Electric Vehicle Additive Manufacturing (EVAM) Interior Design

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Electric Vehicle Additive Manufacturing (EVAM) Interior Design

At the forefront of design and innovation, Singapore University of Technology and Design (SUTD) is manufacturing components for their electric vehicle project, known as Electric Vehicle Additive Manufacturing (EVAM). As the name suggests, they employ fabricating methods such as Selective Laser Melting (SLM), Fused Deposition Modeling (FDM), Multi Jet Fusion (MJF) and Stereolithography (SLA).

As part of our 60.003 Product Design Studio, we have been tasked with designing the interior of the vehicle.

Background

Firstly, we would need to understand the current users' needs for the vehicle. As the vehicle is still in its testing stage, the users are mainly the engineering staff and students. To better understand future user needs, we conducted user (engineer) interviews, the AEIOU Observation Framework, and a Value Proposition.

User Interview

When we first viewed the vehicle, we prepared some questions for Senior Specialist Mr Liew Zhen Hui, to understand what they required us to design. This was followed up with questions to Mr Matthew Dylan Wong Jian Xiong for his vision and the concept for the car. These questions and answers can be found in *Appendix A*. In summary, the concept of the car is to demonstrate additive manufacturing capabilities in the manufacturing of a race car. It should be designed to look 'dynamic, aggressive and sporty', with the necessary functions required for it to be driven in a race.

AEIOU Observation Framework

Next, we explored the AEIOU[1] Observation Framework of the EVAM. A mind map of our AEIOU can be seen in *Appendix B*.

Value Proposition

Lastly, based on our User Interviews and AEIOU, a value proposition was planned to categorise possible needs into demands and wishes. The demands are what we can fully design within our timeline and are of highest priority. They are as follows:

1. **Dashboard.** In order to enhance user experience, the users must be able to see all necessary information about the vehicle at all times.

2. **Steering wheel.** To control more car settings for improved performance, the driver must be able to reach buttons, while still firmly holding the wheel.

3. **Mobility.** The users should be able to get into and out of the car with ease, regardless of their height or size.

On the other hand, wishes are additional features that we could provide. They can be found in *Appendix C*. A storyboard was drawn to better visualise the value proposition, found in *Appendix D*.

[1] Acronym for Activities, Environment, Objects, Interactions and Users

Design Brief

Problem Statement
Through our design process of empathise, define and ideate, we decided to **design a means to enhance user experience of the interior of the vehicle with added lightness.**

Design Specification
To accomplish our problem statement efficiently, we merged certain design wishes with the demands to create three cohesive design goals:

1. To design a **dashboard**, for both driver and passenger, that displays all necessary information at the appropriate times, depending on its driving modes. These modes include static, demonstration and race mode. The telemetry must, at least, include Speed, Temperature of battery and motor, Battery Charge, and must be intuitive.

2. To design a **steering wheel**, with other controls besides steering input, for customizability of car functions. The design should be ergonomic so that the wheel is comfortable to hold and grip for prolonged periods, and also to reflect the SUTD identity onto the steering wheel design. Additionally, controls should be easily reachable by fingers, even when the driver is steering the car.

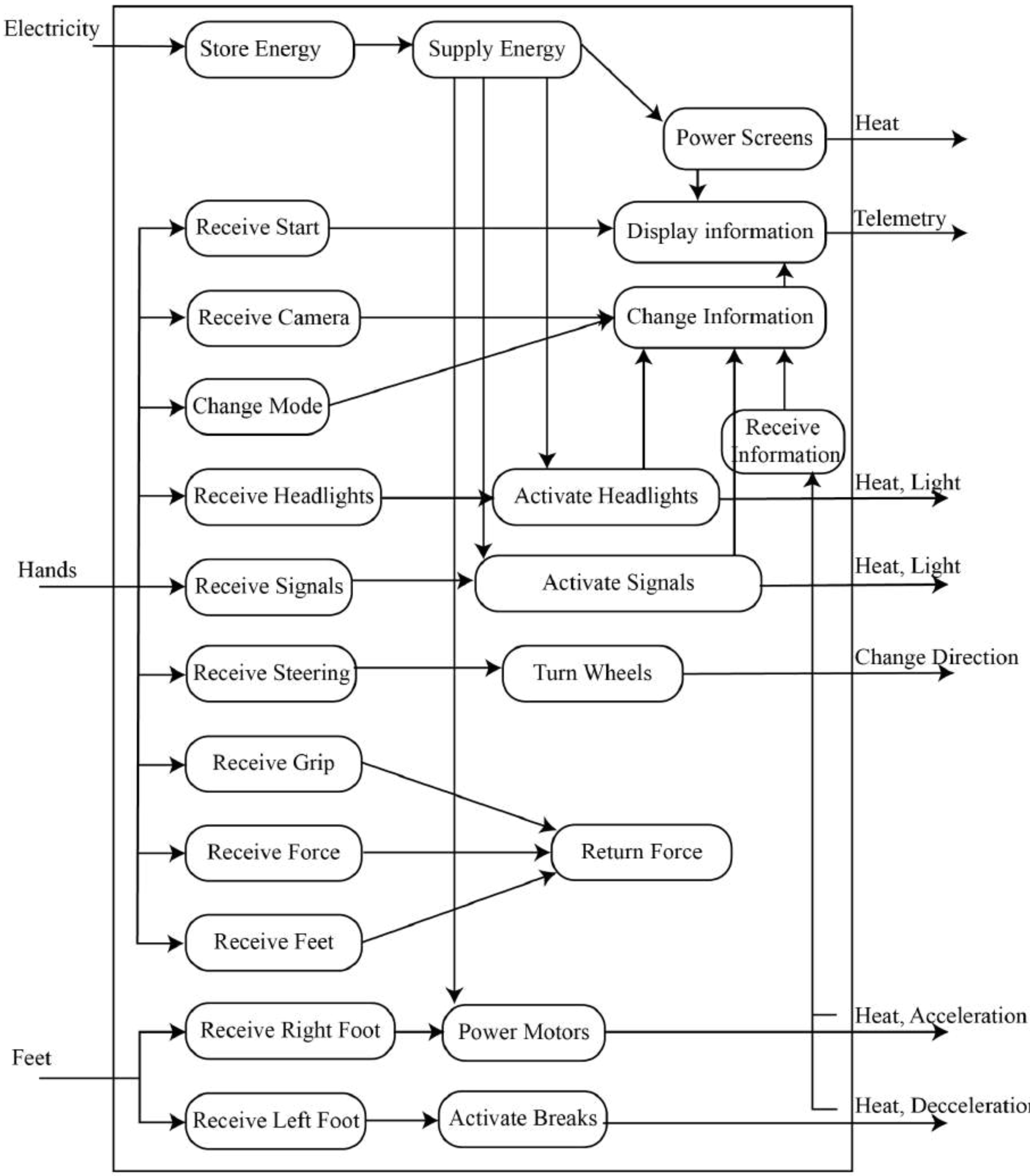
3. To design a way for the trained driver and any able-bodied passenger to **enter and exit the vehicle with ease**, regardless of their heights or sizes.

Concept Development
This means that although the final product is the interior of the goal, there is a need to design three separate components that can still complement each other.

Functional Analysis
Hence, in our concept development, there is a need to perform a functional analysis for the three components. Two types of analysis are the system and process perspectives, with the former shown in *Figure 1*, and the latter in *Appendix E.*

Figure 1

Functional Analysis System Perspective of Dashboard, Steering Wheel, Ingress/Egress

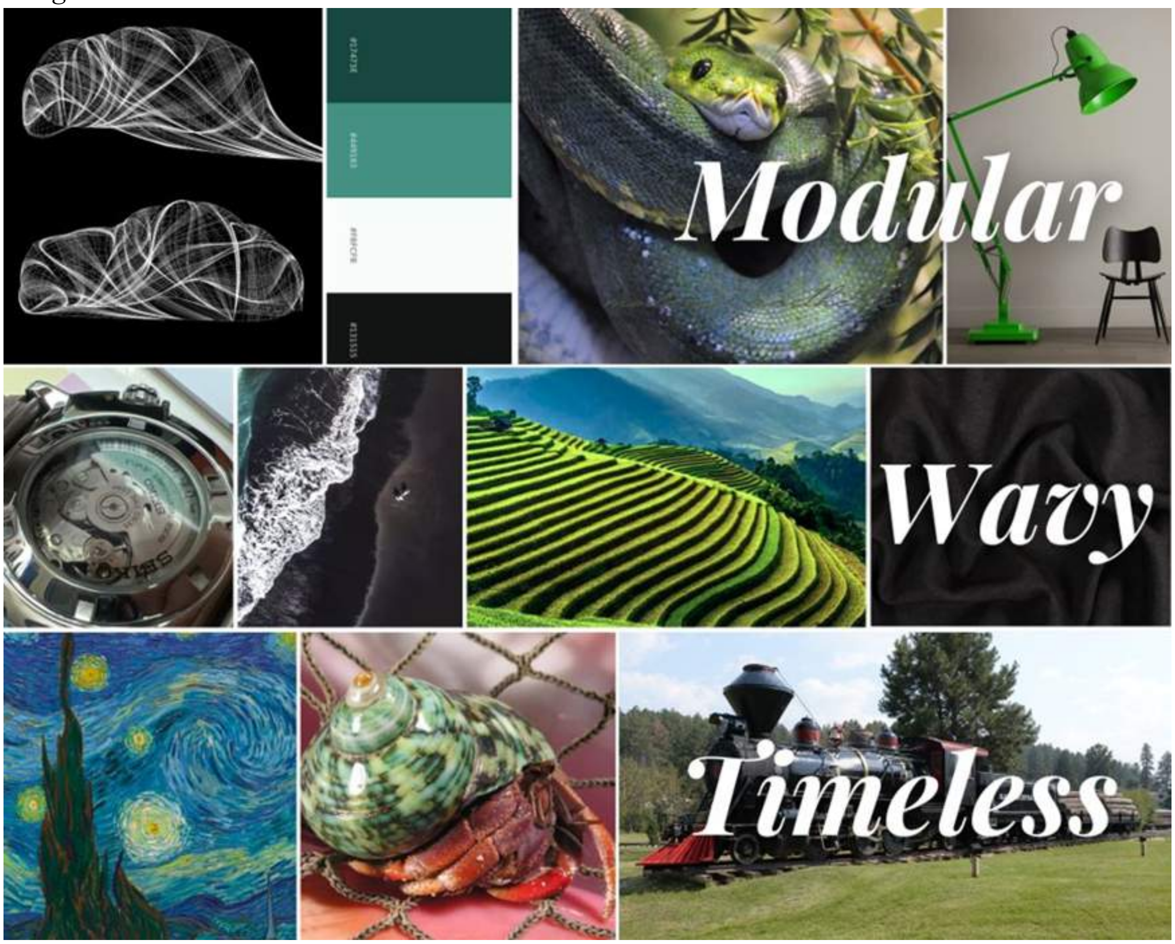


Mood Board

For the design of each component to complement each other, the designs should be inspired by a common mood board, as seen in *Figure 2*.

Figure 2

Design Mood Board



Additionally, a mood board was designed by DALL-E[2]. We wanted to use an AI-generated mood board for inspiration. However, it did not align with our vision so we did not use it. The generated mood board can be found in *Appendix F*.

Concept Generation

Using functional analysis, a morphological chart can be created to aid in concept generation, as seen in *Table 1*. However, due to the complexity of the vehicle, only functions related to these three components will be used.

[2] DALL-E is an Artificial Intelligence System that generates images for text input, created by OpenAI. (Johnson, 2021)

Table 1
Morphological Chart Concept Generation

Function	Solution Principles			
Display Information	LCD Screens	Tablet Device	Vacuum Fluorescent Displays	E-paper
Change Information	Raspberry Pi	Libre Computer	Orange Pi	Asus Tinker Board
Receive Start	Button	Keys	Rocker Switch	Knob
Receive Camera	Finger Pedal	Button	Toggle Switch	Proximity Sensor
Change Mode	Knob	Scroll	Engine Order Telegraph	Touch Panel
Receive Headlights	Button	Switch	Light Sensor	Clock
Receive Signals	Lever	Button	Finger Pedal	-
Receive Steering	Steering Wheel	Joystick	-	-
Receive Grip	Handles	Rubber Pads	Grooved Pads	-
Receive Force	Steps	Leg Rests	-	-
Receive Right Foot	Heel Rests	-	-	-
Receive Left Foot	Heel Rests	-	-	-

We selected and combined these functions to form our concepts. Since we have three design goals (dashboard, steering, getting in/out), a total of nine concepts is needed. The functions for the concepts are highlighted in *Table 1*, using the legend in *Table 2*.

