the primary objectives were successfully fulfilled. The primary objectives were:

- Provide a concept that facilitates safe boat operation practices
- Adapt the bridge design to accommodate the different levels of autonomy

The final concept has measures in place to protect not only the ship officer physically, but also compliant passengers, should somebody gain unauthorized access to the console and put them in harm's way.

The secondary objectives were somewhat successfully fulfilled, although more research and work needs to be done to completely fulfill them. The secondary objectives are:

- Identify and design for the ship officers different roles during the varying operational modes and emergency scenarios
- Consider sustainability aspects in the design and aim to reduce environmental impact
- Demonstrate the feasibility of the final bridge design through relevant testing methods

As mentioned in the discussion, the first secondary objective was not prioritized as the focus of the project shifted. An FMEA was performed to identify potential failure modes in the final concept which is a first step in fulfilling the second secondary objective. The third and last secondary objectives were also not a focus of the project, however suggestions for future work to fulfill the objectives will be mentioned in the next subsection.

In summary, the primary objectives of the project were fulfilled, resulting in a concept that includes a front wall to provide some privacy, personal item storage, an emergency door for protection, an adjustable seat and standing mat for comfort as well as a desk developed utilizing user-centered design. The final concept successfully fulfills the majority of the requirements, with all the explicit requirements being fulfilled.

The findings from this report can be used to further evaluate and test the proposed concepts and the final concept can be used as a foundation for CStrider in their journey of developing a ship officer's bridge.

7.2 Recommendations and Future Work

A first step in continuing the development of this project is to create reasonable verification methods for the listed requirements. As mentioned in the discussion, many of the requirements are qualitative and more extensive research needs to be done to define verification methods for the fulfillment of the requirements. Verification can either be done by performing extensive testing with more candidates, preferably of different demographics, or by using methods to convert qualitative metrics to quantitative in order to receive more numerical results.
Although the secondary objective regarding sustainability aspects in the design was not a priority for this project, it is still a priority for future development for CStrider. As mentioned in chapter 1, CStrider focuses on eco-friendly development which can be considered for the future of this project as well. A material selection process with sustainability in mind should be done to ensure that the concept fits in with the company's vision for the future.
Furthermore, no economic consideration was taken when developing the concept as the project did not have any budget limitations since the expected result was a concept and not a physical product. The safety and comfort of the people on board was the priority when developing the concepts so there are some features that have the possibility of being removed if there is a wish to keep costs down when actually producing the concept without losing the design integrity of it. The recommendations are:

- Remove/replace the digital lock and have a physical barrier to the console instead
- There are multiple tools for the counting aspect, one can be removed to lower the development cost (e.g lights for the progress bar vs lights on each side of the door)
- Simplify the seat by either removing the height adjustability option or remove the combination with the leaning pad
- Remove visor and keep the screens exposed
- Rather than a custom remote, an app could be developed

Note that these are recommendations for lowering the cost at the expense of the comfort of the ship officer, no feature that compromises their safety is recommended. It is therefore up to CStrider to revise the concept and decide what is economically feasible for them, this list is only added as a recommendation for possible cost cuts.

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A
Interview Questions

A.1 Interview questions: Boat Passengers

Questions regarding safety

- What role do you think the captain has in an emergency?
- Would you feel better if you could see a steering wheel/dashboard (i.e. knowing that it could be driven in an emergency)
- What safety aspects do you would be missing from a self-driving boat compared to a boat operated by a captain?

Questions regarding automation

- If Västtrafik had manned self-driving boats, maximum 12 passengers, would you have chosen to ride them over the "regular ferries"? Avoided them? Indifferent?
- Does the idea of unmanned self-driving boats make you feel differently?
- Would it make a difference whether you can see the person on board or not?

A.2 Interview questions: Boat captains

- What kinds of boats are you most used to driving?
- Are there any notable differences between your needs when you're driving a larger vs smaller boat?
- What else can typically be found in the bridge area that is not the navigation/communication/steering?
- Is there anything you like to have close to you/in your space that is not related to navigation/communication/steering?
- What is the first thing you notice (both in a positive or negative way) when you walk into a boat bridge?
  - Is it just how it looks, or the practicality of the layout?
  - If practicality, what makes this so?
- Would you be willing to be the ship officer on an automated vessel?
  - If yes, is there anything you would like to change in the captains bridge?
- What are your secondary tasks besides operating your boat?

A.3 Interview questions: CEO of CStrider

- We found these competitors who are already in the Nordic market, what makes you stand out from them?
- What level of autonomy is your plan for the boats?
- Is the thought that they'll only be used at this level or that they can be used at different levels depending on the customer desires? (e.g If they're totally autonomous CAN they be operated as just autopilot with more responsibility put on the captain or will they only be used as totally autonomous)(not including emergencies)
- Will they be remotely captained at all?
- Does the 12 person limit mean that anyone can operate the boat or do you still need some kind of training?

