GRAPH3N3

TEAM GRAPH3N3

Universal Computer for a Yacht

IPDP – International Product Development Project

2024

Mohammad Salim Sulaiman Khail

Carlos Trujillo Goicochea

Niels Kochert

Daniil Ostrogradksii

Lena Rehmann

David Breitenbach

inno.space DESIGN FACTORY MANNHEIM

HAMK Design Factory

MEGAMORPH GRAPHENE DISPLAYS

Universal computer for a yacht	Abstract
Team GRAPHENE	Year 2024

Coaches Kirstin Kohler, Markku Mikkonen, Jali Närhi, Manuel Walter

Writers Mohammad Salim Sulaiman Khail

The aim of the project was to find use cases for GMODs, a reflective display using graphene that would provide a good market entry point for Megamorph. During the project we have gathered information about the technology and studied its important specifications. Taking those into account we have come up with different ideas but due to some important factors such as Graphene price which is currently high and can deter customers. That is why yacht screens were identified as an excellent use case for graphene, because price is less of an issue in the yacht market and yacht screens make perfect use of graphene's reflective properties as well as its strength and durability. There are also several different possibilities to expand the idea that could be used moving forward. In this report all the information which we have been through during the project period have been mentioned and explained wisely, the challenge that we had, the methods that we used, the idea that we came up with and so on.

Keywords Yacht screen, Graphene screen, GMOD technology, reflective screen technology

Pages 36 pages and 4 appendices 20 pages

Table of contents

1 Introduction

The wind blows gently through your hair, you enjoy the Odor of the salt water and feel the sun on your skin. It is an extremely hot & sunny day, and you enjoy another yachting adventure. However, sometimes the saltwater, sun and heat can become a problem. Especially to the electronic equipment on board. Corrosion, overheating and the reflection of the sunlight limit the function.

Graphene offers a solution to this, through the use of the Megamorph GMOD technology a new area of extreme sport equipment can be produced. the yachting screen graphene is due to its unique display resilient to saltwater, resistant to heat and even perfectly useable in direct sunlight.

Graphene displays are stronger and more electricity friendly than the normal available displays and can be seen more clearly during the direct sunlight. The display pixels in graphene displays are much bigger and the sunlight helps it to be seen even more clearly. Not only clear view of the display plus it will be less harmful for the eyes compared to the existent display which are very harmful to eyes specially if used continuously. (Graphene mechanical pixels for Interferometric Modulator Displays, 2018)

Megamorph graphene displays are aiming to replace the existent displays in the market and make a big impact at the display industry. Megamorph technology is working on making more safe and more reliable displays for the future to solve the problems that people have with the existent displays such as: heating, electricity usage, unclear seen in sunlight, harmful for eyes and so on. We are working on finding useful and suitable ways to use this technology and introduce it to the world. Display industry is very big and with different areas, so we need to start with the most suitable area to have a better impact on this industry. (ATTRACT stories: behind the MEGAMORPH project, 2023)

Our target audience are the sponsor company and groups of stakeholders who will have the benefits of this solution. The sponsor will use the solution to make their impact at the market and the stakeholders who will get benefits from this solution are the yacht and boat owners who had difficulties while using their yacht or boat displays, with this technology they no longer have that problem and will enjoy their trips without any issues.

Figure 1 Stakeholders Map [1]

During the project period which has started on 13.03.2024 and ended at 30.06.2024. our Final Gala was at 19.06.2024, we have used our studies, skills and experience and done some research and interviews with feedback from people and making different ideas and prototypes we have finally made it to our best suitable and innovative idea universal computer for yacht with Graphene display which will change the future of display technology.

2 Team

Team GRAPH3N3 is made up of 6 students and as you can see in our team's name as well, we are 3 and 3 which means team GRAPH3N3 is made up 3 German students from Inno.Space design factory of Mannheim University of Applied Sciences and 3 Finnish students from HAMK Design Factory of Häme University of Applied Sciences. Here is some brief information about our team members and about their contribution in the project and team:

Mohammad Salim Sulaiman Khail

I am studying Bachelor of Information and Communication Technology and Bioeconomy at Häme University of Applied Sciences in Hämeenliinä Finland. I have been in different PDP projects such as Heathrow Airport Project, Katumajäarvi and so on during my degree program and have some experience from that. I am really interested in working with different teams and international projects. And I am happy to be part of team Graph3n3.

Contribution in team during project: I have been a member of this team since day 1 and have contributed in every part of project since beginning such as: team name, team logo, ideation, researches, interviews, low fidelity prototype, interviews and feedbacks, medium fidelity prototype, presentations, writing report, product video, trailer video for product, making the product prototype screen, making the software for the final prototype, helping with making the Booth for Final Gala and etc…

David Breitenbach

He is a student of Master in Process and Chemical Technology at the University of Applied Sciences in Mannheim. Prior to this, he has successfully completed an apprenticeship as a Chemical Laboratory Technician at DSM, a company specializing in water-soluble vitamins. As you might already guess, he loves acquiring new knowledge and gaining new experiences. His strongest attributes are my ambition and my drive to learn new things. He is always open to new challenges, which is why he was particularly looking forward to this international project.

His contribution in the team during the project: active enough, doing tasks given by coaches, low fidelity prototype, research, interview, helping with presentations, report writing and making the Booth for Final Gala.

Carlos Trujillo Goicochea

He is a bachelor student in the program of Mechanical engineering and production technologies at Häme University of Applied Sciences in Riihimäki, Finland. He loves new challenges and consider himself curious for new technologies and am obsessed with improvement, he likes to find a better way to do something everywhere he goes, and he feels that this program is an excellent chance to conduct this characteristic of him and to expand his professional net for the future, so he was really excited to be part of Graph3n3 team.

His contributions in the team during the project: being active member of group, doing tasks given by coaches, research, contacts with client, low fidelity prototype, presenting the presentation, making Booth for Final Gala.

Niels Kochert

He is a bachelor student in Enterprise Computing at the University of Applied Sciences in Mannheim. He has been a passionate software developer for years, often working with teams to create specific products. With this project, He is looking forward to an exchange with students from other fields and another country, and he is excited to work with an innovative technology that has a lot of potential.

His contributions in the team during the project: active enough, doing the tasks given by coaches, research, interview, helping with team name and logo, helping with presentations, low fidelity prototype, making Booth for Final Gala and writing report.

Lena Rehmann

She is a communication design bachelor student at the University of Applied Sciences in Mannheim. This is her second degree, as she additionally has a Master of Science in Psychology. For this she has studied as well at the university of Maastricht, the University of Sydney and the Ruprecht-Karls Universität of Heidelberg. She loves to learn and experience new things. This is why she is always open for a new adventure. Therefore, she was also looking forward for this international project, so she is happy to be part of Team Graph3n3.

Her contributions in the team during the project: active member, doing tasks given by coaches, helping with team logo, helping presentations, team assignments, making posters, making Booth for Final Gala, writing report.

Daniil Ostrogradksii

He is a bachelor student in the program of Mechanical Engineering and Production Technologies at Häme University of Applied Sciences Finland. His curiosity drives me to explore new fields and continuously expand my knowledge. He completed an internship at Engineering Company 555, which specializes in the repair of industrial electrical equipment from leading European brands. This experience provided him with valuable practical engineering skills and a deeper understanding of the industry. He is excited to bring his enthusiasm to Team Graph3n3, contributing to the development of groundbreaking solutions.

His contributions in the team during the project: active enough, doing tasks given by coaches, helping with presentations, research, prototypes, making 3D printing case for prototype, helping with Booth for Final Gala, writing report.

2.1 Project sponsor background

Scale Nanotech is a digital startup from Estonia and operating in Spain that provides R&D and consulting services. They offer their expertise on nanotechnology by means of simulations, design, in-situ fabrication, experiment realization, project management and business development.

Scale Nanotech has the approval and funding of their project “Market-Entry of Graphene-based large-Area Modulators with a Radical Production of Holographic displays” (**Megamorph**). That was part of ATTRACT Phase 2 that has received funding from the European Union’s Horizon 2020 research and innovation programme.

For the last 26 months, Scale Nanotech has coordinated the Megamorph project funded with 2 million Euros to develop evaluation kits that will integrate graphene-MEMS display technology. This project will help establish the steppingstone for commercialization of such display technology for many applications.

Megamorph is a follow-up to the Graphene Interferometric Modulator Display (GIMOD) project implemented through ATTRACT Phase 1 with renewed ambitions. Megamorph project consortium is composed of innovation leaders with a market-driven: Graphenea Semiconductor, Morphotonics, TNO, CIN-ergy and VividQ.

The value-chain concept of the Megamorph consortium aims at producing evaluation kits with industrial drive to enable a fast and disruptive market entry by 2024. (Scale Nanotech, MEGAMORPH Project to commercialize graphene-based holographic displays, 2022)

Scale Nanotech company lead by **Santiago J. Cartamil-Bueno** Managing Director of the Company and **Juan P. Prieto-Ruiz** Operations Manager of the company.

Dr. Cartamil-Bueno is an Electronic engineer (B.Eng. + M.Eng.), physicist (B.Sc. + M.Sc.) and nanomaterial scientist (M.Sc. + Ph.D) with 14 years of experience including 8 years of applied research on graphene and other 2D materials. He is also an entrepreneur with knowledge of European funding schemes, business and project management, intellectual property protection, incorporation of companies in Germany and negotiations. He is reliable, committed to finishing tasks in due time and passionate to deal with new challenges, as proven by the track record of scientific publications, online news, social activities and entrepreneurial abilities. His main area of expertise is material science and engineering, with coverage of applied physics, semiconductor devices and processes and nanotechnology (with a focus on nanomechanics, nanophotonics and nanoelectronics). He has 13 publications and applied for 2 patents as main inventor. (Scale Nanotech, Team)

Dr. Prieto-Ruiz studied Physics at the University of Valencia (Spain). He obtained his Master of Science in Molecular Nanoscience and Nanotechnology, as well as his Doctorate in Nanoscience and Nanotechnology at the Institute of Molecular Science (Univ. Valencia). During that time, he focused his work in the field of molecular spintronic. After completing his Doctorate in 2015, he moved to Wroclaw (Poland) to join Saule Technologies, a vibrant start-up with the ambitious objective of commercializing metal halide perovskite solar cells by inkjet printing. His expertise in device fabrication and characterization allowed him to take this new generation of solar cells from lab to fab by setting up and optimizing the first pilot production line of inkjet-printed perovskite solar cells in the world. In 2023, he returned home and joined Scale Nanotech to put all his scientific expertise to the service of GMOD technology, working to make possible the upscaling of the fabrication processes that will take this exciting new generation of displays to the market. (Scale Nanotech, Team)

2.2 Problem background

The challenge we got from the sponsor was about their newly produced product which is GMOD Graphene (a disruptive green tech (as mentioned by Santiago J in Introduction video of Megamorph) for next-gen colourful display) display with 3 different HMWs: 1: How might we apply the display solution from Megamorph to increase the learning experience in Education?, 2: How might we apply the technology from Megamorph to wearables that improve the lives of the future?, 3: How might we apply the technology from Megamorph for a smart device that helps civil authority to be more sustainable?. These displays are not yet in the market and will be an innovative technology that will impact the display market. Also, these displays will be much expensive than the existent display when it come out as a product. And this technology has a direct connection with sunlight which helps these displays to show the things from display clearly by the help of sunlight but during the night when there is no sunlight there will be some issues with the display.

So, taking these problems in to account we have worked hard during the project period to come up with most suitable and innovative solution for these challenges. We have used the design factory trainings and workshops which we studied during the project period to find these suitable ideas and we have produced so many different ideas which needed to be developed increasingly until we get to our best idea.

During the halfway gala we have been produce 3 different and suitable ideas which were innovative and have been produced based on the interview and feedback we got from our interviewees. Those solutions have been presented to the sponsors and audience and we had so much positive feedback that helped us to know that we are in right route.

After the halfway gala and before the final gala we had the chance to visit our sponsor and have the better understanding of their technology. During this trip to Valencia, Spain we have visited our sponsor office and their laboratory and other facilities and got more information about their technology and other principal issues. This trip has helped us a lot to choose the main and suitable idea out of the 3 ideas we had.

We choose the yachts Graphene display idea as our main idea because our sponsors were also agreed with that idea, and they also had similar idea but did not have enough time and data to focus on it. This helped us to find our focus area and idea, and we have done some final development of our idea, and we were all ready for our final gala presentation.

3 Theoretical background

This section describes the advantages of graphene-based display technology compared to other display technologies. Additionally, the manufacturing process and functionality of Graphene Modulator Displays (GMODs) are explained.

3.1 Design thinking process

The Design Thinking process is a structured approach to solving complex problems in a user-centric manner. It is a mindset and a methodology that prioritizes understanding the user's needs and creating innovative solutions that meet these needs effectively. The process is typically divided into five phases: Empathize, Define, Ideate, Prototype, and Test.

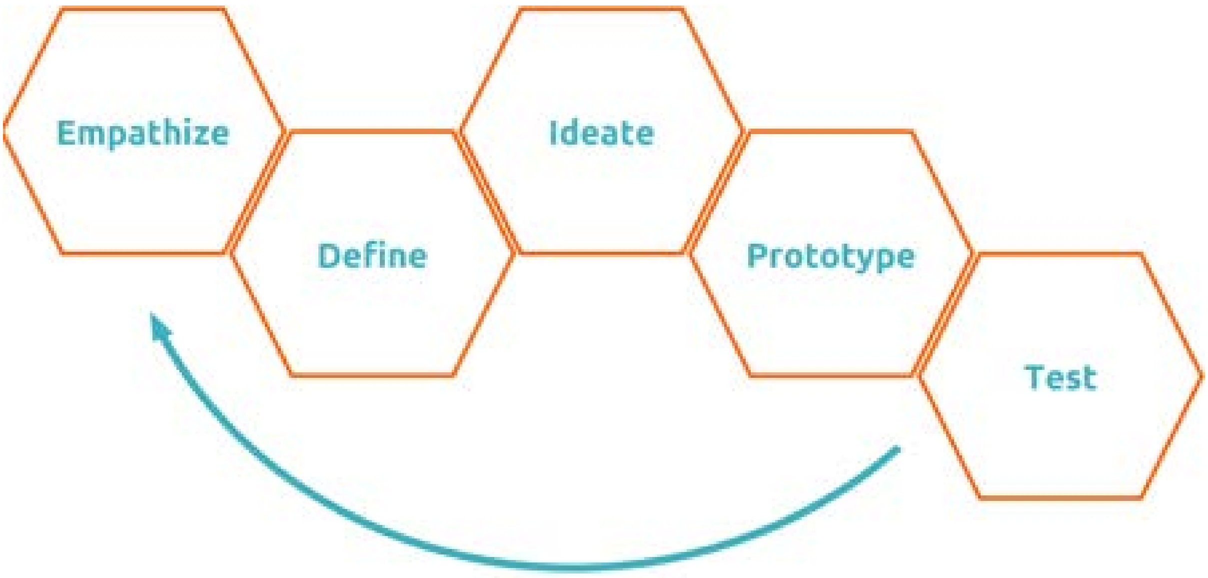


Figure 2 Design thinking process [2]

3.1.1 Empathize

In the Empathize phase, the goal is to gain a deep understanding of the users and their needs. This involves engaging with users, observing their behaviour, and immersing oneself in their experiences. Techniques such as interviews, shadowing, and user journey mapping are commonly used to collect insights and understand the problems users face. This phase is crucial for building empathy and ensuring that the solutions developed are truly user centred. (Dam, 2024)

3.1.2 Define

The Define phase focuses on synthesizing the insights gathered during the Empathize phase to articulate a clear problem statement. This involves identifying patterns, challenges, and core issues from the user data. The aim is to frame the problem in a human centred way, often using “How Might We” (HMW) statements to open possibilities for innovative solutions. A well-defined problem statement serves as a guiding light for the subsequent phases. (Dam,2024)

3.1.3 Ideate

During the Ideate phase, the focus shifts to generating a wide range of ideas to solve the defined problem. This phase encourages creativity and free thinking, where participants are urged to think outside the box and challenge assumptions. Various brainstorming techniques, such as mind mapping, brainwriting, and analogies, are employed to foster idea generation. The goal is to explore a broad spectrum of solutions without immediate judgment or constraints.