Table 2

Legend for Function Selection for Concept Generation in Morphological Chart

	Concept 1	Concept 2	Concept 3
Dashboard	Red	Orange	Yellow
Steering Wheel	Green	Cyan	Blue
Getting in/out	Dark Blue	Purple	Pink

Concept Selection

These concepts were then put through a selection criteria, seen in *Appendix G*, and rated among team members. The ratings are on a scale from 1 to 5, with 5 being the most ideal. With four criteria being looked at, the score for a component ranges from 1 to 20. This is summarised in Table 3. With six group members, the total score for a component will range from 6 to 120. The highest scores would then undergo the design process in the next step.

Table 3

Criteria and Rankings of EVAM Component Concepts

Team Member	**Dashboard**			**Steering**			**Getting in/out**		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Ethan	18	16	9	5	17	19	17	5	8
Caitlin	20	13	4	11	15	7	10	8	11
Tian Li	17	11	5	14	16	14	11	12	19
Wei Ming	18	15	7	6	15	11	13	20	16
Aditya	17	12	10	15	19	17	15	14	5
Yu Jie	19	13	4	5	18	7	10	8	11
Total	**109**	80	39	56	**100**	75	**76**	67	70

Note: The selected concepts have their **'Total' boxes** highlighted in their respective colour codes.

Design Process

Once the concepts were selected, we began the design process. This process consists of ideation, iterations and further development.

Dashboard

The dashboard could be split into two main components: user interface and screens. Each component would go through ideation, iteration, and development as well.

Screens

Initially, there were only plans to develop a front dashboard. However, taking inspiration from co-pilots in fighter aircraft, a passenger dashboard was deemed necessary to assist the driver during races. Hence, a dashboard was required for driver and passenger, with each displaying different information. This information can be categorised into two categories: telemetry and camera views, which will be further elaborated on under 'User Interface'.

The front dashboard only had a 360 by 140 millimetre space while the rear dashboard had a 200 by 200 millimetre space. At the rear, there was also more space below the central support bar, but that area had to be clear for the passenger to enter and exit the vehicle. Furthermore, only the upper section of the dashboard space could be used to narrow down the driver's field of view, especially when he needs to focus on the track. Hence, we decided to use two 3.5-inch LCDs and one 7-inch LCD at the front, and five 7-inch LCDs at the back.

At the front, the dashboard holder was designed more aesthetically than functionally. Taking inspiration from wind tunnel flow visualisation (Hall, 2021), and our mood board, wavy lines were etched into the dashboard, with incrementing depths of two millimetres. These lines would continue towards the interior side panelling of the vehicle. The front screen holder is also tilted five degrees upwards to account for the elevated height of the perspective of the driver. Similarly, the screens are tilted five degrees inwards to face the driver. An isometric view of this design can be found in *Appendix H Figure H1*.

To account for ease of manufacturing and theme of additive manufacturing, the screen holder had to be broken up to fit the 3D Printer bed size. In the end, the dashboard was divided into two, with excess material trimmed for added lightness. A screen cover was added to seal the screen in the dashboard, as well as to hide any exposed electronics. Its assembly can be found in *Appendix H Figure H2*.

At the back, we decided to implement adjustable screen holders. This is because unlike the user of the front seat, who is usually the same trained driver, the user of the back seat can be any able-bodied person, regardless of his/her height. This means that different passengers may have different perspectives, hence the screen tilt must be different. Furthermore, as we chose to utilise the space below the central support beam for more screens as well, the screens should be able to tuck away so that it is easier for the user to get in and out of the vehicle.

We based the design of these adjustable screens on monitor stands. This usually involves arms with joints or hinges that can be tightened or loosened. We simulated this design by 3D printing arms, which were connected using M10 hex bolts and wing nuts. This means that the joints could be tightened and loosened using the wing nuts. Similarly, the clamps that held the screen holders to the central support beam of the chassis could be tightened and loosened to provide a cylindrical joint for further adjustment by the passenger.

While sharing with the engineering team about our design plans, they told us that testers often hold on to the central support beam to steady themselves to counter the G-forces during acceleration and deceleration. This means that the initial plan for placement of screens would block the support beam. As we did not want to eliminate this, we decided to implement grips into the clamps. This would not only allow passengers to support themselves during high lateral forces, but also for ease in adjusting the clamp's tilt. The final design can be found in *Appendix H Figure H3*, with its exploded assembly in *Figure H4*.

The parts list for these dashboards can be found in *Appendix H Table H1* while the fasteners used are in *Table H2*.

User Interface

Due to the different modes, two different interfaces must be designed: Race and Demonstration. The codes for this (including all the connections of the user interfaces to the various components of the steering wheel) can be found at this repository: https://github.com/CaitlinChiang/EV-Screens

Race. Inspiration was taken from F1 cars because the car concepts are similar: open wheel racing. Specifically, we took inspiration from the Aston Martin Aramco Cognizant F1 Team, which displayed their wheel layout and the telemetry for each. The race driver would require telemetry such as speed, tyre/brake/motor/battery temperatures, battery charge, race deltas, lap timings, brake bias and migration, race positions, laps done and drinking water remaining. All this data is colour coded, with orange being too hot or almost depleted, blue being too cold or half used, and white being optimum temperature or full. The race-standard colours purple, green and white are used for race timings as well. This is so that the driver can instantaneously tell if their brakes/tyres/motor/battery is too warm or cold.

As for the camera views, they were placed at the usual positions that the rear view mirrors would be in an ordinary car. This is so that it is more intuitive.

We tested the designs by printing out the interface onto paper the size of the actual screens. We then pasted them on the vehicle and tested how readable the interface is, as seen in *Appendix I Figure I1*. Initially, the fonts were too small so we increased the sizes. Additionally, we decided to remove the front facing camera as the speedometer was too low and was blocked by the steering wheel, since the speed is of higher importance than the front facing camera.

The final interface can be found in *Appendix I Figure I2*.

Demonstration. The first iteration was a simple layout only including the absolute essential telemetry given to us during the interview, but we realised that a lot of space is being put to waste, and that users actually don't know that seeing certain data is convenient until we already present it to them. With that, we iterated another design, this time adding telemetry that we think is necessary based on research. The telemetry here is the same as the ones used in race mode, except designed and presented differently.

On the third iteration, we focused more on the experience of the interfaces and making sure that they were pleasing to look at. We started to use colours to depict certain values (e.g. using red when a certain part is overheating), and placed telemetry in a way that made more sense to the user, allowing it to be more intuitive as well. We also added camera views here, the same as race mode, to the positions as to where rear view mirrors would normally be.

The final iteration included creating similar but different interfaces such that the user can switch to them at appropriate times, and therefore be able to see certain telemetry at specific situations at a larger view. We kept refining them such that there is a flow to which gets shown at various button presses.

The final interface can be found in *Appendix I Figure I3*.

Steering Wheel

The design process for our steering wheel began with a collaborative effort among team members, with each contributing their best ideas to create an initial concept. We refined the design through trial and error, experimenting with specifications like size and button placement to achieve the desired functionality and aesthetics which can be seen in *Appendix J Figure J1* and *Figure J2*.

However, we realised that we had overlooked important factors such as budget and manufacturing limitations, which led us to revisit the design and incorporate these factors. The iterations of steering wheel designs can be seen in *Appendix J Figure J3*.

To achieve a practical and cost-effective design, we began with a robust and lightweight aluminium chassis that provided structural support and stability. We carefully designed the chassis with cutouts for buttons and screws, ensuring a precise and secure fit for all components as seen in *Appendix J Figure J4* and *Figure J5*. Another point to note is that, when we designed the steering wheel, we made sure to position the buttons in a way that would allow for easy access by the thumb for an average adult male. The button placements, as well as their functions can be seen in *Appendix J Figure J6* and *Table J1* respectively.

The handles, buttons, and button shell were 3D printed using advanced additive manufacturing techniques, allowing for a high degree of customisation and precision. This reduced production costs and lead times while also ensuring optimal functionality and aesthetics. The paddle shifters were designed with simplicity and effectiveness in mind, featuring a micro lever switch to which the paddle attaches. We utilised a magnet instead of a traditional spring to provide haptic feedback, enhancing the tactile experience for the user. The list of fasteners used to assemble the steering wheel can be found in *Appendix J Table J3*.

To cover the wires coming out the back of the steering wheel, we designed and 3D printed a custom casing that also housed the paddle shifters. This provided a clean and professional look while ensuring that the wires were protected from damage and interference.

Overall, our steering wheel design incorporated a range of advanced manufacturing techniques and materials, from the precision-cut aluminium chassis to the 3D printed components and custom casings. Every element was carefully considered and optimised for maximum functionality and user experience, resulting in a high-performance and aesthetically pleasing product as seen in *Appendix J Figure J7*.

Getting In / Out

This particular aspect of the EVAM's experience was rather tricky to enhance. Mainly because of the space constraints of the car's interior, as well as how the car was not initially designed for an easy ingress and egress in mind. Both this obstacle has created a particularly awkward way for the user of the vehicle to get in and out of the car as illustrated in *Figure 3* below.

Here are the steps for the ingress and egress processes:

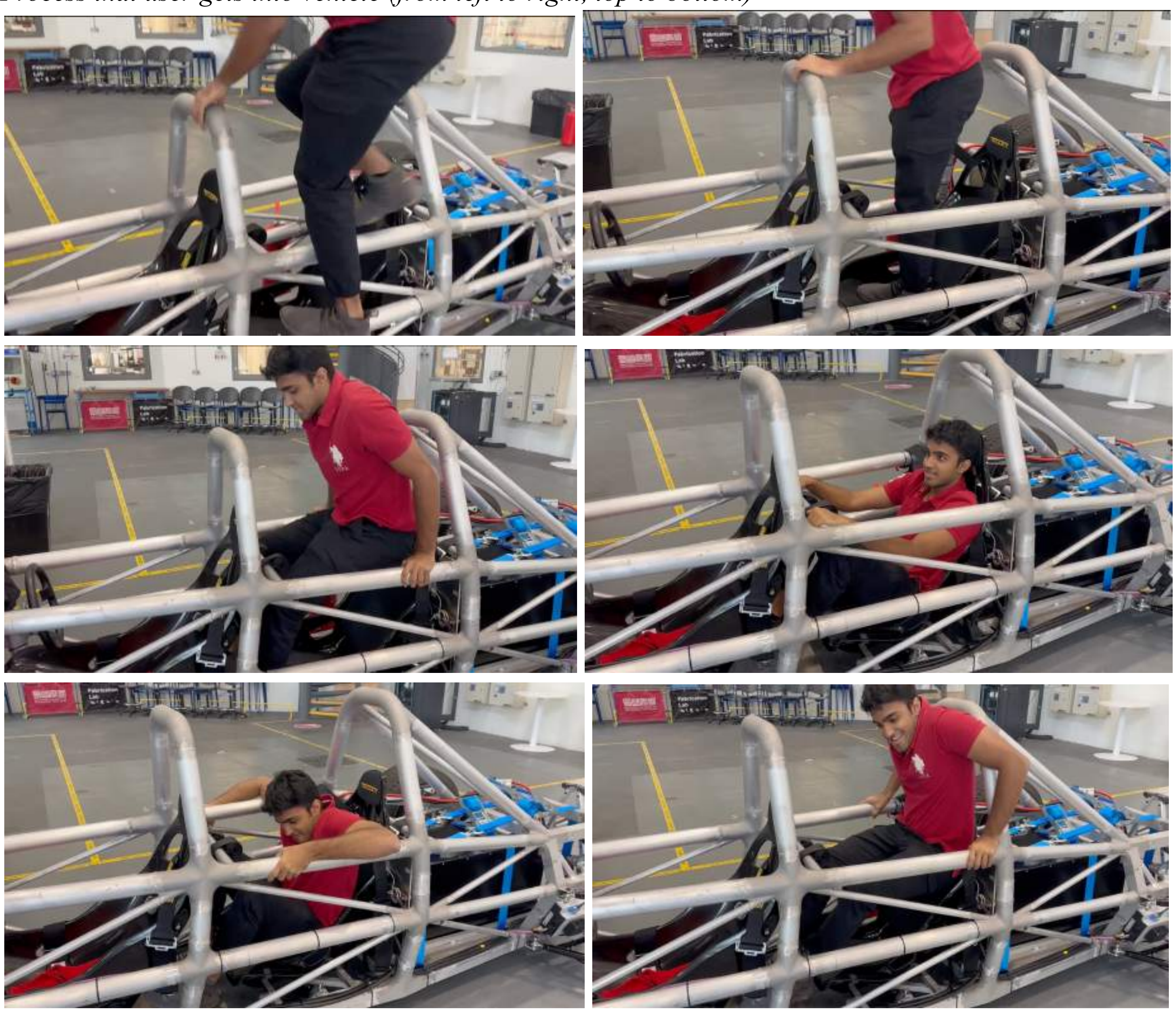
Ingress
(1) Put one foot on the chassis
(2) Put both feet onto the seat
(3) Using the side chassis as support, the user will slowly lower him/herself
(4) User will then successfully get into the car

Egress
(1) Hold on the the side chassis
(2) Push him/herself up
(3) Stand up on the seat
(4) Step one foot onto the chassis
(5) Step the other foot onto the higher chassis bar and eventually get out of the car

First, we will illustrate with pictures how an average person enters the back seat of the vehicle. We have decided to put our main focus on the back seat because we have been informed that the user profile of the front seat will be a fit and athletic racer.

