Escola Politècnica Superior
d'Enginyeria de Vilanova i la Geltrú
UNIVERSITAT POLITÈCNICA DE CATALUNYA

# TREBALL FINAL DE GRAU

**TÍTOL:** Improving the Design of Virtual Reality Headsets Applying an Ergonomic Guideline

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## RESUM

L’objectiu d’aquest projecte és estudiar l’ergonomia d’ulleres de Realitat Virtual (VR) de baix cost i millorar els seus punts febles. Una Guia de Disseny Ergonòmic ha sigut creada per facilitar l’avaluació de dissenys actuals, basada en l’observació i en comentaris d’usuaris. Aquesta Guia ha sigut avaluada per experts en VR de l’Associació d’Interacció Persona-Ordinador (AIPO).

La metodologia emprada és el model del Procés d’Enginyeria de l’Usabilitat i l’Accessibilitat (MPIu+a), en el qual l’usuari és el centre del procés de disseny en tot moment. Aquest model és iteratiu, repetint el cicle d’anàlisi de requeriments, disseny, implementació, prototipatge, avaluació i llançament fins que un resultat satisfactori ha sigut obtingut.

Participants voluntaris han avaluat la qualitat de diferents ulleres de VR i han ajudat a crear una Guia de Disseny Ergonòmic. Les seves idees han generat preguntes per millores de disseny aplicades a les noves ulleres, i han validat les modificacions fetes.

El resultat final són unes ulleres de cartró, basades en el model Cardboard d’Easy Phone però millorant la seva ergonomia modificant el disseny per satisfer les necessitats de l’usuari. Aquests canvis han reduït significativament el dolor als pòmuls, el nas i el front, i el disseny general és ara més atractiu per els usuaris. Més investigació serà necessària per resoldre problemes d’usabilitat trobats al utilitzar la tecnologia de Realitat Virtual amb aquestes ulleres.



**Paraules clau:**

| | | | |
|---|---|---|---|
| Realitat Virtual | Experiència d’usuari | Usabilitat | Identitat visual |
| Ergonomia | Metodologia de Disseny | | |
| | | | |

## ABSTRACT

The aim of this project is to study the ergonomics of low-cost Virtual Reality (VR) headsets and improve their weak spots. An Ergonomic Design Guideline has been created to assist in the evaluation of current designs based on observation and user comments. This Guideline has been assessed by experts in VR from the Human-Computer Interaction Association (AIPO).

The methodology used is the Process of Usability and Accessibility Engineering model (MPIu+a), in which the user is the centre of the design process at all times. This model is iterative, repeating the cycle of requirement analysis, design, implementation, prototyping, evaluation and launch until a satisfactory result has been obtained.

Voluntary participants have assessed the quality of different VR headsets and have helped create an Ergonomic Design Guideline. Their insight has raised questions for further design improvements applied in the new headset, as well as validation of modifications made.

The final result is a cardboard headset, based on Easy Phone's Cardboard model but improving its ergonomics by modifying the design to satisfy the user's needs. This has reduced pain on cheekbones, nose and forehead significantly, and the general design is now more attractive to users. Further investigation will be necessary in order to solve the usability problems encountered when using Virtual Reality technology with these devices.

**Keywords:**

| | | | |
|---|---|---|---|
| Virtual Reality | User experience | Usability | Visual identity |
| Ergonomics | Design Methodology | | |
| | | | |

## SUMMARY

## SUMMARY OF FIGURES AND TABLES

## GLOSSARY OF SIGNS, SYMBOLS, ABREVIATIONS, ACRONYMS AND TERMS

***Asociación Interacción Persona-Ordenador*: "**A professional association open to everyone interested in Person-Computer interaction. Its goals are to promote and spread the Person-Computer interaction and serve as a link between scientists and professionals developing activities in this area." Its abbreviation is AIPO.[1]

**International Conference on Applied Human Factors and Ergonomics: "**The conference objective is to provide an international forum for the dissemination and exchange of scientific information on theoretical, generic, and applied areas of human factors and ergonomics. This will be accomplished through the following six modes of communication: keynote presentation, parallel sessions, demonstration and poster sessions, tutorials, exhibitions, and meetings of special interest groups. The five-day conference will start with tutorials. Tutorials will be offered at introductory, intermediate, and advanced levels covering the entire spectrum of the conference."[2]

**User Experience:** "The judicious application of certain user-centred design practices, a highly contextual design mentality, and use of certain methods and techniques that are applied through process management to produce cohesive, predictable and desirable effects in a specific person, or persona. All so that the effects produced meet the user's own goals and measures of success and enjoyment, as well as the objectives of the providing organisation. Its abbreviation is UX."[3]

**User-Centred Design:** "The User-Centred Design process outlines the phases throughout a design and development life-cycle all while focusing on gaining a deep understanding of who will be using the product. It is important to note that the User-Centred Design process does not specify exact methods for each phase. Its abbreviation is UCD."[4]

**Virtual Reality Headset: "**A device that one wears over the eyes like a pair of goggles. It blocks out external light and shows a Virtual Reality image on high-definition screens in front of the eyes."[5]

**Virtual Reality: "**A realistic and immersive simulation of a three-dimensional environment, created using interactive software and hardware, and experienced or controlled by movement of the body. Its abbreviation is VR."[6]

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[1] Asociación Interacción Persona-Ordenador. [Consulted: 16 Jun 2017] Available at: <http://aipo.es/>
[2] AHFE. *AHFE 2017 Objective and Areas of Interest*. [Consulted: 28 Jun 2017] Available at: <http://www.ahfe2017.org/>
[3] UX Design Defined. [Consulted: 16 Jun 2017] Available at: <http://uxdesign.com/ux-defined>
[4] Usability.gov. [Consulted: 16 Jun 2017] Available at: <https://www.usability.gov/what-and-why/user-centered-design.html>
[5] O. Gilbert. J.. *What Is a Virtual Reality Headset, and Why Would I Want One?* Yahoo Tech, March 2014. [Consulted: 16 Jun 2017]. Available at: <https://www.yahoo.com/tech/what-is-a-virtual-reality-headset-and-why-would-i-want-80171656771.html>
[6] *Dictionary* [Consulted: 16 Jun 2017]. Available at: <http://www.dictionary.com/browse/virtual-reality?s=t>

# 1. INTRODUCTION

## 1.1. INTRODUCTION

The term Virtual Reality has existed since 1985, but it has not been until the past few years when it has started to attract the average user with the increased use of smartphones and videogames. Even so, today's Virtual Reality (VR) devices still have improvements to be made to ameliorate their ergonomics. Dizziness, vertigo and an increase in perspiration are some of the symptoms reported by users, as well as pain on the head and face due to unsatisfactory subjection system designs.