During this phase, we refined the "How Might We" (HMW) question (from the 3 original HMWs we got at the beginning) to better align with the technology, and additionally, we collected new ideas for prototypes. The following ideas were gathered:

- Screens for cars or aircraft
- Use in hospitals as a portable patient screen
- Universal computer for a yacht with navigation and other sensor indicators
- Integration in VR headsets
- Smart table
- Portable roll-up screen
- Advertisement boards
- Interactive mirror
- Heads-Up Display (HUD) in motorcycle helmets
- Applications in warships
- Use in war machines

After considering moral perspectives and existing patents, we decided to proceed with the smartboard table, the portable roll-up screen, and the Universal computer for a yacht.

The finalized HMW question we focused on was:
How might we use graphene displays to create an economically feasible product?

3.1.4 Prototype

The Prototype phase involves turning the best ideas from the Ideate phase into tangible, scaled-down versions. Prototypes are inexpensive and simple models that allow teams to visualize and test their ideas quickly. The purpose is to create something that can be interacted with, which helps in communicating the concept within the team and with users. Prototyping is iterative; it involves creating multiple versions, each one improving on the previous based on feedback. (Dam, 2023)

3.1.5 Test

The final phase, Test, is about evaluating the prototypes with real users. This phase involves gathering feedback on the prototypes to understand how users interact with them and how well the solutions meet their needs. Testing is an iterative process where feedback is used to refine and improve the prototypes. The insights gained from testing help in making informed decisions about what works, what does not, and what needs to be adjusted. (Dam, 2024)

3.2 Useful Properties of Graphene and GMODs

Graphene is a remarkable material with a multitude of outstanding properties. It is the thinnest and strongest known material, making it particularly suitable for mechanical microdevices. Moreover, graphene is transparent and flexible, making it ideal for applications in modern electronics. It is also skin-compatible and non-toxic, making it a promising material for wearable electronics or skin implants. Its chemical stability ensures longevity and reliability in various environments. Another significant advantage is the abundance of carbon atoms from which graphene is composed, making it a readily available and cost-effective material.

GMOD utilize these exceptional properties of graphene. They offer significant energy savings and use electrically controlled pixels that are semi-transparent, enabling innovative display technologies. GMOD pixels are ultra-small and provide the ultimate resolution in VR displays, creating a truly realistic virtual experience. Overall, GMODs represent a sustainable and advanced technology supported by the unique properties of graphene. They enable energy-efficient, high-resolution, and environmentally friendly displays [3]. Figure 3 shows the benchmarking aspects we originally identified for GMOD technology.

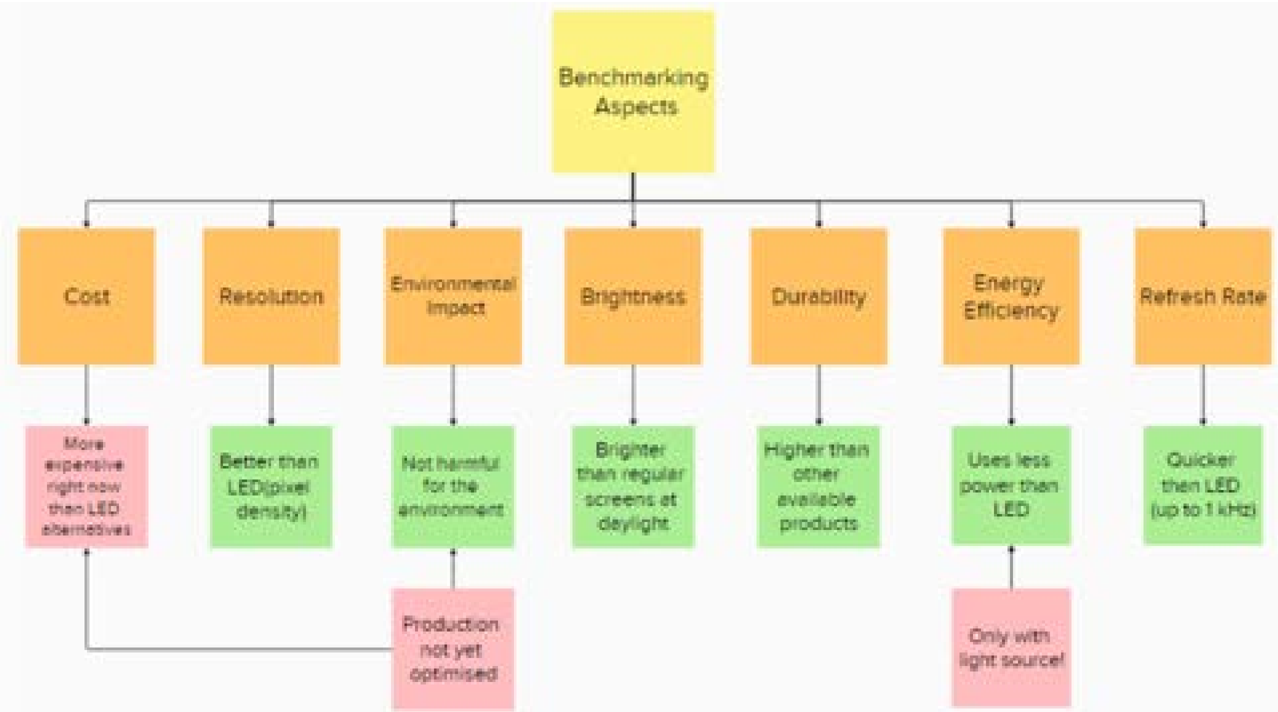


Figure 3 Benchmarking [1]

3.3 Manufacturing process of GMODs

3.3.1 Graphene Synthesis

Graphene is produced on a large scale using chemical vapor deposition (CVD), as illustrated in **Error! Reference source not found.**. In the first step, gaseous methane and hydrogen a re introduced into the CVD process chamber. Methane serves as the carbon source and provides the carbon atoms for the graphene, while hydrogen, although not directly involved in the reaction, plays a crucial role in graphene growth.

Initially, the gases are directed into the tube furnace, which operates at a temperature of 1000 to 1300 K. The tube furnace contains a substrate and a copper plate that acts as a catalyst. Upon entering the tube furnace, the gases are heated to the prevailing temperature. Subsequently, the methane molecules adsorb onto the copper plate.

In the next step, the adsorbed methane molecules undergo dehydrogenation, as depicted in Equation 1, where the hydrogen atoms bound to the carbon atom are removed.

Equation 1 Thermal decomposition of Methane

$$\mathrm{CH_4} \rightarrow \mathrm{C} + 2\,\mathrm{H_2}$$

Finally, the released carbon atoms diffuse across the surface of the copper plate and coalesce to form a graphene layer. The adsorbed hydrogen atoms desorb from the copper plate as hydrogen molecules.

To illustrate the CVD process, the schematic is depicted in figure 4.

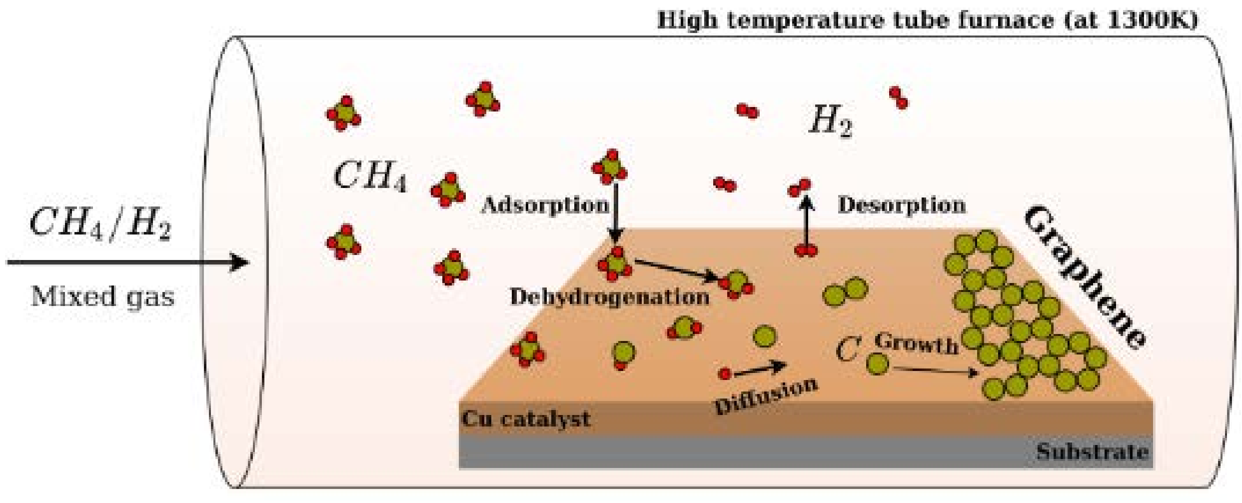


Figure 4 CVD [3]

In figure 5, the characteristic hexagonal structure of graphene is depicted. Each hexagon represents a single carbon atom bonded to three other carbon atoms, forming a two-dimensional, honeycomb-like lattice. Graphene is also only one atom thick.

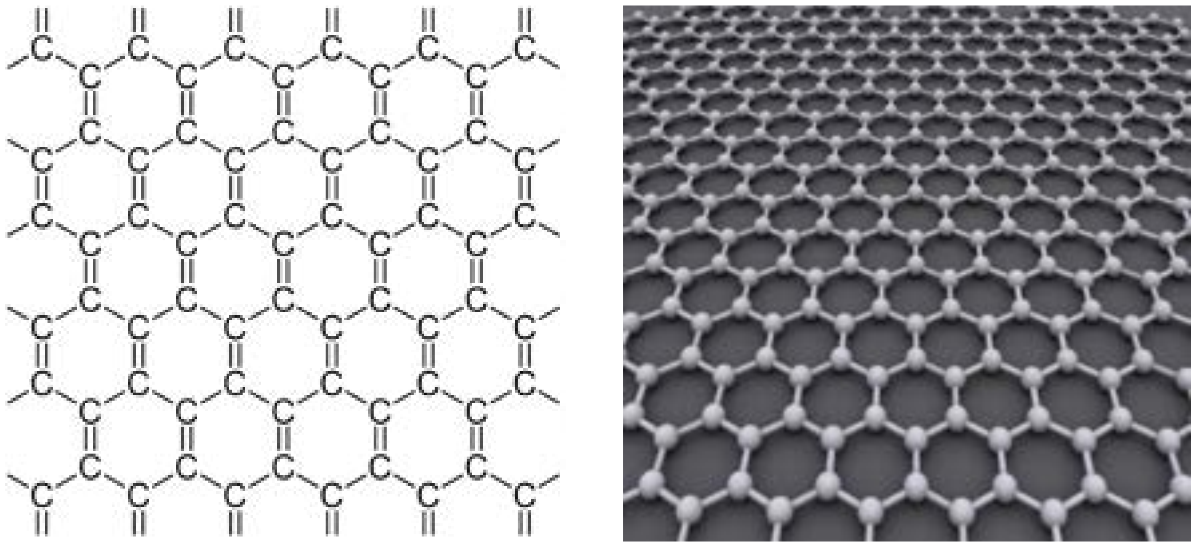


Figure 5 Graphene [3]

3.3.2 Preparation of the carrier material

Using reactive ion etching (RIE), square cavities of 25 µm² are etched into silicon substrates through thermally grown silicon dioxide (SiO_2). The depth of these cavities can vary between 300 and 1180 nm as needed.

The schematic of RIE is illustrated in figure 6.

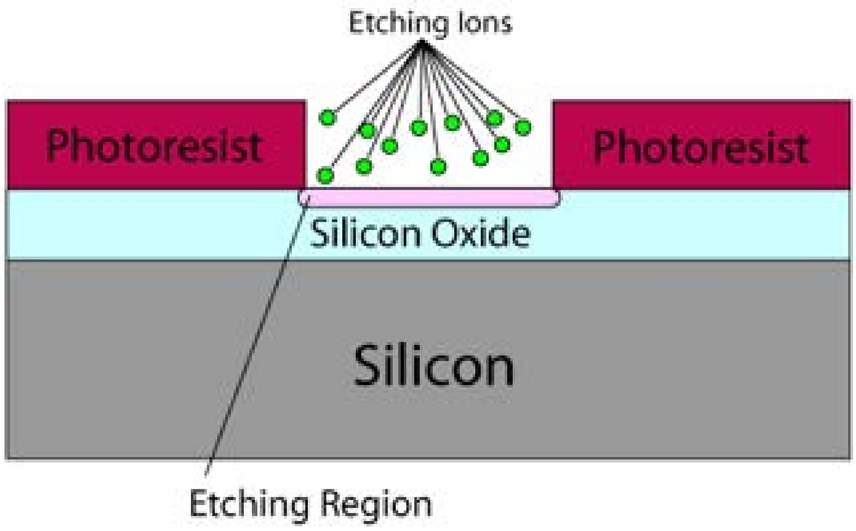


Figure 6 Reactive ion etching (RIE) [4]

Ions are accelerated in the electric field, causing them to collide with the sample surface. A hard mask is used to protect specific areas from etching, exposing only the areas to be etched.

3.3.3 Transfer and Integration of Graphene onto the Carrier Material

To transfer and integrate graphene onto the silicon dioxide carrier material, two CVD single-layer graphene (SLG) layers are first stacked to create a double-layer graphene (DLG). This stacking improves the mechanical and optical properties of the material, such as higher stability and improved light absorption.

Subsequently, the produced DLG layers are transferred onto the structured silicon dioxide using a semi-dry transfer technique.

3.4 Functionality of GMODs

3.4.1 Membrane

The membrane in the described technology exhibits an electro-optical colour change in response to the applied voltage. When no voltage is applied, the membrane is in a relaxed state and appears yellow. When a voltage is applied, the membrane bends inward or outward depending on the strength and direction of the voltage.

At a positive voltage, the membrane bends inward, resulting in a blue colour. At a different voltage with the opposite effect, the membrane bends outward, displaying a red colour.

This adaptability of the membrane to electrical fields allows for precise colour control, thus representing the entire wavelength range of visible light optically.

The structure of a GMOD pixel and the full colour spectrum are shown in figure 7.

