

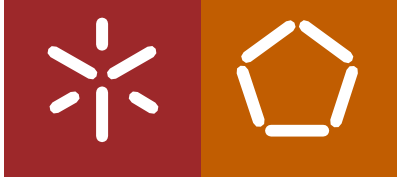


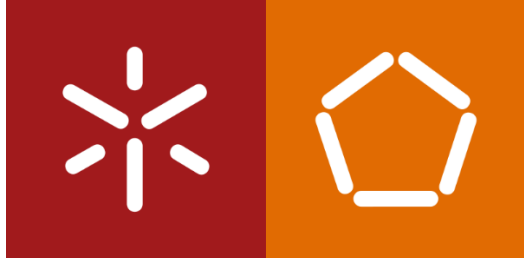
Countermeasures to Motion Sickness in Automobile Context

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Countermeasures to Motion Sickness
in Automobile Context

Dissertação de Mestrado

Mestrado em Engenharia do Produto

Trabalho efetuado sob a orientação de

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June 2022

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Acknowledgements

I wouldn't have been a part of this project if not for my housemate Adriano Carvalho who told me about it and picked my interest in contributing to it. In second place, my best regards to both my coordinators, both Professor António José Vilela Pontes and Professor Paulo Francisco Silva Ribeiro for accepting the position and for supporting me when necessary.

My parents and other family members also deserve my gratitude for supporting me throughout the entirety of my school years, and of course my girlfriend for always believing in me and supporting my ideas, thank you Alda.

Lastly, a thank you to everyone who worked by my side in these projects, especially Rui Gomes with whom I discussed problems at length to come up with the best possible solutions.

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

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Abstract

Motion sickness is something that affects many humans in several situations, being one of those traveling on a vehicle, for example a car. When self-driven cars become something common in our society, the tendencies point to a rise in the number of people getting afflicted with motion sickness, especially if they choose to engage in non-driving related tasks.

This upcoming situation creates a necessity for mechanisms that will help avoid motion sickness, or if it sets in, mitigate its symptoms. This study will be focused on two devices that will work towards preventing motion sickness and one device to try and mitigate motion sickness symptoms. For preventing motion sickness there is the Feet Platform – a platform under the user’s feet that feeds haptic information to the user and warns him when and where the car will be turning or accelerating – and the Visual Cues – projections of an animated body that will provide the same information as the Feet Platform but in visual manner. To mitigate the motion sickness symptoms there is the Airflow system that has two variants – the Cold Airflow that will blow cold air directly on the user’s face and the Aromatic Airflow that will lightly blow a scent towards the user in order to try and mitigate motion sickness symptoms.

Keywords: Motion Sickness, Prevention, Mitigation, Haptic Cues, Visual Cues

Resumo

O enjoo do movimento é algo que afeta várias pessoas em diferentes situações, sendo uma dessas causas as viagens em veículos, por exemplo um carro. Quando os carros autónomos se tornarem algo comum na nossa sociedade, a tendência aponta para um aumento no número de pessoas afetadas por enjoo do movimento, especialmente se decidirem dedicar-se a tarefas não relacionadas com a condução.

Esta situação que se aproxima cria a necessidade de mecanismos que ajudarão a prevenir o enjoo do movimento, ou, se acontecer, mitigar os sintomas. Este estudo irá focar-se em dois dispositivos que funcionarão para prevenir o enjoo do movimento e um dispositivo que funcionará para mitigar os sintomas do enjoo do movimento. Para a prevenção do enjoo do movimento temos a Plataforma dos Pés – uma plataforma por baixo dos pés do utilizador que informa o utilizador através de sinais hápticos de quando o carro irá virar, acelerar ou abrandar – e os sinais visuais – projeções de um corpo animado que fornecerão ao utilizador as mesmas informações que a Plataforma dos Pés, mas em aspeto visual. Para mitigar os sintomas do enjoo do movimento temos o sistema de Fluxo de Ar que se apresenta em duas variantes – o Fluxo de Ar Frio que será apontado diretamente para a face do utilizador e o Fluxo de Ar Aromatizado que libertará ar com um odor na direção do utilizador, ambos com intenção de mitigar sintomas do enjoo do movimento.

Palavras-chave: Enjoo do Movimento, Prevenção, Mitigação, Sinais Hápticos, Sinais Visuais

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List of abbreviations

AV – audio/video

BC – baseline condition

CNS – central nervous system

DLP – digital light processing

FDM – fused deposition modeling

HUD – head-up display

MS – motion sickness

MSPS – motion sickness prevention system

OLED – organic light emitting diodes

PA – polyamide

RPS – route prediction system

SA – situation awareness

SLA – stereolithography

SLS – selective laser sintering

UI – user interface

VC – visual condition

1. Introduction

1.1. Context

With every passing day, self-driven cars come closer to be a reality in our society. Because they are self-driving, drivers will soon become a thing of the past being replaced by a computer that will assess each situation and safely act on it. Without the responsibility of driving, passengers will now be able to enjoy leisure activities or perform work tasks, turning cars into an extension of the passenger's home or workplace. This also provides car manufacturers with new possibilities to design new interiors for their vehicles as well as redesigning the Human-Machine Interface. One matter that will be getting addressed with this redesign, is motion sickness as it will start being an issue for some users.

Motion Sickness may prevent users from fully engaging in and/or enjoying non-driving tasks, losing the advantages of the autonomous driving experience. In answer to this issue still to come, three solutions were explored: airflow systems; visual cues; feet platform.

This document will explore the design and the prototyping processes and explain how each of them work on preventing or mitigating motion sickness.

1.2. Motivation

The study of ways to countermeasure MS is an important area that should continuously evolve to improve products created to prevent or mitigate MS. This motivated a study that covered three different kinds of cues: visual cues, haptic cues and olfactory cues.

The products that came out of this study aimed at the same objective, prevent and/or mitigate motion sickness symptoms.

The entire project culminated in the creation of four prototypes.

1.2. Objectives

The development of new products is an enticing and complex task because it must implement functionalities that must coexist with the design aimed at human interaction.

The interaction between the teams is also a pressure point for any project. Establishing good relations between coworkers is key to success.

Material selection is a crucial step in a project like this. The right materials must be selected to make sure the products can withstand being handled by the users.

1.3. Document Organization

This document is organized in a way that starts by presenting the state of the art for MS in an automotive context and how it can be countered through cues or mitigated through other systems, followed by the state of the art for 3D modeling software and 3D printing systems ending with a list of the selected software to use in this project. The following section is a brief introduction to the products that were developed, followed by a list of software used throughout the project and the 3D printing technology chosen to create the prototypes.

At this point, the products themselves start to be explored. Starting with the Feet Platform, how it evolved, reasons for those evolutions and what components make the final version; followed by the Visual Cues, exploring the evolution of the videogame; and finally, both Airflow Systems, exploring the functionality of each of them, what components make them, how they were made, how they are put together and how they work.

To finalize, a conclusion that goes through each concept and evaluates them for respecting their requirements and their functionality.

2. State of the art

2.1. Motion sickness

Virtual reality devices, driving simulators and the upcoming self-driven cars make motion sickness a growing concern that may affect their users. This makes research on motion sickness relevant to aid in the creation of new technologies to fight it.

Motion sickness is not an illness, but rather a natural autonomic response to an unfamiliar or specific stimulus (Dahlman, 2009). It includes symptoms of nausea, dizziness, and other physical discomfort. In-vehicles passengers frequently report bodily warmth, dry mouth, headache, drowsiness, lethargy, 'stomach awareness', nausea, pallor, and vomiting (Mansfield, 2017).

Motion sickness can be caused by many different movements of the body (e.g., translational and rotational oscillation, constant speed rotation about an off-vertical axis, Coriolis stimulation), movements of the visual scene, and other stimuli producing sensations associated with movement of the body (Griffin, 2012). Body motion can be detected by three basic sensory systems: the vestibular system, the visual system, and the somatosensory system. The vestibular system is in the inner ear and comprises the semicircular canals, which respond to the rotation of the head, and the otoliths, which respond to translational forces (either translational acceleration or rotation of the head relative to an acceleration field, such as the force of gravity). The vestibular system provides us with our sense of balance. The eyes detect relative motion between the head and the environment, caused by either head movements (in translation or rotation) or movements of the environment or a combination of the two. The somatosensory systems respond to force and displacement of parts of the body and give rise to sensations of body movement, or force. All three sensory systems provide information that leads to an unambiguous indication of the movements of the body in space (Griffin, 2012).

The most widely accepted theory to explain motion sickness symptoms is the Sensory Rearrangement theory, which predicts the symptoms to occur whenever one sensory system generates signals to the brain that are not in agreement with another set of sensory signals (Mansfield, 2017). That is, motion sickness symptoms are assumed to arise from a mismatch between the motion cues provided by the vestibular system, visual cues and the central nervous system (CNS), which integrates visual and vestibular signals (Mansfield, 2017).

2.1.1. Motion sickness in the automotive context

Although drivers rarely experience motion sickness, passengers often report symptoms associated with it. Motion sickness typically occurs when we are exposed to motion that, from an evolutionary perspective, we are not used to. In the automotive context, is associated with horizontal accelerations caused by accelerating, braking, and cornering (Turner & Griffin, 1999). It seems to be mainly influenced by the quality of the driver and the condition of the road (e.g., curvy cross-country versus highway), both factors determining lateral oscillations (Bertolini & Straumann, 2016). When experiencing curvature, the passengers normally tilt their head in the same direction as the lateral acceleration, while the driver tilts his/her head against it, which seems to influence the motion sickness severity level (Saruchi, Ariff, Zamzuri, Hassan, & Wahid, 2019). Saruchi et al. (2019) has recently established models for the correlation between the lateral acceleration of a vehicle and the head movement of the passengers and drivers using an artificial neural network [for details on this issue see Saruchi et al. (2019) and Saruchi, Zamzuri, Hasan, & Ariff (2018)]. Vertical acceleration, however, may be the largest contributor to motion sickness incidence, but only combined with other motions, such as roll velocity and lateral acceleration, will motion sickness be experienced (Ekchian et al., 2016). Also, low frequency translational motion is a crucial cause of motion sickness in cars (Diels & Bos, 2016; Griffin, 2012). Even if the relative effects of vertical and lateral oscillation have not been studied extensively, Donohew & Griffin (2004), concluded that for 0.0315 to 0.2 Hz lateral oscillations having the same peak velocity, the probability of mild nausea increases with increasing frequency of oscillation. In conclusion, some experiments have shown that motion sickness cannot be correlated to a specific motion or occurrence but is an accumulated effect from multiple stimuli caused by vehicle motion. Road surface, vehicle speed, frequency of curves in the road, vehicle displacement, traffic conditions, weather conditions, ambient light, among other, are variables that need to be considered (Ekchian et al., 2016).

2.1.2. Motion sickness and automation

Self-driven cars will liberate its passengers to do different kinds of non-driving related activities. The issue in this situation is that it makes the user much more susceptible to motion sickness.

It is expectable that people's "spare time" will be used to work or consume media using devices such as tablets, laptops, or in-vehicle displays (Diels & Bos, 2015). Either way, when engaging in these activities, the sensory channels do not provide a consistent cognitive model, as the somatic and vestibular systems are detecting motion, but the visual system is not. The mismatch between the expected combination of sensory

signals and the experienced combination of sensory signals, it is known as sensory rearrangement (Mansfield, 2017). As mentioned previously, this conflict raises an important concern regarding motion sickness.

Besides the conflict between the vestibular and visual inputs, the inability to anticipate the direction of motion and the lack of control over the direction of motion, contribute to this physiological response to motion (Sivak & Schoettle, 2015). It is frequently suggested a scenario for self-driving cars, in which drivers and front seat passengers can swivel their seats and face each other, turning the car into a social space (Diels & Bos, 2016). The absence of a clear view of the road ahead means that the ability to predict the future motion path based on visual information may be compromised (Diels & Bos, 2016). Facing rearwards not only reduces the ability to anticipate the future motion trajectory, it also increases the likelihood of conflicting visual-vestibular motion cues (Salter, Diels, Herriotts, Kanarachos, & Thake, 2019). In sum, vehicle automation can be predicted to increase the likelihood and severity of motion sickness, or what Diels & Bos (2016) refer to as “Self-Driving Carsickness”.

2.1.3. Sensory Cues

According to the Psychology Dictionary, a sensory cue is *“a sense stimulus that evokes a response or a behavior pattern”*. In this project, specifically, the researched cues were visual, haptic, audio and olfactory, and the intention is to evoke a response from the user’s body answering MS symptoms or mitigating them.

The following chart represents the quantitative distribution of the specific countermeasures of sensory cues explored in the found literature, named visual, haptic, audio and olfactory cues.

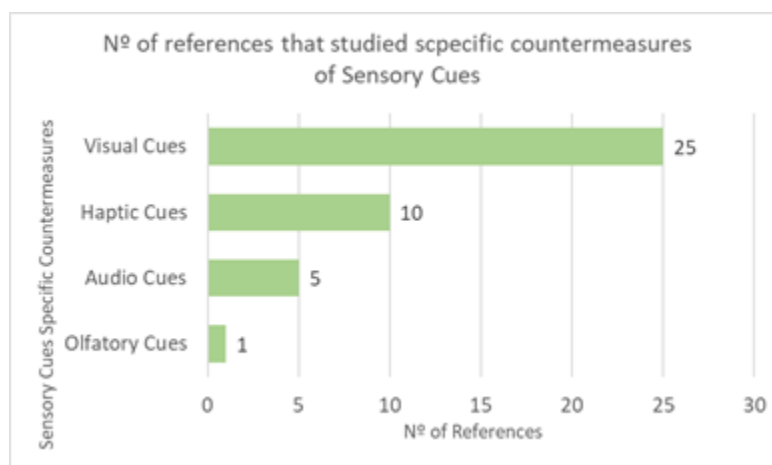


Figure 1 – Quantitative distribution of Specific countermeasures of sensory cues.

Most of the sensory cues of UIs are visual. Nevertheless, the use of haptic and audio cues also stood out in the study of countermeasures. Olfactory cues were only cited by one author. In this document only the visual, haptic and olfactory cues will be explored since the audio cues were to be researched by a different team with specific skills for the creation of audio prototypes.

2.1.3.1. Visual Cues

Visual cues are associated with movement prediction to avoid, as much as possible, the conflict of information between what is expected and what will be felt by the sensory system. All measures that reduce it may be useful to mitigate MS, once they can prevent factors that might cause nausea, and promote psychological factors which enable the sufferer to deal efficiently with his/her condition (C Diels, 2009).