A.4 Interview questions: Tram Driver

Questions regarding emergencies/safety

- What is your role as a chauffeur in an emergency situation? What are situations that are beyond your jurisdictions?
- Can you think of a situation where it would have been beneficial to operate an automated vehicle?
- Does the sense of security increase if you have a screen between you and the passengers?

Questions regarding automation

- What are your secondary duties besides driving your vehicle?
- How do you feel about the idea of operating a self-driving vehicle?
- How would it have affected your work duties? Would you have enough tasks besides driving?

Questions regarding comfort

- What do you appreciate about the layout of your vehicle's driver's seat?
- Is there anything you wish your vehicle had to increase your comfort while driving?

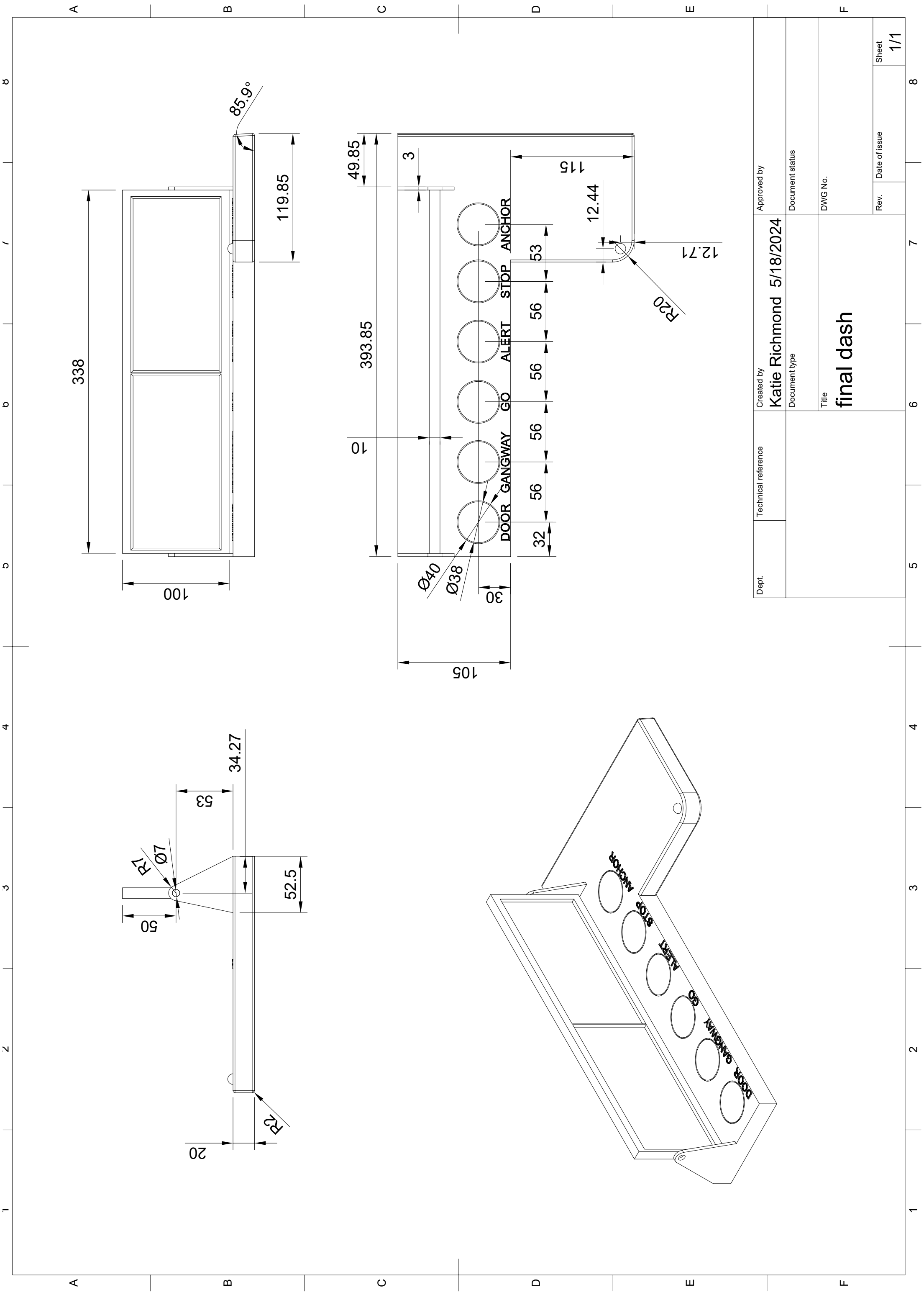
B
List of Ideas for Counting Mechanisms

- Lights changes when it hits 12 (green-to red), staff has clicker
- Digital countdown connected to the clicker
- Sensors that count amount of passengers
- Doors close automatically after 12 passengers have boarded
- Turnstile that stops allowing passengers through after 12
- Passengers book their spot in the Västtrafik app
- Callout from speakers that inform passengers that it is full
- Count on portable screen that the personnel carries with them