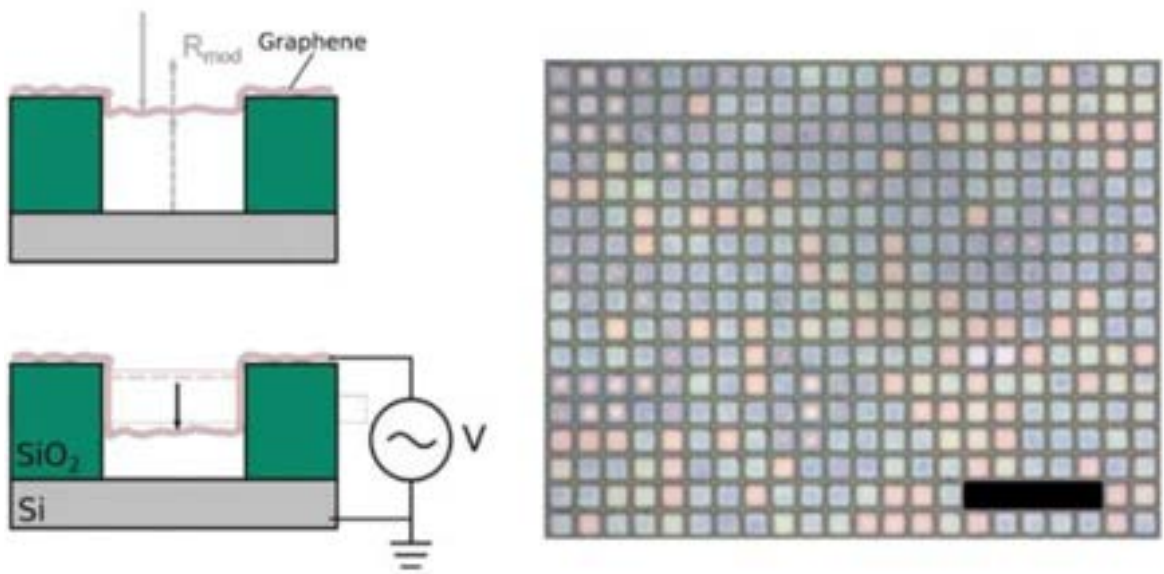


Figure 7 GMOD-Pixel + Optical image of full-spectrum squared GMOD pixels [3]

3.4.2 Interaction of light with graphene

This colour change is caused by the interaction of light with the altered geometry and optical properties of the membrane. When light hits the membrane, certain wavelengths are absorbed while others are reflected. The membrane itself does not absorb all the light but only specific wavelengths depending on its position (inward or outward bending). The reflected wavelengths determine the colour we see. In the yellow state (no voltage), the membrane primarily reflects yellow light, while in the blue state (voltage applied, inward bending), it mainly reflects blue light. At another voltage, the membrane can bend outward and reflect red light.

The range of visible light is shown in figure 8.

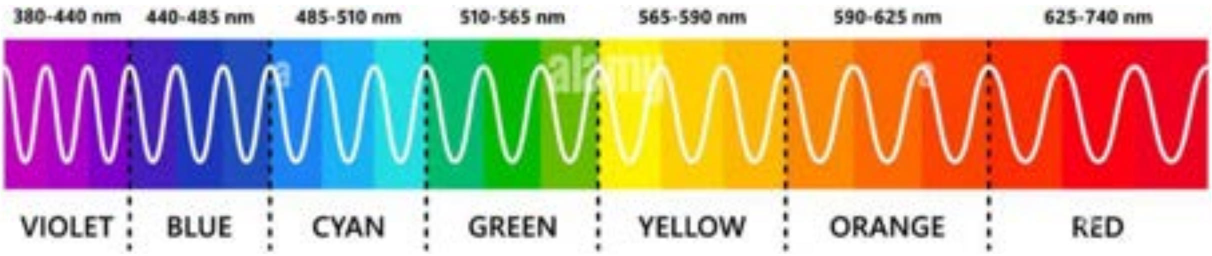


Figure 8 Visible Spectrum [5]

4 Design Thinking Process

Here are how we used the design thinking process stages.

4.1 Empathize

To gain a sense of what potential end users expect from this technology, various individuals encountered in daily life were interviewed during the Empathize phase. Several application areas emerged from these interviews. Some of them are shown in figure 9. All results can be found in the Appendix 2.

Display use	**User group**	**Use case**
Home	Tech-Enthusiasts	Heady up displays
Work	Advertisement	Glasses
Entertaining	Military	Displays
Information gathering	Office-Worker	Smart-Board
Advertising		Jewelry

Figure 9 Empathizing

Also, this innovative technology can be used to replace all current display technologies (desktop, television, table, phones, laptops, watches, etc.)

The identified disadvantages of the technology included:

- Functionality in low light conditions
- The price
- Lack of long-term studies with the material

4.2 Define

During the Define phase, various personas and user journeys were created to gain a better understanding of the potential customer base. The personas that stood out the most were those of tech enthusiasts, such as professional e-sports athletes, the businessperson, which works in an office, the outdoor sportsman, who likes to go hike or jogging, the extreme sports athletes, whether participating in competitions or engaging in extreme sports like climbing and also a boat rental business. Those personas are found in the Appendix 3.

4.3 Ideate

During this phase, we refined the "How Might We" (HMW) question from “How might we apply the technology from Megamorph to wearables that improve the lives of the future” to “**How might we use the technology from Megamorph to create an economically feasible product**” to better align with the technology, and additionally, we collected new ideas for prototypes. The following ideas were gathered:

- Screens for cars or aircraft
- Use in hospitals as a portable patient screen
- Universal computer for a yacht with navigation and other sensor indicators
- Integration in VR headsets
- Smartboard table
- Portable roll-up screen
- Advertisement boards
- Interactive mirror
- Heads-Up Display (HUD) in motorcycle helmets
- Applications in warships
- Use in war machines

After considering moral perspectives and existing patents, we decided to proceed with the smartboard table, the portable roll-up screen, and the Universal computer for a yacht.

4.4 Prototype

During this phase, several interesting prototypes were developed.

4.4.1 Portable Screen (Roll Up): This prototype was designed as a portable home theatre system for outdoor use. It included a retractable screen, a battery, a light source, and two speakers, making it easy to set up and enjoy a movie experience anywhere.

Figure 10 Portable Screen (Roll Up)

4.4.2 Smart Table: There were 2 ideas with a small difference.

David's Idea: This table was intended for schools to alleviate the burden of students carrying heavy materials. The idea was for students to carry only a lightweight display, which could then be connected to the table, integrating seamlessly with the classroom environment.

Figure 11 Smartboard Table

Salim's Idea: Smart Table with display which will replace the books and notebooks in education system. This new technology will help students not carry heavy bags to school and will help the students with disabilities and problems to act as normal students. These Smart tables can be connected with class's board and teacher's device so every student can communicate with board and teacher at needed time, also teachers can control students on what they need to do and check their activities. This technology will help the education system to run more smoothly and avoid paper waste and will be more environmentally friendly. These tables can have touch sensors or can be used with controllers. This technology will help us to control the paper waste and have a smart and innovated education and communication system.

Figure 12 Smart Table

4.4.3 Universal computer for a yacht: This display harnessed the benefits of graphene and combined them with the demands of extreme water sports. The concept was to create a robust and high-performance display suitable for use on yachts, offering advanced functionality and durability in harsh conditions.

Figure 13 Universal computer for a yacht

After creating the prototypes, our sponsor informed us that the technology is not touchscreen nor flexible, which made the first two prototypes unusable, but it can be possible in future when the technology develops more and add touch sensors.

Given this setback, we had to rethink our approach and make significant adjustments to our design and development process. The initial prototypes were created with the assumption that the technology would support touchscreen functionality and offer flexibility, both crucial elements for the intended user experience.

4.5 Testing

Despite the limitations identified during the test phase, all prototypes were still evaluated. It turned out that each of the three prototypes had potential users. However, we ultimately decided to proceed with the universal computer for yacht computer, as it utilized the advantages of the technology and was feasible to build, whereas the other two prototypes were currently not realizable. The feedback is found in the Appendix 4.

5 Research

5.1 Literature review and background research

At the beginning we did some literature review and background research. We started with research to understand the material graphene better. In summary, graphene is an amazing material that is flexible, has incredibly good electrical conductivity, is resistant, has high light transparency, chemical and thermal stability, and has a high resolution (Miao et al., 2023). Therefore, a display made of graphene offers amazing opportunities. Next, we carried out further research into GMOD displays, looking at possible competitors and existing solutions. For example, we found out that Samsung is also working on graphene displays, focusing on flexible screens for displays and wearables (Samsung, 2014). Therefore, we did not want to go in the direction of flexible displays.

5.2 User research

User research was important to us, as it helped us to understand if there is a user need for our solution. A user-centred perspective is the key to a promising idea. We followed the process of a double diamond (Nessler, 2018). So, we continued the research with qualitative user interviews. At first, we struggled to find an effective way to start the interview and to collect appropriate questions, as a graphene display is automatically a complex topic.

However, we managed to approach the topic in a way as simple as possible. We ended up with a detailed and structured interview guide, which can be found in the attachment “Appendix 1: Interview guide”. We decided to work with a semi-structured interview as this allowed everyone to adapt to their interviewee (Barclay, 2018). This was important to us as people may have various levels of knowledge depending on their background. This approach worked well for us. Our target group had an age range from 15 to 60 years. We interviewed 5 men and 3 women. The results can be found in the Appendix 2.

After the interviews, we summarized and evaluated the results. The responses in the interviews were relatively broad. We found out what users like about graphene displays. Quite often it was mentioned that the lower energy consumption is a nice advantage, as sustainability is huge factor now. The higher resistance of the screen was also seen as a big advantage. Surprisingly to us was that one user was convinced from graphene displays but did not saw any new market potential, as they are just improving current displays but not really offering new use cases. The price and the fact that the screen needs an extra light source to work at night were seen as negative.

5.3 Personas & journey map

Part of our research process was to build a representation of our users, to understand their needs, pains, and goals. We wanted to empathize more strongly with them and therefore came up with personas. The focus was on the ideal user, an extreme user, and the user group on which will have a major impact. We choose those user groups to get a good feeling for the specific group of our users, and to realize the boundaries between them. Based on the insights and findings from our interviews, we produced four different personas: tech enthusiast, businessperson, outdoor sportsmen, and a competitive athlete. Those personas are found in the Appendix 3. Together as a team, we decided that the ones we wanted to take forward were athletes and technology enthusiasts. The decision was made, as we assumed that those are the people who probably value the advantages of the graphene display the most. An outdoor sportsmen will love the resistance, the readability in sunlight as well as the minimal use of the battery capacity. A tech enthusiast will additionally be fascinated by the greater electrical conductivity of graphene.

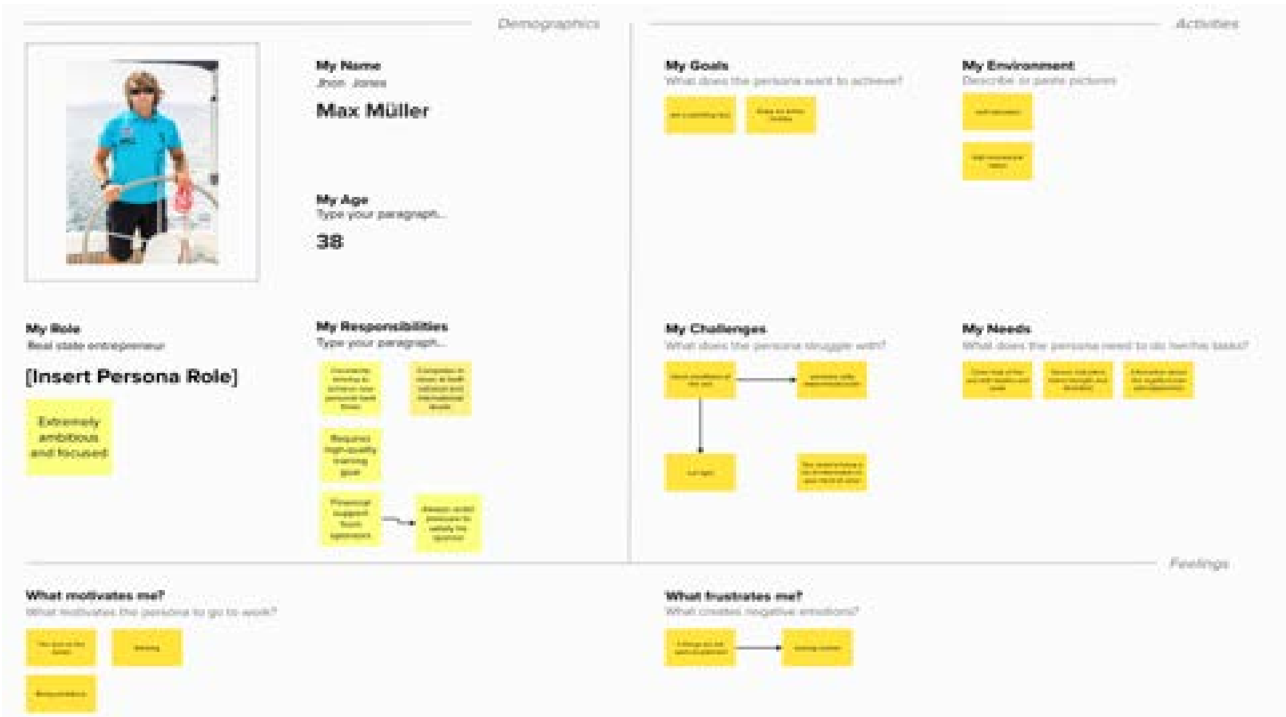


Figure 14 Detailed persona Max Müller

Later in the process we focused mainly on the persona Max Müller, a competitive sailor – shown in figure 13. In general, to think and build all the personas helped us to get a good feeling for our potential target groups.

To understand the journey our users, must go through, the next step was to focus on a journey map. We tried to identify pain points and needs in the journey of our persona Max Müller. The question we had in mind was “Where could graphene displays solve needs & pains?” For example, the outdoor sportsmen could suddenly use his smartwatch with a graphene display in direct sunlight, which solved one of his pain points.