There are several proposed guidelines under the visual cues. As mentioned before, maintaining a good view of the road ahead is associated with the ability to estimate the future motion path. Nevertheless, in all situations that compromise visibility, especially in a scenario of AV's with huge use of displays, there will be a reduction in anticipation of body movement, highly correlated with MS' development (Wada, 2016).

Towards finding new approaches, broad considerations have been made regarding the visual information received through the peripheral vision, to assemble information on the direction of travel and the adjustments in the velocity (Cyriel Diels & Bos, 2015; Cyriel Diels & Bos, 2016; Kuiper et al., 2018a; Mu, Chien, & Wu, 2020; Kuiper et al., 2019; Smyth et al., 2020).

Recently, a French company (Boarding Ring) begun selling a pair of glasses filled with a blue liquid claiming that they reduce MS symptoms. The patented medical device, the Boarding Glasses, respond to the accelerations of the vehicle, and the liquid moves around the eyes in the frontal direction (right-left) and in the sagittal direction (front-back). In the available commercial website, the technology used is explained: "It creates an artificial horizon in the peripheral field of view, without disturbing the central vision (Bording Ring, 2020). The eye then has access to the reality of the moves, the sensorial conflict instantly disappears and MS fades in a few minutes" (Jeannin, Eole, Wright, & Ring, 2016).

In line with the above-mentioned study, Kuiper, O. and Bos, J. (2018), developed an experiment to test the hypothesis that increasing peripheral vision can reduce car sickness. For that, displays were used in different positions, 1) eye-height in front of the windscreen, providing considerable peripheral out-the-window view, and 2) at the height of the glove compartment, offering considerably less peripheral vision. Kuiper found a 43% reduction of illness scores. In another experiment, Salter et al., (2019) found a slight difference in

subjective scoring (17%), even so stated that “the looking down condition takes longer to recover due to a deeper level of assumed motion sickness”.

Mu, Chien, & Wu (2020), also considered the importance of peripheral vision. The authors developed a navigation information system to present the navigation information in the peripheral area, positioned above the passengers’ reading device to allow participants to read a text and simultaneously perceive the driving information.

The results show a minor decrease in the reduction of MS, although with evidence in reducing the onset of symptoms.

Despite the redundancy of the results, it is still paramount that the perception of movement could be inferred through the peripheral vision (Smyth et al., 2020), for being a modulation factor when the central vision is limited, decreasing false perceptions of self-motion (Kuiper et al., 2018). Notwithstanding the foregoing, Kuiper, O., Bos. J. Diels, C. and Schmidt, E. (2020), established that audio or haptic cues may be more desirable than visual, due tovection and cybersickness that may increase MS.

An alternative approach to reduce MS could be the inclusion of a light base system. In fact, lighting technologies simulating optic flow, such as Organic Light Emitting Diodes (OLED), may prove to be promising (Cyriel Diels, 2014). This visual cue is meant to reduce the sensory conflict between the perceived acceleration and the lack of matching visuals.

Sivak et al. (2018) disclosure a system with “a light matrix system configured to output visual stimuli presented only in a peripheral field of view of the user, and a controller outputting a control signal to the light array system configured to activate the light array system in such a way as to mimic the visual input one would receive if one were to look outside the vehicle”. The patented device suggests that the moving lights resemble the moving brain. The device seems to consider the neural bases of MS, combining visual field rotation with rotation in space (Cohen et al., 2019).

Another product was presented by Sweeney, M & Bartel, E. (2017), providing visual information. The developed system uses “a light base that is activated in order to warn the passenger before performing each maneuver and so signal the future motion path”.

In line with the above-mentioned Karjanto et al. (2017) proposed to assess the level of situation awareness (SA) and MS when users are watching a video and subjected to accelerations produced by automated

defensive driving style. This time, a light- based prototype was placed within the users' peripheral field of view to indicate the future direction of the automated car.

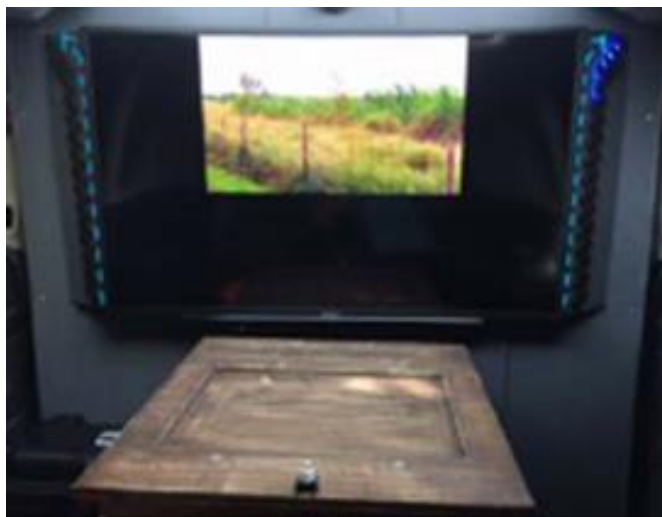


Figure 2 - Bin Karjanto et al., 2017 - Passenger's field of view with visual prototype superimposed with dashed blue arrow.

A within-subject design with two different conditions: a baseline condition (BC) with no cues on the behavior of the vehicle; and a visual condition (VC) in which cues were provided by visual means (LED stripes) placed within the peripheral vision area. The visual prototype's function was designed to deliver feed-forward intention of the car (3 seconds prior to turning left or right). The LEDs would continuously move along the shape four times within three seconds to indicate that the curves are coming. Results indicated that the visual prototype had a favorable decrease in MS level when compared to baseline.

Recently, Novares launched a MS device also using lighting technologies. In the available commercial website, the technology applied is explained: "My Travel Therapy® is a motion sickness prevention device which creates a virtual horizon. It enables passengers to read a book, work or even surf on their tablet computer without getting motion sickness" (Novares, 2017).



Figure 3 - Illustration of My travel Therapy® device.

The increasingly number of e-readers that take advantage on autonomous commutes, led to a study by Miksch, Steiner and Meschtscherjakov (2016) in which participants were presented to the Motion Sickness Prevention System (MSPS) prototype, an approach that allows reading while driving observing the road, decreasing the symptoms of MS. It simply uses the live video stream of the road ahead as a background for reading, providing the eye with a moving image, corresponding to the information the motion sense receives.



Figure 4 - Miksch et al., 2016 - Behind a text visualized on a semi-transparent background, a live video stream from the webcam is shown.

However, due to the small sample size, the authors noted that results could not be generalized, even if the general conclusion points to MSPS as having the potential to lower negative effects of MS for some people.

Hanau and Popescu (2017) also investigated a solution for MS mitigation for those who use e-readers while traveling. Using an e-reader application, they provided the users with visual cues of the acceleration to

eliminate the sensory mismatch that is thought to cause MS. The results were inconclusive, as no significant differences were found between the group assigned to the control condition involving a conventional e-reader application, the Text Inertia condition group that provided acceleration cues through the displacement of the text, and an animated Gizmo condition group where acceleration was displayed through displacement of a ball and spring animation.

Given the inconclusive results, the authors have drawn attention to the need for investigating additional visually conveying acceleration cues (e.g. a virtual window simulated through augmented reality).

Weißgerber & Damböck (2012) used a contact-analogue Head-up Display (HUD) to provide the driver an augmented view road ahead indicating the vehicle's future trajectory and found good technology acceptance (Cyriel Diels & Bos, 2016 citing Weißgerber & Damböck, 2012). Feenstra et al. (2011), in a simulator study, providing information about earth fixed horizon in flight environments, found a reduction in average of 50% of sickness (Salter, Thake, et al., 2019 citing Feenstra et al., (2011). Likewise, Krueger, WWO., Bonato, F. & Bubka, A. (2017), used an eye worn display with specific user orientation symbology and demonstrated the efficacy of reducing MS and vection when an artificial horizon is used. In fact, visual fixation is also used to suppress eye movements, hence reducing MS (Peißl, Wickens, & Baruah, 2018). Recently, Robert et al. (2018) launched a Virtual Immersive display. This Apple patented device includes a head-mounted device (HMD) that displays the frames to the passenger, whose goal is to replace the real world with a virtual world that matches the visual cues with vestibular and sensory information”.

Despite the proven importance of visual cues to mitigate MS, the use of displays with visual information needs further investigations, since the display can itself be a source of MS. For that reason, it should be safeguarded the mitigation of MS rather than the increasing of it (Dobie, 2019; Kuiper et al., 2020).

2.1.3.2. Haptic Cues

The results found for haptic cues were entirely related to the use of vibrations as cues for the users. That is something that has already been developed and exists in our society, so all this information was discarded for this study. For the haptic cue there was the need for an innovative solution with no direct reference.

2.1.3.3. Olfactory Cues

According to the data in the present study, the use of olfactory cues is the countermeasure less referred to and explored. Moreover, the studies that considered this cue presented inconclusive results. For now, there is no significant evidence that by providing olfactory cues to passengers the symptoms of MS will reduce.

Nevertheless, a study by Keshavarz, Stelzmann, Paillard and Hecht (2015), revealed that a pleasant odor can potentially reduce MS. Participants were randomly assigned to one of three groups; pleasant odor (rose), unpleasant odor (leather), and no odor. During the experiment, symptoms were measured using a verbal rating scale (0-20) and the Simulator Sickness Questionnaire. Results showed that among the participants who did notice the odor (half of the participants), the rose scent significantly reduced the severity of the symptoms compared to the group that did not notice the odor. Although it seems promising, its impact on driving performance variables has not been tested (Gálvez-García et al., 2020)

2.2. 3D Modeling Software

Used in animation, game design, architecture, manufacturing, and product design, 3D models play a crucial role in digital and physical production. At the moment there are almost one hundred 3D modeling software available to users. Some are freeware (no monetary cost to the end user), like Blender; but most are commercial software, like 3ds Max. Inside the commercial software there are also freemium software which offer a free basic version of the product, but to unlock more functionalities the user must pay for it, like SketchUp for example. Of all these software only a few were taken as possibilities to be used in this project.

2.2.1. Blender

Blender is a very powerful 3D modeling software and is considered by many the “Swiss Army Tool” when it comes to create 3D content. Blender is open source, meaning the involvement of the community that uses it feeds back into its improvement and pushes its usability and feature set.

Upon startup, Blender offers a variety of workspaces for different kinds of use. This includes animation, video editing, visual effects, sculpting and the “general” workspace where is possible to access the modeling workspace.

In the beginning this software was infamous for its overwhelming menu options and difficulty, but these are issues of the past. Nowadays, Blender presents a much cleaner UI and there is an immense tutelage from

the Blender Foundation and from the community alike, that allow newcomers to find the software easy to learn and use.

Besides all this features, what really sets Blender apart from other 3D software is its render engine - Eevee. Eevee was added to Blender 2.8 back in 2019 and became one of the best possible choices for rendering as it is not a raytraced render engine. Instead of computing each ray of light, Eevee uses a process called rasterization that estimates the way light interacts with objects and materials using numerous algorithms.

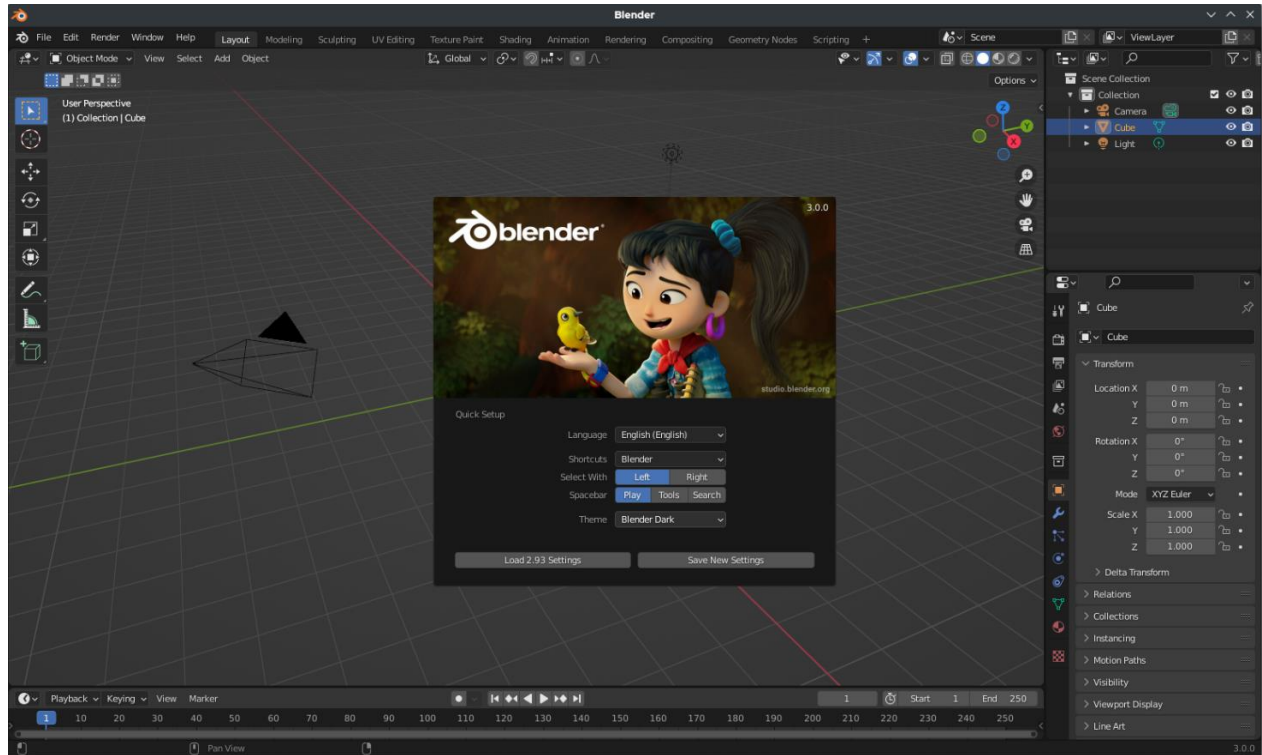


Figure 5 - João Martins, 2022 - Blender interface.

2.2.2. SketchUp

SketchUp is a 3D modeling software known for its simplicity and ease of use. Its modeling capabilities are mostly pointed at hard surface modeling and is mostly used to put together visualizations of interiors of buildings. The software also comes with a community driven warehouse repository where users can upload their own models or download 3D models uploaded by other users.