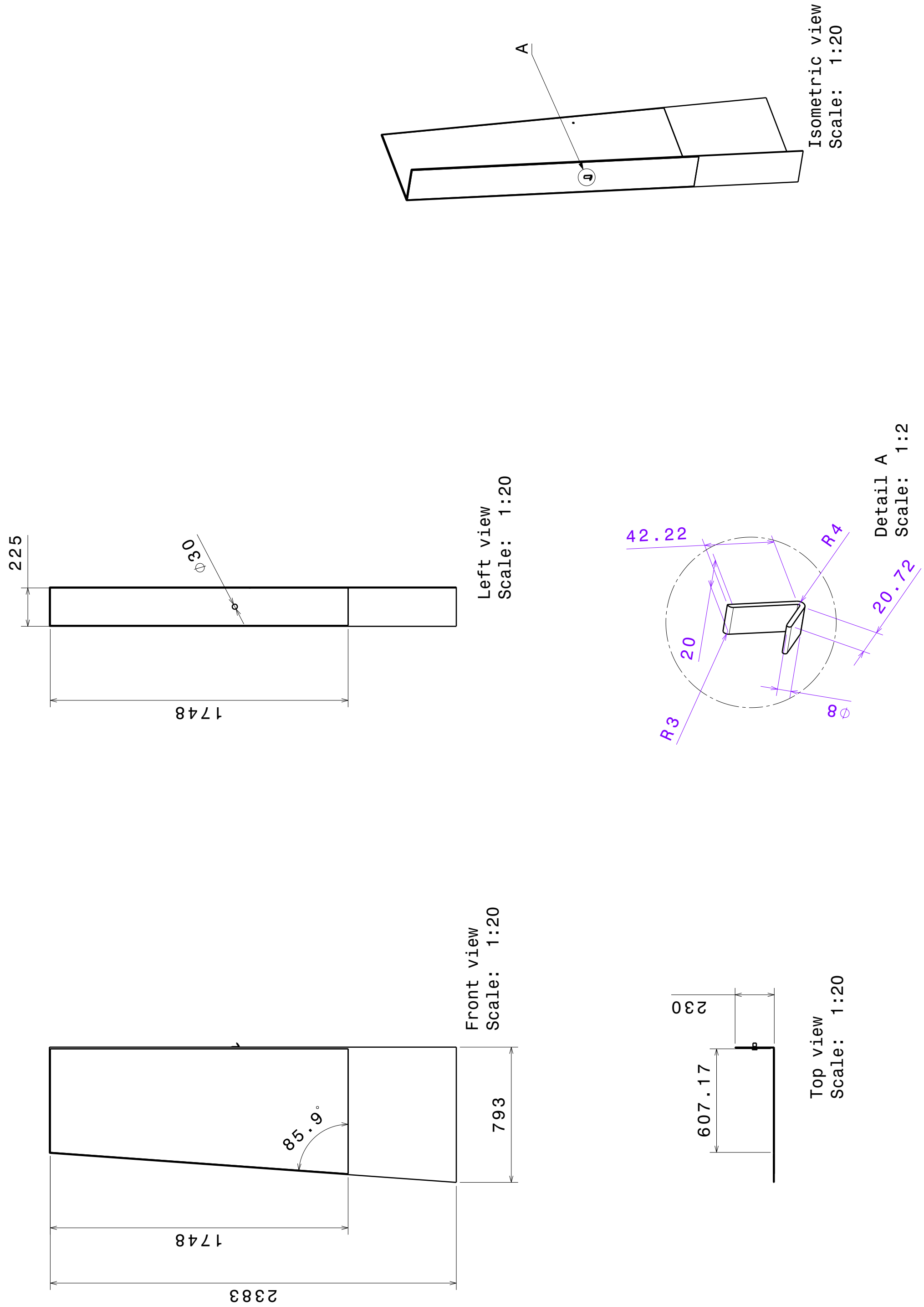
C

Engineering Drawings for Pulpit Components