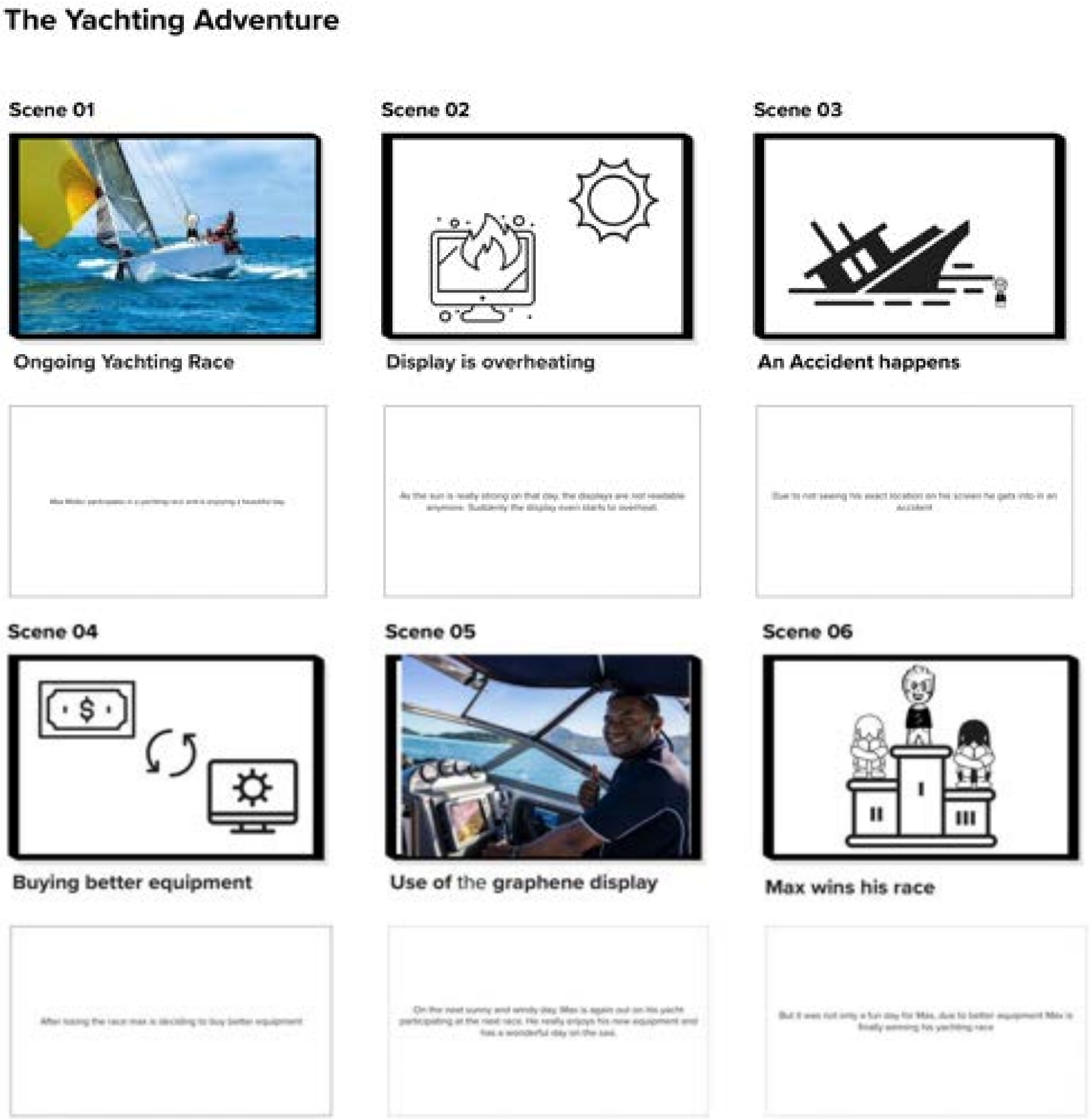


Figure 15 User Journey of the persona Max Müller

After this part of the research, we focused on finding different ideas that fit the personas and the input from the user interviews. Each of us of us concentrated on ideas and thought them through. As well everybody sketched ideas briefly. Those ideation part brought us then to the next step in our research.

5.4 Testing of the prototype

After doing the 8 user interviews, the personas and a user journey to empathise with our users, we concentrated on testing our prototypes. We built six low-fidelity prototypes, two per chosen idea. One prototype per idea was produced and tested in Germany and the other one in Finland. The ideas we tested were a roll-up screen, a smart table, and a yacht screen. Our goal was to show rather than talk about the abstract topic any longer. This gave us direct and valuable feedback. This time we decided not to have a detailed interview guide, but to let the user explore the prototype and react to it. As our prototypes were not that complex, we also decided to not define specific interactions, that had to be tested in this particular order. Nevertheless, we did have a short test script and collected some basic questions together, to get a feeling for the direction we wanted to go. We focused on questions like: What could be improved? What worked? Was it understandable? Would the user like to use it? We tried to interview users as close to our personas as possible.

In this research part, it is especially important not to get attached to our own ideas, as we need to be neutral and open to improvements, feedback and even forgetting an idea entirely (Bowman, 2022). That is what we did in the next step. We all documented our test findings. The results can be found in the Appendix 4. After analysing the input we gathered, we decided that the most viable of the three solutions of was the yacht screen. Then the need and the idea were understood by the three tested users, which was not the case with the other prototypes. We then focused on what could be improved in this prototype, in order to develop it further – with this step we started the next iteration.

5.5 Another iteration round

All the previous steps were repeated in a very quick ideation round. We collected new ideas using a creative matrix, thought about a suitable persona and user journey, and came up with a new product idea. This process was difficult for us, as we did not have much time.

However, we managed to produce a new idea: an augmented reality motorbike helmet using the graphene screen integrated into the hinge. Unfortunately, when we did more background research, we found that this idea already existed on the market (Ludmann, 2022). As a result of this, we went back to the sailing screen and modified the journey map to fit this scenario.

Also, during the additional coaching with Mrs. Kloe we came up with a new persona: The owner of a yacht rental company: Lia King. We thought this would also be a good target group, as they want to have durable material for their boats. As a rental company, they use their yachts more than most other yacht owners, who mostly sail in their spare time.

Anyway, we wanted to do more user interviews, specifically asking about our prototype in the marina during our sponsorship trip to Valencia in July. We decided to look for either competitive sailors or yacht rental company owners. However, we only managed to interview three competitive sailors and no boat rental company owners. Although Nielsen (2000) recommends interviewing about 5 users to identify most of the problems in a user test, we had to stop with these three interviews. We could simply not find any more competitive sailors willing to talk to us. However, the feedback was quite positive and all three understood the prototype and the need. Unfortunately, one of them mentioned that he would only buy our prototype if it was not too expensive compared to his current screen.

As we did not find an owner of a rental yacht company, we can only recommend the persona Lia King as an additional target group. As we did not manage to get any closer to this very specific group, we also did not gather any insights in this specific group. As a result, out of this, we continued with the competitive sailors.

6 Solution

Taking all the research and interviews into account and processing all the data we have gathered and after applying all the Innovation methods we have come up with our final Idea which can be a suitable and innovative solution for our challenge. The idea we come up with is Universal Yacht Screen made of Graphene. This technology will solve the issues people have with their existing technologies such as higher power consumption, unclear sight, screen durability and so on.

6.1 System Setup

The solution comprises three essential components, which collectively make up the new yachting console. The GMOD display, the solar panel and the light source. These components effectively replace parts of a traditional yachting console, offering enhanced functionality and convenience.

The GMOD display, which is superior to traditional LED displays, is a key feature of the new console and can be controlled using buttons. To ensure visibility during daylight hours, a light source is integrated above the screen, charging during the day with a solar panel that is also included in the console.

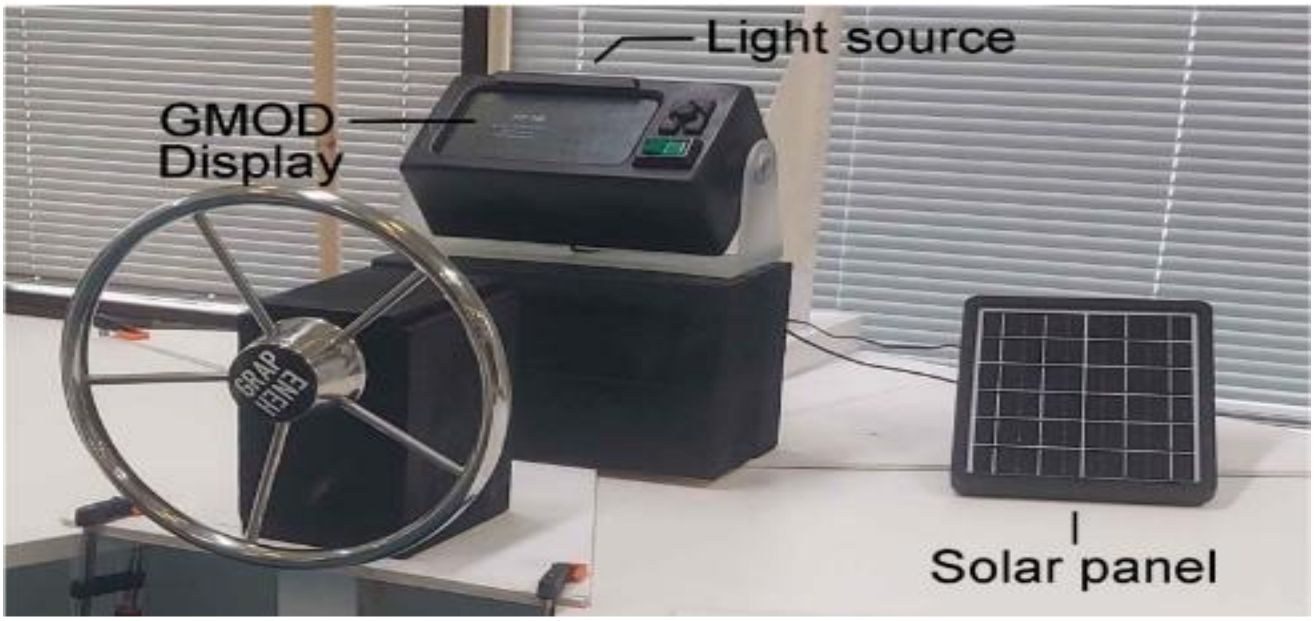


Figure 16 Our Solution Prototype

6.2 Components

For the graphene display to work effectively and sustainable, we identified three main components for our setup.

6.2.1 GMOD-Display

The core of our solution is the GMOD-display, which makes use of Megamorph’s display technology. A screen like this is a realistic prospect for the Megamorph project, which already created small-scale pixel screens in the past. The GMOD-display will replace the traditional yachting console display, which currently displays data such as cartography information. To navigate the screen, the display case includes buttons. Those are the power button and directional buttons that can navigate the screen.

6.2.2 Light Source

The light source, attached to the yachting console above the screen, has been added to ensure visibility of the GMOD screen during night-time usage. To achieve this, the light is charged during daylight hours using a solar panel. When it is dark, the light can be turned on. In our case, the lamp is in the shape of a sliced cylinder, with the flat long flat part, which includes the actual light source, being directed downwards towards the GMOD display. That way the screen could be lit up without light blinding the user.

6.2.3 Solar Panel

The solar panel is a key component in the power source for the light source. During daylight hours, it charges to provide the light source with energy at night. This contributes to the sustainability of the product.

6.3 Justification for our system setup

In today's world, the reliance on advanced technology is indispensable, especially in complex and critical fields such as marine navigation. When you are on a boat in the open sea, you require a vast array of information, ranging from your current location and course to the precise degree of change in wind direction. The captain needs to simultaneously view the navigation map, compass, and all boat sensor readings on the screen, while effortlessly managing radio communication with other vessels. This is where we see the optimal use of GMOD (Graphene Modulated Optical Display) technology.

Our team has numerous arguments to support this, and we will discuss the main ones in detail.

6.3.1 Superior Visibility Under Direct Sunlight

Conventional screens often fail to provide sufficient brightness under direct sunlight, making them challenge to use in marine environments. The core functionality of GMOD technology lies in its ability to reflect and refract sunlight. This means that the screen will always have adequate brightness, ensuring comfortable usage regardless of the surrounding light conditions.

6.3.2 Heat Resistance and Durability

Another significant issue with traditional displays is overheating and screen burn-in. The mirror-like coating of the GMOD screen reflects light along with its energy, preventing heat from building up and damaging the display. This feature ensures that the screen remains cool and functional even under prolonged exposure to sunlight. Additionally, the unique physical and chemical properties of the graphene layer guarantee its longevity in any weather conditions. The crystalline structure of graphene makes it ideal for use in harsh marine environments.

6.3.3 Environmental Friendliness and Energy Efficiency

All materials used in GMOD technology are environmentally friendly, aligning with the growing demand for sustainable solutions. The energy efficiency of this technology is particularly beneficial in situations where you are miles away from power sources. The low power consumption of GMOD displays means that they can operate longer on limited energy reserves.

6.3.4 Analog Control Compatibility

Our sponsor's requirements specified a solution that does not necessitate the integration of touch sensors. In open-air conditions, where weather can be unpredictable (such as rain), people often prefer analogy control methods like buttons, knobs, and levers. The GMOD display is designed to work seamlessly with these traditional control mechanisms, providing a reliable and user-friendly interface for the captain and crew.

6.3.5 Cost-Effectiveness

Thanks to its unique characteristics, the GMOD display can emerge as a leader in the price to quality ratio. The long-term benefits of reduced maintenance costs, lower energy consumption, and enhanced durability translate into significant savings for marine operators.

Summarizing, GMOD technology offers a comprehensive solution for marine navigation, addressing the critical needs of visibility, durability, environmental sustainability, and cost-effectiveness. Our team has meticulously considered every aspect to ensure that this technology not only meets but exceeds the demands of modern marine navigation.

6.4 Early phases

All phases of our project were guided by the Design Thinking process, which involved empathizing with users, defining the problem, ideating potential solutions, and iteratively prototyping and testing.

Prototype 1: Physical Steering Column with Touchscreen

Figure 17 Early prototype of the yachting console

Our first prototype was a physical steering column designed for installation in the cockpit of a sailboat. It featured a large touchscreen for the navigation system, providing a modern and interactive experience. However, users found the touchscreen impractical due to size constraints and the need for a more rugged, tactile interface. Additionally, the touch functionality was less reliable in wet conditions. Based on user feedback and practical considerations, we decided to move away from the touchscreen design.

Prototype 2: Virtual Steering Column with Separate Control Units

The second prototype was a virtual design featuring a steering column with separate small screens for navigation, marine charts, and a compass, along with dedicated control units in the form of buttons and touchpads. While this design offered a comprehensive control system, users found it too complicated. Additionally, it was challenging to create a universal design that could fit all types of boats, yachts, and catamarans. Due to its complexity and the need for a more streamlined and adaptable solution, this prototype was not chosen.

Additional Lighting Solution

Parallel to the development of the prototypes, the need for additional lighting for night time navigation was also addressed. Initially, the use of special glasses with integrated flashlights and an additional screen for nighttime use was considered. However, these ideas were discarded due to practicality and complexity. An external light source in the form of a small, unobtrusive lamp was implemented, which proved to be a simple and effective solution.

6.5 Final prototype

Conceptualization and Decision-Making

The initial phase involved extensive research and brainstorming to determine the optimal solution that would meet all necessary requirements and user demands. After evaluating diverse options, it was concluded that a chart plotter, a universal marine onboard computer, would be the best fit. This decision was driven by the need for a device that could provide detailed depth maps and navigation information, crucial for the safety of any boat captain.

Component Selection

The next step was to choose the right components. A 7″ touchscreen display for Raspberry Pi was selected due to its suitable size and programmability. This display allowed for the demonstration of the core functionalities intended for integration into the chart plotter.

3D Printing and Casing Design

To house the display, a custom casing was designed and 3D-printed. This casing was tailored to fit the display perfectly and featured an adjustable angle for optimal viewing. Ensuring that the casing was water-resistant was a critical requirement for marine environments. The design included convenient control elements such as buttons, knobs, and switches, enhancing the user experience.

Additional Features

Understanding the importance of usability in low-light conditions, a small lamp was integrated into the design. This lamp serves as an external light source during nighttime navigation. A robust mounting system was also developed, allowing for quick and easy installation on any vessel.

6.6 Final Presentation

For the final presentation, an immersive setup was created which includes the yachting console. This allowed guests to experience the prototype the way it is intended to work on the boat. Apart from the main components, which are the GMOD display, the light and the solar panel, we also added a steering wheel, an adjustable case for the display and buttons for said display.

Also 2 videos have been made, one of them was prototype introduction video, in which we briefly introduced our technology and other important issues, and the other one was product trailer video in which we shortly shown our product team and technology but didn’t give any information. Both videos have been submitted in Final Deliverables files.

Figure 18 Our Final Prototype (Final Gala Booth)

7 Finance

To complete our project, our team received funding from the ATTRACT project. This money was used to fund sponsor visits, travel costs and prototyping materials.