This project, based on the concepts studied in the Inclusive Design and User-Centred Design itinerary of the Product Design Engineering studies, aims to improve the use of low-cost VR headsets and create an Ergonomic Design Guideline for future designs. These devices have a huge potential amongst all types of users, with many applications that have not yet been discovered. Its improvement would translate in an increase of users and value of VR.

Although there are many existing devices used for the practice of such technologies, this work is centred on low-cost headsets. These are supports for mobile phones compatible with VR apps, including a minimum of a set of lenses, a subjection system and a main body to place all the elements. This focus on a particular type of product eliminates most electronics involved in the use of VR applications and gives space for more ergonomics improvements on the final product. In this work, devices are considered as low-cost when the price is under €100.00. This range of prices allows for a wide variety of headsets to compare, study and improve.

The initial goal of the project was to analyse the problems encountered with the use of this technology, such as dizziness or vertigo, but during the initial phase of requirement search, it was noticed that the current designs had to be greatly improved in order to reduce feelings of pain or discomfort while wearing the headsets. This then became the new objective of the investigation, mainly focusing on the direct interaction of the device and the user's face.

## 1.2. MOTIVATION

While studying the User-Centred Design itinerary of the Industrial Design Engineering studies, several concepts were introduced. It has always been clear that the user has to be at the centre of the design process, but this group of subjects (Inclusive Design and User-Centred Design, Usability and Accessibility Engineering, and Person-Machine Interaction) taught different tools to investigate the needs of the final user and solve their needs and desires.

Amongst these contents, VR was a recurring topic that seemed to be growing but one that had no real applications yet. Also, VR headsets still produce dizziness, headaches and other secondary effects, and this appeared to be an obvious problem to address. Studying these different problems related to VR headsets and VR technology, it was clear to me that a new investigation could be carried out.

## 1.3. OBJECTIVES

The objectives of this project are related to the improvement of the design of VR headsets. The first of them is to choose a VR headset to modify, which should score low in ergonomic design assessments with identifiable faults.

The second objective is to create a design Guideline which will, on the one hand, help improve VR headsets in design or re-design phases, and on the other hand, assist in the assessment of these devices. This Guideline should be easily applied on any VR headset, or it will not be useful for the evaluation of this kind of products.

Finally, the re-design of the headset has to score better than the original device in the user's perspective, in order to validate the Guideline and the design process. If it does not score better, it is important to study the re-designed version of the headset and analyse why it is scoring worse than the original product.

A secondary objective is to include application proposals for VR technology. It is important to justify each alternative with tests.

These objectives have to be completed by keeping the user at the centre of the design, and at all phases of the re-design process. This will ensure that the final product will be accepted by the user and that it will include the features that the user considers most important.

## 1.4. METHOD

Following the methodologies taught in various subjects in the Industrial Design Engineering studies, the user has always been at the centre of the design process. The main method used are interviews with different user profiles that offer enough information to proceed to the next task.

The first step for this project was to create a user requirements list, analysing different VR headset models and comparing the participants' reactions to each of them. An Ergonomic Design Guideline was then created based on the information collected.

Using this Guideline, which was still in process, new design proposals were created, improving the current cardboard headset (Easy Phone's Cardboard Black). These were tested with new users and assessed with the ergonomic design Guideline, completing it with new comments from the users.

A final design proposal was tested through an interview with new participants. This helped validate the new headset and compare it to the original.

Other tools have also been used, such as Quality-Function Deployment (QFD), eco-design, or poka-yoke design. Each of these are further described throughout this project.

## 1.5. STRUCTURE

The structure used throughout this dissertation follows the Process of Usability and Accessibility Engineering Model (MPIu+a)[7], according to the ISO 9241-210_2010(E) international standard in relation to ergonomics in human-centred design for interactive systems. This model places the user at the centre of the research and works in iterative cycles until a satisfactory result has been obtained (Figure 1. MPIu+a model).

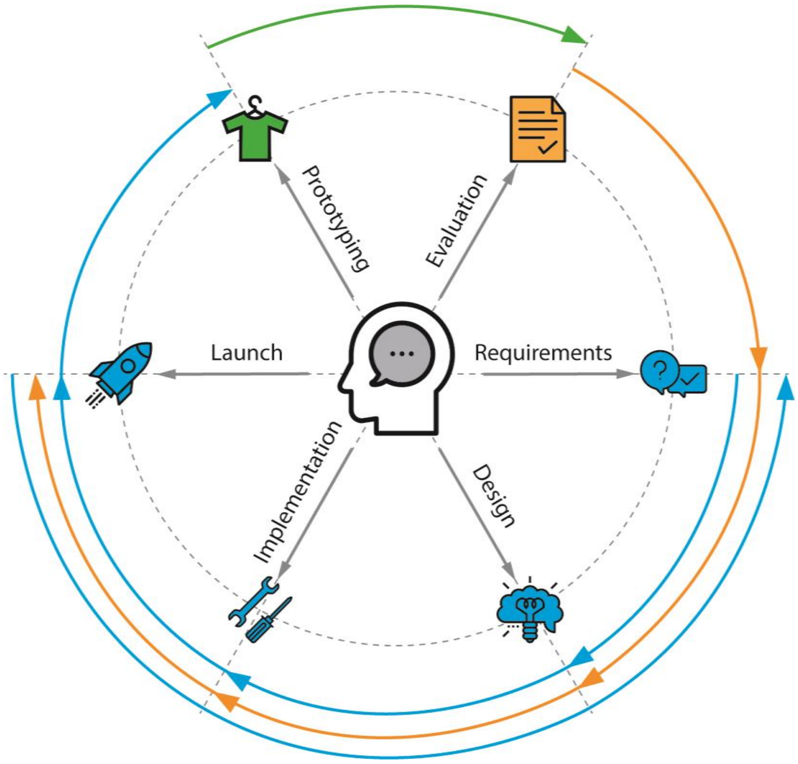


Figure 1. MPIu+a model

The index of this dissertation follows the steps proposed in the MPIu+a model, even though it works in cycles and thus the final structure will not be shown in a chronological order. The contents included are the following:

- **Framework (Chapter 2):** Previous to the start of the investigation, a market study is presented. This will help understand the history of VR headsets, their current position in the market and legal regulations that apply to these designs.
- **Requirements (Chapter 3):** The user will be studied, as well as the chosen VR headset to redesign. With the gathered information, a design brief is elaborated with the requirements of the final product.
- **Design (Chapter 4):** Concepts and sketches are presented in the search of design alternatives to the current product.
- **Prototyping (Chapter 5):** Mock-ups are made to test the designs proposed, and prototypes are then created using the changes applied through the mock-ups.

[7] Granollers, T., Lorés, J., Canás, J.J. *Diseño de sistemas interactivos centrados en el usuario.* Editorial UOC, October 2005. Collection 43, Manuales: Informática. ISBN 8497883209.

- **Evaluation (Chapter 6):** The final proposal is then evaluated to assess its ergonomics and comfort using different design methods, as well as a Guideline based on user studies and product analysis.
- **Implementation (Chapter 7):** At this stage, material alternatives are studied and a visual identity is created for the final product. Technical documentation and costs are also presented.
- **Launch (Chapter 8):** The launch of the product is out of scope of this project. A tool for quicker and more effective production is presented.

This structure has been combined with a variety of design tools, implemented within each of the chapters of the dissertation. These are not part of the original MPIu+a model, but are essential for the re-design of a product.

# 2. FRAMEWORK

## 2.1. TIMELINE

The term Virtual Reality, understood as "A realistic and immersive simulation of a three-dimensional environment, created using interactive software and hardware, and experienced or controlled by movement of the body"[8], was not used until 1985 by Jaron Lanier. Still, contrary to popular belief, similar concepts have existed for many more years. In 1798, Phantasmagoria made its first appearance. It was an illusion of figures projected into a translucent screen.

Later on, in 1838, a holographic-type of image was created by using a stereoscope. It consisted of two mirrors facing the centre of the device, reflecting two slightly different images. This created a feeling of depth in the image. In 1849, a stereoscope, similar to today's VR headsets, was invented.

With the discovery of chromostereopsis, the concept that blue objects are perceived as being further away than red objects, the kinetoscope was invented in 1888. It was a machine that quickly showed a series of images to create the illusion of movement. Later on, the first three-dimensional images were discovered by overlaying two layers of images, one blue and one red, when viewed with special lenses.

With all of these discoveries, the first movies were invented. In 1895, the cinematograph appeared, and in 1900, the cinéorama. The first was a machine projecting photos on a screen, and the latter, the projection of a 3D image by using ten projectors facing the same spot. Two accompany these inventions, fantasound was created by Walt Disney in 1939: a sound system surrounding the audience to create an immersive feeling.

The first VR devices appeared in 1957, when the sensorama and the telesphere mask were created. They were devices used for the immersion into pre-recorded films. The Ultimate Display, the first concept of Virtual Reality, appeared in 1965. Two years later, in 1967, Grope was invented. It was a system with which the user could "touch" objects in the VR environment by a force feedback system.

More recently, in 1968, the leader company in 3D panoramic cinema systems was opened. In the following years, VIP100 (a voice recognition system), Videoplace (interactive video system recording the user and creating its silhouette on screen) and Sayre Glove (a glove recognising hand movements and interpreting them) were invented.

It was then when, in 1985, Jaron Lanier used the term "Virtual Reality" for the first time. From this point on, many advanced VR devices were created, such as VIVED, used for pilot training at NASA, or SIMNET, used for military training by the USA army.

In 2012, the first VR headset as we know them today appeared. It was DK1 by Oculus, which opened many possibilities in the market. This timeline can be found in Annex A: Virtual Reality Timeline.

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[8] *Dictionary* [Consulted: 16 Jun 2017]. Available at: <http://www.dictionary.com/browse/virtual-reality?s=t>

## 2.2. TRENDS

Gartner Inc. studies the phase in which different emerging technologies can be found. This information is represented in a hype cycle, showing the maturity of technologies and their adoption for the exploration of new company opportunities.

As seen in Figure 2. Gartner's Hype Cicle for Emerging Technologies, 2016, Virtual Reality is at the slope of enlightment. This means that the technology is started to be understood and more applications are appearing. Conservative companies remain cautious to the application of such technologies, but can be adopted by the mainstream users in five to ten years. Once this has been done, it is said to have reached the plateau of productivity, in which the technology is widely applied in the market.[9] [10]


**Figure 2. Gartner's Hype Cicle for Emerging Technologies, 2016[11]**

## 2.3. STATE OF THE ART

Four low-cost VR headsets have been studied to compare their characteristics and to choose one of them to improve. Please note that a device is considered as low-cost when its price is lower than €100.00. The devices are Samsung's Gear VR, Easy Phone's Cardboard Black, Woxter's NEO VR1 and Juguetrónica's VR Phone Glasses

[9] Gartner. *Gartner Hype Cycle.* [Consulted: 16 Jun 2017] Available at: <http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp>
[10] Follett, J. *Designing for Emerging Technologies*. 1st edition. California, United States of America: O'Reilly Media. November 2014. ISBN 978-1-4493-7051-0.
[11] Forni, A.A., Van der Meulen, R. *Gartner's 2016 Hype Cycle for Emerging Technologies Identifies Three Key Trends That Organisations Must Track to Gain Competitive Advantage*. [Consulted: 16 Jun 2017] Available at: <http://www.gartner.com/newsroom/id/3412017>