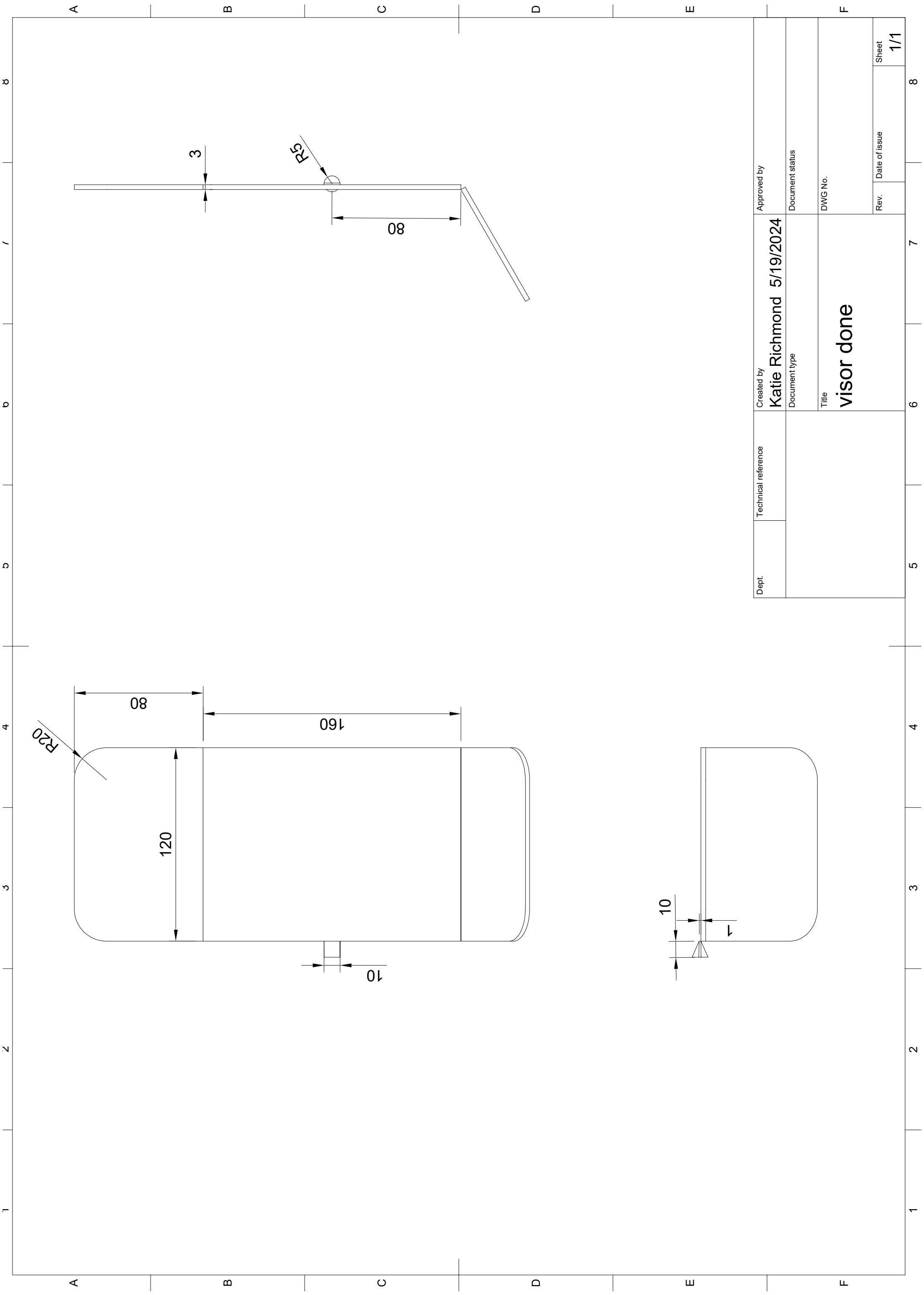
C.1 Dashboard Drawing



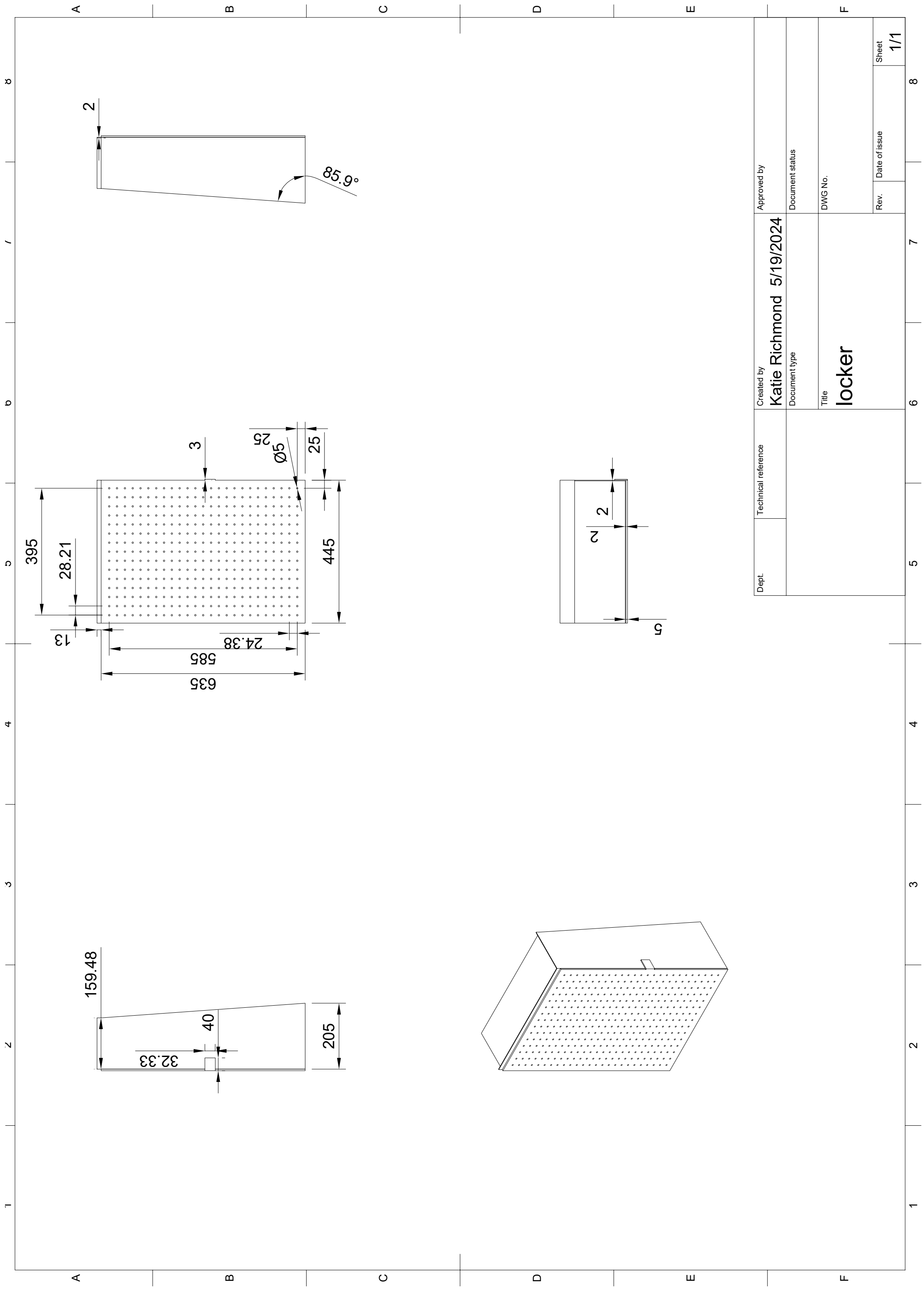