The biggest expense was the sponsor visit to Valencia, which was a significant help to the project. The trip gave us a clear idea of how to move forward with our idea and strengthened our confidence in our prototype. It also gave us an insight into Megamorph's facilities and approach. Thus, the money was well spent. The sponsorship trip included travel expenses such as train tickets and hotel costs.

Most of the prototyping materials were bought towards the end of the project when we were building the stand at HAMK for the final gala.

The costs for the project are composed as follows:

Inno.space

Travel to Finland

- Flights: 1677€ (559€ per student)
- Train rides: 238,2€ (79,4€ per student)
- Accommodation: 1310€

Sponsor trip to Valencia

- Flights: 2097,9€ (699,3€ per student)
- Accommodation: 1266€
- Prototyping materials: 24,91€
- Total on inno.space side: 6614,01€

HAMK Design Factory

- Travel to Germany: 2412,58€
- Sponsor trip to Valencia: 4111,03€
- Prototyping materials: 1016,73€
- Total on HAMK Design Factory side: 7540,34€

➢ This means that the total costs amount to 14154,35€

8 Project Business Plan for Yacht Displays using GMODs

Thanks to the exchange with Juan Pablo and Santiago from Megamorph, it was possible to clarify an approximate business plan.

When discussing the issue of high prices for graphene products, Megamorph made it clear to us that they are hoping for a significant price reduction for graphene products in the long term. This is because prices would fall with high demand due to higher production values. Megamorph underlined this by stating that this has happened with other products in the past. There are also several companies that are already capable of producing graphene. These could produce more graphene at a cheaper price as demand increases.

Based on the following findings and observations, we determined that the marine environment is a good entry point for graphene products.

We compared the prices of yacht screens and, depending on the brand and features, the prices ranged from around €500 to €2000, although it can go much higher. Compared to other sectors, this is extremely expensive for relatively small screens.

Based on our user research and market prices, we believe that price is not a major concern for boat owners (see Appendix 2). This is largely due to the wealth of the average boat owner. This, coupled with the fact that graphene has truly clear advantages over traditional yacht screens, mainly in terms of head resistance and sunlight readability, leads us to believe that it would be easy to market graphene products in the boating environment, even if they are still more expensive.

This means that these screens represent a short-term opportunity for the Megamorph project that does not depend on a significant price reduction. Marine screens would therefore be a market entry point for Megamorph products. Our confidence in this idea was strengthened when Megamorph confirmed that they had independently considered going down the sports route at some point but had not yet done much research.

For Megamorph, this means that it is a very viable option to move forward with Yachting Screens shortly after the GMOD displays can be produced in serious quantities with all the promised features.

9 Future development

Throughout the prototyping process, we had various ideas about different directions we could go in the future. Some of these ideas were not realised due to concerns about cost or lack of time, and in some cases the technology simply did not allow it. However, we still see potential in some of these ideas.

One of these ideas is to give the yacht screen the functionality of a touch screen, as several users claimed that a touch screen would be beneficial. Currently, the GMOD screens developed by Megamorph do not allow for touch functionality. We see this as a good upgrade for the GMOD yacht screen, making navigation easier and more intuitive. Megamorph have told us that touch screens are an option in the future, so it is highly likely that they will move forward with this.

The same goes for flexibility and transparency, neither of which can be fully achieved with Megamorph's technology at the moment but could be an option in the future. For example, it may be possible to create yacht screens that can be flexibly rolled up and out or see through screens that use transparent GMOD technology.

Another additional feature that was suggested to us through user testing is a wristwatch that can be connected to the yacht console via Bluetooth or radio. This could be both an additional screen to view the console display and an emergency device that could be triggered via the GMOD display or via the smartwatch if a person falls off the boat. That way, it could act as an additional safety feature for the display. In the end we didn’t go with the idea because it requires a lot more resources and considerations and doesn’t directly relate to the GMOD technology.

We also considered adding another screen to the prototype to enhance the experience. However, we decided to focus on using only one GMOD screen to highlight its capabilities and reduce costs. We determined that the benefits of adding another screen would not outweigh the additional cost and complications of using it.

Also, adding speakers to the yacht's console would be a good enhancement to provide audio feedback and play music or emergency alerts.

10 Reflection concerning design thinking and learnings

The project enriched us with new knowledge, skills, and competences. The international teamwork required good and constant communication.

We learned to use a wide range of new tools. For example, we had specific introductions to 3D lasers, laser cutting and Figma software to help us make better prototypes.

We also learned about different design principles, especially ways to make posters and logos more visually appealing and aesthetically pleasing.

The course put a lot of emphasis on the design thinking process, constantly iterating through the process with weekly assignments and more. This taught us how the concept works and why it works.

We also learned about graphene and screen technology and Megamorph itself. In addition, we gained skills regarding communication with our sponsors.

The preparation for the final gala came with lots of time pressure for our team as we had a lot planned for the little time we had. However, we managed to get everything done by the time the Final Gala began and the feedback we received was positive.

A challenge for us was the internal communication between the German and Finnish sides. This was mainly due to conflicting schedules, different time zones and a lack of meeting space at inno.space. We eventually solved this by finding a meeting routine that worked.

In the end, we managed to create a viable product that could realistically work the way we wanted it to, and that occupied an occupied place in the market that could serve as an entry point for Megamorph in the future.

11 References

Cartamil-Bueno, S.J., Davidovikj, D., Centeno, A. *et al.* Graphene mechanical pixels for Interferometric Modulator Displays. *Nat Commun* 9, 4837 (2018). https://doi.org/10.1038/s41467-018-07230-w.

Attract, ATTRACT stories: behind the MEGAMORPH project, (2023), https://attract-eu.com/attract-stories-behind-the-megamorph-project/.

Santiago J. Cartamil-Bueno, MEGAMORPH Project to commercialize graphene-based holographic displays, Scale Nanotech, (2022), www.scalenano.tech/megamorph-project-announced/.

La Caixa, Graphene Flagship, Scale Nanotech, Team, www.scalenano.tech/team/.

Barclay, C. (2018). Semi-structured interviews. *KnowHow.* https://know.fife.scot/__data/assets/pdf_file/0028/177607/KnowHow-Semistructured-interviews.pdf (retrieved on the 08.07.2024)

Bowmann, L. (2022). The Best User Research Questions (+ how to ask them). *Maze*. https://maze.co/blog/research-questions/ (retrieved on the 08.07.2024)

Cartamil-Bueno, S. J., Davidovikj, D., Centeno, A., Zurutuza, A., van der Zant, H. S., Steeneken, P. G., & Houri, S. (2018a). Graphene mechanical pixels for interferometric modulator displays. *Nature Communications*, *9*(1). https://doi.org/10.1038/s41467018-07230-w

Cartamil-Bueno, S. J., Davidovikj, D., Centeno, A., Zurutuza, A., van der Zant, H. S., Steeneken, P. G., & Houri, S. (2018b). Graphene mechanical pixels for interferometric modulator displays. *Nature Communications*, *9*(1). https://doi.org/10.1038/s41467-01807230-w

Cartamil-Bueno, S. J., Steeneken, P. G., Centeno, A., Zurutuza, A., van der Zant, H. S., & Houri, S. (2016). Colorimetry technique for scalable characterization of suspended graphene. *Nano Letters*, *16*(11), 6792–6796. https://doi.org/10.1021/acs.nanolett.6b02416

Dam, R. F. (2024). The 5 Stages in the Design Thinking Process. The Interaction Design Foundation. https://www.interaction-design.org/literature/article/5-stages-in-thedesign-thinking-process (retrieved on the 22.07.2024)

Jin, L., Zhao, C., Gong, Z., Pan, J., Wei, W., Wang, G., & Cui, Y. (2021). Hydrogen-promoted graphene growth on Pt (111) via CVD methods. *Surfaces and Interfaces*, *26*, 101383. https://doi.org/10.1016/j.surfin.2021.101383

Lewrick, M., Leifer, L., & Thommen, J. (2020). *The Design Thinking Life Playbook*. Wiley.

Ludmann, D. (2022). Navi, Freisprecheinrichtung und Kamera https://www.motorradonline.de/bekleidung/smarter-motorradhelm-livemap/ (retrieved on the 24.06.2024).

Miao, J., & Fan, T. (2023). Flexible and stretchable transparent conductive graphene-based electrodes for emerging wearable electronics. Carbon, 202, 495–5 27. https://doi.org/10.1016/j.carbon.2022.11.018

Nessler, D. (2018). How to solve problems applying a uxdesign designthinking HCD or any design process from scratch V2. https://uxdesign.cc/how-to-solve-problems-applying-a-uxdesign-designthinking-hcd-or-any-design-process-from-scratch-v2aa16e2dd550b (retrieved on the 08.07.2024)

Nielsen, J. (2000, February 2). Why you only need to test with 5 users. Nielsen Norman Group. https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/ (retrieved on the 08.07.2024)

Samsung (2014). Samsung Electronics discovers groundbreaking method to commercialize new material for electronics. https://news.samsung.com/global/35576 (retrieved on the 24.06.2024).

12 **Picture-References**

[1] Lecture slides

[2] https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process

[3] https://megamorph.eu/the-technology/

[4] https://cleanroom.groups.et.byu.net/rie_etching.phtml

[5] https://pngtree.com/freepng/visible-light-spectrum-wavelength-ray_8654421.html

[6] https://www.mdpi.com/1422-0067/24/10/8563

[7] https://www.alamy.de/sichtbares-lichtspektrum-wellenlange-des-optischen-lichts-elektromagnetisches-sichtbares-farbspektrum-fur-das-menschliche-auge-vektorgradienten-diagramm-mit-wellenlange-und-image470194471.html

[8] https://chatgpt.com/ for paraphrasing texts

[9] https://pngtree.com/freepng/visible-light-spectrum-wavelength-ray_8654421.html

[10] https://commons.wikimedia.org/w/index.php?title=User:AlexanderA lUS&action=edit&redlink=1

13 List of figures

14 Appendix

Appendix 1: Interview guide

User Group:

Tech Enthusiasts and businesspeople, Age 12 – 60, using electrical devices frequently & using for example projectors

Exclude: students of Inno.space

Introduction and Warm-up:

Hello, I am (Name) and are part of the student project Graphene. For this, we work together with Megamorph, a company based in Valencia. I am very thankful for you time to participate in the interview. Your Feedback is unbelievably valuable for our product development process.

Have you ever done a user interview before? There are no right or wrong answers, the only thing we are interested in is your honest opinion. So please tell us what ever comes up to your mind. If you have any questions, feel free to ask them at any time. The interview will take approximately 45 minutes.

Before we start, one more thing concerning the data security. We would love to record your answers, is this okay for you? No worries, we will not share the input outside our project or publish those files.

Establishing Rapport

But let us talk about you.

What is your age?

What is your educational background?

What is your current profession?

How often do you use technical devices? (Screening question for tech enthusiast, if seldom --> OUT!)

Deep Dive into displays & wearables

If you think about displays, where do you use them in your everyday life?

Can you tell me about your current usage of display technology in your daily life or work?

What features or characteristics do you find most important in a display technology?

Do you know what wearables are?

If not, explain --> Wearables are Wearable technology, also known as "wearables," is a category of electronic devices that can be worn as accessories, embedded in clothing, implanted in the user's body, or even tattooed on the skin. The devices are hands-free gadgets with practical uses, powered by microprocessors and enhanced with the ability to send and receive data via the Internet.

What do you like about wearables?

What do you not like about wearables?

Context Setting for graphene displays

Do you know graphene?

No worries, Graphene is a material made out of pure carbon, it is really flexible, light, tough and has a high resistance.

Have you heard of graphene displays before? If so, what do you know about them?

Graphene Displays are resistant, thin, and flexible. They have a really high resolution and are less energy consuming. However, they need a light source to work.

In what ways do you think graphene displays could improve upon existing display technologies?

What tasks/activities do you think graphene displays could enhance?

If we now think back to wearables, which wearables do you think could benefit from graphene displays?

How do you think the properties of graphene, such as its flexibility and durability, could be leveraged in display technology?

Are there any challenges or limitations you foresee with implementing graphene displays in real-world scenarios?

Do you think there are any specific user groups/demographics that would benefit the most from graphene displays?

Can you envision any industries where graphene displays might be beneficial?

How do you think the energy efficiency of graphene displays could impact their adoption in various devices or applications?

Can you think of any unconventional or unexpected ways that graphene displays could be used?

Finally, how do you imagine the widespread adoption of graphene displays might change the landscape of display technology in the future?

Additional Questions in Case we talk with a businessperson:

What factors do you consider when evaluating new display technologies for integration into your products or projects?

Have you encountered any barriers or concerns related to adopting new display technologies in the past? If so, what were they?

Ending the Interview

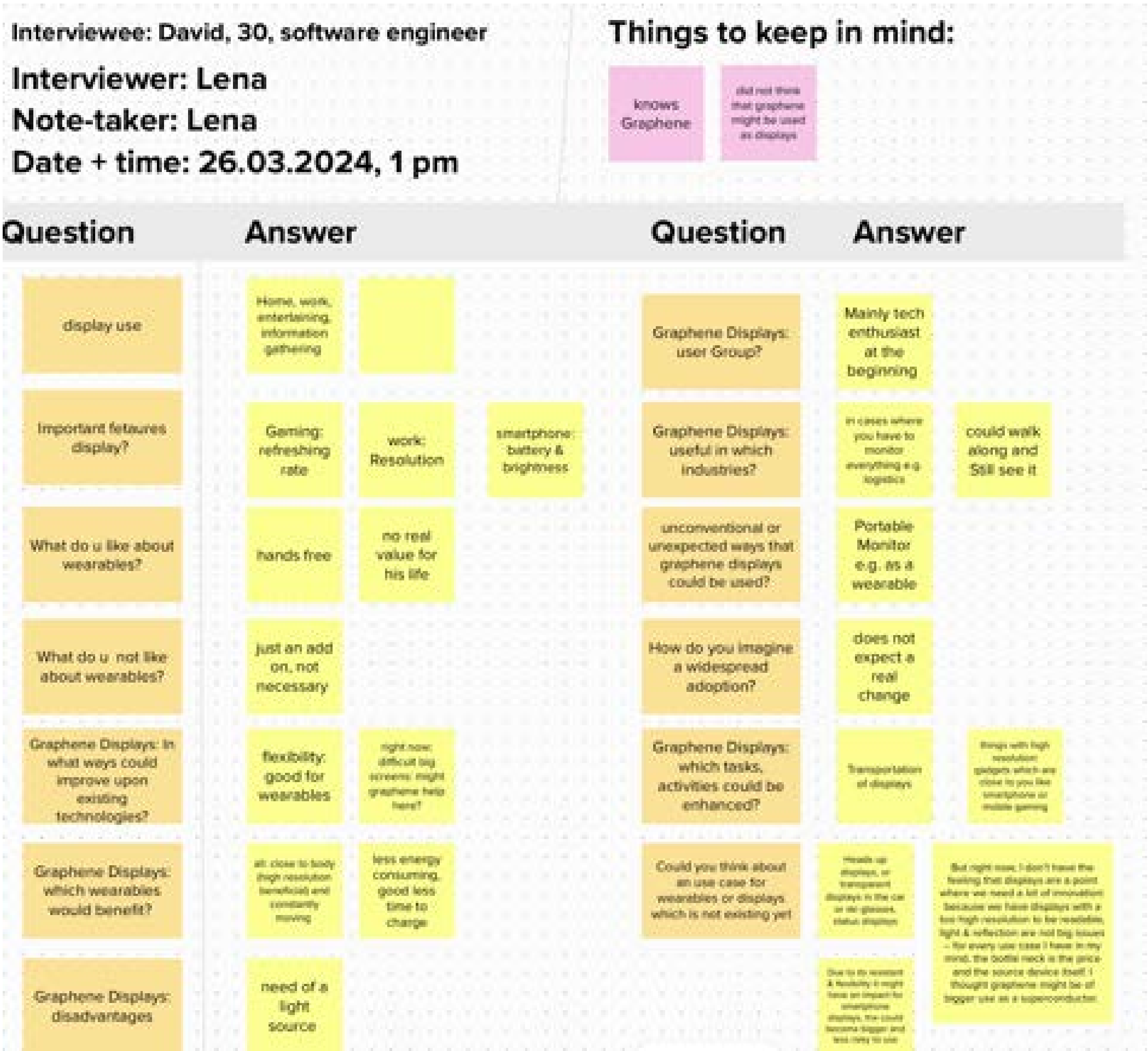
As a very last question, we have a more difficult one:

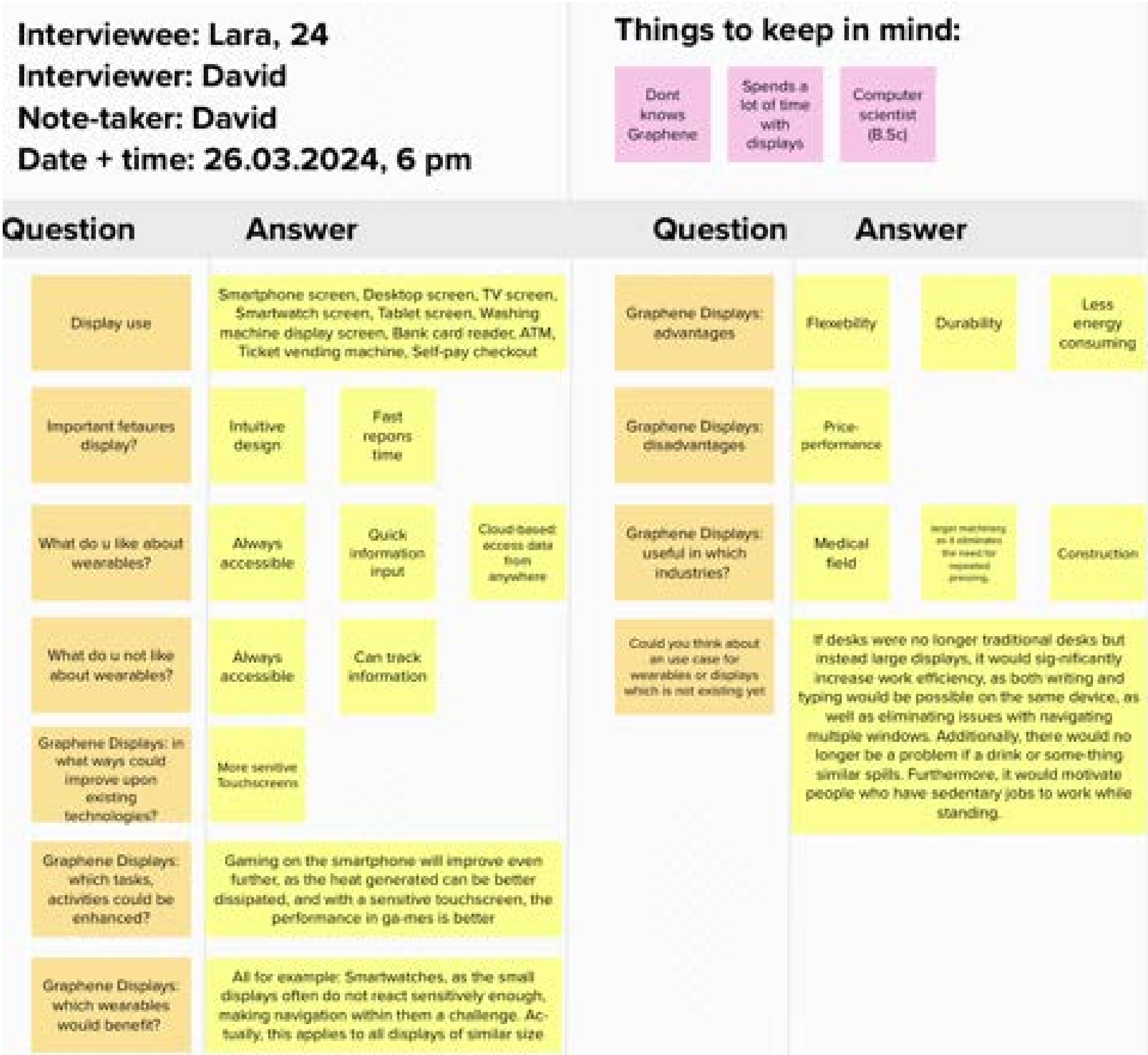
We talk a lot about displays, Wearables and graphene displays. Now please try to forget that there are limitations and imagine you could just use displays everywhere. Could you think about a use case for wearables or displays which is not existing yet? For example, I would love to have a display on my shoes showing me the direction I have to walk whenever I look down to my shoes. Be free, it can be as crazy as it gets!

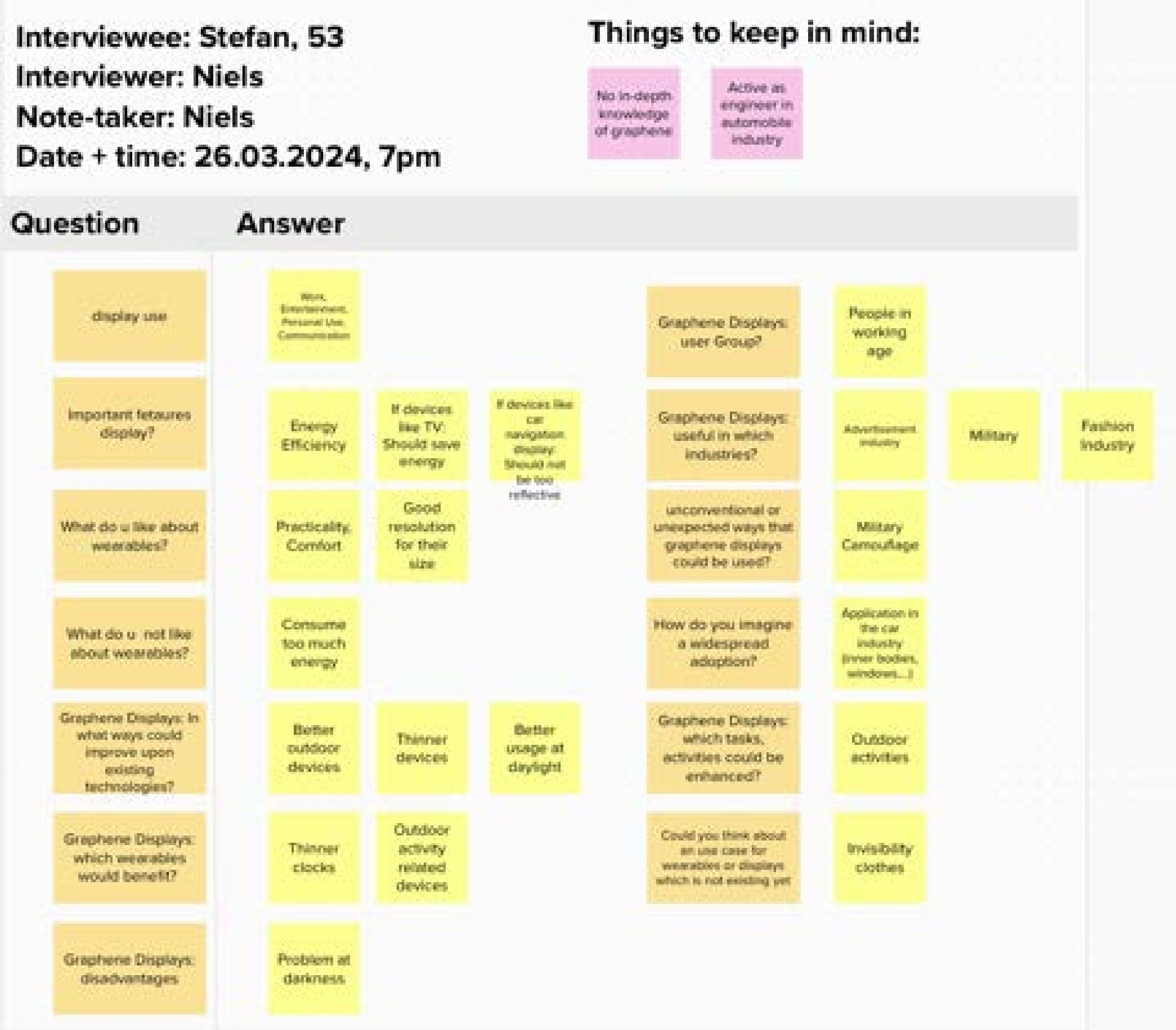
Would you like to add something?

Do you have any questions left?

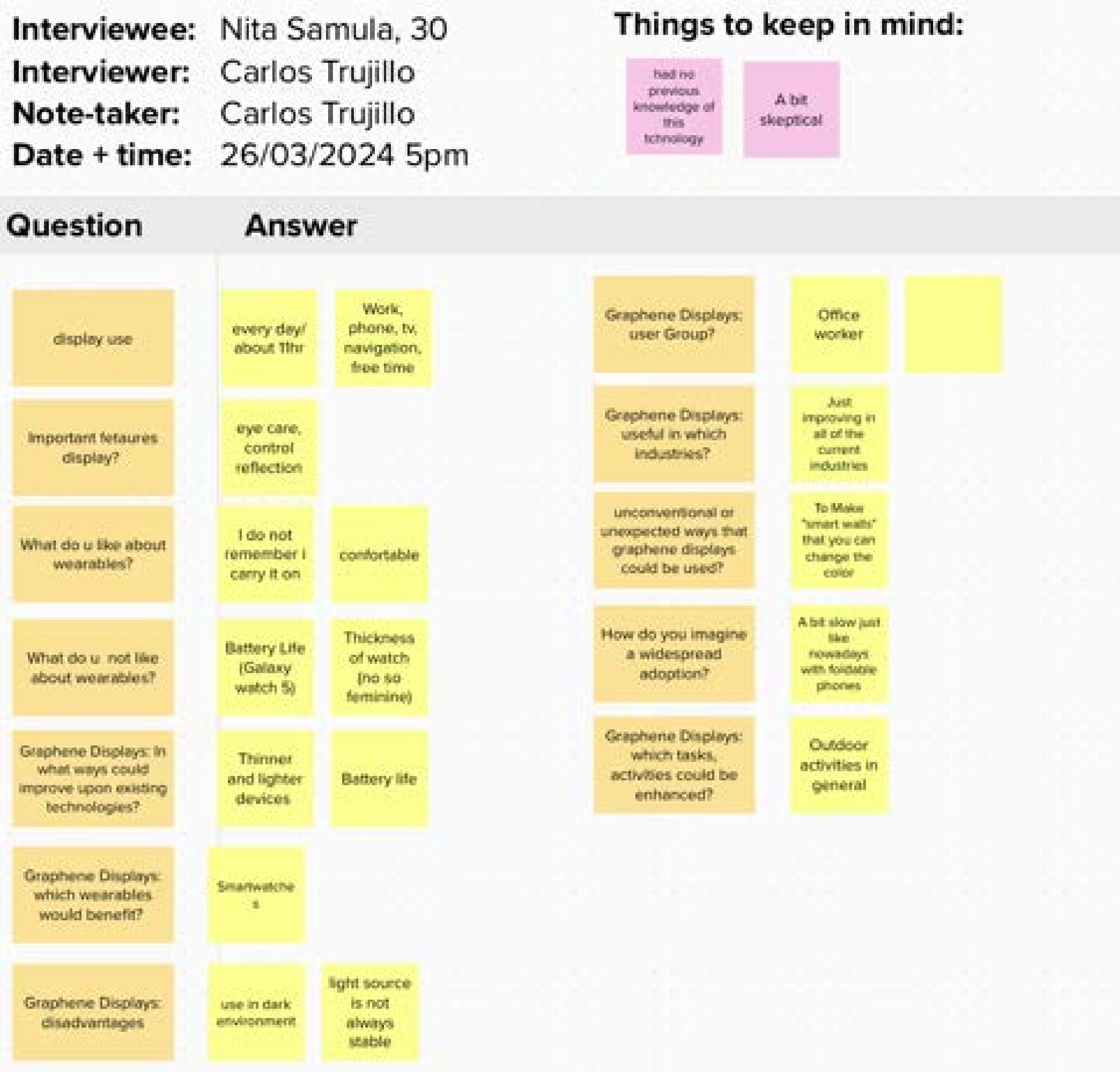
Appendix 2: Summarized findings of the user interviews