Figure 3

Process that user gets into vehicle (from left to right, top to bottom)



As illustrated in the pictures above, it is extremely uncomfortable and awkward even for a rather fit and athletic person. So imagine if during a showcase of the car, an old person would like to sit in the car. With the current design, it will be very difficult for that to happen.

Before we start going into ideating what a design solution for this would be. We first analyse what are the touchpoints, by hand and foot, of different users when they get in and out of the car. And eventually bringing us to understand in which area of the car is commonly used as support when they enter and exit the car. An illustration of the common touch points is shown in *Appendix K Figure K1*.

Furthermore, we had to understand what are the space constraints we are limited to within the car. To do this, using Fusion 360, we modelled out the space inside the car, allowing us to know the exact measurements of space that we could work with. An illustration of the space constraint is shown in *Appendix K Figure K2*.

After which we explored multiple ideas as seen in *Appendix K Figure K3,* which eventually we realised is not very practical. One of the ideas was to lift the seat up to a certain level that will be easier for users to get into a sitting position first, then using some sort of mechanism to slowly lower the seat down and same for bringing the seat up. But we were soon notified by Mr Liew that we are not able to disassemble the seat, therefore this idea was removed. Another idea was to have panels which are able to flap open as stairs for the user to step into the car in multiple levels, but it was soon realised that these flaps would not be able to support the weight of an adult person.

Soon after, we realised that the most amount of space that is available inside the car, is actually the sides of the seats. Which led us to think of designing a modular side compartment, which serves as an armrest, storage space, as well as steps to ease the ingress and egress of users. It also acts as a space for functional buttons that were not placed on the steering wheel.

Having used Fusion 360 to model out what the side compartment looks like, we ensured that the size of the armrest will be within the size constraint of the interior of the EVAM. *Figure 4* shows the design of the modular side compartment, while *Figure 5* and *Figure 6* show its functionalities.

Figure 4
Designs for easing ingress and egress

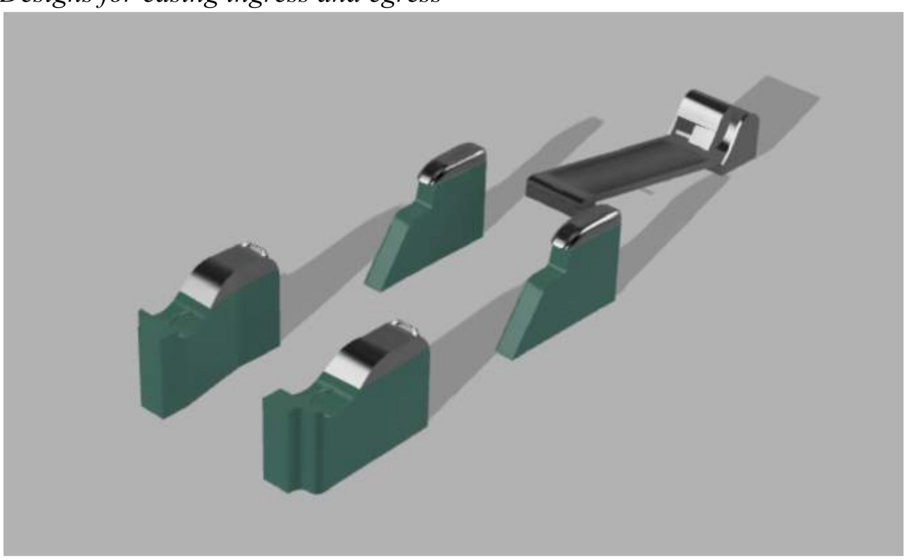


Figure 5

Design for easing ingress

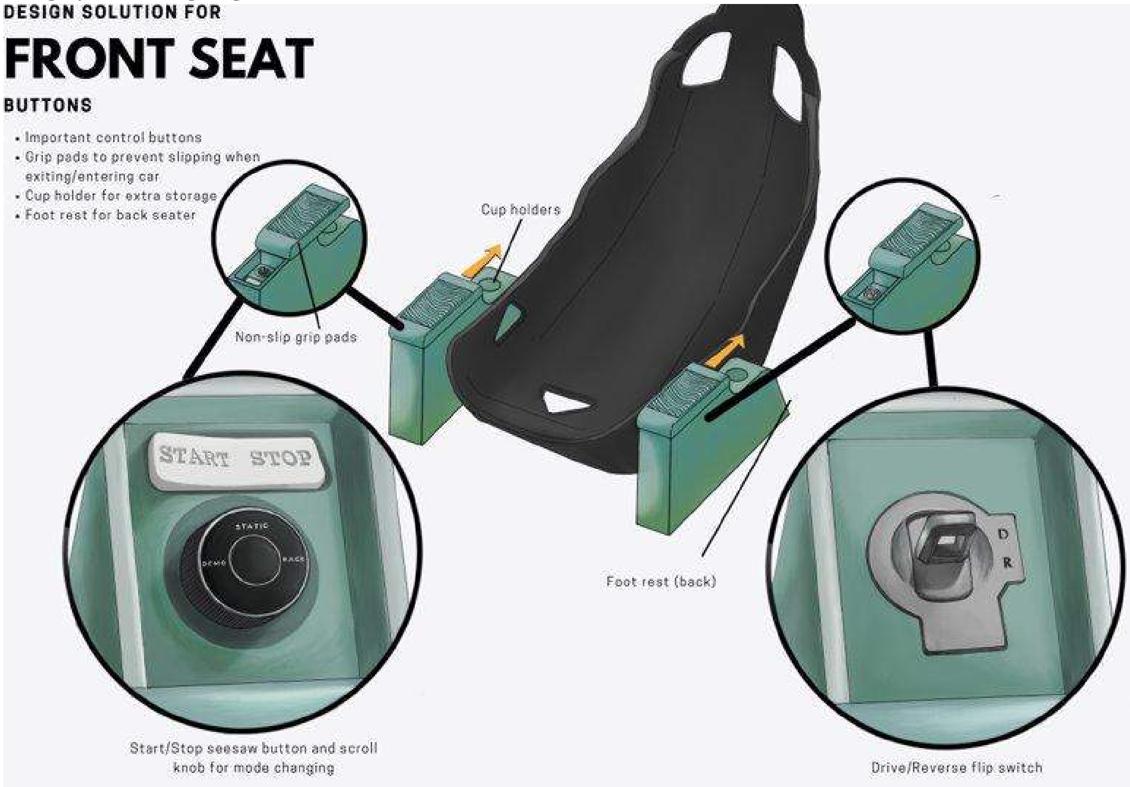


Figure 6

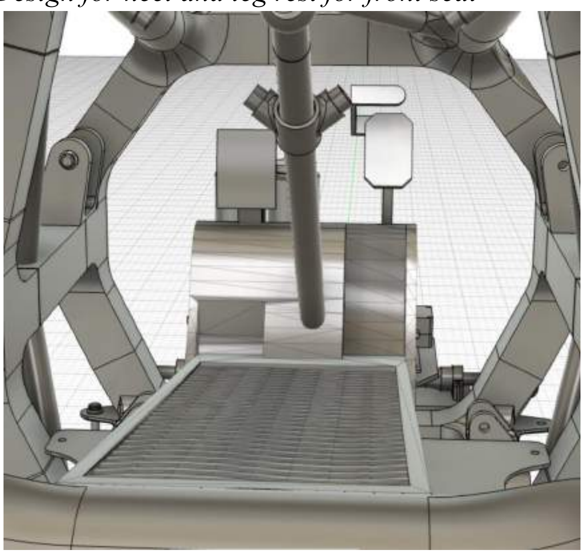
Design for easing egress

Another issue that we found was that there is no place for the driver to rest their heel when operating the vehicle. Using Midjourney, an AI image generator, we asked it to show us designs of a F1 heel rest for inspiration. Generated images can be found at *Appendix K Figure K4*.

We then proceeded to design a heel rest, which also includes a leg rest that will further aid the driver to get in and out of the car. Furthermore, when our team tried getting into the vehicle to test out the space we had, there was one engineer who was worried that our team, being inexperienced with the car, would step on some of the wiring that was exposed. Having added a leg rest, there was now a cover for the wires and no longer the worry of stepping on sensitive wiring.

Figure 7 below shows a picture of the heel and leg rest.

Figure 7
Design for heel and leg rest for front seat



The design for the heel rest is heavily inspired by the Midjourney generated images. As for the leg rest, the driver is able to 'feel' his/her legs into the car and eventually reach the pedals. Wavy patterns can be seen throughout the design of the car, these patterns are made rubbery with very high friction which serves as steps users take. A better illustration of the wavy patterns on the rest of the car can be seen at *Appendix K Figure K5.*