V2 (Figure 3. Initial benchmark).[12] [13] [14] [15]

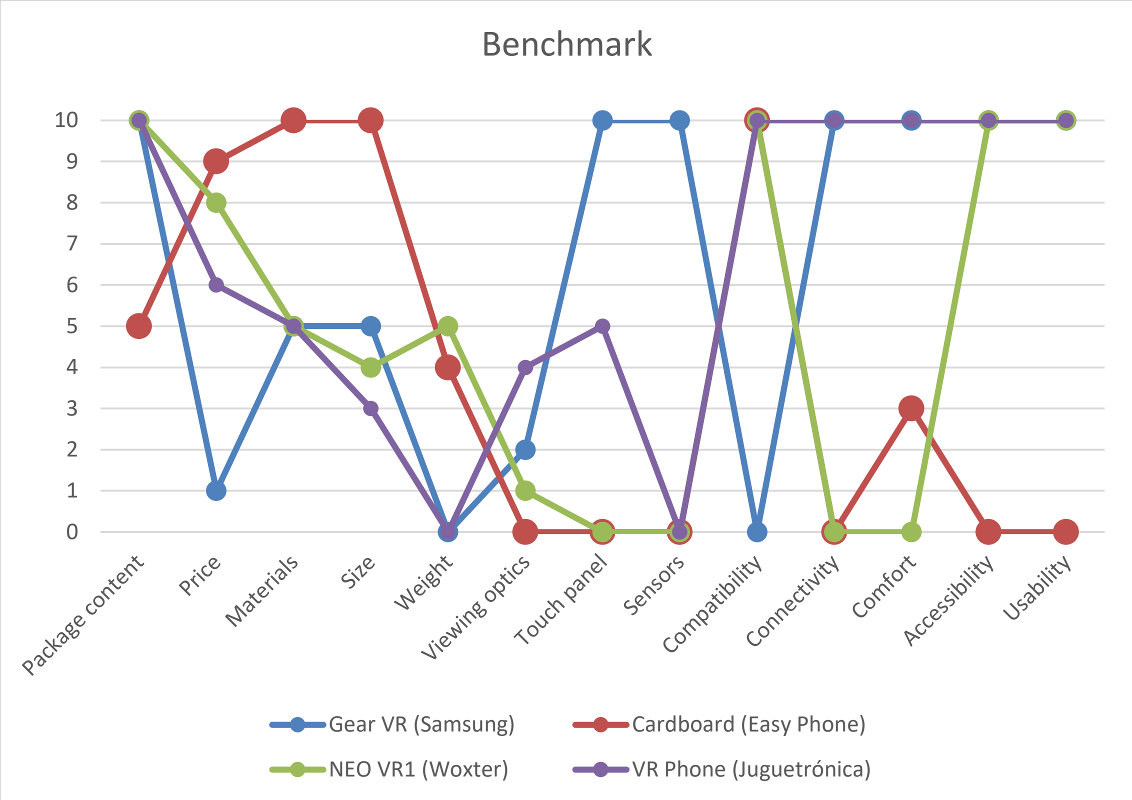


**Figure 3. Initial benchmark**

These headsets have been assessed individually according to the criteria guide (Annex B: Headset comparison criteria, Annex C: Easy Phone's Cardboard Black analysis, Annex D: Samsung's Gear VR analysis, Annex E: Juguetrónica's VR Phone Glasses V2 analysis and Annex F: Woxter's NEO VR1 analysis) based on general parameters of VR headsets and human anthropology. The result of the study shows that, on a scale from 0 (most improvable) to 10 (least improvable), the devices are ranked in the following order: Gear VR (6.4), VR Phone Glasses V2 (6.4), NEO VR1 (4.8), Cardboard Black (3.9). Thus, the chosen device to study is Easy Phone's Cardboard Black.

This study will have to be validated by testing with users and seeing their point of view, which will be explained in section 3.1.1. Test with users.

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[12] Google. *Specifications for viewer design.* [Consulted: 14 May 2017] Available at: <https://support.google.com/cardboard/manufacturers/answer/6323398?hl=en>
[13] Sánchez Manzhirova, V. *Samsung Gear VR, probamos las gafas de realidad de Samsung*. Tuexperto. March 2016. [Consulted 14 May 2017] Available at: <https://www.tuexperto.com/2016/03/21/samsung-gear-vr-probamos-las-gafas-de-realidad-virtual-de-samsung-2/>
[14] Juguetrónica. *VR Phone Glasses 2.0*. [Consulted: 14 May 2017] Available at: <http://www.distribucion.juguetronica.com/gadgets/vr-phone-glasses-20.html>
[15] Bravo, D. *Gafas de realidad virtual baratas Easy Phone VR Cardboard Black y Easy Phone VR Fit*. Revista Gadget. [Consulted: 14 May 2017] Available at: <http://www.revista-gadget.es/noticia/gafas-de-realidad-virtual-baratas-easy-phone-cardboard-black-easy-phone-vr-fit/>

## 2.4. LEGAL REGULATIONS

Virtual Reality headsets are a relatively new invention. Their legal regulations are related to those designed for screens and mobile phones. It is important to keep in mind that the lowest recommended distance between the eyes and the mobile phone screen is of 30 cm[16], but these VR devices place the mobile phone at a distance of approximately 4 cm.

The ISO 9241-210:2010 standard provides a framework for user-centred activities, adaptable to different areas of development. It is a general model that can be used as a reference in user-centred design processes, described as a process for the development of interactive systems with the goal of making systems more usable by means of human factor and ergonomics techniques.[17]

Other legal regulations related to design and use of VR technologies have not been considered. These would be applicable for further studies of this line of work, but given that this dissertation only analyses the ergonomics of the headset, they are not required for this work.