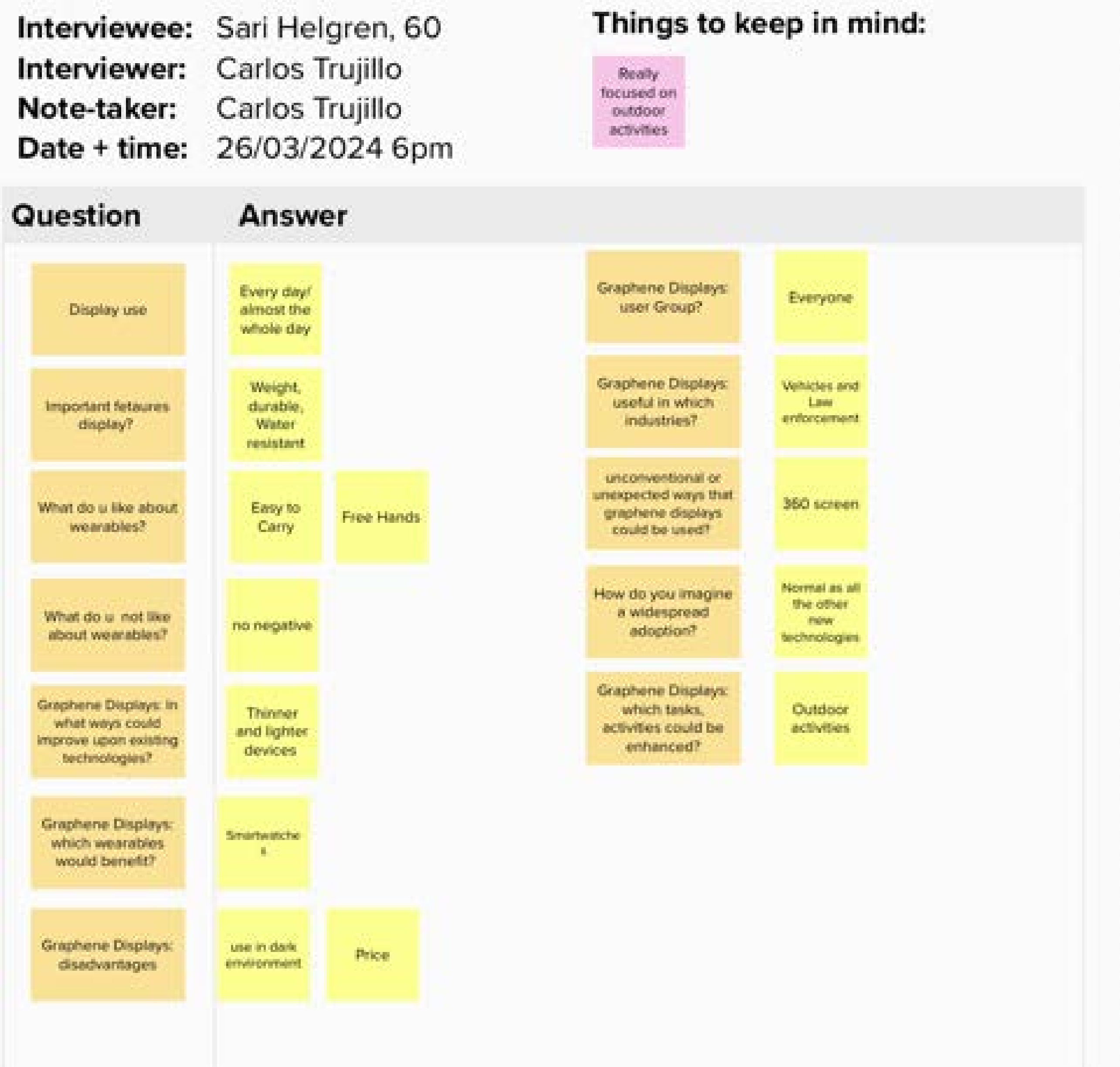

Interviewee: Lara, 24
Interviewer: David
Note-taker: David
Date + time: 26.03.2024, 6 pm
Things to keep in mind:
Dont knows Graphene
Spends a lot of time with displays
Computer scientist (B.Sc)
Question
Answer
Display use
Smartphone screen, Desktop screen, TV screen, Smartwatch screen, Tablet screen, Washing machine display screen, Bank card reader, ATM, Ticket vending machine, Self-pay checkout
Important fetaures display?
Intuitive design
Fast repons time
What do u like about wearables?
Always accessible
Quick information input
Cloud-based: access data from anywhere
What do u not like about wearables?
Always accessible
Can track information
Graphene Displays: in what ways could improve upon existing technologies?
More senitive Touchscreens
Graphene Displays: which tasks, activities could be enhanced?
Gaming on the smartphone will improve even further, as the heat generated can be better dissipated, and with a sensitive touchscreen, the performance in ga-mes is better
Graphene Displays: which wearables would benefit?
All for example: Smartwatches, as the small displays often do not react sensitively enough, making navigation within them a challenge. Ac-tually, this applies to all displays of similar size
Question
Answer
Graphene Displays: advantages
Flexebility
Durability
Less energy consuming
Graphene Displays: disadvantages
Price-performance
Graphene Displays: useful in which industries?
Medical field
Construction
Could you think about an use case for wearables or displays which is not existing yet
If desks were no longer traditional desks but instead large displays, it would sig-nificantly increase work efficiency, as both writing and typing would be possible on the same device, as well as eliminating issues with navigating multiple windows. Additionally, there would no longer be a problem if a drink or some-thing similar spills. Furthermore, it would motivate people who have sedentary jobs to work while standing.


Interviewee: Stefan, 53
Interviewer: Niels
Note-taker: Niels
Date + time: 26.03.2024, 7pm
Things to keep in mind:
No in-depth knowledge of graphene
Active as engineer in automobile industry
Question
Answer
display use
Work, Entertainment, Personal Use, Communication
Important fetaures display?
Energy Efficiency
If devices like TV: Should save energy
If devices like car navigation display: Should not be too reflective
What do u like about wearables?
Practicality, Comfort
Good resolution for their size
What do u not like about wearables?
Consume too much energy
Graphene Displays: In what ways could improve upon existing technologies?
Better outdoor devices
Thinner devices
Better usage at daylight
Graphene Displays: which wearables would benefit?
Thinner clocks
Outdoor activity related devices
Graphene Displays: disadvantages
Problem at darkness
Graphene Displays: user Group?
People in working age
Graphene Displays: useful in which industries?
Advertisement industry
Military
Fashion Industry
unconventional or unexpected ways that graphene displays could be used?
Military Camouflage
How do you imagine a widespread adoption?
Application in the car industry (inner bodies, windows...)
Graphene Displays: which tasks, activities could be enhanced?
Outdoor activities
Could you think about an use case for wearables or displays which is not existing yet
Invisibility clothes


Interviewee: Grit, 54
Interviewer: Niels
Note-taker: Niels
Date + time: 26.03.2024, 7pm
Things to keep in mind:
No prior knowledge of graphene
Educational background in administratio n
Works in Internal Administration Services
Question
Answer
display use
All day, for all kinds of uses -> very important
Work, Entertainment, Personal organisation
Important fetaures display?
Good visibility
What do u like about wearables?
Practicality
What do u not like about wearables?
Need too much energy
Graphene Displays: In what ways could improve upon existing technologies?
Electricity consumption
Visibility
Graphene Displays: which wearables would benefit?
E-Biking equipment
Advertising boards
Smartwatche s
Graphene Displays: disadvantages
Price
Graphene Displays: user Group?
Young people
Graphene Displays: useful in which industries?
Phone industry
(Glasses industry)
unconventional or unexpected ways that graphene displays could be used?
How do you imagine a widespread adoption?
More flexible (bendy) and smaller screens
Positively
Graphene Displays: which tasks, activities could be enhanced?
Outdoor activities
Work



Interviewee: Nita Samula, 30
Interviewer: Carlos Trujillo
Note-taker: Carlos Trujillo
Date + time: 26/03/2024 5pm
Things to keep in mind:
had no previous knowledge of this tchnology
A bit skeptical
Question
Answer
display use
every day/ about 11hr
Work, phone, tv, navigation, free time
Important fetaures display?
eye care, control reflection
What do u like about wearables?
I do not remember i carry it on
confortable
What do u not like about wearables?
Battery Life (Galaxy watch 5)
Thickness of watch (no so feminine)
Graphene Displays: In what ways could improve upon existing technologies?
Thinner and lighter devices
Battery life
Graphene Displays: which wearables would benefit?
Smartwatche s
Graphene Displays: disadvantages
use in dark environment
light source is not always stable
Graphene Displays: user Group?
Office worker
Graphene Displays: useful in which industries?
Just improving in all of the current industries
unconventional or unexpected ways that graphene displays could be used?
To Make "smart walls" that you can change the color
How do you imagine a widespread adoption?
A bit slow just like nowadays with foldable phones
Graphene Displays: which tasks, activities could be enhanced?
Outdoor activities in general

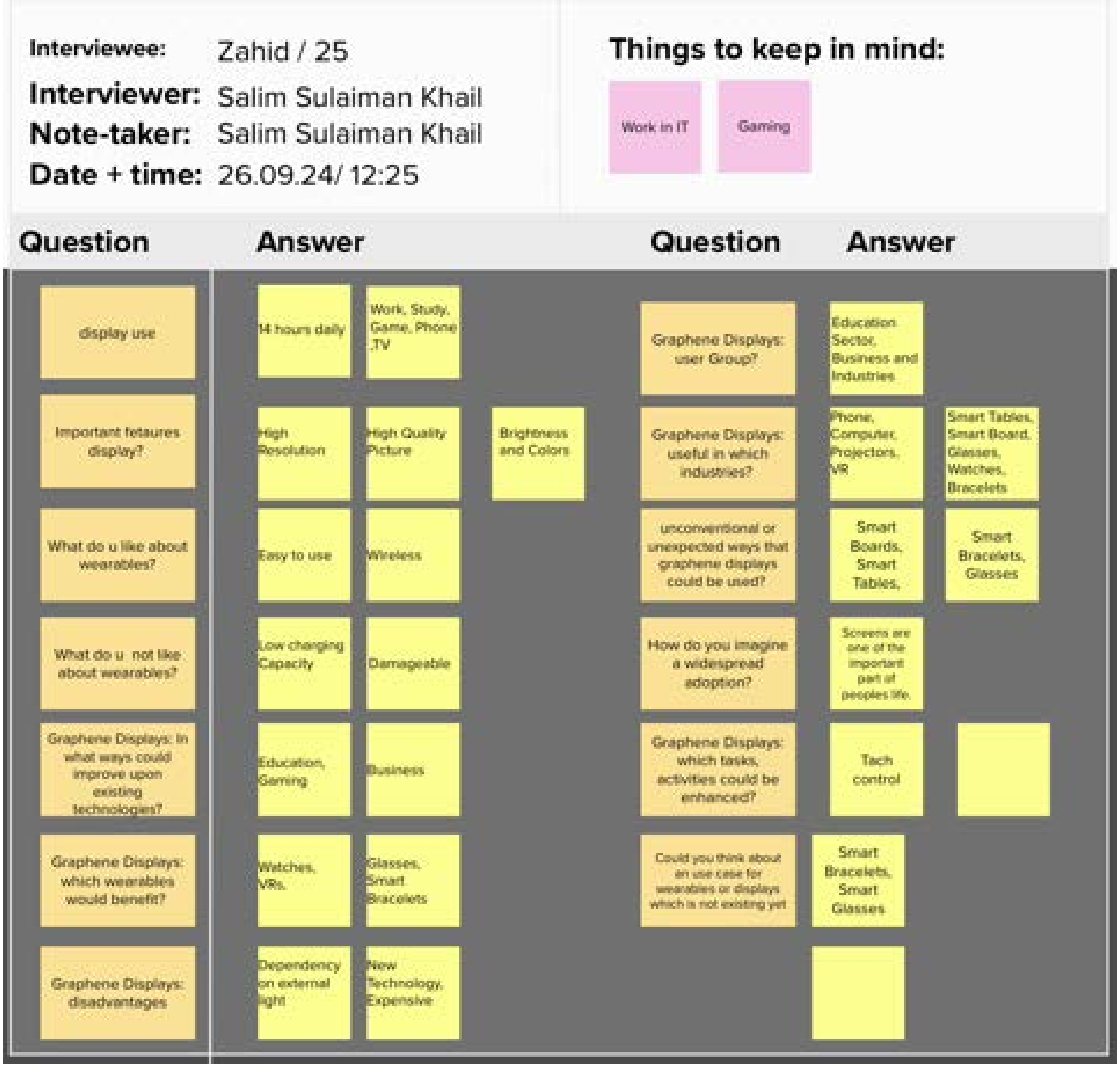


Interviewee: Sari Helgren, 60
Interviewer: Carlos Trujillo
Note-taker: Carlos Trujillo
Date + time: 26/03/2024 6pm

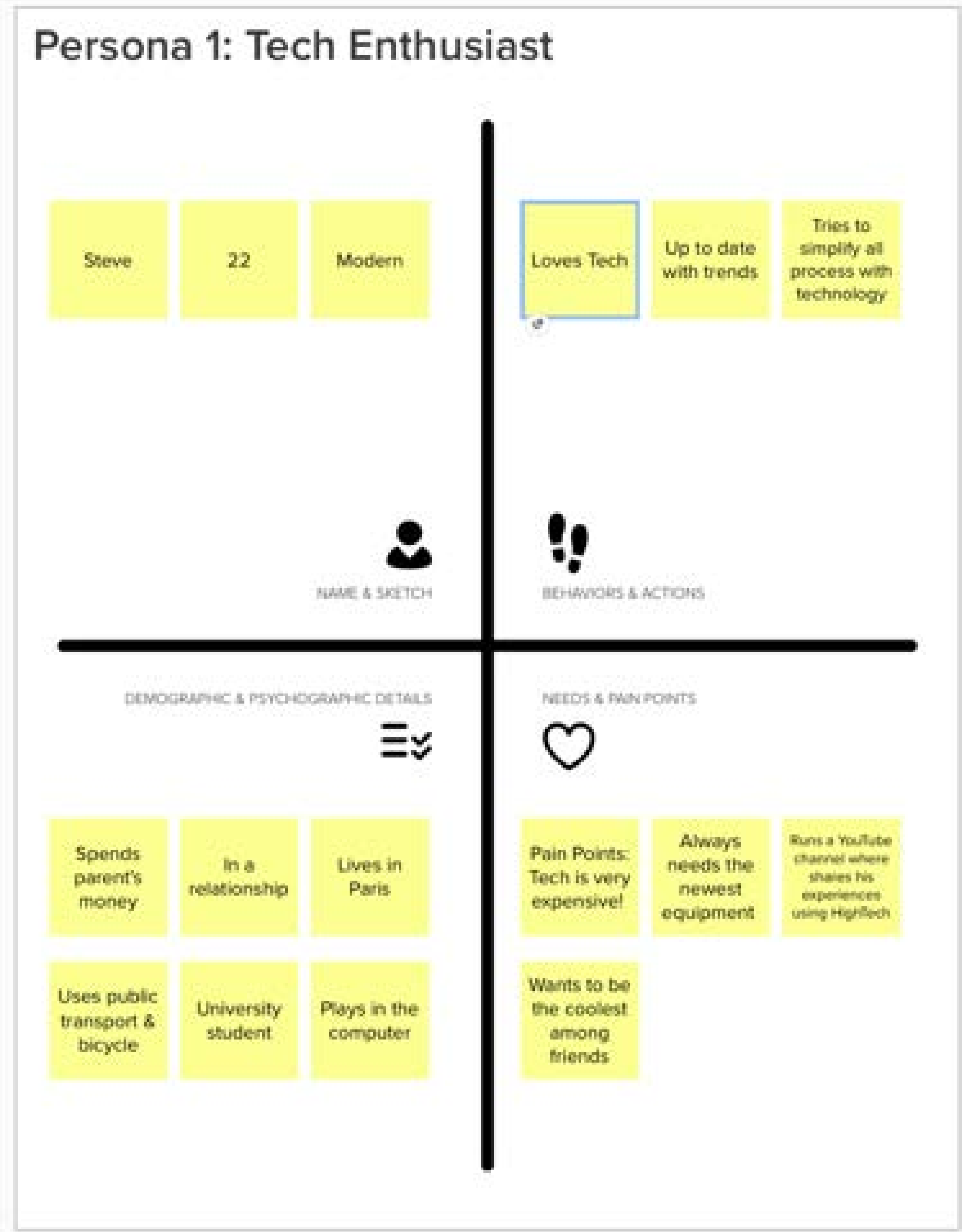
Things to keep in mind:
Really focused on outdoor activities