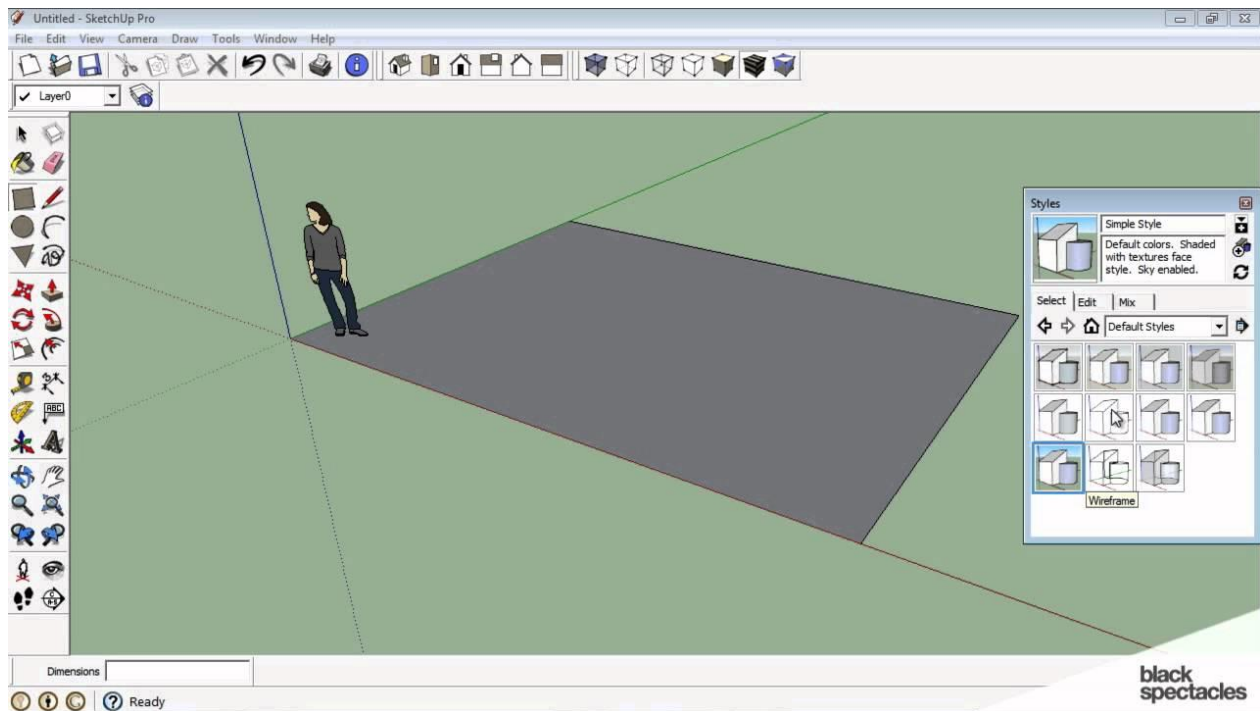


Figure 6 - Black Spectacles, 2012 - Sketchup interface.

2.2.3. Solidworks

Solidworks is a solid modeling computer-aided design (CAD) and computer aided engineering (CAE) computer program published by Dassault Systèmes. It utilizes a parametric feature-based approach to create models and assemblies. Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric, such as line lengths or circle radius; or geometric, such as tangent or parallel.

Creating a model in Solidworks starts with a 2D sketch. This sketch is composed by points, lines, arcs and others. From this sketch the 3D model can be created using extrude tools. On this new shape, new sketches can be created in order to add or remove components to the 3D object.

In assembly, the user is allowed to bring different parts together and assemble them into an object using the relation known as mates. Assembly mates define relations, such as tangency or parallelism, between parts allowing an easy construction of assemblies.

From created parts or assemblies, the user can create drawings. Views of the part or assembly and generated from the model and notes such as dimensions and tolerances can be easily added to the drawing as needed.

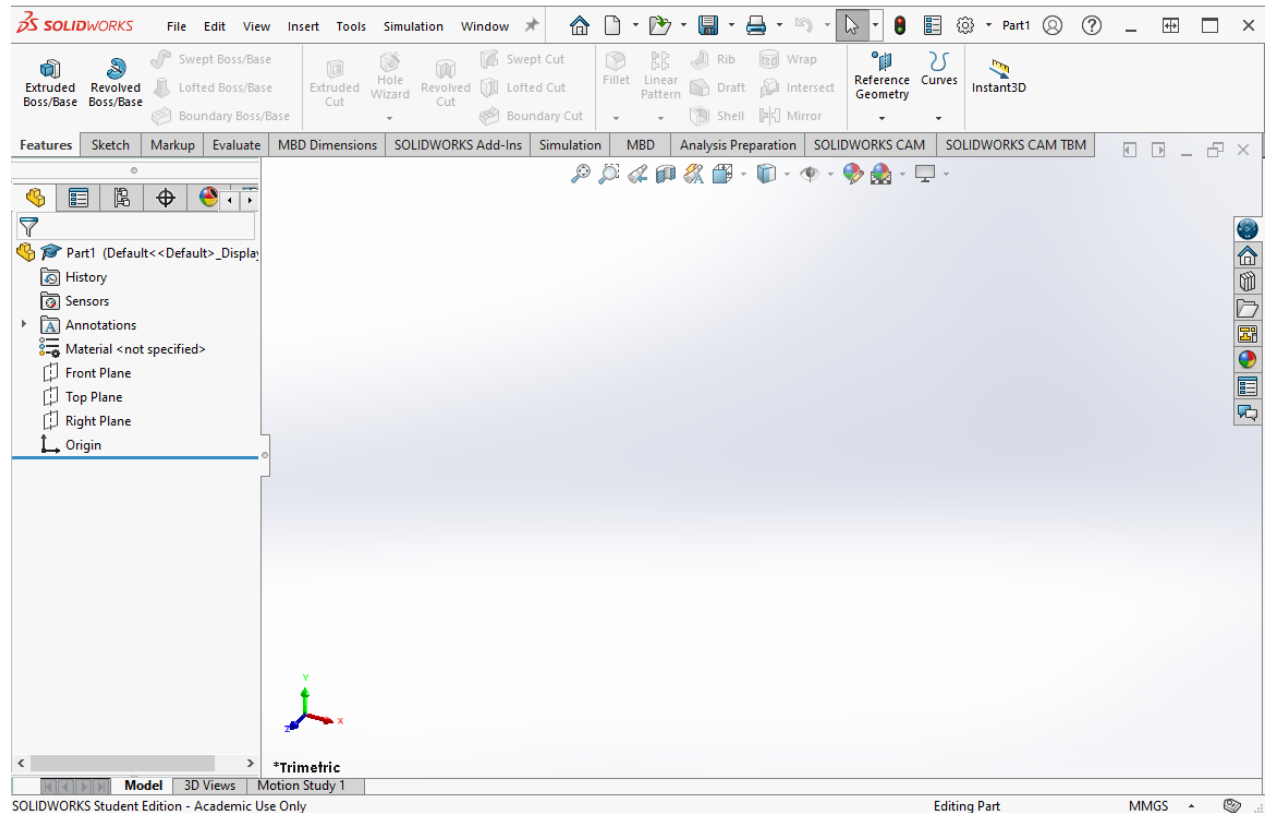


Figure 7 - João Martins, 2022 - Solidworks interface.

2.2.4. 3ds Max

3ds Max, originally called Studio 3D, is a software created in the early nineties. The span of time of this product in the market means there is a lot of knowledge available online for it. Besides knowledge for the software, plugins and libraries that add greater functionalities can be added.

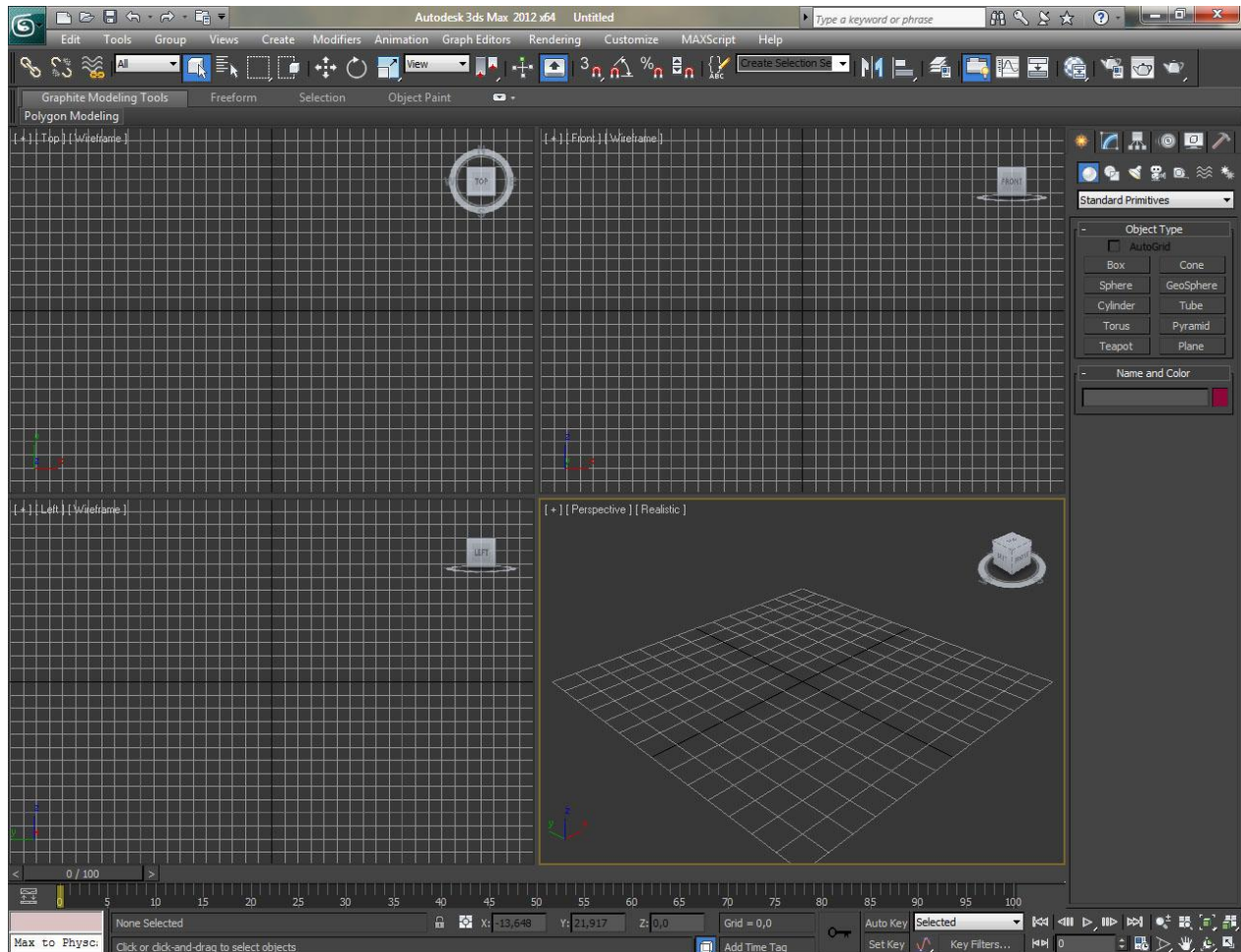


Figure 8 - reagannism, 2015 - 3ds Max interface.

2.3. 3D Printing Technologies

3D printing is a process of additive manufacturing. After creating a design in a 3D modeling software, a 3D printer can create a physical copy of the object by adding layer upon layer of material until the shape of the object is formed.

2.3.1. Stereolithography (SLA)

Stereolithography uses a vat filled with liquid plastic as the source material. This plastic is transformed into a 3D object layer by layer using an Ultraviolet laser to trace a pattern on the liquid resin from the bottom of the vat that cures and solidifies the plastic. As the laser solidifies the plastic, a lifting platform progressively drags the 3D object up until the object is complete.

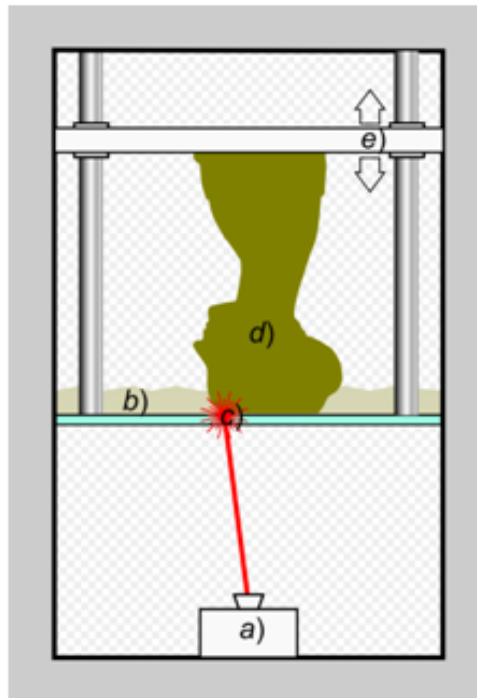


Figure 9 - TechPats - SLA printer working scheme.

2.3.2. Digital Light Processing (DLP)

DLP printing is very similar to Stereolithography the main difference is that it uses a different light source and makes use of a liquid crystal display panel. This technology makes use of a more conventional light source and it is controlled using micro mirrors to control the light incidence on the surface of the object being printed. The liquid crystal display panel works as a photomask. This allows a larger amount of light to be projected onto the surface to be cured, allowing the resin to harden faster.

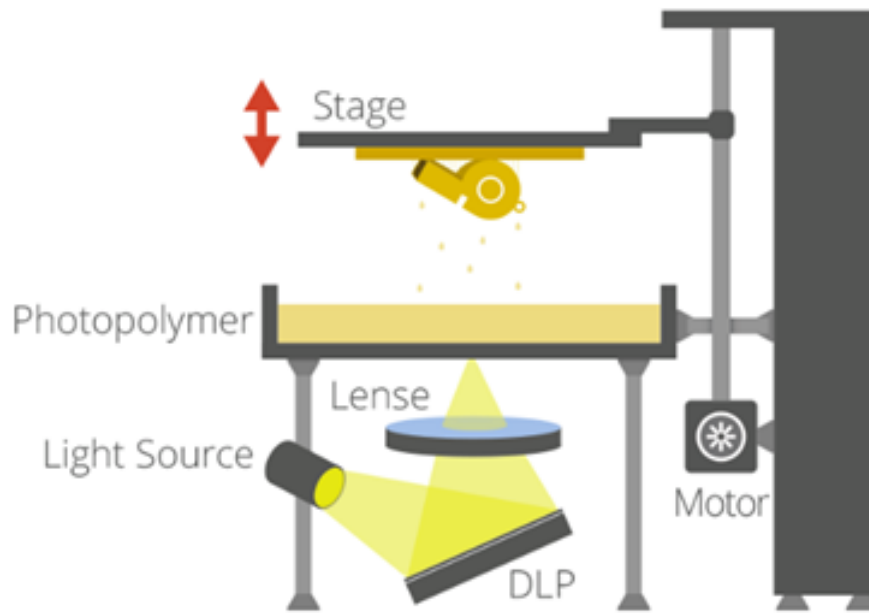


Figure 10 - Bitfab - DLP printer working scheme.