Final Design

Renders

Figure 8

Overhead view of the final interior design of the EVAM

Figure 9

Overhead view of the final interior design of the EVAM

Figure 10
Driver's perspective of the final interior design

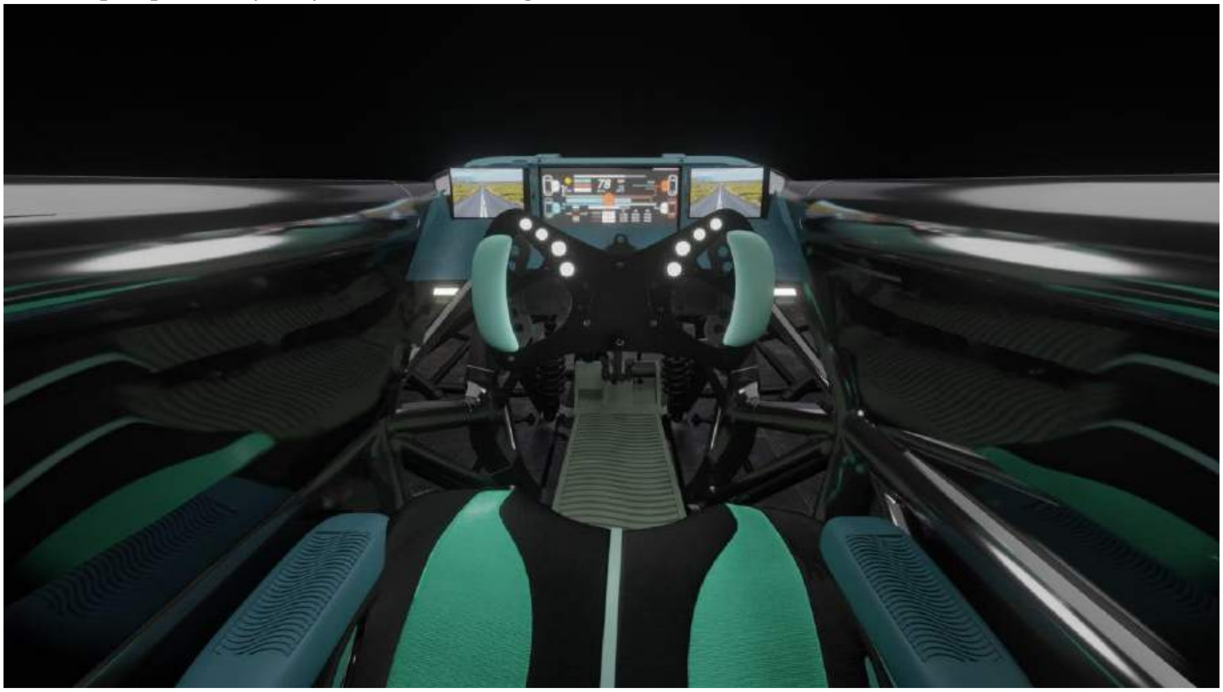
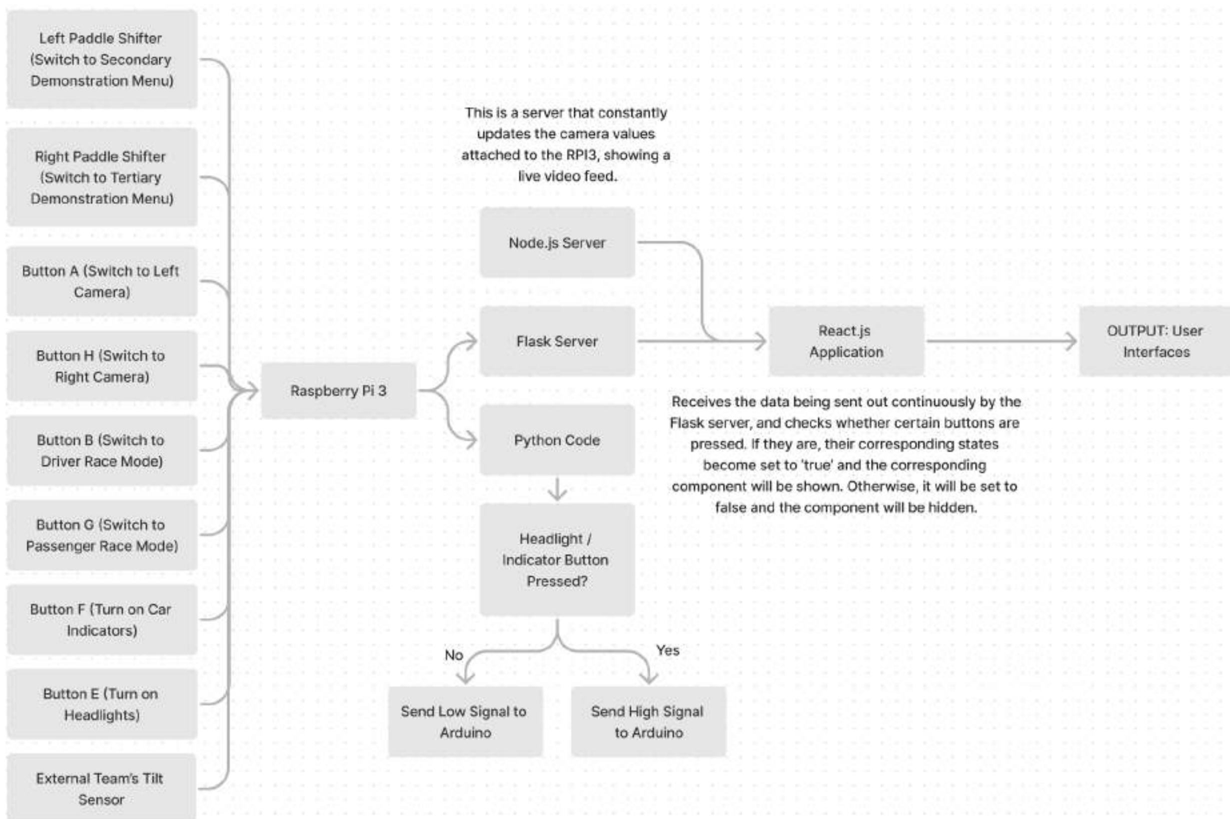


Figure 11
Passenger's perspective of the final interior design

System Diagram
To illustrate the new functions of the dashboards and steering a wheel, a System Diagram has been drawn as seen in *Figure 12*.

Figure 12
Systems Diagram of EVAM Interior Design



This can also be represented in a storyboard for the solutions, as seen in *Appendix L*.

Evaluation

Budgeting

For this project, we were given a budget of $1000 for the production of our product. We will be breaking down how much was spent in the making of each component in this section, as well as justification of why these purchases are necessary for our project. The detailed list of how much was spent can be found in *Appendix M*.

Dashboard

A total of $737 of the budget was spent on creating the dashboard. It was particularly expensive because of the display that is compatible with the raspberry pi module, that is necessary for us to show exactly what it would look like exactly in the actual car. Second reason being that we were constantly faced with the issue of not supplying enough power to the Raspberry Pi and its display. And soon later found out that for each screen and Raspberry Pi, it needed a separate power source which we then needed to buy a charging plug for each display. For each screen, we also needed a SD card slotted into it for it to function. Therefore a part of the budget also went to the purchase of SD cards. Other than that, we also intended 2 of our screens to display the live rear camera view in the car. Therefore we purchased 2 raspberry pi cameras to connect to the Raspberry Pi which eventually is able to display camera views onto the Raspberry Pi display that we purchased. Other than that, we purchased quite a few cables that are necessary to connect between the Raspberry Pi module, the display, and as well as the power source. For each display, 1x HDMI to HDMI cable, 2x USB to micro USB cable is required. Therefore with 5 displays, we needed 5x HDMI to HDMI cable, and 10x USB to micro USB cable.

Steering Wheel

A total of $138 of the budget was spent on the production of the steering wheel. When creating the base metal plate of the wheel, we first attempted to purchase our own metal plate and cut it out in the Fabrication Lab (FabLab), but was soon met with the obstacle of it being too heavy and difficult in cutting precisely to scale. We then seeked help from an external source which provided us with a laser cutting service as well as a good lightweight material that is most suitable for our use case. Some amount of the budget was also spent on switches that were necessary for us to make functionally buttons in the steering wheel. We also spent some amount to purchase the screws and nuts that were not provided by Fablab mainly because it didn't have the length and size that we needed. Lastly, we purchased spray paints for the final finish of the steering wheel. Note that some of the items purchased like clay and non-slip mats were for the rapid prototyping phase of the steering wheel, and were not used in the production final steering wheel. Finally, we also seek help from an external 3D printing service for the production of our back casing for better 3D printing finish and quality.

Product Weight

As seen in *Appendix H Table H1* and *Appendix J Table J2*, the total weight of fabricated products is estimated to be approximately 3.628 kilograms. This is below our design specification wish of five kilograms. This means that additional functionality would have a very minor dent on the performance of the vehicle.

Client Feedback

The client was particularly impressed with the seamless integration of the steering wheel and dashboard. They felt that the design concept was innovative and unique, and appreciated the attention to detail that went into creating a cohesive and aesthetically pleasing product. The client noted that the design created a more streamlined and ergonomic experience for the driver, which they felt was a significant improvement over the traditional design.

While the client was impressed with the overall design concept and integration of the steering wheel and dashboard, they did have some minor critiques. The use of trial-and-error for determining measurements was seen as a potential setback, as the client recommended the use of Anthropometric data for more precise results. Additionally, the client suggested modifying the line width and increasing the infill density for the 3D prints in order to enhance the durability of the product, especially if it will be used while driving.

Despite these minor setbacks, the client remained highly satisfied with the design and expressed excitement for the potential of the product.

Areas of Improvement

Dashboard

Due to the lack of time, more iterations of the screen holders could not be fabricated. The front dashboard holder should be designed to hide the Raspberry Pi. Similarly, the passenger dashboard should have a way to hide the cables that run out of it. Screen casings should be made, together with sealant, to weatherproof the electronics. A more flexible material should be used to make the hinges so that the hinges can tighten better.

In terms of improvements in regards to the user interfaces, the various functionalities of the steering wheel can have more impact on the displays aside from changing the interface completely from one menu to another. Instead, we can have the values on the display itself change depending on the tilt of the car. Furthermore, we aim to include warning interfaces that have the ability to completely override the current interface being displayed to the driver / passenger (with the ability to close it quickly) when a certain vehicle component is overheating or underperforming. This way, the driver and passenger can operate more safely and with a better peace of mind, knowing that anything that goes wrong will be alerted before in critical condition.

Steering Wheel

During the design and manufacturing process of our steering wheel, we encountered some challenges that revealed areas for improvement. Specifically, we found that our wiring management was lacking and our soldering skills needed improvement, resulting in a delicate final product. Additionally, the 3D printing process had some flaws that required workarounds. Furthermore, we were unable to complete the setup of the dashboard due to lack of planning and insufficiently long wires, which caused constant reboots. These challenges highlight the need for more comprehensive planning and better execution of manufacturing processes in the future.

Getting in/out

Seeing how the rest of the components blend so seamlessly with the interior of the car. This particular component that is aiding the ingress and egress process for the user, specially seemed like a complete separate component and does not entirely blend into the interior of the vehicle. Therefore, more thoughts on how these side compartments could blend more seamlessly with the design of the rest of the interior of the components would definitely improve the overall design of the vehicle's interior.

Also because this is one of the more obvious components when someone looks into the car, mainly because of its size compared to other components. We could also put more thoughts on how its functionality and aesthetic of the design of the side compartment could better reflect the SUTD identity of being future-oriented, design-centric, and interdisciplinary. So that when visitors come and visit the EVAM, they are constantly reminded that this is specially produced by SUTD students and as well as the SUTD identity.

Reflection

As mentioned in the client feedback, our group did not use precise measurements. This led to issues such as the back casing of our steering wheel not fitting the base plate exactly. As such, we had to file down the back casing in order to fit it to the base plate. Having faced this avoidable issue, our group now knows the importance of taking precise measurements, especially in the preliminary stages of the project.

Our group also made use of Dall-E and Midjourney in our project to give us inspiration. While they did help us make the design process easier, we understand that it is only a tool to aid us, and should not be used as a solution in itself. There is still the need for humans (i.e. our group) to get involved to test out a design and see if it works for our project. This can be seen when we decided that the mood board provided by Dall-E did not suit our vision and that we would not want to use it. Another example is when we used Midjourney to give us design inspirations for the foot rest. We still had to go down to the vehicle and see if the foot rest was indeed able to be implemented, with the constraint mainly being the amount of space we had.

Effective and precise communication of ideas is very crucial at the ideating part of this project. Especially when we needed to explore and compare between different design solutions. Therefore, the skill of hand sketching in a 2D diagram is crucial, in the sense where we are able to explain our ideas to each other in a quick and precise manner. After which when this particular idea seems like a good one in the 2D perspective, we will then have to model it out in any 3D software available and 3D print it for us to see the component physically. We will then place it in the actual position in the vehicle of where it is intended to be. These steps will then allow us to analyse possible issues that may arise with this particular design solution, which we can then iterate and improve on until we reach our final design solution.

Acknowledgement

We would like to express our deepest gratitude to Mr Liew and the rest of the team for their guidance in our project, and to the EV Club's Wei Ming for taking the time to come down to the FabLab to assist us with measurements and testing, despite her busy schedule.

We would also like to acknowledge with gratitude, the support from our professors and supervisors. We would like to thank Mr Michael Alexander Reeves and Dr Edwin Koh, for giving us different perspectives on the project, as well as Dr Kwan Wei Lek for helping us with the connection of electronics and providing us with multiple microcontrollers.

Special thanks to Ms Zerline Tan for ensuring we have a conducive place to work in. Last but not least, thank you to our Teaching Assistants (TAs), Ke Wei and Eugene for sparing time to give us insights on existing car designs we can use as inspiration for our project.

Special mentions to the exterior team consisting of Aaron, Billy, Joshua, Jun Xiang, Valencia and Wei Xuan. It was thanks to the collaboration between both teams that we managed to showcase the EV as a whole, rather than separate projects.