Many other regulations should be implemented before further use of VR devices takes place. "Legal Issues in the Innovation of Virtual Reality"[18] explores the legal issues related to VR technology, classified as follows:

- Current legal challenges in VR
    - Protecting company secrets during VR development
    - Intellectual property rights in VR
    - Patent rights and copyright
- Future legal challenges in VR
    - Privacy risks
    - Cognitive and physical risks

[16] Ergológico. *¿Tienes la pantalla a la distancia correcta?* [Consulted: 21 Jun 2017] Available at: <http://www.ergologico.com/distancia-de-la-pantalla-recomendada/>
[17] International Organization for Standarization. *Ergonomics of human-system interaction – Part 210: Human-centred design for interactive systems.* ISO 9241-210:2010. 1st Edition. March 2010.
[18] Nwanery, C. Legal Issues in the Innovation of Virtual Reality. *Harvard Journal of Law & Technology.* 2017, Volume 30, Number 2, p. 601-626.

# 3. REQUIREMENTS

## 3.1. USER ANALYSIS

### 3.1.1. TESTS WITH USERS

The most important validation for this dissertation are tests with users. Three tests have been carried out throughout the project, each with a different goal. Another tool used has been the online questionnaire, allowing for a wider reach and offering a larger variety of users to answer the questions. Knowing that the product will have to be liked by the user, it is important to keep in mind that only they can correctly assess the final result.

#### 3.1.1.1. INITIAL QUESTIONNAIRE

Firstly, a questionnaire to understand the user profile was designed. It was written in Spanish and in English, and it consisted of a set of eight questions maximum (Annex G: Initial questionnaire questions) with the goal of understanding who uses VR technology and who is interested in it. In total, 86 people answered the questionnaire. The questions presented can be seen at Table 1. Initial questionnaire: questions and their motivation.

| | Question | Motivation |
|---|---|---|
| User profile | What is your gender? | This information helps establish basic user profiles. |
| | What is your age range? | |
| | Have you ever used a VR device? | Prior experience might have an effect on the interest in VR. |
| | Would you have any kind of limitation when using this kind of devices? Which kind? | This helps understand the target user, whether these limitations have to be taken into account or not. |
| Motivations | Which VR device have you used? | This shows what the participant understands as a VR device, and whether they have used low-cost headsets before. |
| | What did you use this technology for? | Prior experience might have an effect on the interest in VR. |
| | What would you like to use VR for? | The use of VR technology might change the design of the headset to adapt to the different necessary movements. |

Table 1. Initial questionnaire: questions and their motivation

From this questionnaire, four age groups were profiled: 0-12, 13-25, 26-59, and 60 and over. The results showed a tendency to decrease in the interest of such technologies with age. Younger participants (0-25 years old) have had less experience than the older ones, but show more interest in new applications of VR, such as education or live events. The target group of the final product is discussed in section 3.3. Context of use. The complete results can be found in Annex H: Initial questionnaire results.

### 3.1.1.2. ORIGINAL PRODUCT COMPARISON TEST

**Figure 4. Original product comparison test**

The first test (Figure 4. Original product comparison test) with users was created to assess four VR headsets: Easy Phone's Cardboard Black (Figure 5. Easy Phone's Cardboard Black), Samsung's Gear VR (Figure 7. Samsung's Gear VR), Juguetrónica's VR Phone Glasses V2 (Figure 6. Juguetrónica's VR Phone Glasses V2) and Woxter's NEO VR1 (Figure 8. Woxter's NEO VR1). These headsets were first analysed with a criteria guide (section 2.3. State of the art), but in this case the user validated the first study by comparing and contrasting them.

This test took place at Escola Politècnica Superior d'Enginyeria de Vilanova I la Geltrú (EPSEVG), in the Interactive Design laboratory, on 2$^{nd}$ of December, 2016. The participants were students from the Person-System Interaction class who were taken to the room of the test, where the test conductor would introduce them to the activity they were going to participate in.

**Figure 5. Easy Phone's Cardboard Black**

**Figure 6. Juguetrónica's VR Phone Glasses V2**

Figure 7. Samsung's Gear VR

Figure 8. Woxter's NEO VR1

Users (16 Product Design Engineering students) were taken one by one, and later on by three participants at once, into a controlled room. Once there, they signed a consent form (Annex I: Consent form for original comparison test) and were then asked to take a seat. An online questionnaire was prepared for them to answer, with questions related to the comparison of the devices. They were allowed to wear the different headsets to complete the questionnaire. Table 2. Original product comparison test: questions and their motivations analyses the questions asked and the motivation behind them.

| | Question | Motivation |
|---|---|---|
| User profile | What is your gender? | This information helps establish basic user profiles. |
| | What is your age? | |
| | What kind of mobile phone system do you use? | Understanding the environment to which the participant is used may help design a new VR headset environment. |
| | Which mobile phone model is it? | |
| | Have you ever used a VR device before? | Prior experience might have an effect on the interest in VR. |
| | If so, which? | This shows what the participant understands as a VR device, and whether they have used low-cost headsets before. |

Table 2. Original product comparison test: questions and their motivations

| | Question | Motivation |
|---|---|---|
| First impressions | How would you describe the headset? | This allows the user to give any kind of information about the headsets without being biased by the following questions. |
| Comparison of VR headsets | How would you grade each of the headsets? | Prior experience might have an effect on the interest in VR. |
| | How attractive do you find each of the headsets? | The use of VR technology might change the design of the headset to adapt to the different necessary movements. |
| | How much do you think each of the headsets cost? | This helps see what the perception of the user is. If the headset is expensive but perceived as inexpensive, or vice versa, it means that the design is not communicating correctly. |
| | What do you think about the weight of each of the headsets? | This establishes what the participant considers acceptable or not. |
| | How comfortable are each of the headsets? | |
| | How would you grade the material in which the headsets are made? | |
| | Do you think VR headsets can be useful in your daily life? | New VR applications can be studied if the technology can be applied to daily life. |
| Design | Which aspects of shape do you think are important in VR headsets? | This establishes what the participant considers important in the new design. |
| | Which aspects of function do you think are important in VR headsets? | |
| | What kind of application would you like to use with VR headsets? | New VR applications can be studied with the ideas offered by the participants. |