C.2 Front Wall Drawing



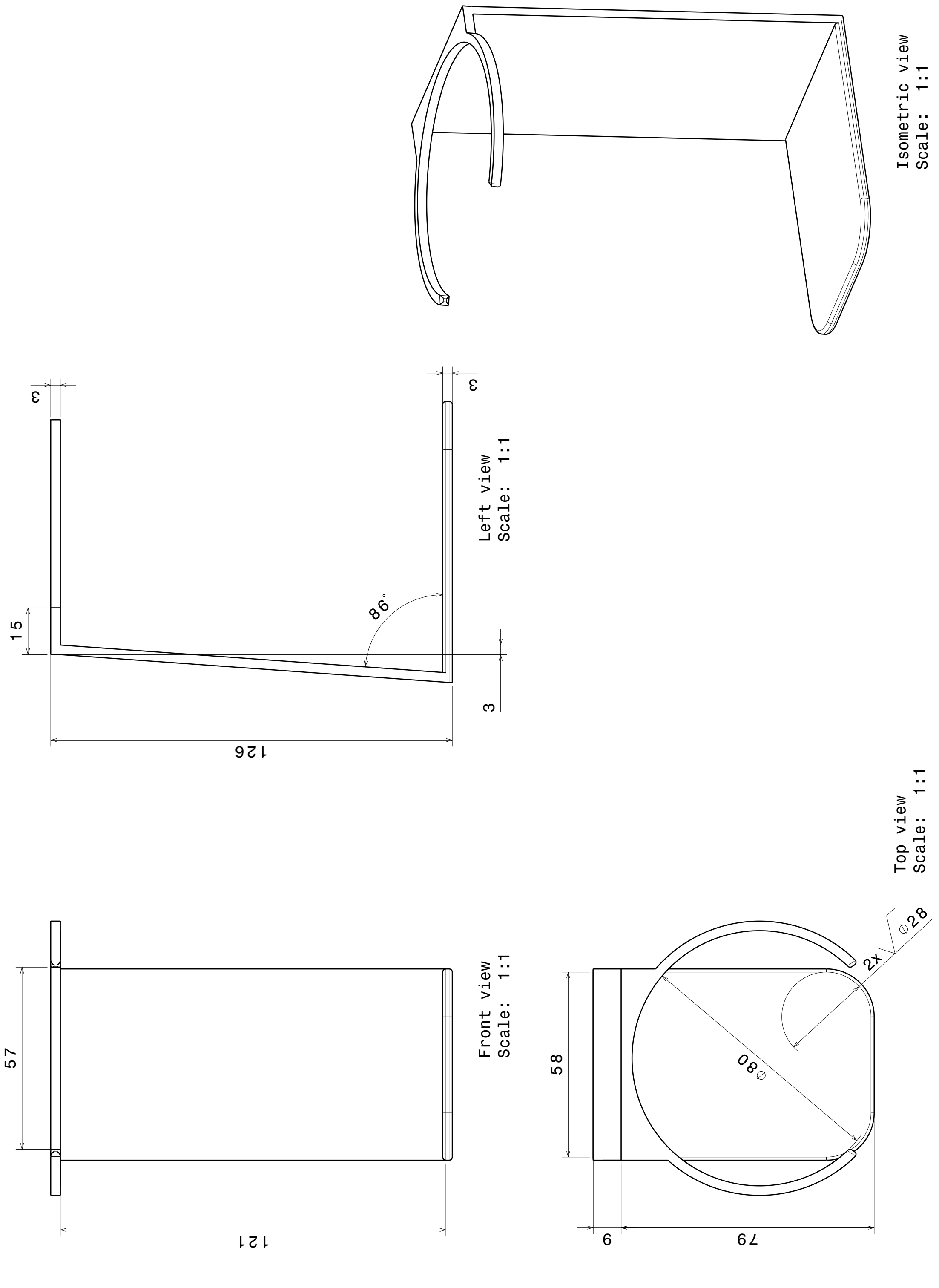
C.3 Visor Drawing