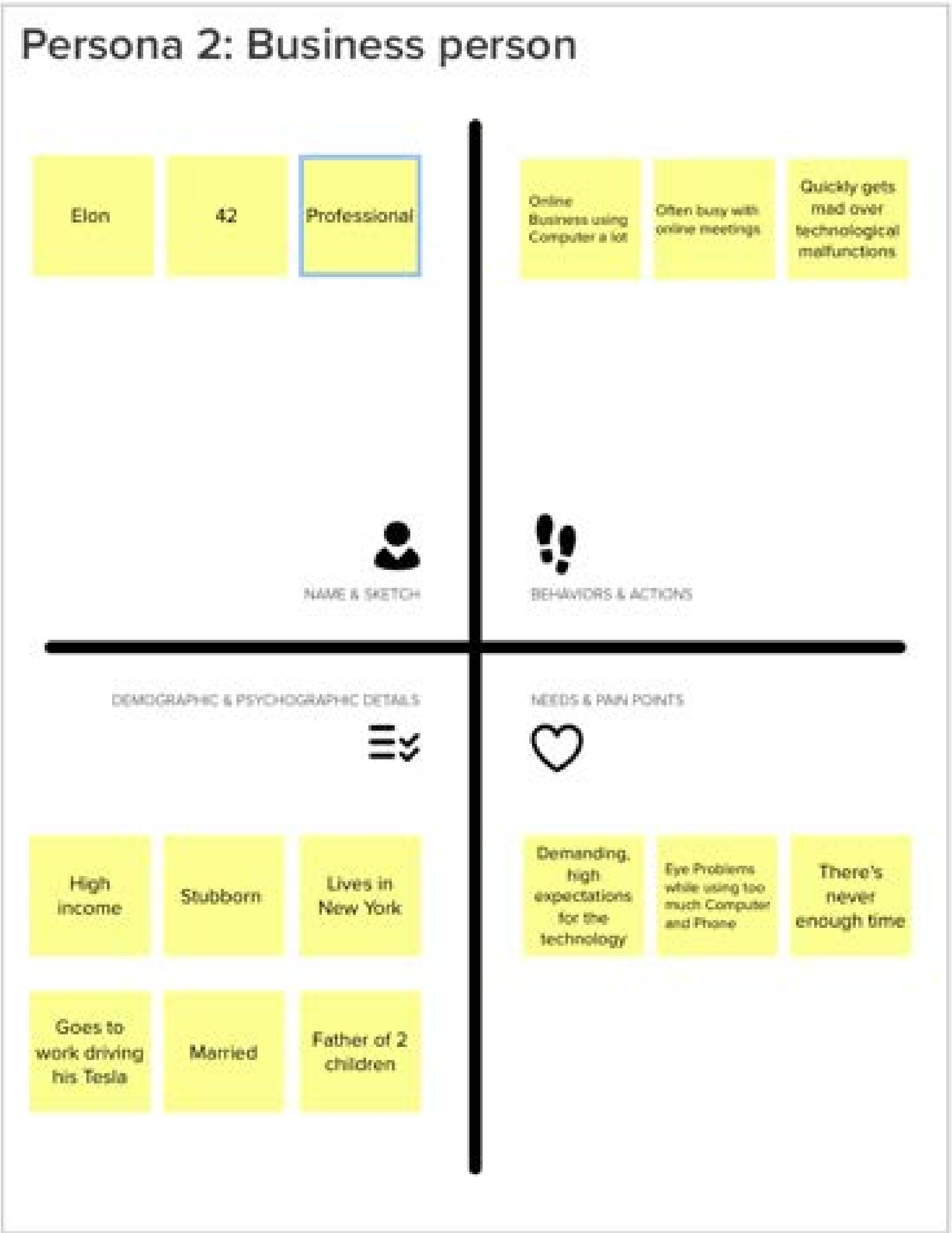
Question	Answer	
Display use	Every day/ almost the whole day	
Important fetaures display?	Weight, durable, Water resistant	
What do u like about wearables?	Easy to Carry	Free Hands
What do u not like about wearables?	no negative	
Graphene Displays: In what ways could improve upon existing technologies?	Thinner and lighter devices	
Graphene Displays: which wearables would benefit?	Smartwatches	
Graphene Displays: disadvantages	use in dark environment	Price
Graphene Displays: user Group?	Everyone	
Graphene Displays: useful in which industries?	Vehicles and Law enforcement	
unconventional or unexpected ways that graphene displays could be used?	360 screen	
How do you imagine a widespread adoption?	Normal as all the other new technologies	
Graphene Displays: which tasks, activities could be enhanced?	Outdoor activities	

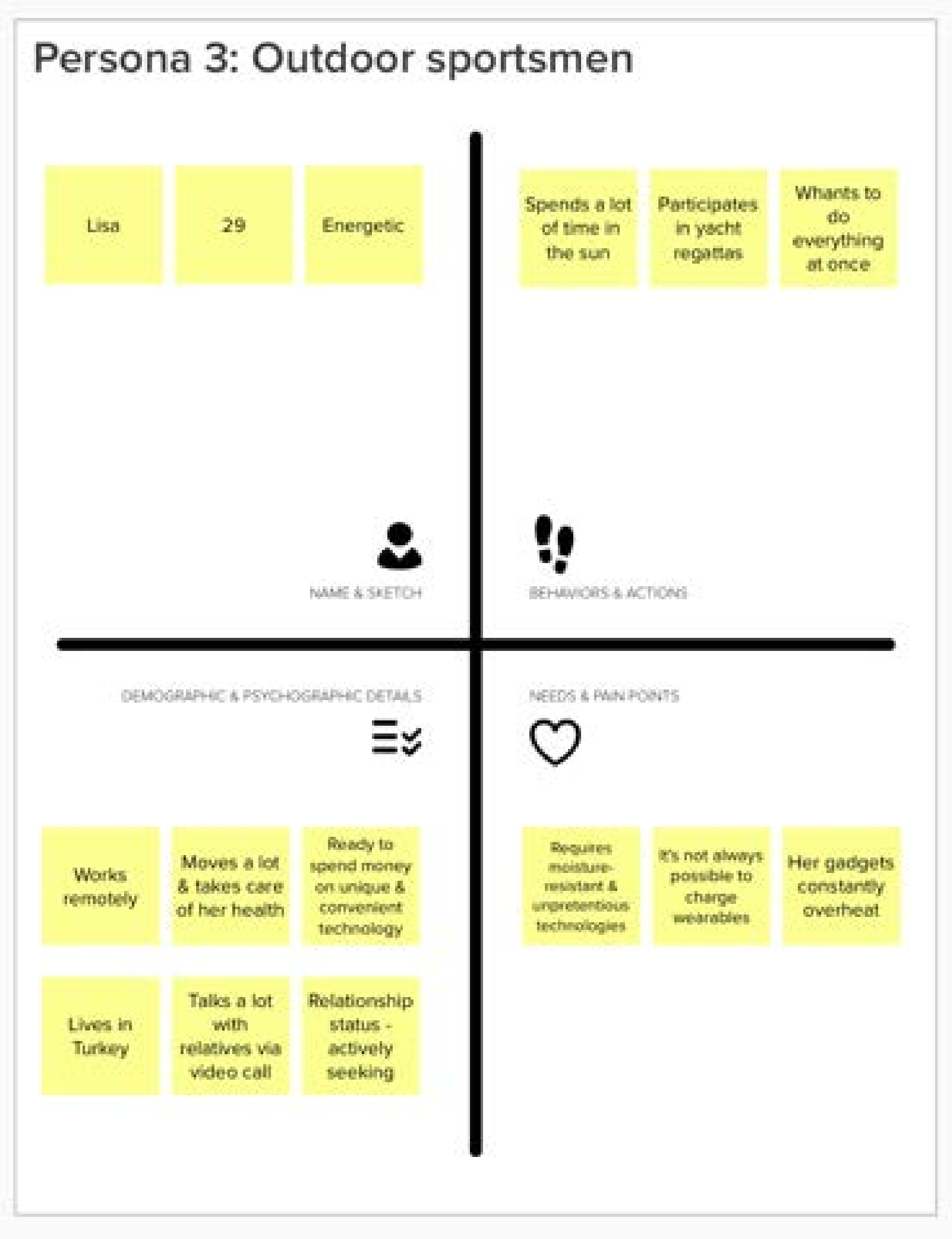

Interviewee:
Interviewer: Daniil Ostrogradskii
Note-taker: Daniil Ostrogrdsakii
Date + time: 25.09.24/ 14:00
Things to keep in mind:
IT specialist
Trader
Question
Answer
Question
Answer
display use
Work (a laptop, tablet, and phone)
Everyday live (like screens in the car)
Important fetaures display?
image quality
now because their high quality has become a given
What do u like about wearables?
it's convenient and interesting for some people
What do u not like about wearables?
What's the point of all this when all functions fit into a mobile phone?
Graphene Displays: In what ways could improve upon existing technologies?
esistant to overheating from sunlight
it's more durable than glass in LED displays
Graphene Displays: which wearables would benefit?
energy efficiency & thickness are advantages
Graphene Displays: disadvantages
Graphene Displays: user Group?
Marine Navigation, Aviation Industry & Automotive Industry
Graphene Displays: useful in which industries?
Marine Navigation, Aviation Industry & Automotive Industry
unconventional or unexpected ways that graphene displays could be used?
you could think about space
How do you imagine a widespread adoption?
Graphene Displays: which tasks, activities could be enhanced?
Add a sensor
Could you think about an use case for wearables or displays which is not existing yet
Painted walls

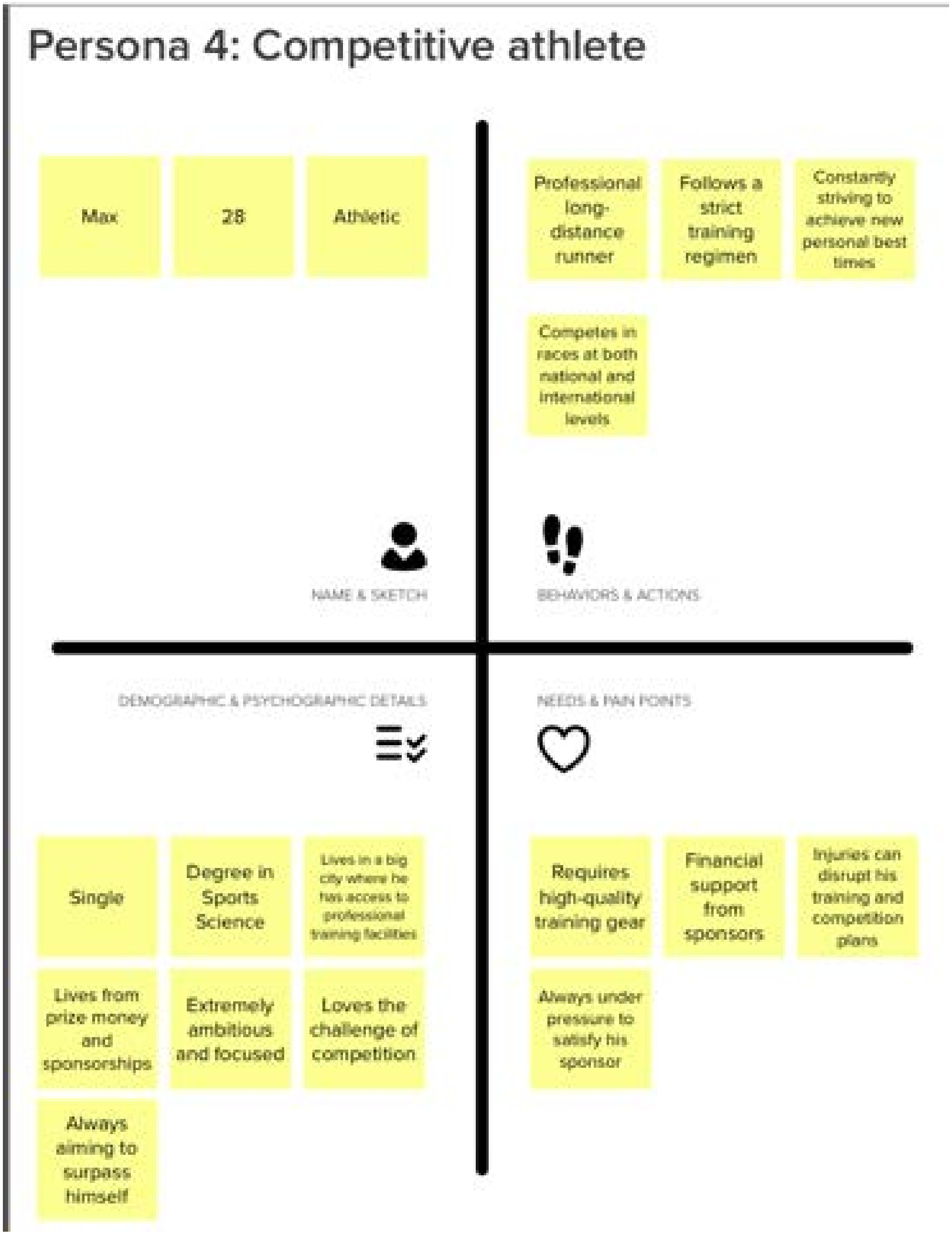

Interviewee: Zahid / 25
Interviewer: Salim Sulaiman Khail
Note-taker: Salim Sulaiman Khail
Date + time: 26.09.24/ 12:25
Things to keep in mind:
Work in IT
Gaming
Question
Answer
Question
Answer
display use
14 hours daily
Work, Study, Game, Phone ,TV
Important fetaures display?
High Resolution
High Quality Picture
Brightness and Colors
What do u like about wearables?
Easy to use
Wireless
What do u not like about wearables?
Low charging Capacity
Damageable
Graphene Displays: In what ways could improve upon existing technologies?
Education, Gaming
Business
Graphene Displays: which wearables would benefit?
Watches, VRs,
Glasses, Smart Bracelets
Graphene Displays: disadvantages
Dependency on external light
New Technology, Expensive
Graphene Displays: user Group?
Education Sector, Business and Industries
Graphene Displays: useful in which industries?
Phone, Computer, Projectors, VR
Smart Tables, Smart Board, Glasses, Watches, Bracelets
unconventional or unexpected ways that graphene displays could be used?
Smart Boards, Smart Tables,
Smart Bracelets, Glasses
How do you imagine a widespread adoption?
Screens are one of the important part of peoples life.
Graphene Displays: which tasks, activities could be enhanced?
Tech control
Could you think about an use case for wearables or displays which is not existing yet
Smart Bracelets, Smart Glasses

Appendix 3: Personas




Persona 2: Business person
Elon
42
Professional
Online Business using Computer a lot
Often busy with online meetings
Quickly gets mad over technological malfunctions
NAME & SKETCH
BEHAVIORS & ACTIONS
DEMOGRAPHIC & PSYCHOGRAPHIC DETAILS
NEEDS & PAIN POINTS
High income
Stubborn
Lives in New York
Demanding, high expectations for the technology
Eye Problems while using too much Computer and Phone
There's never enough time
Goes to work driving his Tesla
Married
Father of 2 children


Persona 3: Outdoor sportsmen
Lisa
29
Energetic
Spends a lot of time in the sun
Participates in yacht regattas
Whants to do everything at once
NAME & SKETCH
BEHAVIORS & ACTIONS
DEMOGRAPHIC & PSYCHOGRAPHIC DETAILS
NEEDS & PAIN POINTS
Works remotely
Moves a lot & takes care of her health
Ready to spend money on unique & convenient technology
Requires moisture-resistant & unpretentious technologies
It's not always possible to charge wearables
Her gadgets constantly overheat
Lives in Turkey
Talks a lot with relatives via video call
Relationship status - actively seeking


Persona 4: Competitive athlete
Max
28
Athletic
NAME & SKETCH
Professional long-distance runner
Follows a strict training regimen
Constantly striving to achieve new personal best times
Competes in races at both national and international levels
BEHAVIORS & ACTIONS
DEMOGRAPHIC & PSYCHOGRAPHIC DETAILS
Single
Degree in Sports Science
Lives in a big city where he has access to professional training facilities
Lives from prize money and sponsorships
Extremely ambitious and focused
Loves the challenge of competition
Always aiming to surpass himself
NEEDS & PAIN POINTS
Requires high-quality training gear
Financial support from sponsors
Injuries can disrupt his training and competition plans
Always under pressure to satisfy his sponsor

Appendix 4: Results Testing of the Prototype