It is thanks to all of these people that our group managed to complete this project with such success, and impress our clients with our final physical prototypes and product.

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Appendix A

Interview transcript with EVAM Engineers

The following questions were asked to Senior Specialist Mr Liew Zhen Hui:

1. What is your biggest focus in designing the operations of the vehicle?
   The goal is racing, hence speed is most important.

2. What are some issues you face in the operation of the vehicle?
   There is no car information communicated to the driver.

3. Are there specific telemetries you would like to see?
   Speed, Temperature of battery and motor, Battery Charge.

4. Is comfort important?
   The driver must adapt to the design, but support to the neck, shoulders and lumbar is a bonus.

As a follow up, we text messaged a student engineer who helped design the car, Mr Matthew Dylan Wong Jian Xiong (2023), to offer his perspective on the vehicle. We asked what his original vision for the car was:

> The concept of the car at its core was to exploit additive manufacturing as much as possible to do things that are not conventionally possible and to make the fabrication process more efficient.
>
> (1) Explore how additive manufacturing can be used to fabricate the body shell parts. A huge proportion of the money spent on the car is going into the 3d printed metal joints on the frame.
>
> (2) Highlight the 3d printed joints of the car. This is why I tried to frame them in size the side window.
>
> (3) The car was originally meant to be a "formula-style race car". It has a low ride height, wide track width and low overall height that gives it an aggressive stance.
>
> (4) The design of the car should be to some extent, dynamic, aggressive and sporty. It should look like it can go fast even when it's not moving. At the same time, there should be aerodynamic elements to send the message that this car is meant for performance.

Appendix B

AEIOU Framework Observation Mindmap

Note: The nodes' relationships are represented by the dashed lines.

Appendix C

Value Proposition Wishes

1. **Weight**
   The additional components are lightweight (below 5 kg) to enhance performance despite additional functions.

2. **Hydration**
   The users should be able to have access to water easily so they can sustain themselves during operation of the vehicle.

3. **Safe**
   Users must be able to be removed from the vehicle swiftly and safely if an accident were to happen.

4. **Communication**
   Users need to be able to communicate with each other despite the noise.

5. **Comfort**
   The cockpit should stay cool, and the seating positions should be comfortable.

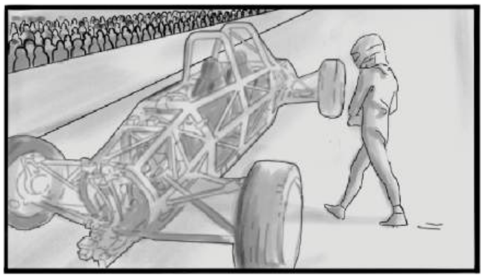
6. **Fabrication**
   The components should be easy and inexpensive to manufacture, preferably done using additive manufacturing to support the original concept of the vehicle.

7. **Affordable**
   Controls are intuitive.

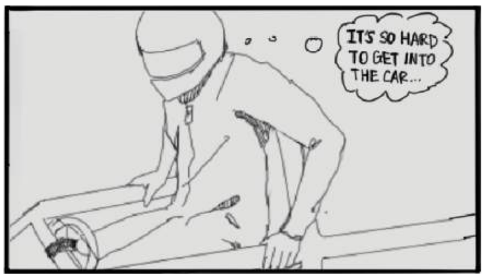
8. **Enjoyable**
   Users will have a positive experience from riding in the vehicle.

Appendix D

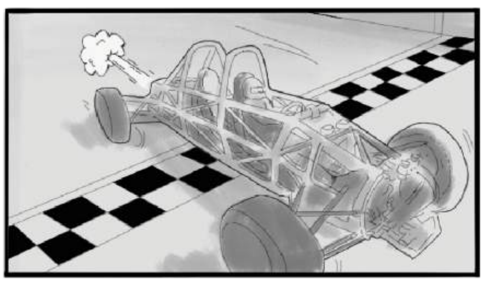
Storyboard (Problems)



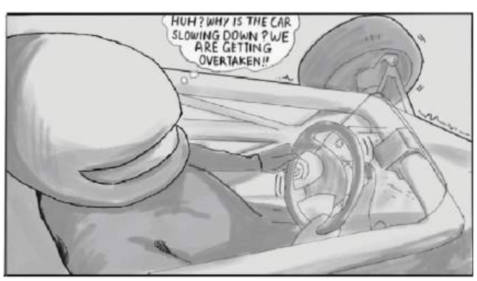
The driver approaches the vehicle. A race is about to begin.



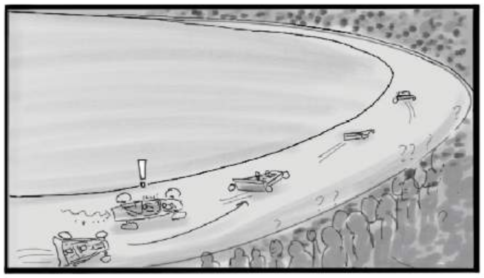
Due to the high walls of the chassis, the driver has difficulty entering the vehicle.



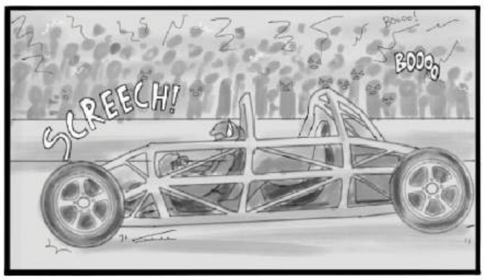
It is lights out and away we go!



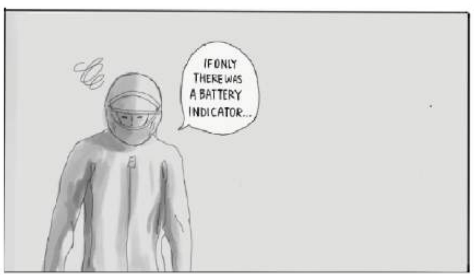
The driver notices that his car is not travelling as fast as usual but is also unable to diagnose the problem.



He enters a corner to quickly and understeers wide, allowing many other cars to overtake him.



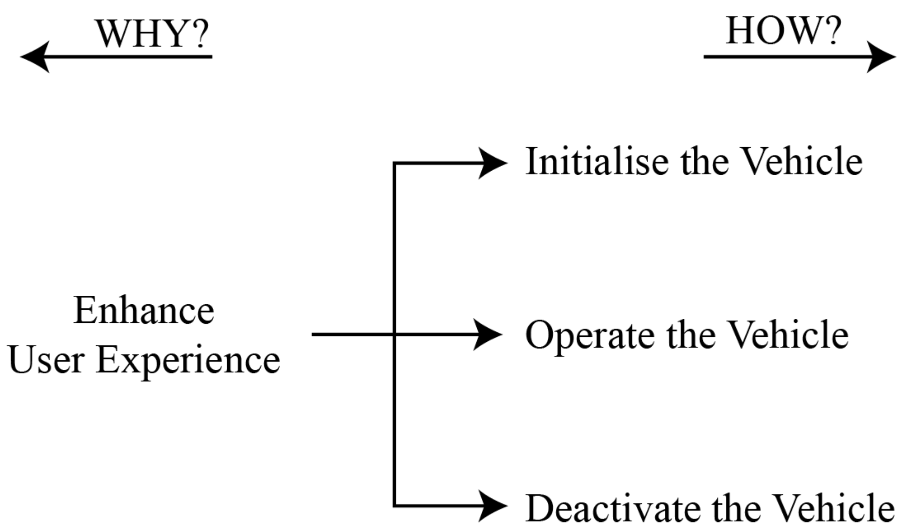
Suddenly, his car comes to halt for an unknown reason.



He believes it was due to insufficient battery power, and is annoyed that he could not see what went wrong.

Appendix E

Workflow of Functional Analysis Process Perspective



1. Initialise the vehicle
    a. Receive user
    b. Receive input to start the vehicle
    c. Initiate startup process
    d. Receive inputs on user settings, if any

2. Operate the vehicle
    a. Receive inputs for drive/reverse mode
    b. Receive inputs on user setting changes, if any
    c. Display information of the user’s settings
    d. Receive inputs on vehicle’s status, if any
    e. Display information on the vehicle’s status
    f. Physically support user
    g. Hydrate user
    h. Cool user
    i. Receive voice input from driver/passenger
    j. Relay voice output to driver/passenger

3. Deactivate the vehicle
    a. Receive input for emergency stop, if any
    b. Receive input to shutdown the vehicle
    c. Initiate shutdown process
    d. Save current inputs of user settings

Appendix F

AI Generated Mood Board

Appendix G

Criteria for scoring and ranking design concepts

Criteria	Score				
Functionality	1	2	3	4	5
Ease of Fabrication	1	2	3	4	5
Ease of use	1	2	3	4	5
Cost	1	2	3	4	5
Total					

Notes from selection

Dashboard

1. Using the Raspberry Pi computer was most ideal because our team could borrow them from our institution, SUTD, allowing us to stay within our given budget.
2. For displaying information, the LCD screens were chosen over Tablet Devices as they would be too expensive, and over e-ink as it cannot respond fast enough for high stress situations such as racing. Lastly, a rocker switch was chosen over its other concepts because it gives a tactile sensation to starting and stopping the car, with two alternative options: start and stop.

Steering

1. Buttons were chosen over all other options for the steering as in a racing scenario, timing to obtain required information is extremely important, and buttons are the most effective in minimising the movement and time needed to obtain the desired dashboard information output, making it the best choice.

Getting in/out

1. We chose to use grooved pads over rubber pads because grooved pads provide more grip strength on the shoe to prevent any slipping. We can also incorporate a wavy design into it for aesthetics, which is what we want as shown in our mood board.
2. Steps have been chosen over leg rests as we realised that the height difference when getting in and out of the car is very deep. By adding steps, it serves as a comfortable intermediary point of manoeuvring to make the process smoother.
3. We decided to use handles for the back seat as we observed that it is easier for drivers to push themselves upwards as compared to pulling themselves up by holding onto the chassis when getting out of the car.
4. We have also implemented grooved heel rests for the front seat as during our investigation, we realised that there is a gap between the heels of the driver when their feet rests on the pedals, making it tiring to hold the driving position for long periods of time. Additionally, when getting out of the car, drivers always push themselves up using their legs, and by adding heel rests, it also serves as a grip making it easier to exit the car.