**Table 3. Original product comparison test: questions and their motivations (continued)**

Derived from this test, a Ergonomic Design Guideline (Annex J: Ergonomic Design Guideline) was created to assess other headsets and offer suggestions to improve their design. A full report of the test can be found on Annex K: Original comparison test report (Spanish) and the full reports on Annex L: Original comparison test results, while the most relevant results in the comparison of the devices are shown on Table 4. Test 1: Summary of results. These represent an average score amongst the answers of all participants. Given the low score of Easy Phone’s headset, this is the chosen device to improve its design and ergonomics.

| | AESTHETICS | APPARENT PRICE | WEIGHT | COMFORT | MATERIAL | OVERALL SCORE |
|---|---|---|---|---|---|---|
| BRAND | 1: Low<br>5: High | 1: Low<br>5: High | 1: Low<br>5: High | 1: Low<br>5: High | 1: Low<br>5: High | 1: Low<br>5: High |
| Easy Phone | 1.9 | 1.3 | 1.8 | 1.5 | 2.0 | 1.9 |
| Woxter | 3.0 | 2.9 | 2.6 | 2.7 | 2.8 | 2.8 |
| Samsung | 4.4 | 4.1 | 3.3 | 3.9 | 3.9 | 3.8 |
| Juguetrónica | 3.6 | 4.4 | 4.3 | 4.0 | 4.0 | 3.6 |

**Table 4. Test 1: Summary of results**

Users, who had mostly (81.3%) not experienced VR technology before, showed concern in terms of comfort (most participants reported perceived pain on the nose, the forehead and the cheekbones) and the compatibility of these devices with the use of glasses.

### 3.1.2. QUALITY-FUNCTION DEPLOYMENT (PART I)

While many aspects such as functionality, usability, aesthetics, price-quality ratio or environment are essential in product design, it is equally important to consider the user, the competition and the production process. Quality-Function Deployment (QFD) is a tool used to unite these three elements and obtain solutions to improving the design in order to surpass the competition. A product may have a huge amount of features or have a very low price, but it can still fail in the market if the user has not been considered in the design process. This is why QFD is a means of translating the users' needs into product characteristics.

The first step to a correct QFD is the Ishikawa diagram. To do this, a list of user requirements is established and organised in categories. Each of this requirements is then placed as the main point of the diagram, which divides into different methods of achieving these requirements (Figure 9. Example of an Ishikawa diagram). The first Ishikawa process can be found at Annex M: Ishikawa diagram I. In this case, the requirements have been established based on the information collected from user testing.

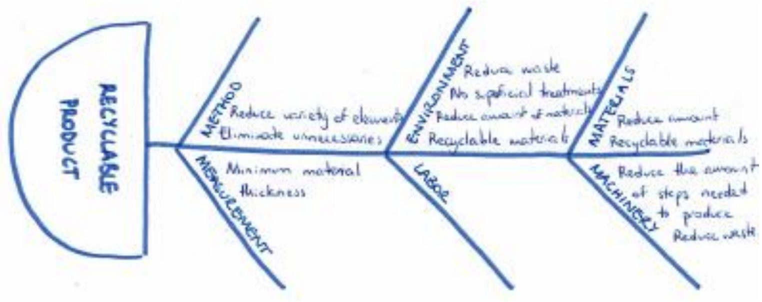



Figure 9. Example of an Ishikawa diagram

Once the Ishikawa diagram is complete, this information is then taken to the QFD table, where each of these solutions is assessed. This table shows the current position of the product in the market, the competition's position and the objectives of the product. This is also a way of clearly seeing the importance of each action and its difficulty. The full QFD is shown in Annex N: Quality Function Deployment I.

The requirements established by the user are those listed below.

- Eliminate pain (on the cheekbones, on the nose, on the forehead or on the neck).
- Good subjection systems (for both the headset itself and for the phone).
- Improve the use (avoid light coming into the device, include headphones, make the headset compatible with the use of glasses, make the design understandable and reduce sweat during VR use).
- Allow for personalisation (adjustment of different elements of the headset).
- Make the product recyclable.

From this table, a set of actions have been taken and have been attached to concrete goals. These are the following:

- A good subjection system must be designed.
- The re-design can solve many of the product's problems.
- It is important to include instructions within the product packaging.
- To include a groove will help with heat dissipation.
- Taking into account mobile phone standardised designs will help create a better phone subjection system.
- Elastic materials may be used for the subjection system.
- Anthropology studies are necessary to improve the ergonomics of the design.
- The product should have security against breakage.

## 3.2. PRODUCT ANALYSIS

The requirements of the product itself differ from those of the user. These include an analysis of the materials used as well as the production process. Ecological aspects are also studied in order to create a final product that is environmentally friendly.

### 3.2.1. PRODUCT MIND MAP

Firstly, a mind map (Figure 10. Product design mind map) is created to see the different design options within the headset. Six blocks are defined: subjection system, adjustment, comfort, main body and packaging. From each of these, a set of alternatives is explored as an initial contact with VR headsets.