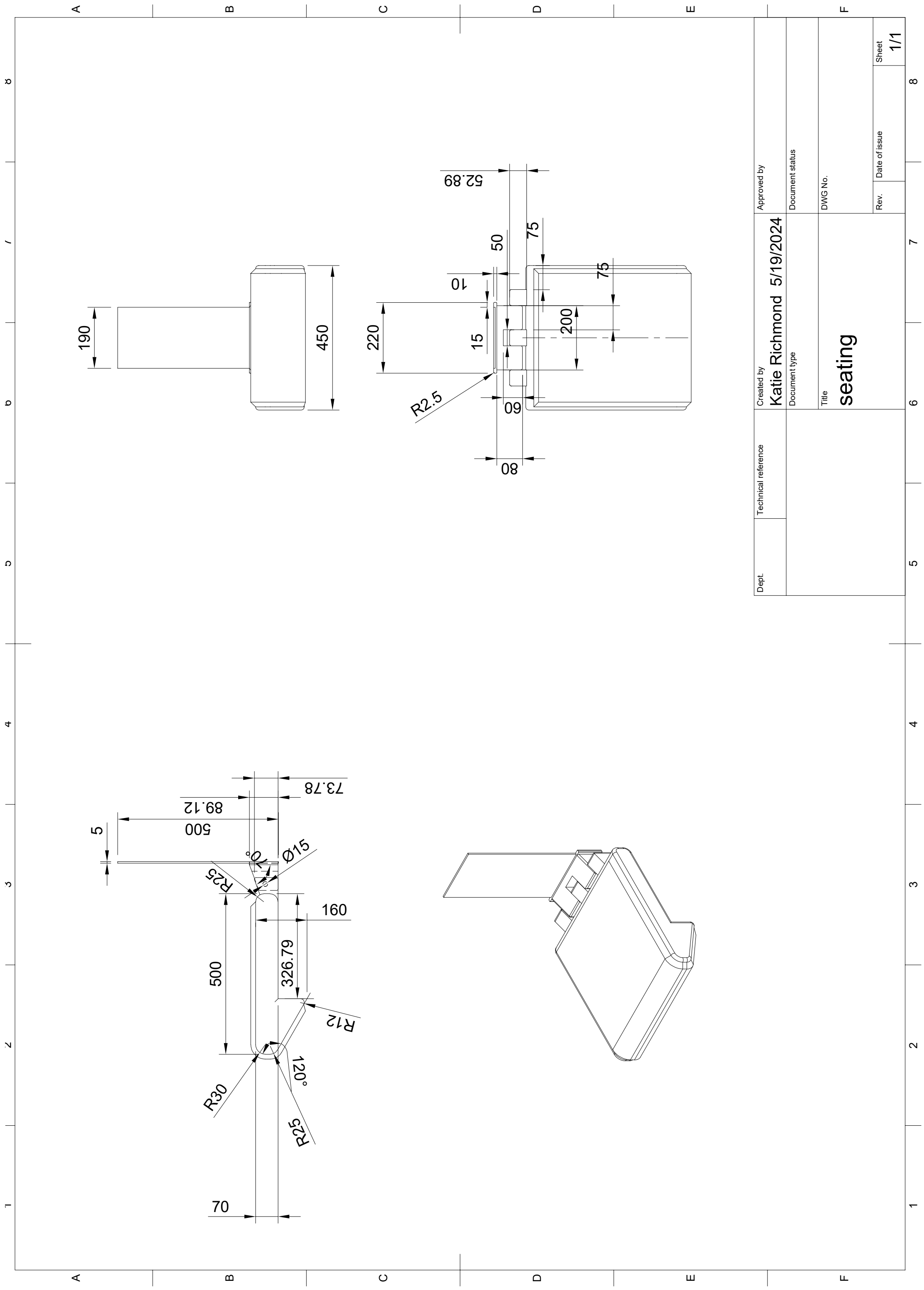
C.4 Locker Drawing



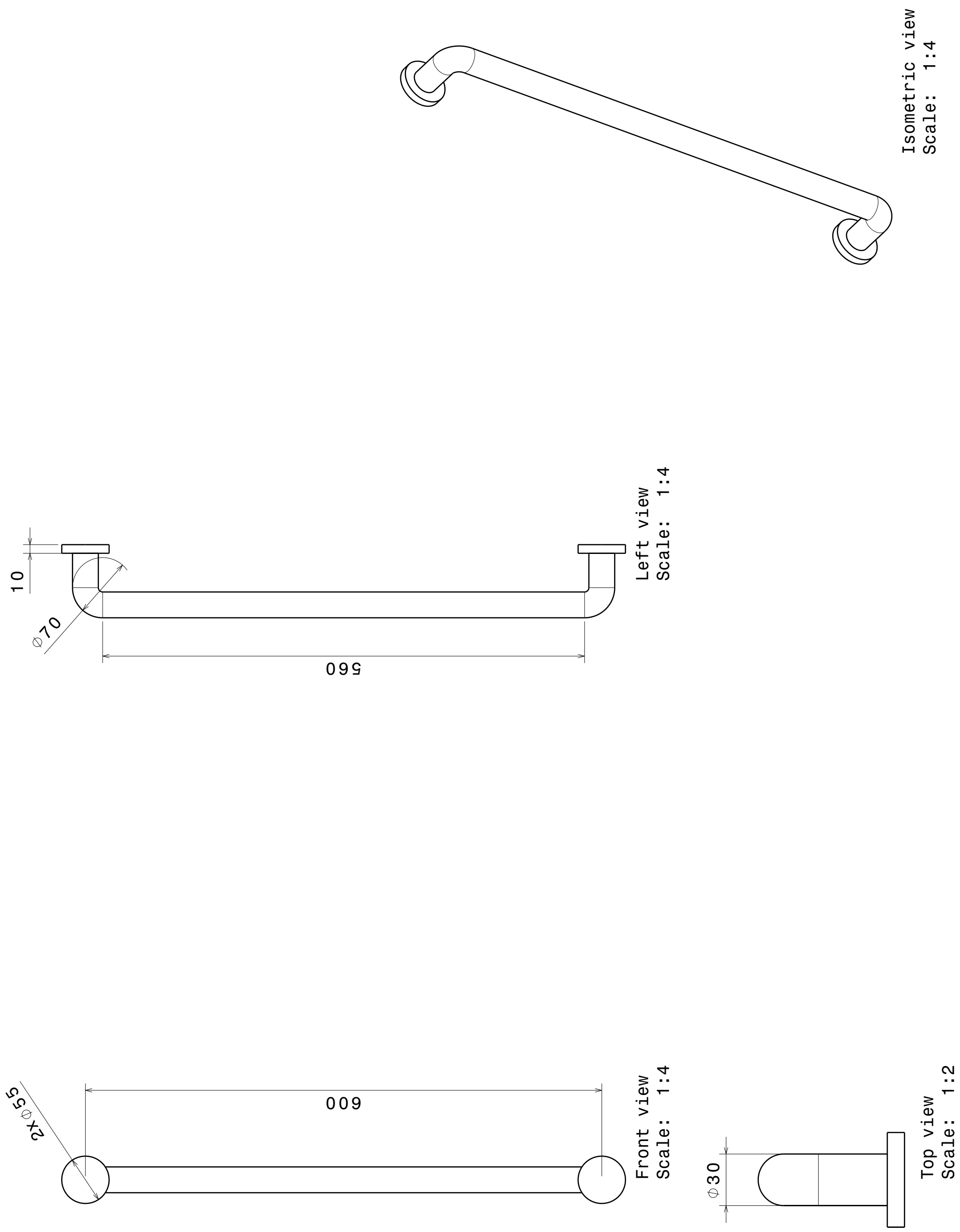