Appendix H
Dashboards Screens Schematics

Figure H1
Initial design of Front Dashboard

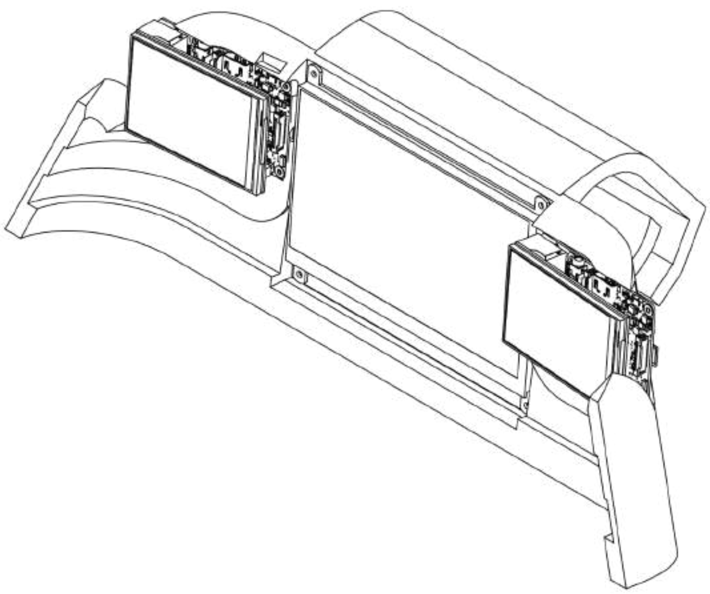


Figure H2
Final exploded assembly view of Front Dashboard

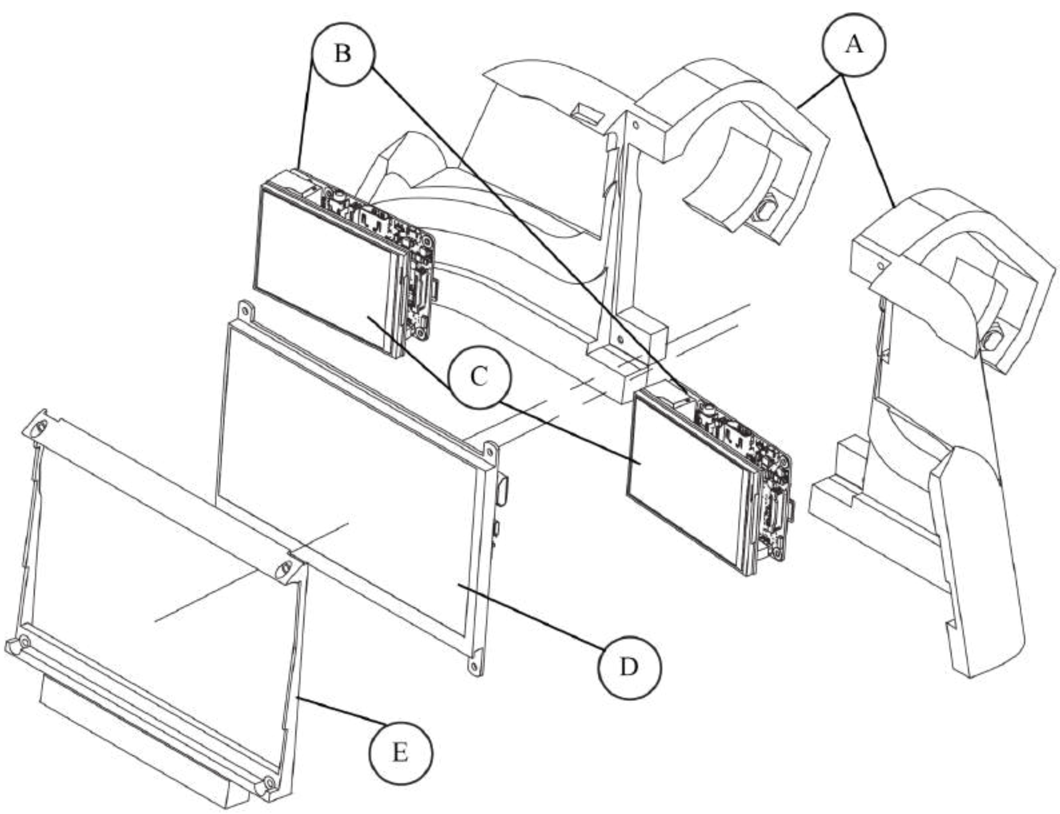
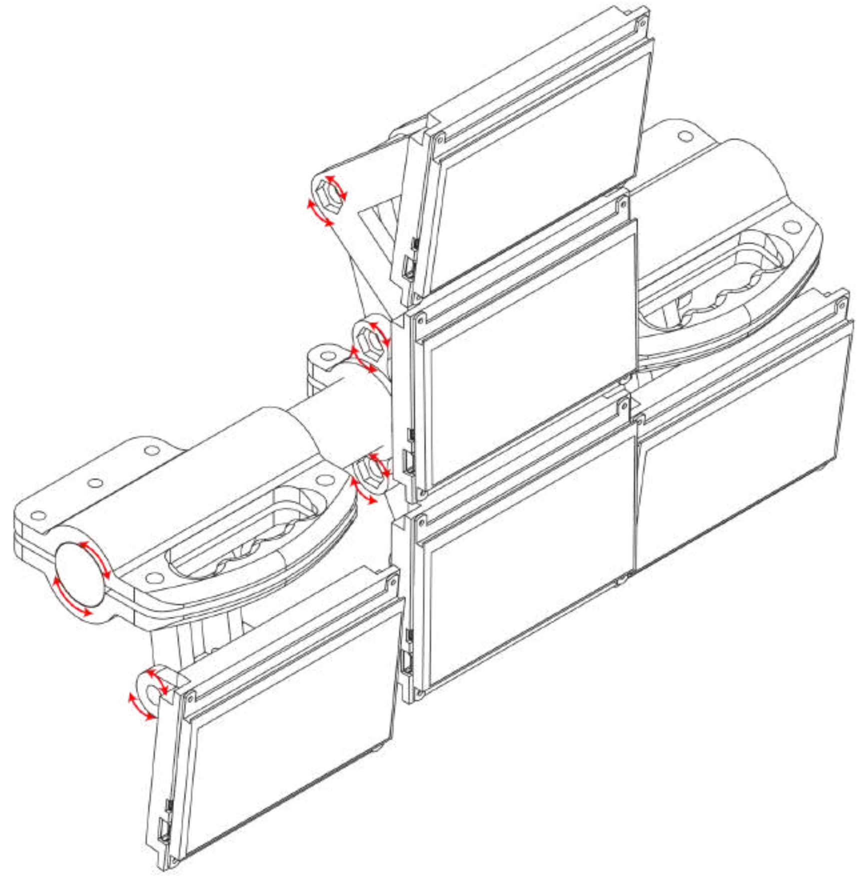


Figure H3

Final fully assembled Passenger Dashboard



Note. Red arrows indicate possible movement of joints. Not all joints can be seen.

Figure H4

Final exploded assembly view of Passenger Dashboard

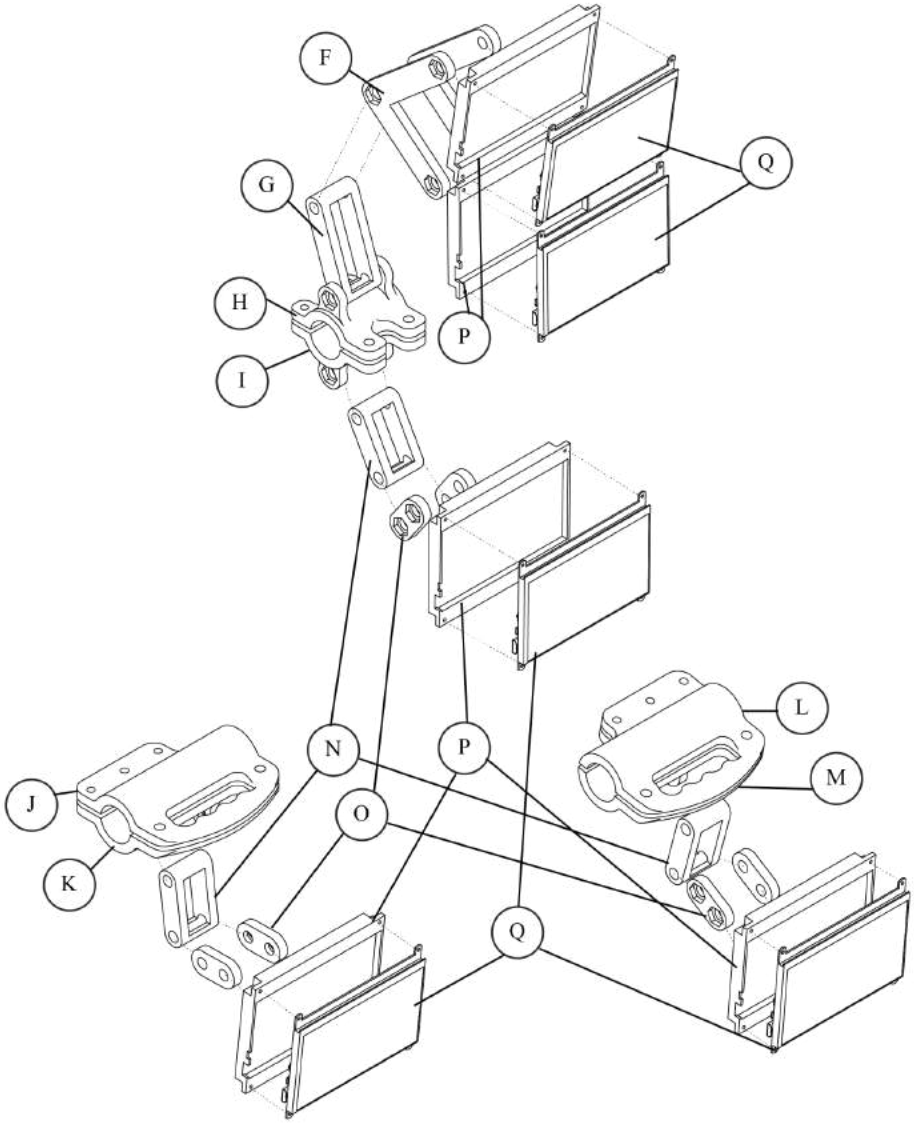


Table H1

Parts list used in Dashboards

Label	Part	Weight (kg)
A	Main Dashboard Bodies	0.347
B	Raspberry Pi 3 Model B[3]	
C	Waveshare 3.5inch RPi LCD (B)[4]	
D	Waveshare 7inch Resistive Touch Screen LCD, 1024×600, HDMI, IPS[5]	
E	Screen Cover	
F	Top Screen Rocker Arms	2.700
G	Top Clamp Arm	
H	Top Middle Clamp	
I	Bottom Middle Clamp	
J	Top Left Clamp	
K	Bottom Left Clamp	
L	Right Top Clamp	
M	Right Bottom Clamp	
N	Bottom Arm	
O	Bottom Hinge	
P	Screen Holder	
Q	Waveshare 7inch Resistive Touch Screen LCD, 1024×600, HDMI, IPS	

[3] CAD Model adapted from *https://grabcad.com/library/raspberry-pi-3-model-b-reference-design-solidworks-cad-raspberry-pi-raspberrypi-rpi-1*

[4] CAD Model adapted from: https://grabcad.com/library/raspberry-lcd-3-5inch-1

[5] CAD Model adapted from: https://www.waveshare.com/wiki/File:7inch_HDMI_LCD_3D_Drawing.zip

Table H2
Fastener list used in Dashboards

S/N	Fastener	Quantity	Joint
1	M8 Wing Bolt 75 mm	4	A (Screw Clamp)
2	M8 Hex Nut	8	A (Screw Clamp)
3	M2 Screw 20 mm + Nut	4	B and A
4	M3 Screw 20 mm + Nut	4	A, D and E
5	M10 Hex Bolt + Wing Nut + Spring Lock Washer	13 (90mm), 6 (40mm)	H and I, J and K, L and M, F/O and P, G/N and F/O, H/I/K/M and G/N
6	M6 Hex Bolt 40mm + Hex Nut + Spring Lock Washer	8	H/J/L and I/K/M
7	M3 Screw 20 mm + Nut	20	P and Q