2.3.3. Fused Deposition Modeling (FDM)

FDM printing consists on the heating of a thermoplastic filament to its melting point and then extruding it layer by layer forming the intended 3D object. The printer can extrude a second material that will be used as a support material to help the first material stay at specific heights while it hardens.

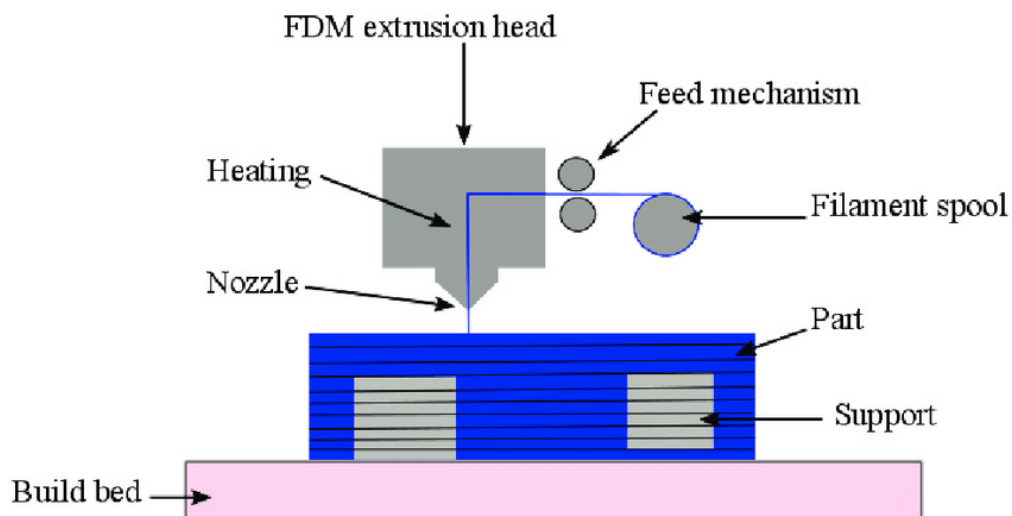


Figure 11 - Scientific Research, 2017 - FDM printer working scheme.

2.3.4. Selective Laser Sintering (SLS)

SLS is a technology that uses a high-power laser to sinter small particles of polymer powder, in a vat, into a solid structure based on a 3D model. The powder that is not sintered serves as support for the 3D object and can be reused for more printings. SLS 3D printing has been a popular choice for engineers and manufacturers for decades. Low cost per part, high productivity, and established materials makes the technology ideal for a range of applications from rapid prototyping to small-batch, bridge, or custom manufacturing.

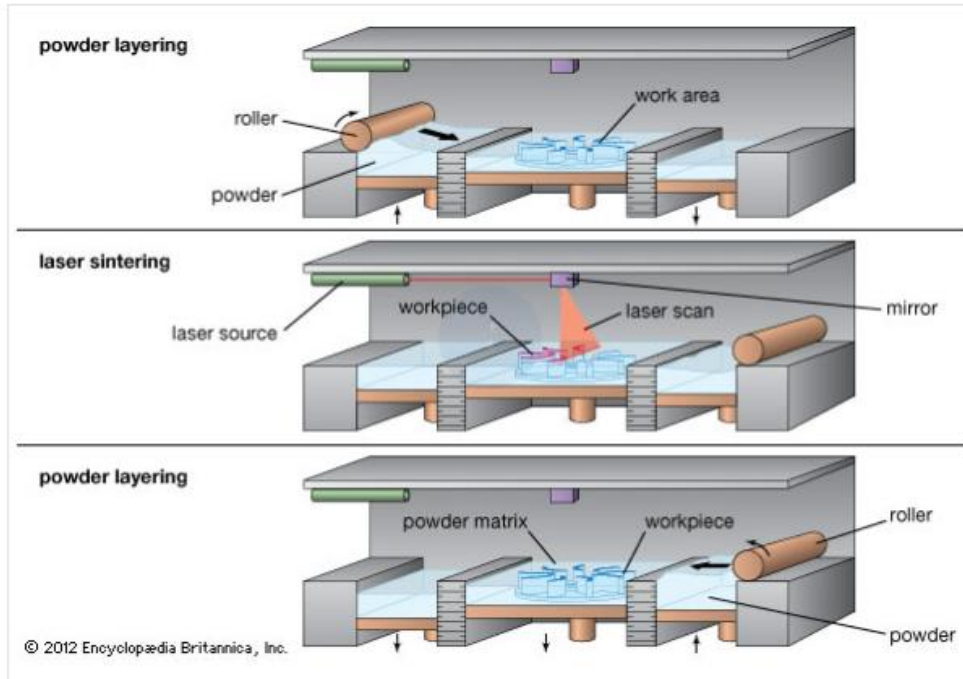


Figure 12 - TechPats - SLS printer working scheme.

2.4. Selected Working Tools

2.4.1. Blender

Blender is the free and open-source 3D creation suite. It supports the entirety of the 3D pipeline—modeling, rigging, animation, simulation, rendering, compositing and motion tracking, even video editing and game creation.

In this project, Blender was used to create several 3D mockups to showcase what certain products would look like after production and for game creation purposes related to the visual cues.

2.4.2. Solidworks

The Solidworks CAD software is a mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings.

In this project, Solidworks was used to create 3D models for 3D printing. Moreover, the software was used to create detailed drawings of parts to be produced in an industrial setup and was also used to create mockups to showcase what final products would look like.

2.4.3. Unity

Unity is a 3D/2D game engine and powerful cross-platform IDE for developers. Let's break down what this means. As a game engine, Unity can provide many of the most important built-in features that make a game work. That means things like physics, 3D rendering, and collision detection.

In this project, Unity was solely used to create the final versions of the visual cues, in place of Blender.

2.4.4. Photoshop

Adobe Photoshop is the predominant photo editing and manipulation software on the market. Its uses range from the full-featured editing of large batches of photos to creating intricate digital paintings and drawings that mimic those done by hand.

In this project, Photoshop was used to create 2D assets to be used in the visual cues project.

2.4.5. 3D Printing Technology

Selective Laser Sintering (SLS) is an additive manufacturing technology that uses a high-power laser to sinter small particles of polymer powder into a solid structure based on a 3D model.

The material used by the printer is polyamide (PA). This material is a semi crystalline thermoplastic with low density and high thermal stability. It also presents an outstanding wear resistance and a good coefficient of friction.

In this project, SLS 3D printing was used in the prototyping of all the parts for the air flow systems and a piece for the feet platform.

3. Feet Platform

3.1. Haptic Cues

Haptic cues are supposed to inform the user through physical interaction. For the haptic cue it was required a platform where the user would rest his feet. The platform will then pitch and roll in a 15° angle, emulating the vehicle's actions. For the platform to fit in the car, the floor measurements must be taken in to consideration, and for the user to be comfortable with his feet on the platform, the products height must be as small as possible.

The mechanism that allows the platform to pitch and roll are four robotic arms that control the platform. To avoid displacement of the platform a pillar goes through the center forcing the platform to that location. Just like with the video projection, this platform is controlled by the car's route prediction system and it moves one second ahead of time.

3.2. Problem Description

When a user is in a self-driven car but has no visibility to the outside it's impossible to know when the car will accelerate or turn. To solve this issue, one of the proposed ideas was the Feet Platform. It is a motion sickness mitigation system that will help the user understand when the car is accelerating, slowing down, or turning.

3.3. Design

Five different solutions were explored for the Feet Platform: the Linear Motors Solution, the Step Motors Solution, the Motorized Goniometers Solution, the Cables Solution and the Mechanical Arms Solution. Each solution presents advantages and disadvantages which were taken in consideration while choosing the best fit for the project

3.3.1. Linear Motors Solution

This was the first implemented solution that works with linear motors placed on the center of two of the sides of the platform, with the objective of moving it while keeping up with the maneuverability of the top plate, using a cardan and spinning discs.

Unfortunately, the flexibility offered by the cardans and the spinning discs attached to the linear motor were not enough to keep up with the top plate maneuverability. But not only that, the total height of the device would also surpass 20 cm making it impractical to place under the user's feet inside a car.

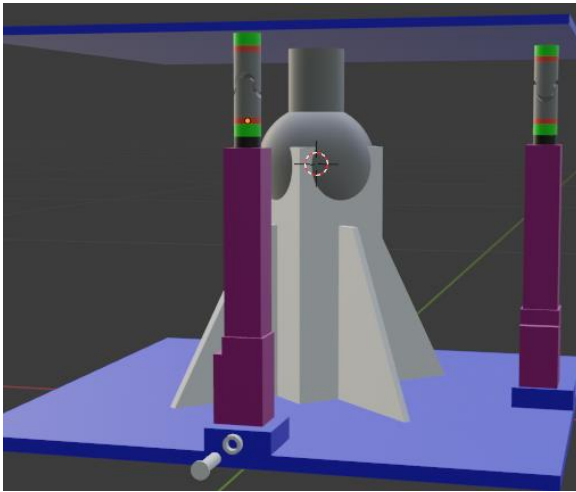


Figure 13 - João Martins, 2022 - Linear motor Feet Platform.

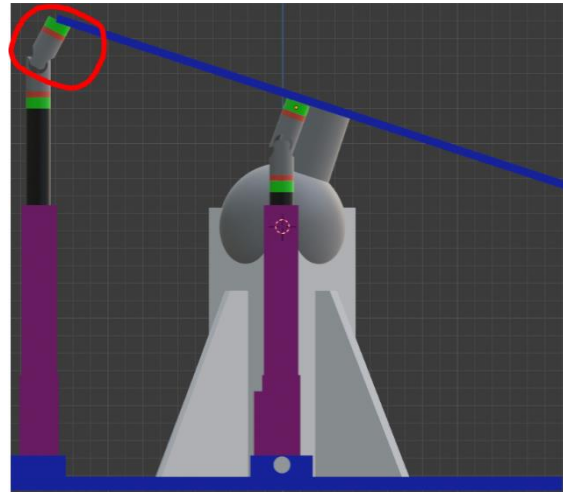


Figure 14 - João Martins, 2022 - Linear motor Feet Platform issue.

3.3.2. Step Motors Solution

This solution consists of four independent step engines, each one feeding a perpendicular screw, making the screw go up or down. Each screw has a ball top that is in contact with the top plate allowing the top plate to incline in any direction.

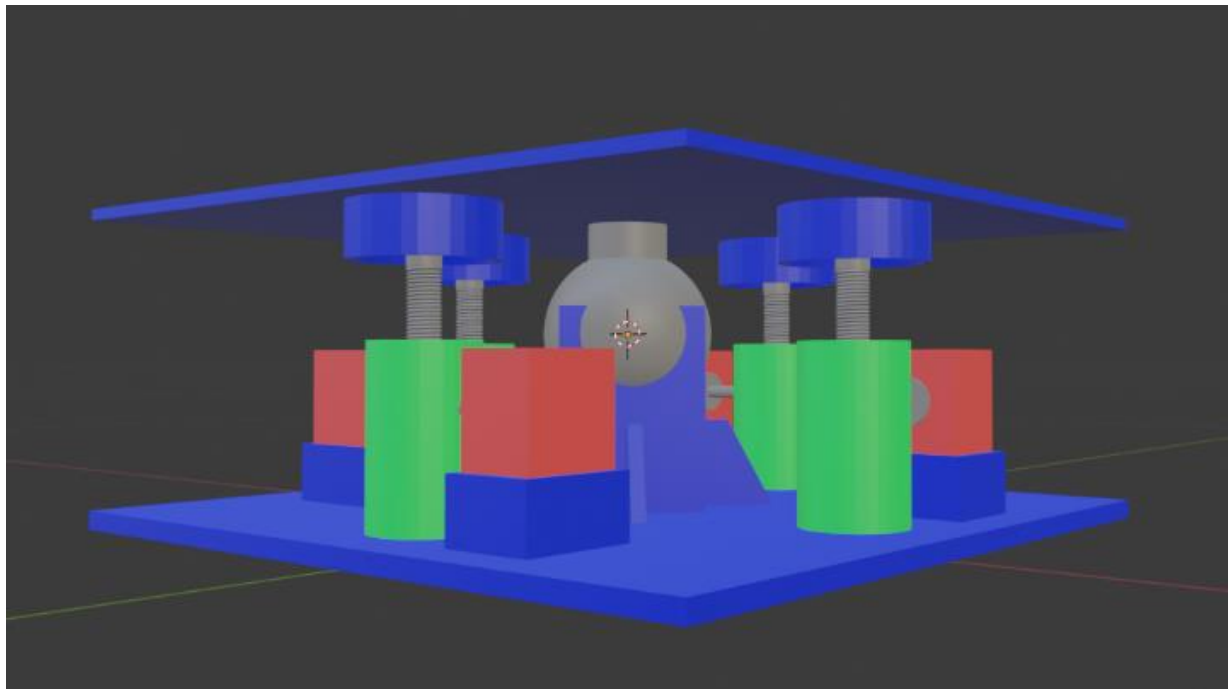


Figure 15 - João Martins, 2022 - Step motors Feet Platform.

Because of its high number of components that would make the prototype and its total height being about 15 cm this idea was discarded.

3.3.3. Motorized Goniometers Solution

Using motorized goniometers was the follow up idea of how to make the feet platform work. A motorized goniometer is a device used to rotate an object precisely, within a small angular range, about a fixed point in space. Goniometers are similar to linear stages, but, rather than providing linear movement, the stage partially rotates about a fixed point above the mounting surface of the stage. This concept is very simple: two motorized goniometers perpendicular to each other and one on top of the other allow the top plate to incline in any direction with smoothness and precision on the movement. To augment the curvature angle of the top plate, a small pillar was added between the top motorized goniometer and the top plate.