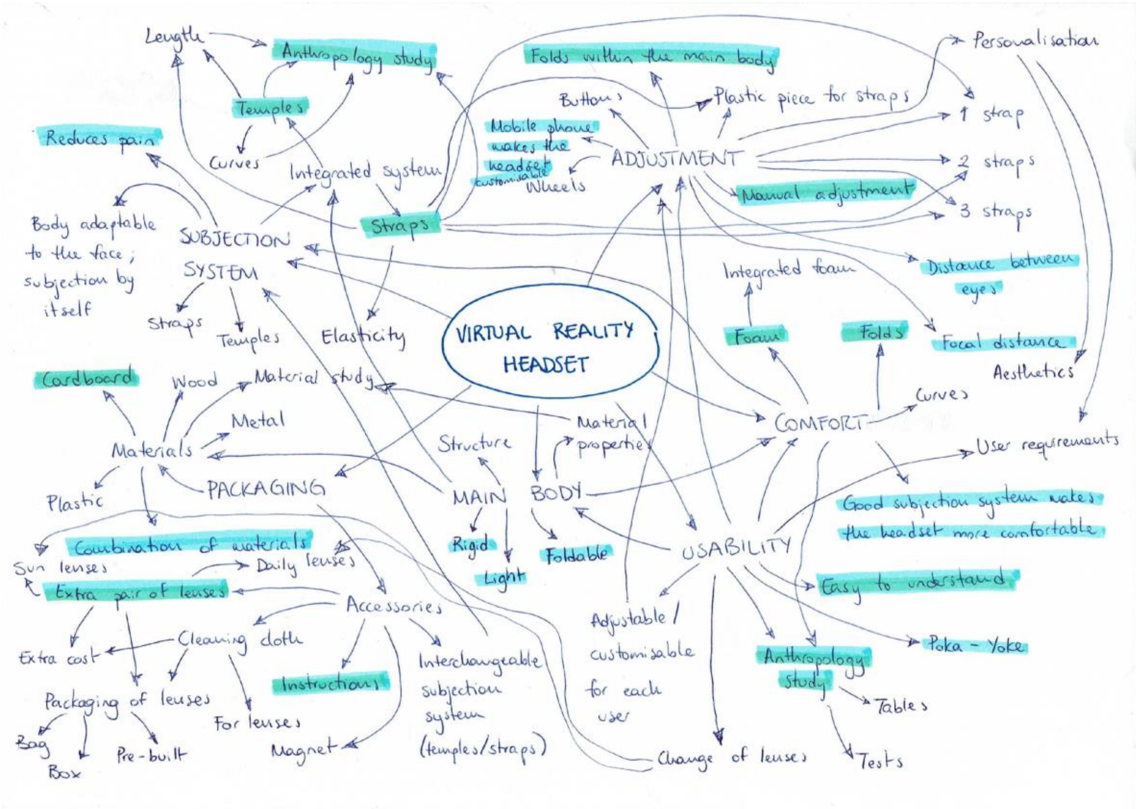



Figure 10. Product design mind map

Some interesting points have been drawn from this mind map. These have been marked in blue as aspects to study further throughout the project. This exercise works to break the ice in relation to product design. The first options are examined, and now the rest of the brainstorming tools will be more productive.

Another type of mind map has been done, by using Post-Its on a whiteboard (Figure 11. Whiteboard mind map). Two sections are created: “What I know” and “What I do not know”. In the first section, some key concepts are placed, as well as the characteristics of the studied headsets. The latter included different aspects, such as the subjection system (straps or temples?), that were there organised into topics and related amongst them.

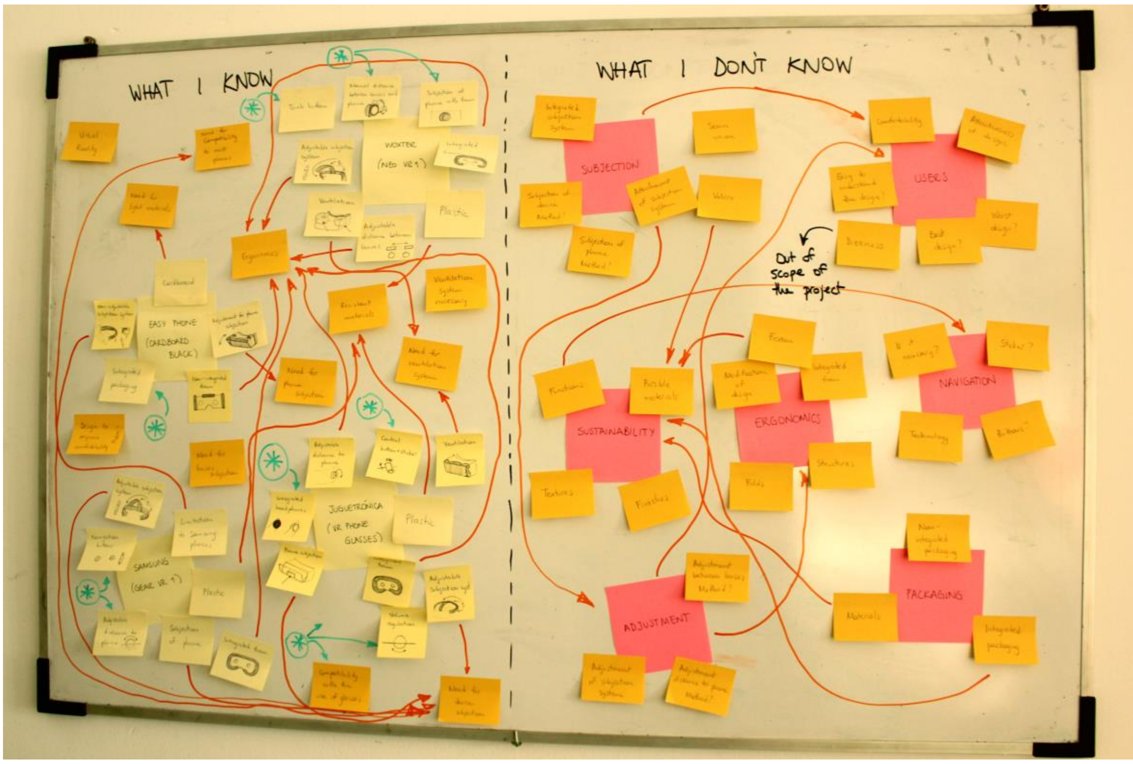



Figure 11. Whiteboard mind map

This offers, once again, a clear overview of the elements that have to be studied and some of the first options available for the re-design of the VR headset.

### 3.2.2. STORYBOARD

A study of the current sequence of use is done before further investigation. Many manufacturers offer little to no information on the use of the headsets, and it is important to understand what the user has to do to experience VR with the device. This analysis shows any other product requirements that may have been overlooked.