Appendix I

User Interface for Screens

Figure I1

Physical Testing of the User Interface

Figure I2
Final User Interface for Race Mode

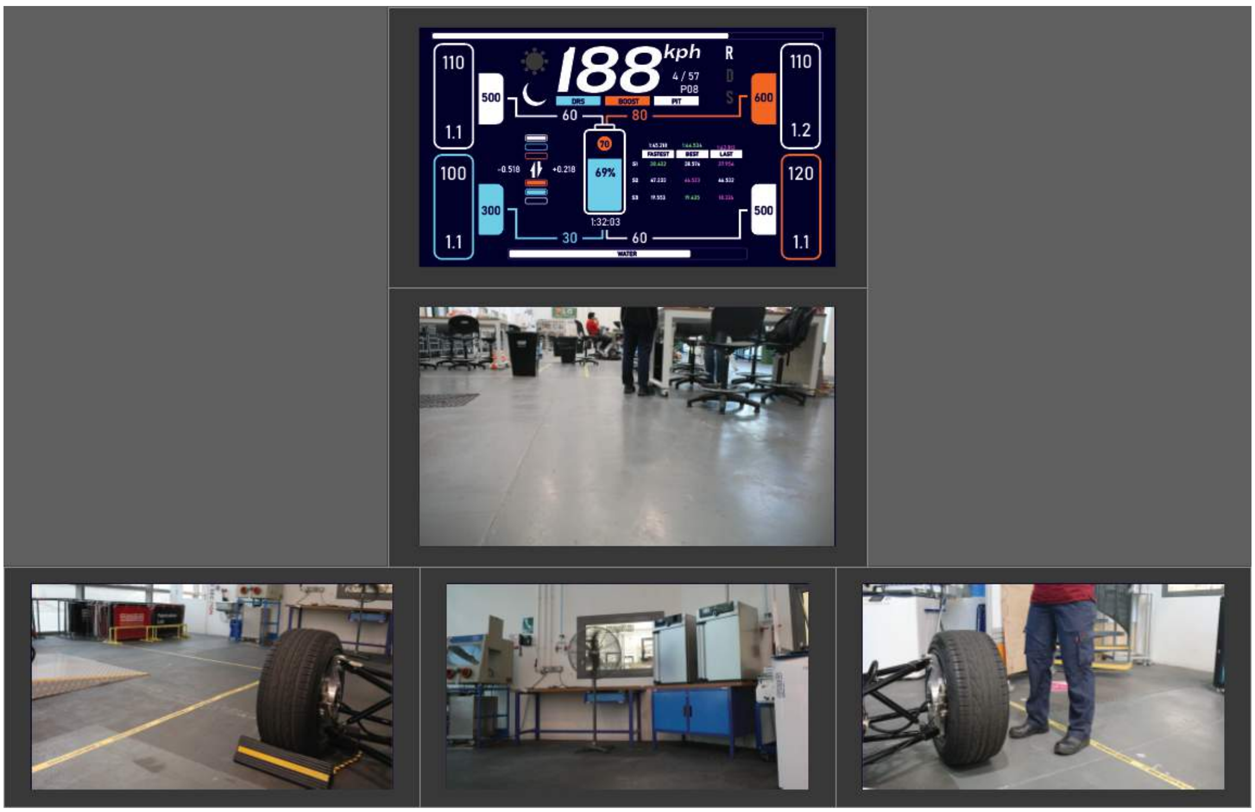


Figure I3
Final User Interfaces for Demonstration & Static Mode


5.432
100%
N
78
KMH
LAP 1:36.373
SECTOR 3:55.104
1.346
100 600 600 100
1.1 1.1
100 200 200 100
1.1 1.1
100 %
1HR 50MINS
LAP 12 1:36.373
LAP 11 1:36.373
LAP 10 1:36.373
LAP 09 1:36.373
LAP 08 1:36.373
LAP 07 1:36.373
LAP 06 1:36.373
LAP 05 1:36.373
LAP 04 1:36.373
LAPS REMAINING 10
SECTOR TIME 3:55.104
500M TURN RIGHT
FRONT 5.432
BACK 1.346
PHOTO OF SUSPENSION
PHOTO OF FRONT OF THE CAR
PHOTO OF DRIVER'S POV

Appendix J

Figure J1

Initial sketches of steering wheel designs.

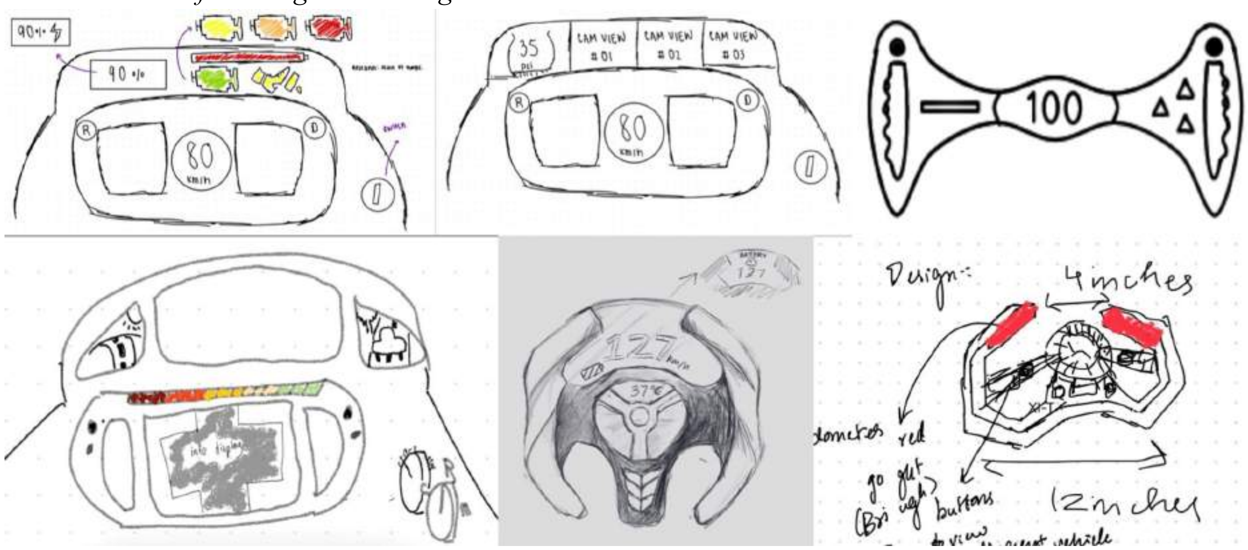


Figure J2

Iterations of final steering wheel designs

Figure J3

Steering wheel physical cut outs

Figure J4

Isometric View of Fully Assembled Steering Wheel

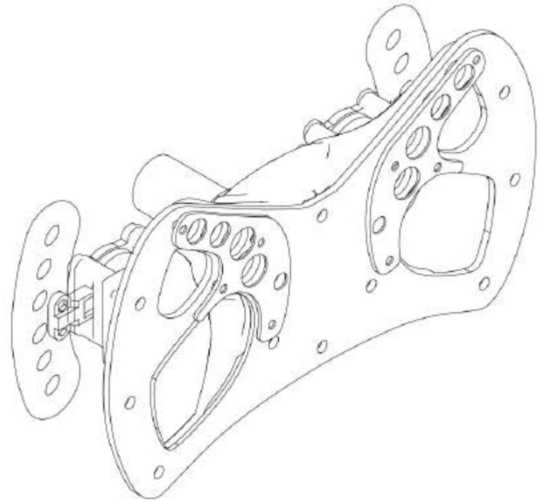


Figure J5

Final exploded assembly view of Steering Wheel

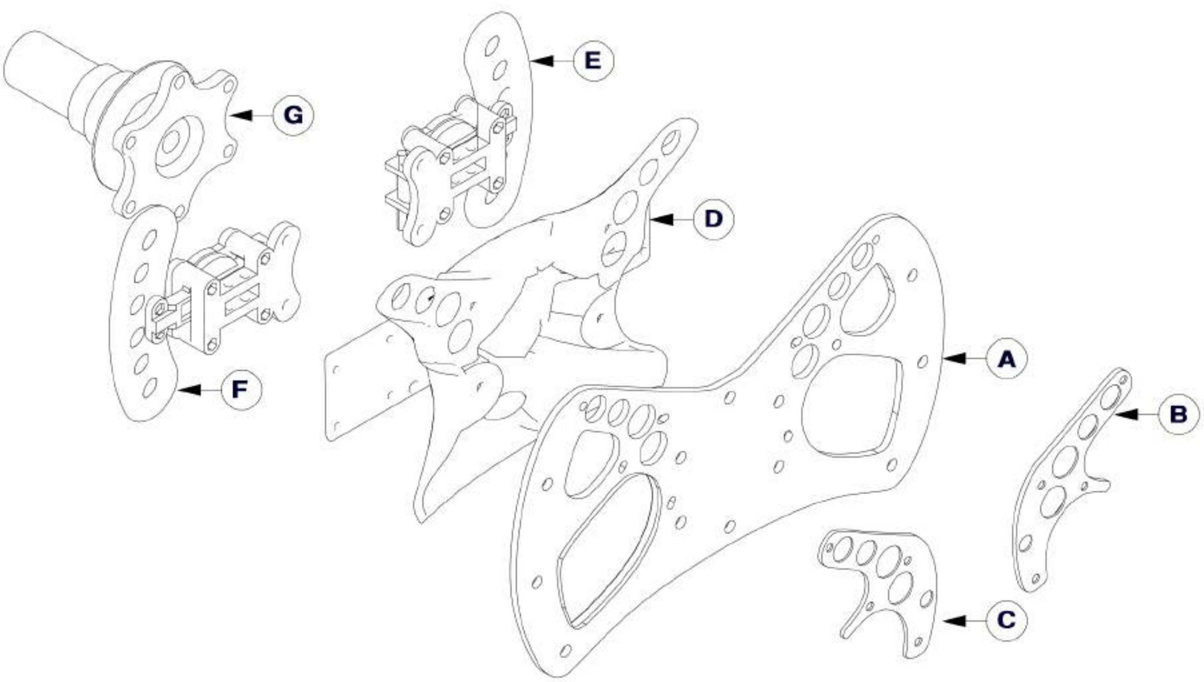


Figure J6

Button Layout for Steering wheel

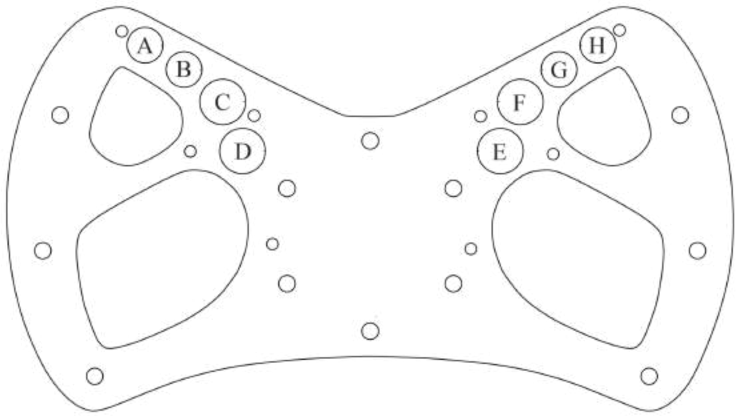


Figure J7

Final iteration of the steering wheel

Table J1
Button Functions for Steering Wheel

Button	Function
A	Switch the user interface on the screen to show the left camera view.
B	Switch the user interface to the main menu of race mode (driver).
C	Turn on the left light indicators of the vehicle (theoretically, not implemented).
D	Turn on the headlights of the vehicle.
E	Turn on the headlights of the vehicle.
F	Turn on the right light indicators of the vehicle.
G	Switch the user interface to the main menu of race mode (passenger).
H	Switch the user interface on the screen to show the right camera view.

Table J2
Parts list used in steering wheel

Label	Part	Weight (kg)
A	Steering wheel Chassis	0.581
B	Right button casing	
C	Left button casing	
D	Back casing for the steering wheel	
E	Right paddle shifter	
F	Left paddle shifter	
G	Quick release mechanism	

Table J3
Fastener list used in the Steering Wheel

S/N	Fastener	Quantity	Joint
1	M3 Screw 20mm + Nut	2	Connecting the Paddle Shifters to the Micro Lever Switch
2	M3 Screw 25mm + Nut	4	Attaching the Paddle shifters to the back casing
3	M5 Screw 20mm + Nut	6	Bind the Quick Release to the Steering Wheel
4	M5 Screws 25mm + Nut	6	Bolting the 3D printed Handles to the Steering Wheel
5	Neodymium Magnets (2mm)	4	Providing the necessary force for paddle shifter feedback
6	M3 Screws 25mm + Nut	6	Tightening the Button Casing to the Steering Wheel