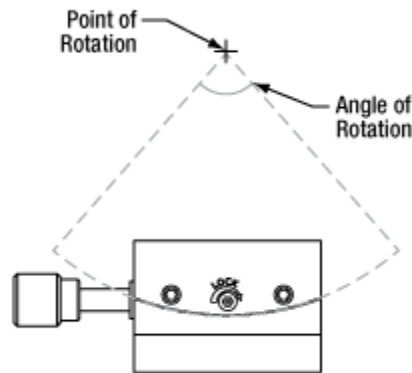


Figure 16 - Thorlabs - Goniometer Scheme.

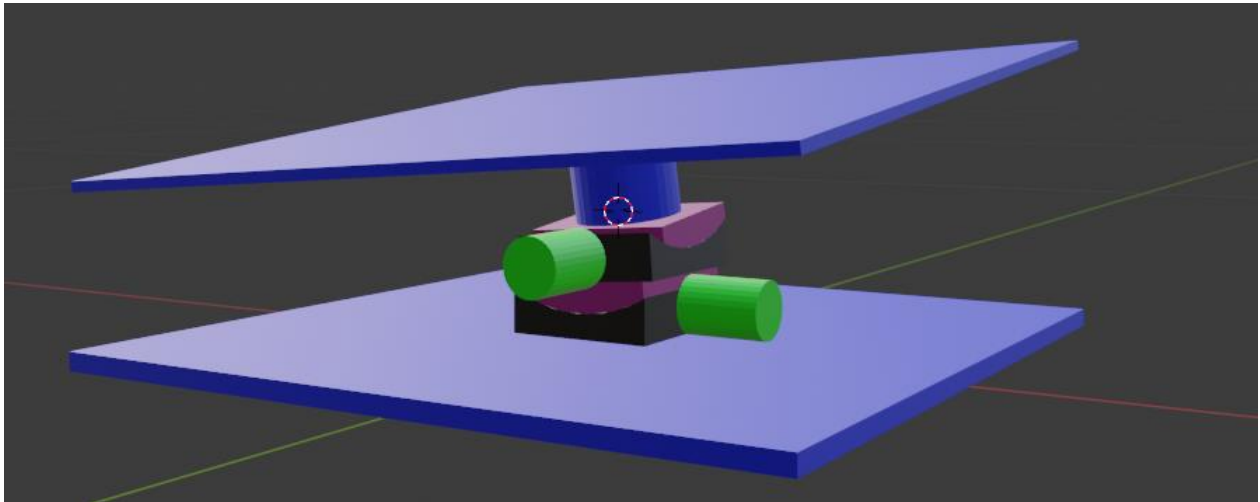


Figure 17 - João Martins, 2022 - Motorized Goniometer Feet Platform.

Motorized goniometers would present as the perfect solution for precision and smooth movement of the feet platform, but their high price in the market and the total height of the prototype being around 12 cm, this idea was also discarded.

3.3.4. Cables Solution

This solution is achieved by synchronizing two motors that allow the two cables to push down the sides of the top plate. The cable version was explored thoroughly and optimized from version to version. In total there were four different versions of this Feet Platform.

3.3.4.1. Version 1

The first version of this feet platform was still exploring the flexibility of the ball jointed tower in the center and because of that its height was too much to be acceptable as a possibility. The reason for this excessive height was the fact that the motors were being applied to the inside of the tower forcing the ball joint to be placed at a higher point.

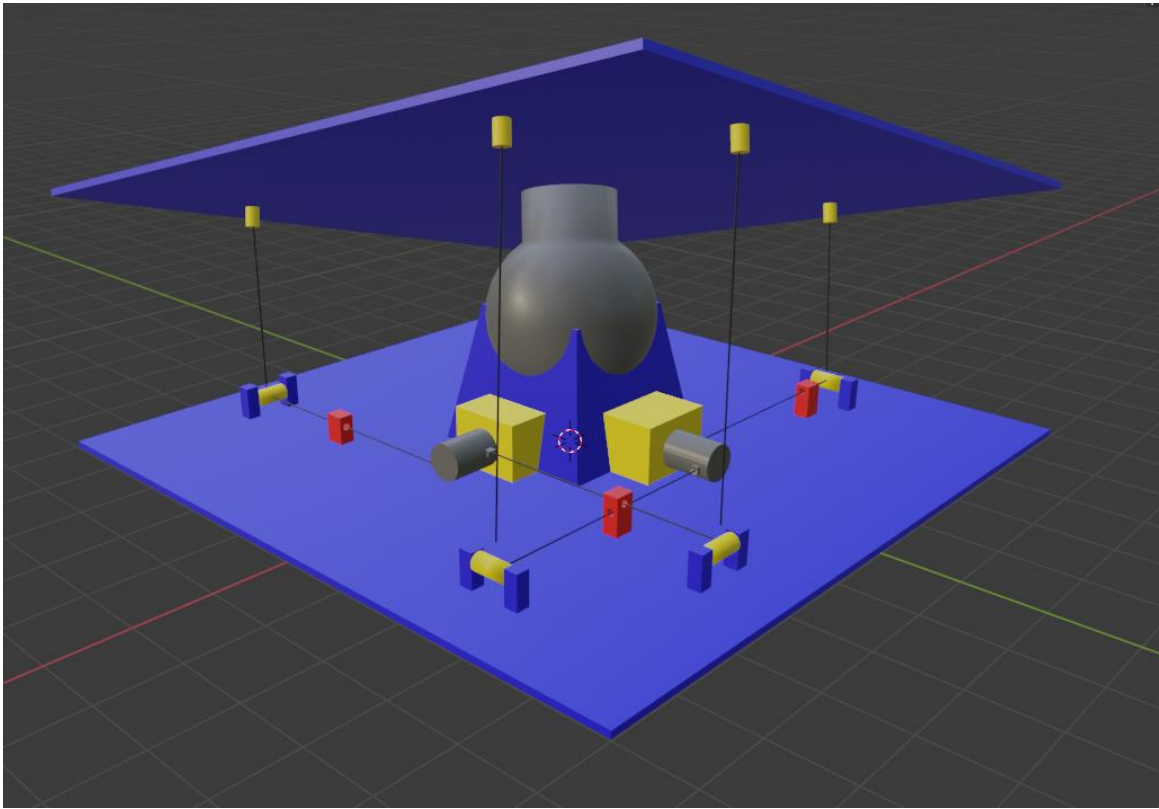


Figure 18 - João Martins, 2022 - Cables Feet Platform Version 1.

4.3.4.2. Version 2

The second version of the cable feet platform presented major upgrades compared to the first one. The motors were now placed outside the tower, allowing its total height to be lower compared to the previous version. The cables now cross the tower through two perpendicular holes at different heights (so there is no friction between the cables) allowing the cables to be centered allowing for a much better control of the feet platform.

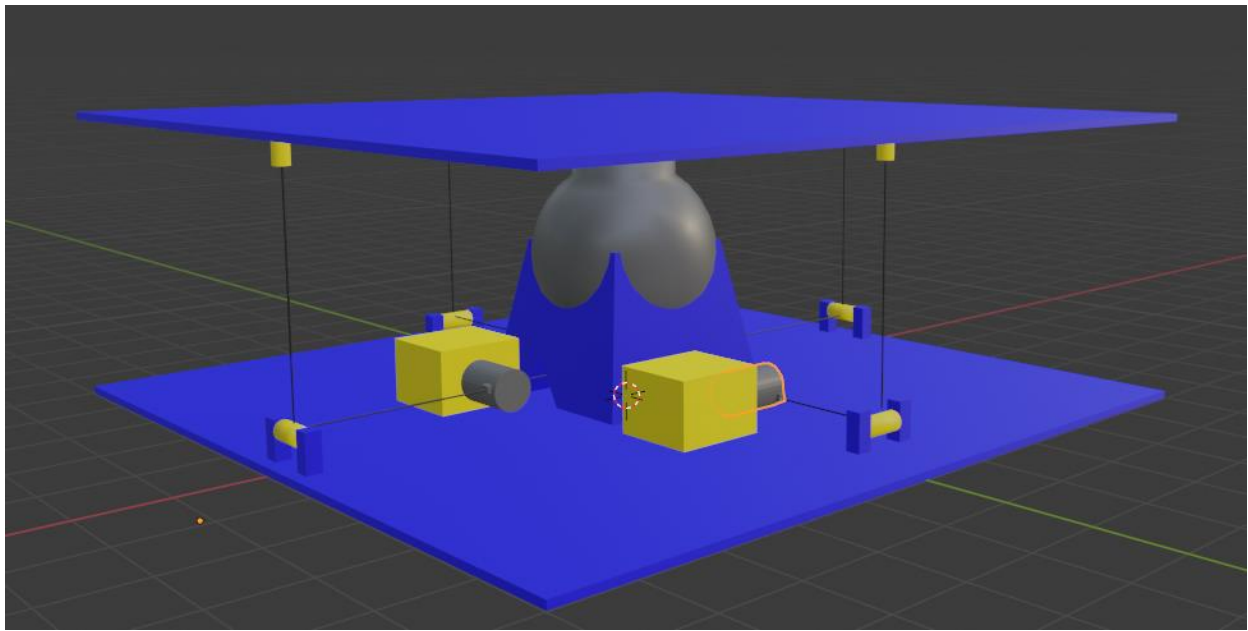


Figure 19 - João Martins, 2022 - Cables Feet Platform Version 2.

4.3.4.3. Version 3

The ball joint was presenting as a big height issue to the feet platform, therefore the priority for the third version was to find a mechanism that would still allow the top plate to roll and pitch.

The solution for this was to cross perpendicularly two cylinders at different heights, where the lower one rolls and the top works as an axis so the parts that attach to it can pitch. This would reduce the height of the feet platform considerably while maintaining the roll and pitch freedom of the top plate.

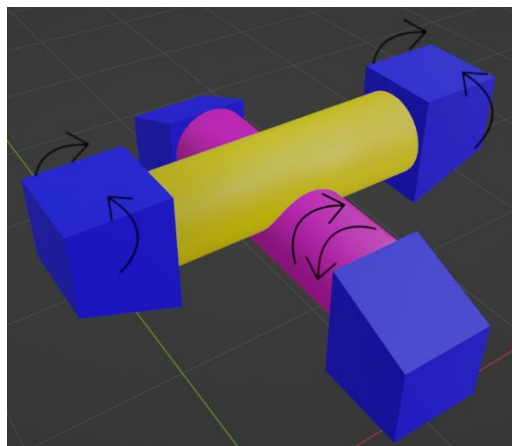


Figure 20 - João Martins, 2022 - Cables Feet Platform Version 3, Roll and Pitch mechanism.

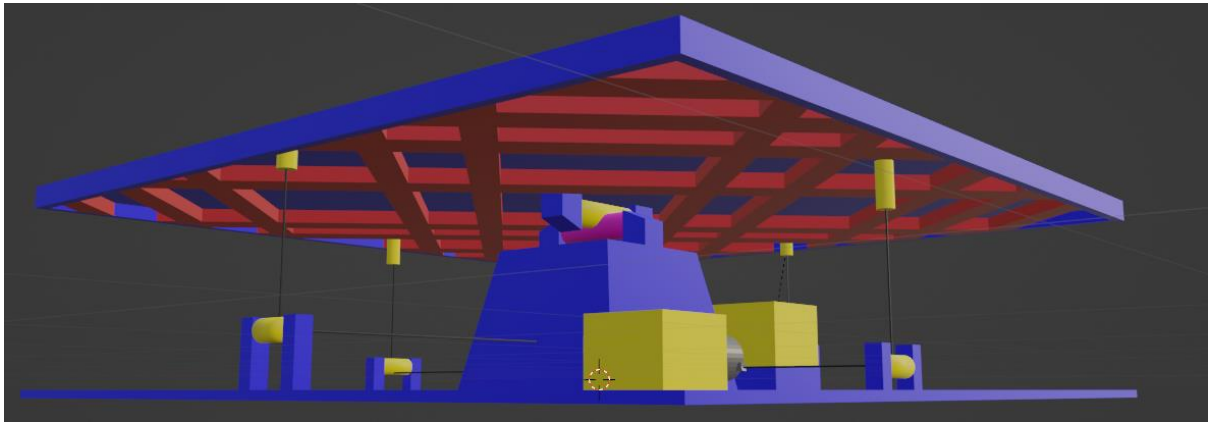


Figure 21 - João Martins, 2022 - Cables Feet Platform Version 3.

4.3.4.4. Version 4

The final version of the cable solutions for the feet platform does not add anything new to it, it is simply a fine tuning of the third version. This includes a major height reduction in the middle tower and a strengthening of the new joint that allows the top plate to roll and pitch, as well as adding cable guiding trenches to the cylinders that guide the cables towards the top plate. The fourth version was modeled using Solidworks to have the required precision to move it to production phase.

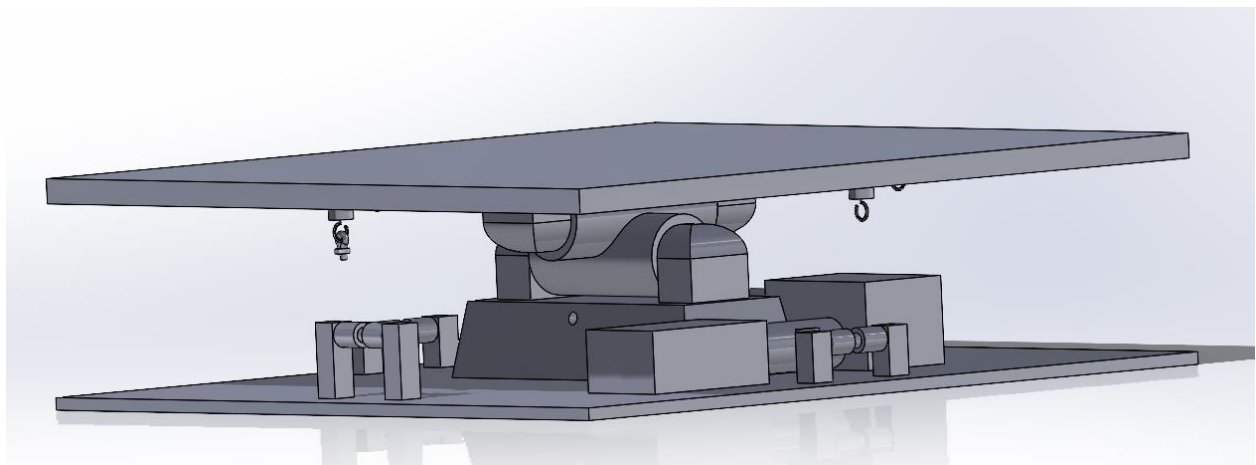


Figure 22 - João Martins, 2022 - Cables Feet Platform Version 4.