C.5 Cup Holder Drawing



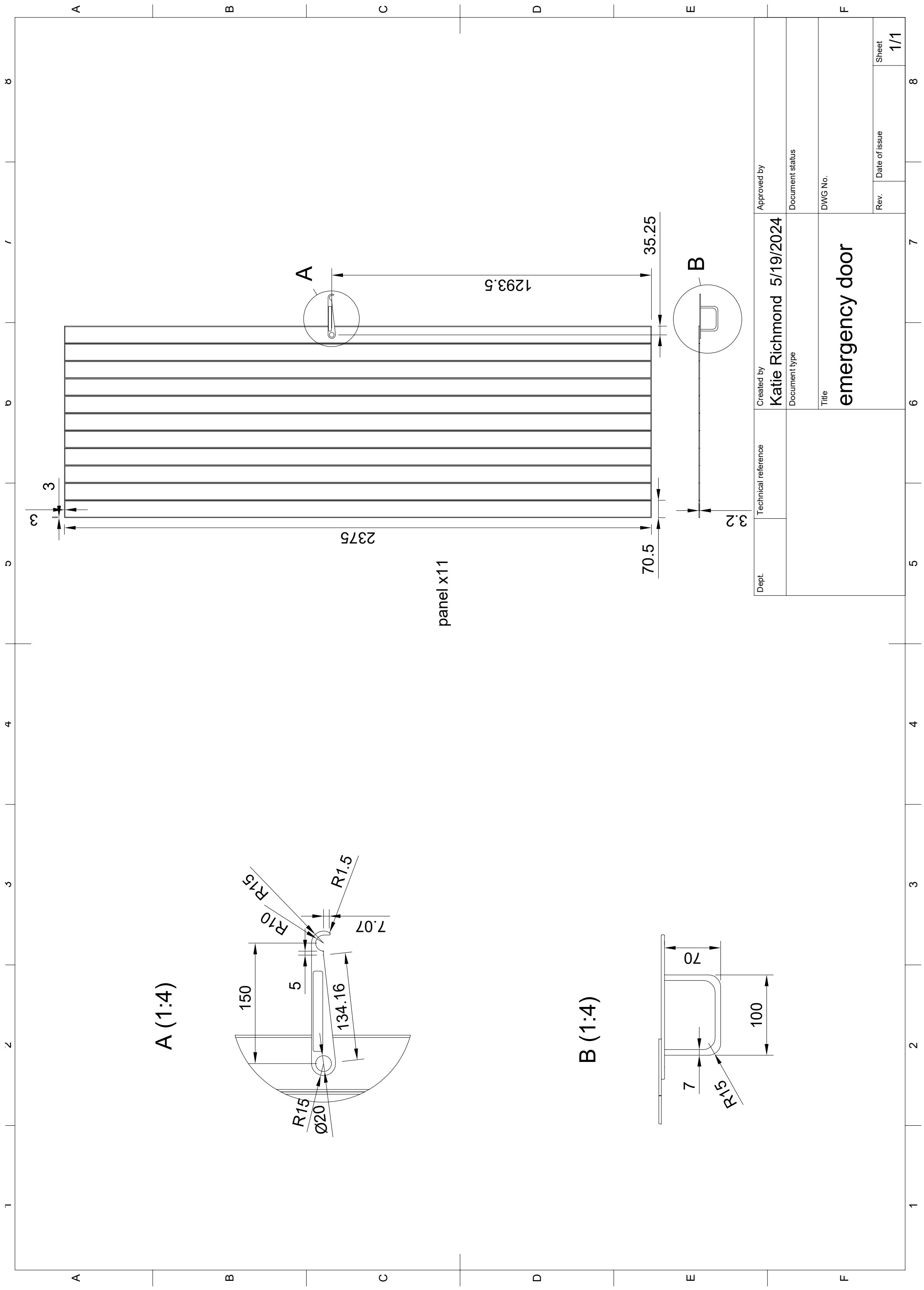
C.6 Seat Drawing



C.7 Wall Support Handle Drawing



C.8 Emergency Door Drawing



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