Appendix K

Figure K1
Touchpoint analysation for ingress and egress of the vehicle

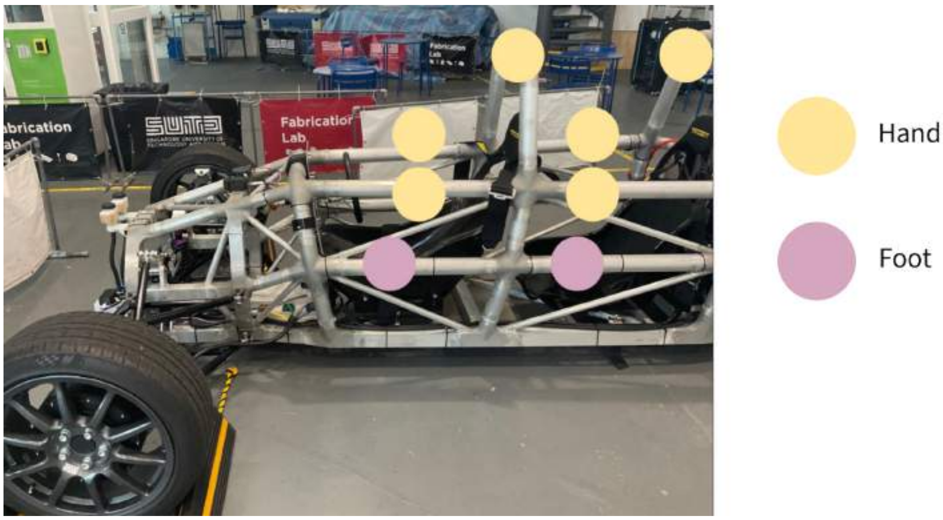


Figure K2
Space constraints within the EVAM

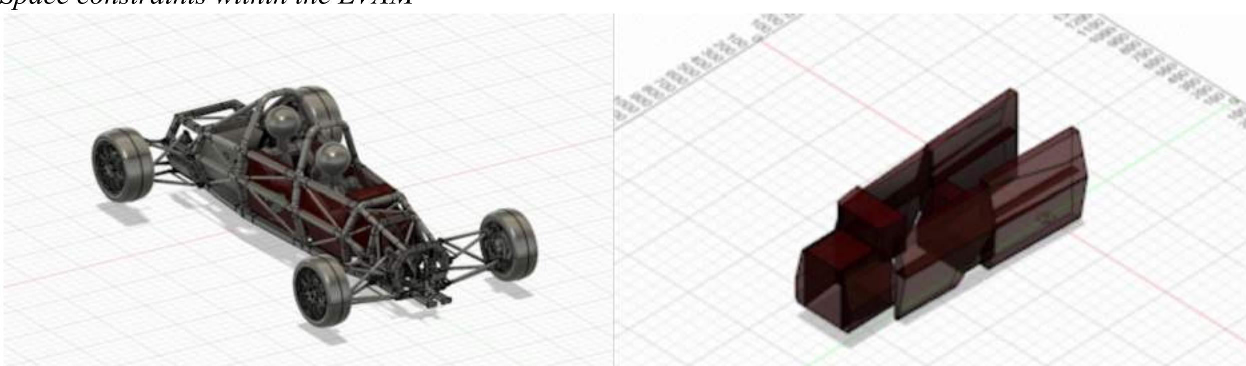


Figure K3
Design exploration for ingress and egress

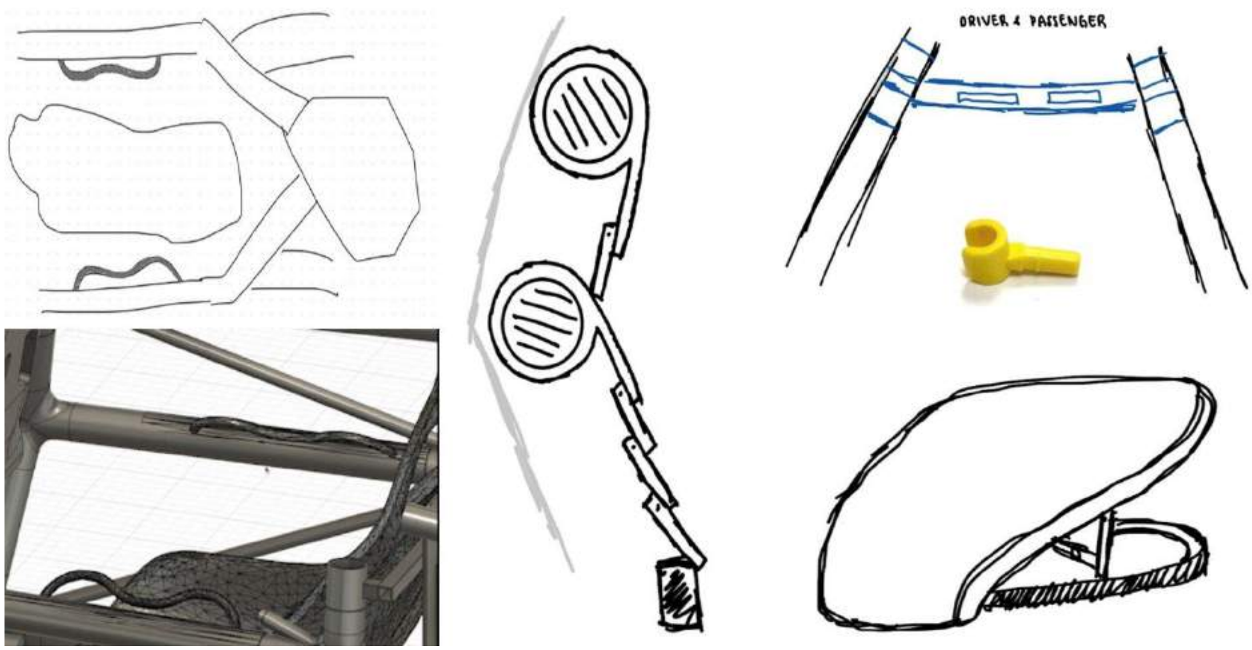
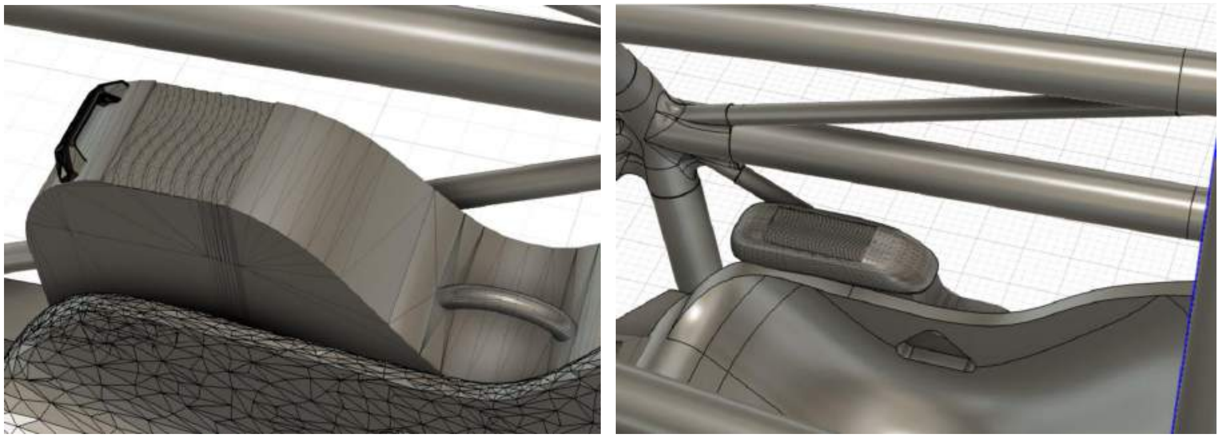


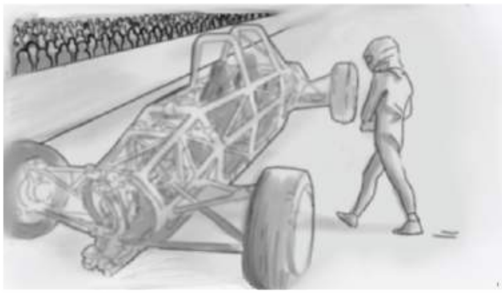
Figure K4
Midjourney generated heel rest images

Figure K5

Illustration of steps throughout the car.

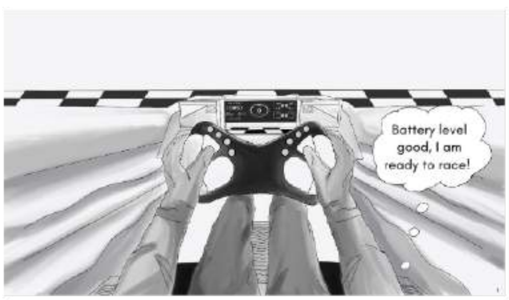


Appendix L
Storyboard (Solutions)

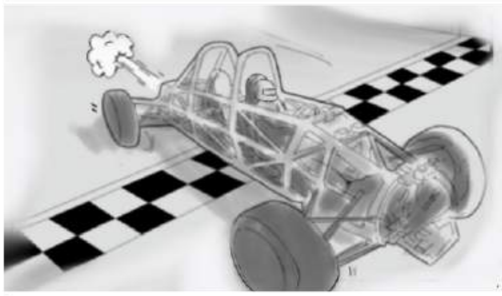


The driver approaches the vehicle. A race is about to begin.

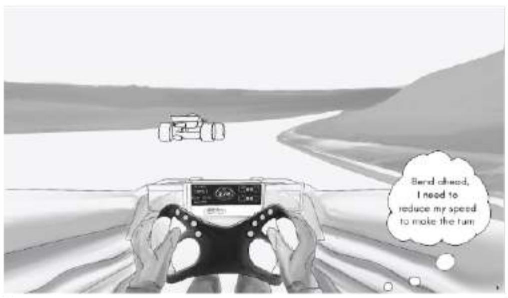
He finds it easy to get in.



The battery level looks good. He is ready to race.



Its lights out and away we go!



He know what speed he needs to take the corner and can decelerate into it.

Winner winner, chicken dinner!

Appendix M
Budget Spending

No.	Item	Qty	Price per piece	Total Price
1	Raspberry Pi 7" HDMI LCD (C) IPS 1024x600 Capacitive Touch	3	85.70	257.10
2	Raspberry Pi 3.5" HDMI LCD (B) IPS 480x320 Resistive Touch	2	57.50	115.00
3	Magnet	3	3.50	10.50
4	MicroSD Card 32GB 100MB/s Class 10 / Sandisk with OS	3	24.00	72.00
5	Raspberry Pi Camera 5MP	3	14.00	42.00
6	Momentary Push Switch 12mm / Red	2	1.50	3.00
7	Momentary Push Switch 12mm / Green	2	1.50	3.00
8	Momentary Push Switch 12mm / Blue	2	1.50	3.00
9	SPDT Limit Switch 13mm	6	1.00	6.00
10	Micro HDMI to Standard HDMI (A/M) Cable / 1m / Black	3	15.00	45.00
11	Brass Spacer Male-Female Screw-Nut M3 10mm 4pcs	1	1.30	1.30
12	Brass Spacer Male-Female Screw-Nut M4 25mm 4pcs	1	2.60	2.60
13	Screw-Nut M3x20 5pcs	2	1.00	2.00
14	Screw-Nut M3x25 5pcs	1	1.00	1.00
15	M10 Nut	4	-	1.00
16	M8x40 Bolt + Wing Nut	6	1.00	6.00
17	4 x 50 Bolt	4	-	2.00
18	5x50 Bolt	4	-	2.00
				x1.08 (GST)
19	MicroSD Card 32GB 100MB/s Class 10 / Sandisk with OS	2	24.00	48.00
20	M Lip&Eye M/Up R70ml	1	12.50	12.50
21	SB H.Duty Refill 1S	1	4.20	4.20
22	MicroSD Card 32GB 100MB/s Class 10 / Sandisk with OS	2	24.00	48.00
23	Laser cut aluminium plate 265mm x 148mm	1	40.00	40.00
				x1.08 (GST)
24	Charging and Data Transfer Cable - For Smartphones - 1m - 2A	3	2.16	6.48
25	Pearl & Metallic Paint	1	5.90	5.90
26	Car Non Slip Mat 50 x 150	1	8.20	8.20
27	Aluminium Plate	1	8.00	8.00

28	Soft Clay Black	2	2.16	4.32
29	Soft Clay Black	2	2.16	4.32
30	HT Hex Bolt GR 838 DIN 933 M10 - 1.5x40 Blue ZN	6	0.40	2.40
31	HT Hex Bolt GR 838 DIN 933 M10 - 1.5x90 Blue ZN	13	0.70	9.10
32	STL Wing Nut M10 - 1.5 NP	19	0.60	11.40
				x1.08 (GST)
33	Switch	6	-	12.50
34	VCE VE AH02 4 in 1 USB3.0 Hub Black	1	18.90	18.90
35	Charging and Transfer Cable microB 1m 2.4A Aluminium	2	2.16	4.32
36	Charging and Transfer Cable microB 1m 2.4A Aluminium Mesh	1	2.16	2.16
37	7CF Spray Paint #4	1	5.20	5.20
38	PG P 66014S 4 Way 2M Power Extension Socket	1	16.90	16.90
39	Omar's OMWC013 Type C + USB Port 20W Wall Charger Black	4	19.90	79.60
40	Brints Co. 3D Printing Services	1	32.00	32.00
				964.81

Accurate as of 16 April 2023