Unfortunately, at a pre-production stage, we discarded the idea because of concerns with the cables tension needing to be constant. If the cables don't maintain tension the top plate can become wobbly, putting in jeopardy the information being transmitted to the user.

3.3.5. Mechanical Arms Solution

This version of the feet platform is very different from all the other versions as the top plate is not in direct contact with the mid pillar and is only held by the four mechanical arms that are fixed to four servos. These servos control the movements of the mechanical arms, allowing the top plate to roll and pitch in a 90 degrees range (45° up and 45° down).

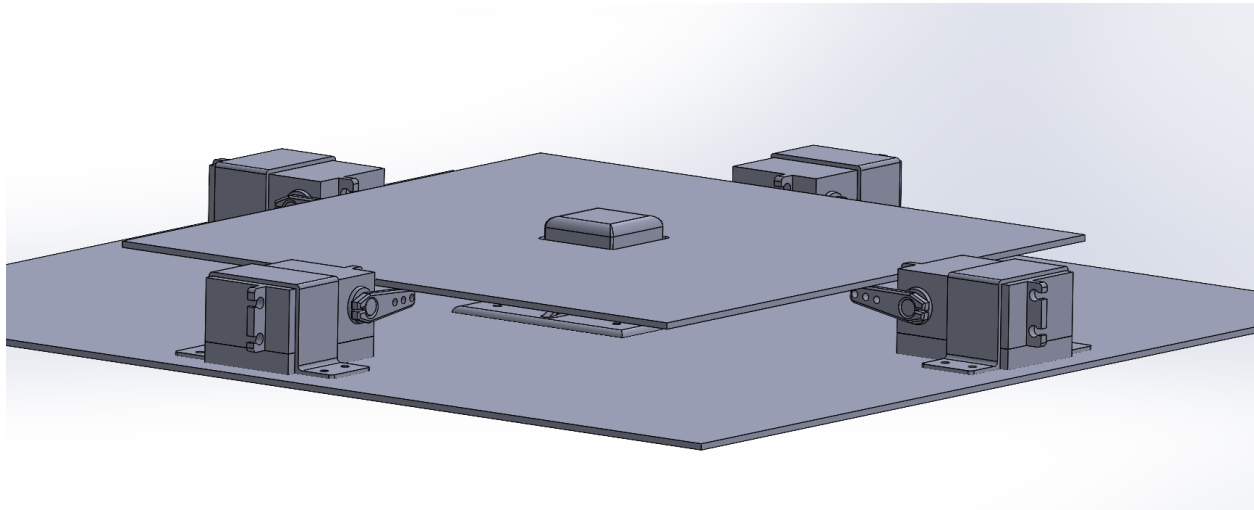


Figure 23 - João Martins, 2022 - Mechanical Arms Feet Platform.

4.3.5.1. Components

Base

The base holds the whole prototype together as all the components, except for the top plate, are fixed to it. It's a 2 mm thick square steel plate with 500*500 mm that presents a square hole in the center to accommodate the tower.

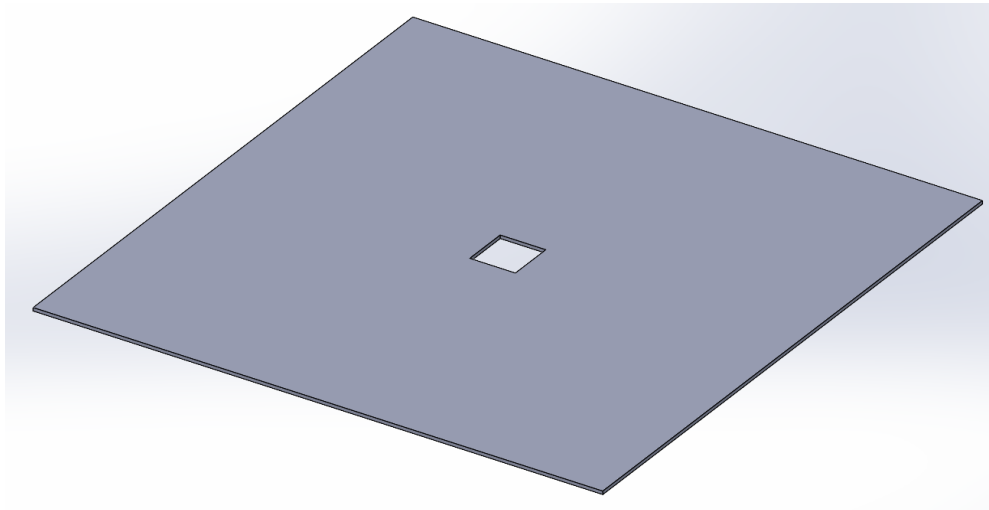


Figure 24 - João Martins, 2022 - Mechanical Arms Feet Platform – Base.

Wood Blocks

The wood blocks are 10 mm thick and work as a height boost for the servos.



Figure 25 - João Martins, 2022 - Mechanical Arms Feet Platform – Wood blocks.

Servos

The servos used on the prototype are from DSSERVO they measure 65*30*48 mm and weigh 162g each. Depending on the voltage fed to the servo the torque and speed may vary between 58kg.cm(6V), 65kg.cm(7.4V), 70kg.cm(8.4V) and 0.17sec/60°(6V), 0.15sec/60°(6.4V), 0.13sec/60°(8.4v).



Figure 26 - João Martins, 2022 - Mechanical Arms Feet Platform – Servos.

Servo Fixers

The servo fixers fit over and hold the servos and the wood blocks to the base using four screws and four bolts each.

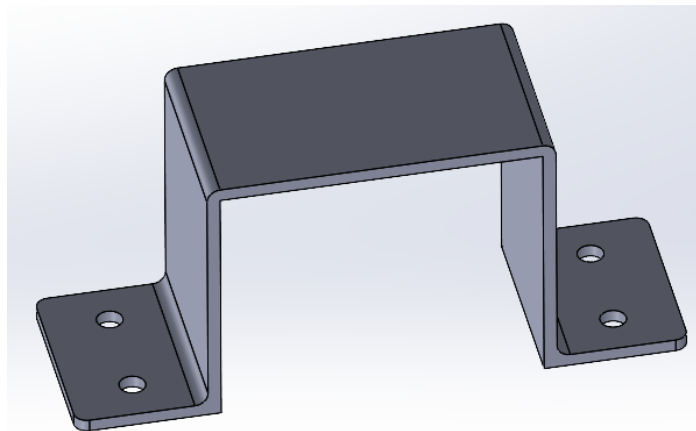


Figure 27 - João Martins, 2022 - Mechanical Arms Feet Platform – Servo Fixers.

Tower

The tower fits in the hole in the middle of the base and stops the top plate from rolling in yaw. The tower is fixed to the base by fitting it in the hole at the base and then using four screws and four bolts to make certain it does not pop out of place.

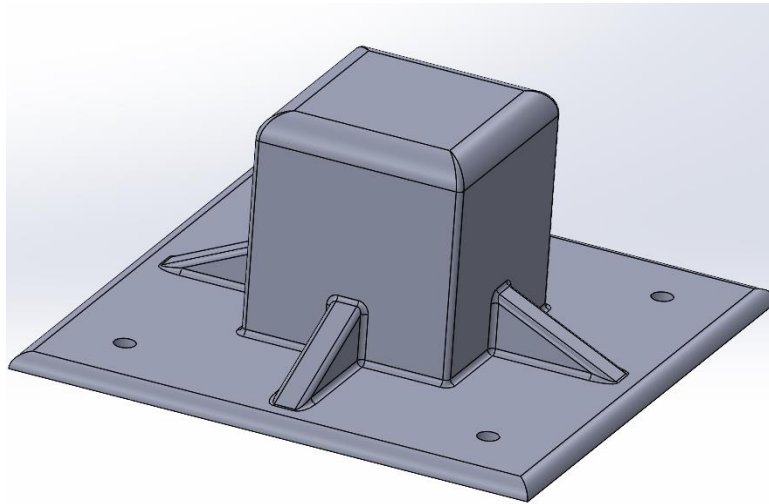


Figure 28 - João Martins, 2022 - Mechanical Arms Feet Platform – Tower.

Top Plate

The top plate is a 3 mm thick square steel plate with 320*320 mm that presents a square hole in the center to accommodate the tower.

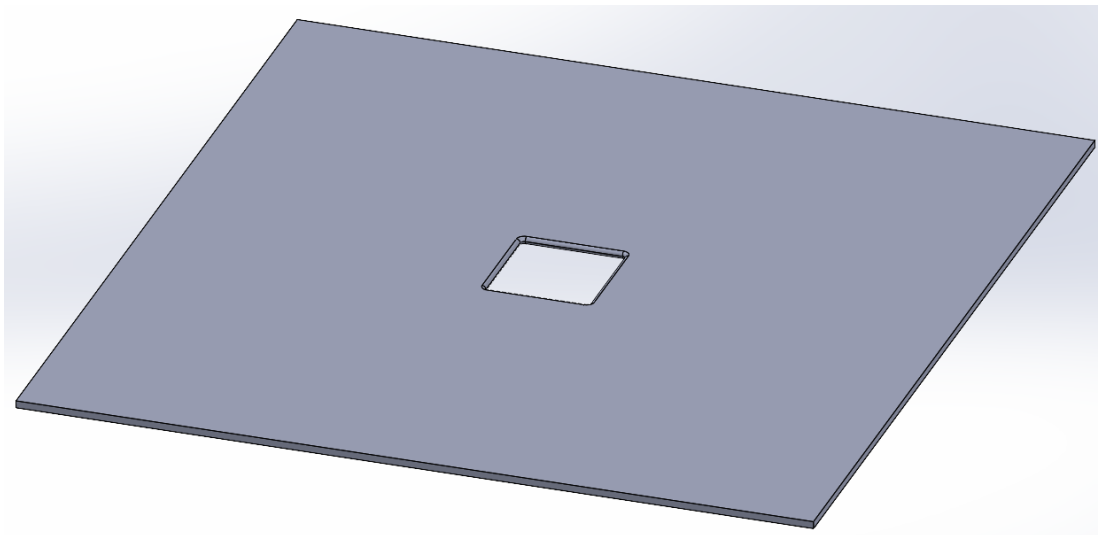


Figure 29 - João Martins, 2022 - Mechanical Arms Feet Platform – Top Plate.

4.3.5.2. Prototyping

The prototype was divided into three kinds of components: bought components, metal work components and 3D printed components. The bought components include the servos, the wood blocks that boost the height of the servos by 1 cm and any screws and bolts used to assemble the prototype.

Metal work components include the base plate, the top plate and the servo fixers. These components were produced in steel as it was required for these components to withstand the torque of the servos without damaging the prototype.

The tower in the center is the only 3D printed component. Polyamide offers very good strength and hardness as a polymer and it allows the prototype to work without producing too much noise when the top platform hits the tower while rolling or pitching.

As mentioned in the components the servo fixers fit over the servos on top of the woodblocks and are screwed to the base holding them in place. The tower fits in the base hole and gets screwed to it so there is no chance of it popping out and the top plate center hole fits over the tower and the top plate rests on top of the mechanical arms.



Figure 30 - João Martins, 2022 - Mechanical Arms Feet Platform prototype.

3.4. Conclusions

It was a huge challenge to find a solution that answered all the requirements that the Feet Platform had, especially the total height of the product. Multiple versions were envisioned before coming up with the mechanical arms solution. This solution allowed the platform to pitch and roll with the mechanical arms turning up and down to a maximum angle of 45° giving it a lot of liberty and the central tower prevents the platform from engaging in yaw movements. The mechanical arms also allow the whole system to have a very small total height which allows for a better implementation of the prototype for testing. The system works paired with the RPS and by inclining the user's legs, it is letting him know whether the vehicle is turning, accelerating, decelerating or braking.

4. Visual Cues

The visual cues are supposed to give subliminal visual information to the user, meaning the user does not have to focus on the cue to receive the information. The cue itself is supposed to be an animation that will emulate the vehicle's actions. For the car to accommodate this animation, and to give extra utility to the window covers, the decision was made to use small projectors that would present the animation on the window. The point of the window where the projection is shown, must be in the peripheral view range of the user. The animated body is controlled by the car's RPS and it moves one second ahead of the car itself. With this projection, even though the user might be focused on a tablet/laptop/book, the fact that he can catch a glimpse of the body's movement is enough to warn him of what the self-driven car is about to do.

4.1. Problem Description

When a user is in a self-driving car but has no visibility to the outside it makes it impossible for the user to know when the car will accelerate or turn. To solve this issue, one of the proposed ideas were the visual cues. It is a motion sickness mitigation system that will help the user understand when the car is accelerating, slowing down, or turning.

4.2. Design

The animation shown to the user would have to be interactive with RPS in order to act in accordance to the car's current trajectory. The solution for this was to create a videogame for the car to control. The animations in the videogame would act as cues for the user informing him if the car is going to turn or accelerate or decelerate. The project started being developed in Blender Game Engine, using Blender 2.79, to take advantage of the "Game Logic" system that simplifies the required programming to make the game work. When the project turned to a particle system basis, it was migrated to Unity for being a more powerful game engine with a deeper setup to personalize the particle systems.

4.2.1. Stream of Balls

The particle system used in the blender versions of the videogame was an artificial one. The spheres were placed between two planes that had a script attached to them that turned them into portals. When the spheres hit one of the planes, they get relocated to the other plane and are released from a random point within the plane's surface creating randomness in the animation instead of a pattern. The spheres then entered a loop of crossing into one plane and coming out from the other.

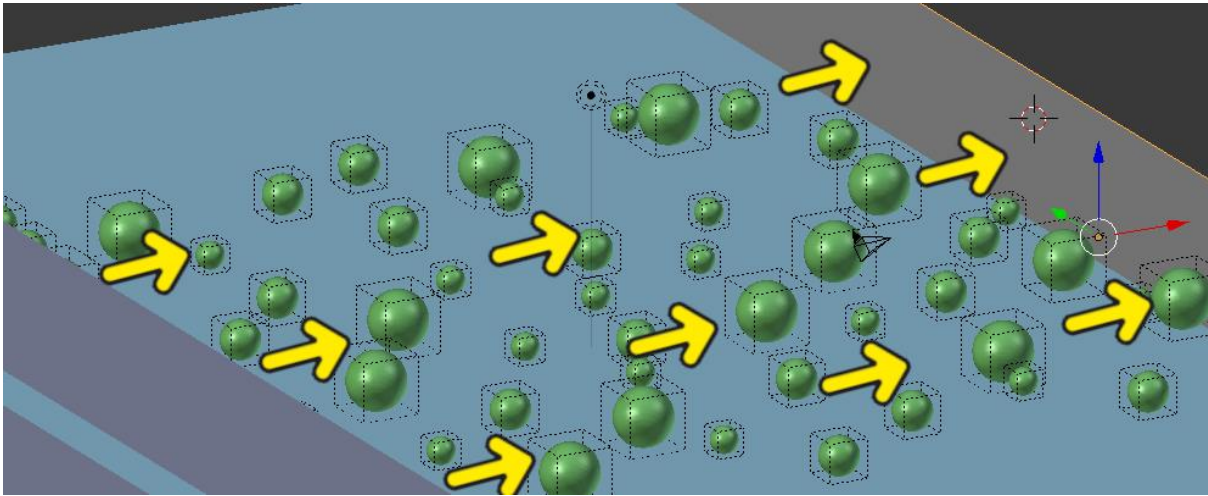


Figure 31 - João Martins, 2022 - Visual Cues – Stream of Balls.

This videogame did not fulfil the vision of the project and the decision was made to create a more interactive and metamorphic videogame. It was at this point that the project was migrated to Unity.

4.2.2. Projectile

The new videogame consists of a projectile divided in two parts, the head and the tail. The head is the always present body and is the origin point for the tail. When the head turns the tail follows the movement. The tail is a particle system that originates on the back of the head and releases a stream of particles that create a trail. If the car is going to accelerate, the trail will extend and move faster, if the car is going to slow down, the trail will get shorter and move slower. If the car is going to turn, the head will turn and the tail will follow creating a curve of particles.

4.2.2.1. 2D Head

This was the first version of the new videogame where the head of the projectile was a 2D shape that would rotate around itself creating the illusion of it being a 3D object with a translucent look to it. The color blue is heavily used as it is considered a soothing color and doesn't capture as much attention as a bright color or a big contrast between colors would.

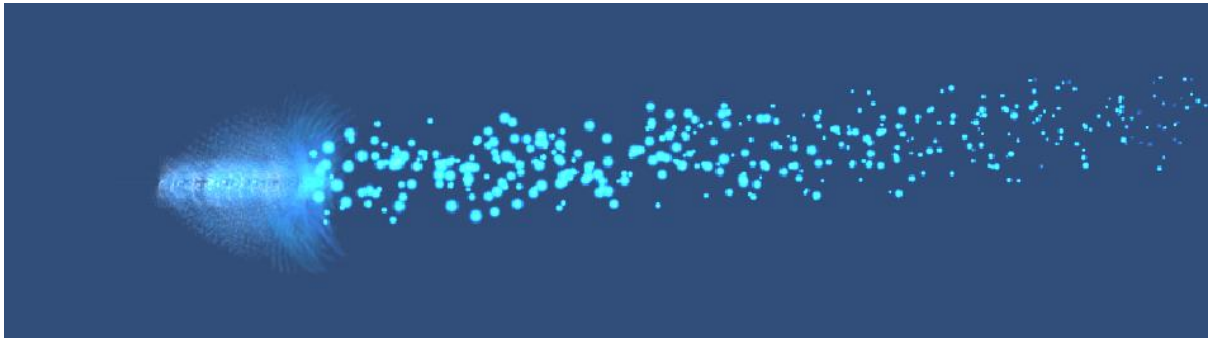


Figure 32 - João Martins, 2022 - Visual Cues – 2D Projectile.

After doing some testing with this version, to move and adjust the in-game camera that shows the projectile was now a necessity. This created an issue between the camera and the head because the head is a 2D object and the camera was pointed from top to bottom over the projectile (creating a 2D environment). By moving the in-game camera around, it turns the 2D environment into a 3D environment although the head is still a 2D object that is always placed in front of the camera. This is demonstrated in the picture below and is the reason why the 2D Head version of the videogame was dropped.

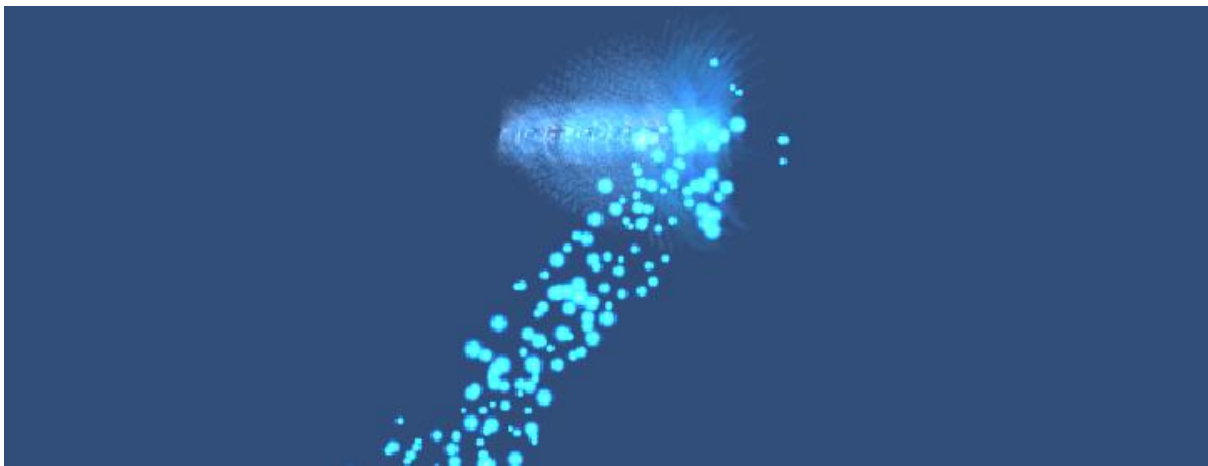


Figure 33 - João Martins, 2022 - Visual Cues – 2D Projectile issue.

5.2.2.2. 3D Head

To answer the necessity of moving and adjusting the ingame camera, a new version of the game was created but this time using a 3D object as the head. The new head was modeled, sculpted and textured using Blender 3.0. The objective was for it to look like a cosmic body drifting through an empty void, maintaining the same colors as in the 2D version. After exporting it to Unity the 2D head was replaced with the new 3D model maintaining most of the previous version coding, allowing to make a functional version of the videogame much faster.

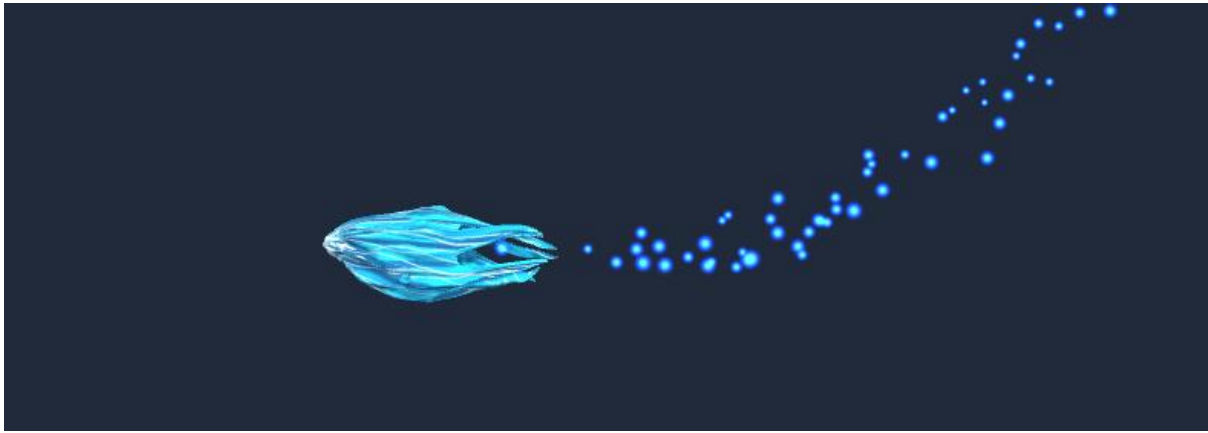


Figure 34 - João Martins, 2022 - Visual Cues – 3D Projectile.

4.3. Prototyping

There are two components to make a prototype for the visual cues, a digital component (the video game) and a delivery mechanism. To show the visual cues to the user inside the car two projectors were acquired. They were strapped to the car sides, pointed at the other side and connected to a computer running the game and connected to the RPS, the projectors will show the user, on both sides of the car, the animation showing what the car will do next.

4.4. Conclusions

The Visual Cues were supposed to be an interactive animation and that translated into a videogame. The first stages of this project were developed in Blender but the project was quickly migrated to Unity in order to have a better game engine and better fine tuning options for the particle systems were a big part of the project. The result is a comet-like body floating through an empty space and leaving a trail of particles behind it. The comet is controlled by the RPS; when the vehicle is going to turn, the comet will turn in that direction and the particles trail will follow the turn; if the vehicle is decelerating, the trail of particles will become shorter and move slower and if it is accelerating it will extend and move faster. Exposing the user to these cues will help him understand what the vehicle will do next.

5. Airflow

5.1. Mitigation Cues

In case the motion sickness symptoms set in with the user, it means the anticipatory cues are no longer working and it is now necessary to mitigate the symptoms the user is suffering of. One of the most common ways to try and mitigate motion sickness symptoms, is to expose the person to a flow of fresh air or expose the person to certain scents. This means two different products are required, one for blowing fresh air on the user's face and a second one to release a scent.

5.2. Problem Description

A cold air flow to the face or exposure to certain scents can help mitigate motion sickness symptoms and even bring the event to an end. Two different setups begun were required as delivery mechanisms for both airflows.

5.3. Cold Airflow System

The cold airflow has to be plugged to the test car's AC outlet and has to redirect the airflow directly to the user's face. The solution is a combination of four parts: a plug to cover the car's AC outlet (1), a long tube to cover the side distance between the user and the car's AC outlet(2), a long tube with a nozzle at the end to precisely aim the airflow (3) and elbow tubes to connect everything at the desired angle(4).

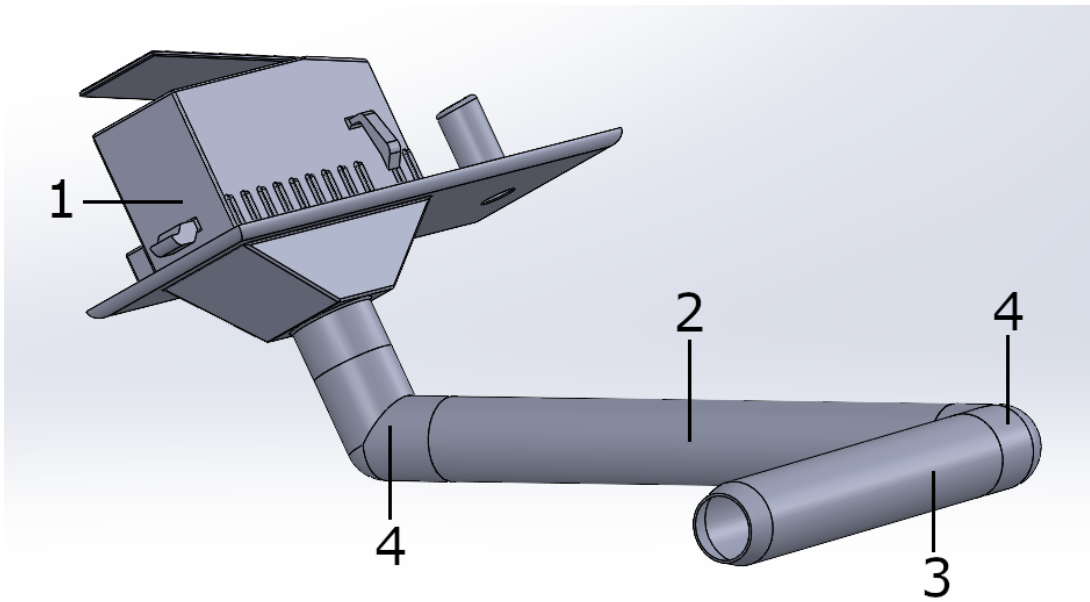


Figure 35 - João Martins, 2022 - Cold Airflow – 3D Assembly

5.2.1. Components

AC Plug

The plug was the most problematic part, mostly because of the fixation point that was a complex area and the smallest error margin in the measurements would make the whole part perform poorly at redirecting the air flow. After two failed attempts of covering the car's outlet with a plug that would fixate on the previously mentioned complex area, the decision was made to entirely remove the test car's AC outlet and copy it with the necessary adjustments made to redirect the airflow to the user's face.

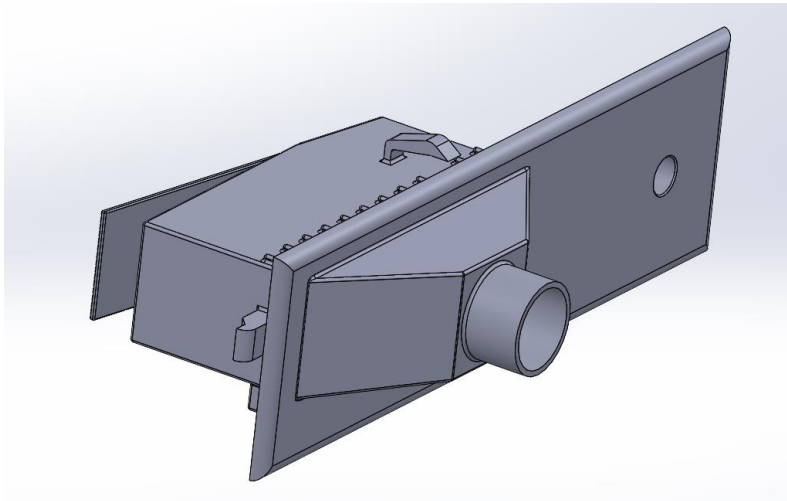


Figure 36 - João Martins, 2022 - Cold Airflow – Plug.

Long Tubes

The long tubes cover the required distance to redirect the airflow to the user's face.

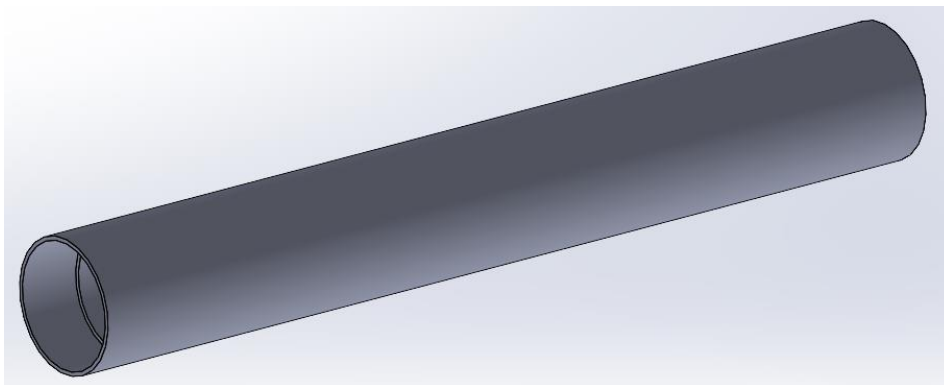


Figure 37 - João Martins, 2022 - Cold Airflow – Long Tubes.

Elbow Tubes

The elbow tubes redirect the air flow to where the user is pointed and act as connections between the other components.

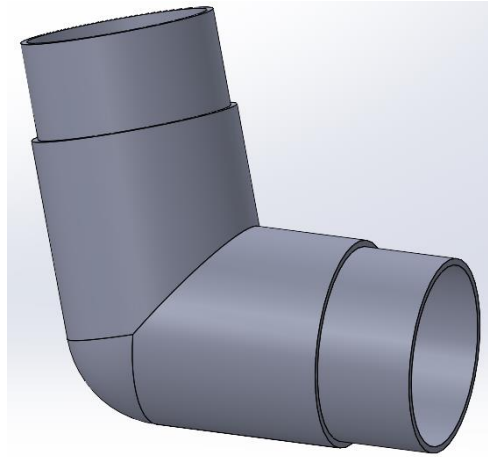


Figure 38 - João Martins, 2022 - Cold Airflow - Elbow Tube (115°).

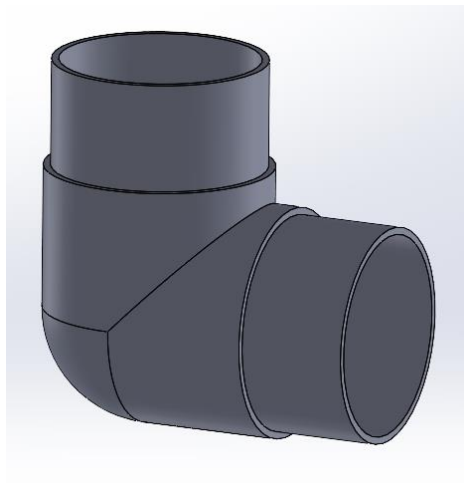


Figure 39 - João Martins, 2022 - Cold Airflow - Elbow Tube (90°).

Nozzle Tube

The nozzle tube covers the rest of the distance the airflow needs to traverse and the nozzle at the end helps focus the airflow on the user's face.

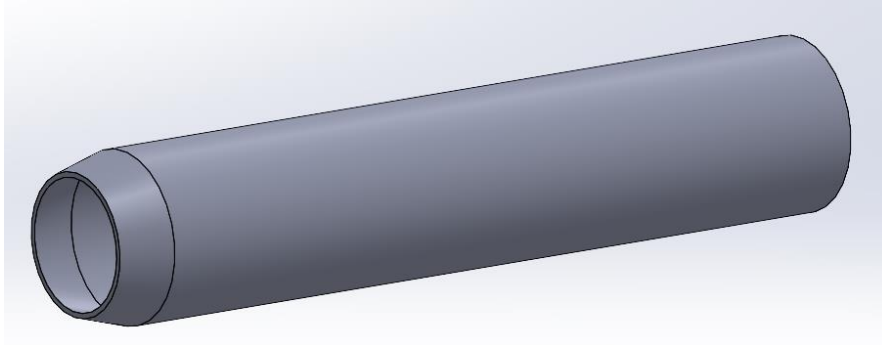


Figure 40 - João Martins, 2022 - Cold Airflow – Nozzle Tube.

5.3. Aromatic Airflow System

The aromatic air flow is to be deployed using an air blower as a source of the low-pressure airflow and a tripod to hold the system. The air blower has a connector (1) that focus the airflow into a tube (2) that provides connection to the tripod and fits the tube with the scent support (3), transporting that scent to the user's general area.

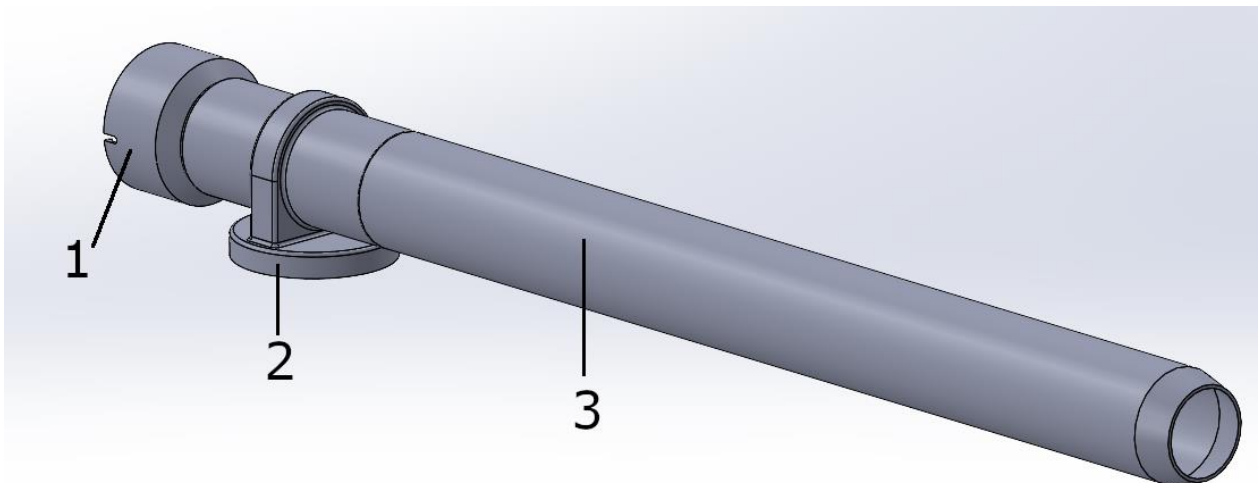


Figure 41 - João Martins, 2022 - Aromatic Airflow - 3D Assembly

5.3.1. Components

Plug

The plug connects to the air blower and fits over one of the base's exits.

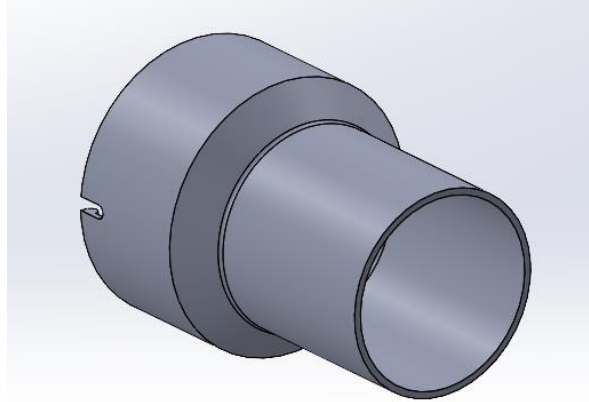


Figure 42 - João Martins, 2022 - Aromatic Airflow – Plug.

Base

The base connects the system to the tripod and serves as a connection between the plug and scent/nozzle tube.

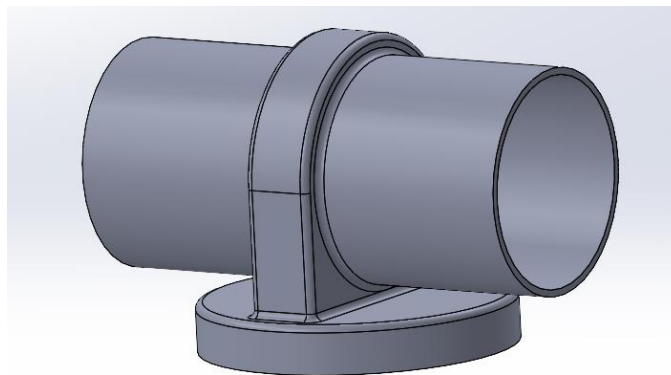


Figure 43 - João Martins, 2022 - Aromatic Airflow – Base.

Scent/Nozzle Tube

This tube has a spiked needle on the inside of the end that connects to the base to add the scented cotton ball and the other end is a nozzle that directs the air flow to the user's area.

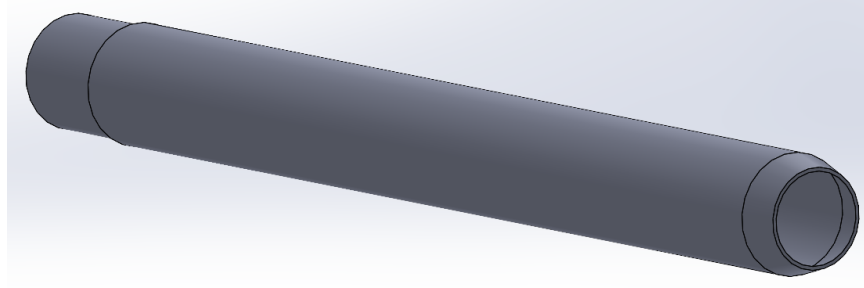


Figure 44 - João Martins, 2022 - Aromatic Airflow – Scent/Nozzle Tube (whole).

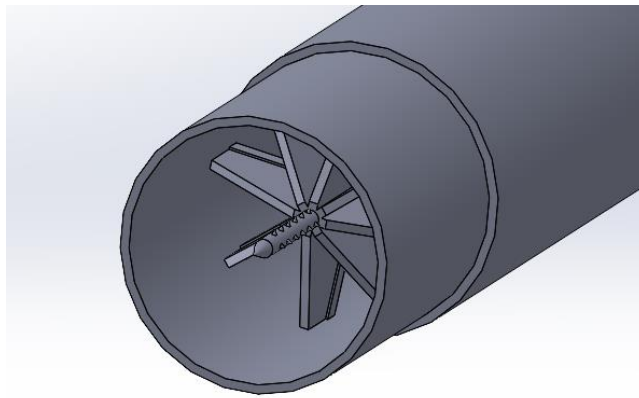


Figure 45 - João Martins, 2022 - Aromatic Airflow – Scent/Nozzle Tube (scent holder).

5.4. Prototyping

All the components for both airflow systems were 3D printed in PA using the SLS printer. The components fit in each other making the prototypes easy to carry and easy to assemble.

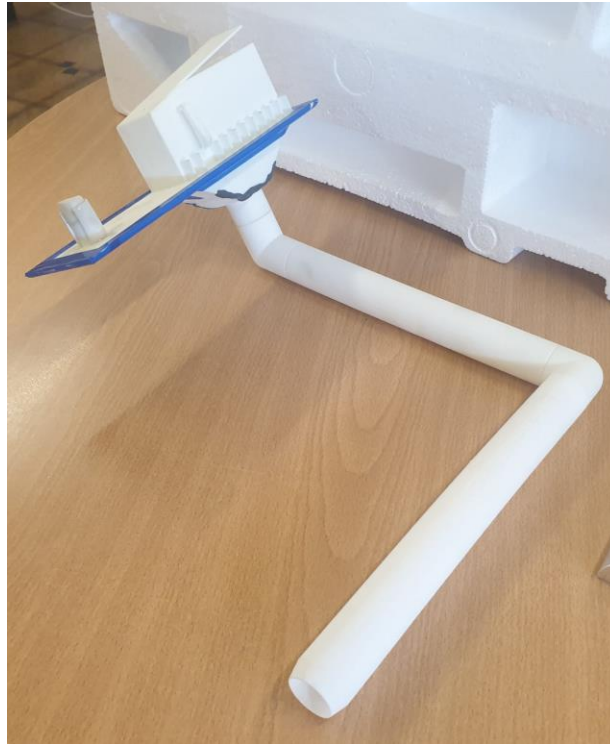


Figure 46 - João Martins, 2022 - Cold Airflow prototype.



Figure 47 - João Martins, 2022 - Aromatic Airflow prototype.

5.5. Conclusions

The Airflow system, unlike the Feet Platform or the Visual Cues works towards mitigating MS symptoms instead of preventing them. The Cold Airflow System consists in a network of tubes that direct a current of cold air towards the user's face to try and help mitigate MS symptoms; the Aromatic Airflow System spreads a scent towards the user's general area with the same intention of mitigating MS symptoms.

6. Conclusions

As self-driven cars come closer to become a day-to-day reality, drivers will soon become a thing of the past being replaced by a computer that will assess each situation and safely act on it. Meaning the passengers can engage in non-driving related activities. This also means some users will probably suffer from MS.

In answer to this issue still to come, three solutions were explored: a haptic cue, a visual cue and mitigation cues.

The haptic cue, in this case the feet platform, was the most problematic in terms of mechanical solutions, specifically the best way to guarantee a fluid and fast motion to keep up with the vehicle's actions. Not only that, but also the total height factor to ensure the comfort of the user, and the right selection of materials to ensure it would withstand having the user's legs resting on top of it and that the frequent use of the product would not wear down the parts.

The visual cue, in this case the animation projection, unlike the feet platform didn't have any mechanical issues to solve. It was instead a work of creativity and patience. The creative part was modeling and painting the body and later, in Unreal Engine, adding the particle systems. Besides all of that, there was the animation of the body and then the fine tuning of the particles and the controls until it was ready to keep up with the vehicle's RPS.

The mitigation cues took the shape of two different airflow systems. The cold airflow was an extension of the car's AC system so the biggest challenge here was to create a plug for the AC outlet. When the plug did not work, the decision was made to remove the outlet and emulate it through a 3D model that then fit perfectly in the outlet slot. The rest of the system was a simple extension of tubes to redirect the airflow to the intended location. Then there was the aromatic airflow which was an entire new system, given that it could not be tested in the car. The first step was to find an air blower that would simply blow a breeze of air towards the user. From there, creating a 3D model for the plug to fit over the air blower was next, followed by the base part to connect to the tripod and finally the scent/nozzle was created through an evolution of ideas in order to make it simple to use and easy to access.

All three systems were prototyped with success, respecting their requirements, and allowing third parties to conduct the experiments related to MS.

6.1. Future Perspectives

The work presented in this thesis shows that it is possible to create products to prevent or mitigate motion sickness. However, it is important to develop further the products presented in this thesis. Heavy and intense testing with subjects would be required to understand if these products actually work or not in the prevention and mitigation of MS. Based on these results adjustments and changes would probably be necessary to the products so they have a better performance.

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