Figure 12. Storyboard: Woxter

Woxter’s headset is opened by a button placed on the top side. It opens a compartment in which to place the phone (which should already be on and with the VR app open) horizontally. To close the compartment, the cover has to be pushed against the main body until it clicks. The user then places the headset and adjusts the three straps with Velcro. The distance between the lenses can be adjusted with two levers placed on top of the headset.

**Figure 13. Storyboard: Juguetrónica**

Juguetrónica’s headset opens a compartment on the front by pushing a button on the top side. The mobile phone, ready for use, is placed horizontally and a cable is attached to the sound port. The compartment is closed by pushing against it until it clicks. It is then placed against the head and the straps are adjusted with the use of Velcro. The distance between the earphones is adjusted by turning a wheel placed on the side of the headset. Finally, the distance between the lenses is adjusted by turning a wheel at the top of the headset.

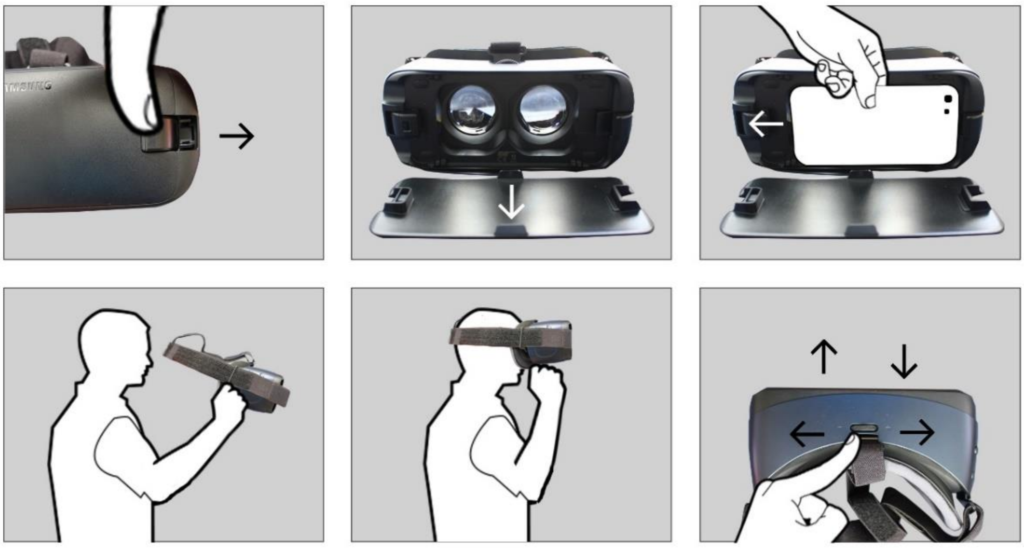


**Figure 14. Storyboard: Samsung**

Samsung's headset has two levers that are pushed to the sides after being unlocked. This allows to remove the cover and place the phone, horizontally and sideways. It is closed by pushing the cover back into its position until it clicks. It is then placed against the head and the straps are adjusted with the use of Velcro. A wheel on the top side of the headset adjusts the distance between the mobile phone compartment and the face.

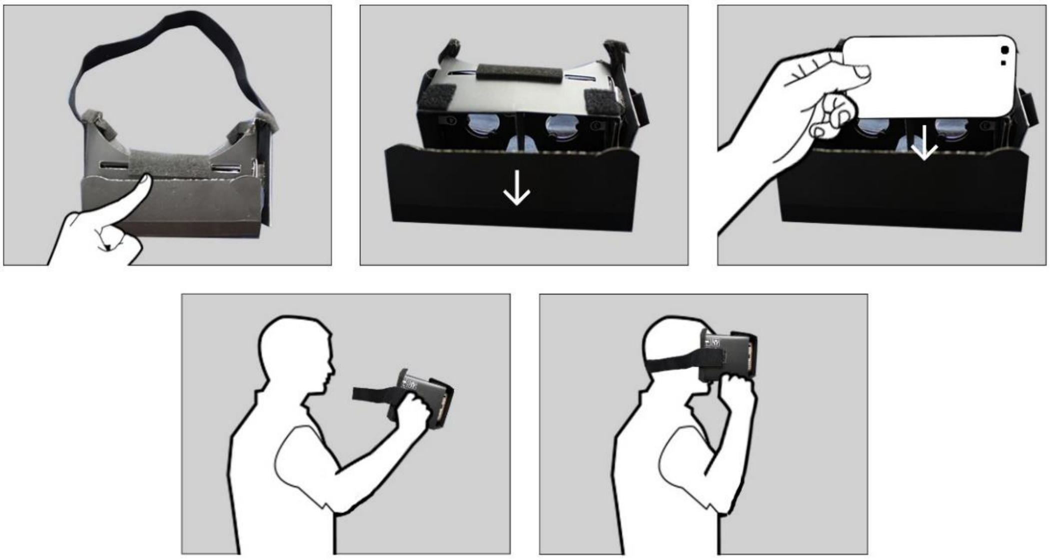


Figure 15. Storyboard: Easy Phone

Easy Phone's headset has a compartment held closed by Velcro. The ready mobile phone is placed horizontally and the compartment is closed the same way as it is opened. It is then placed against the face and the strap is placed around the head. No adjustment is possible.

### 3.2.3. QUALITY-FUNCTION DEPLOYMENT (PART II)

Following the previous QFD (Annex N: Quality-Function Deployment I), the second stage analyses the way to achieve the set goals. New Ishikawa diagrams are made (Annex O: Ishikawa diagram II) taking the actions with objectives and finding all the elements that can be affected by these actions. This new QFD shows which parts have to be modified or re-worked and helps set goals (Annex P: Quality-Function Deployment II).

### 3.2.4. ECO-DESIGN

The eco-design tool is a guideline with a wide variety of options to make a product environmentally friendly. It helps brainstorm different ecological ideas to apply to a product.

In this first stage of the design process, in order to enhance creativity, a solution will be offered for each applicable option (Table 5. Eco-design). In later stages, a selection will have to be made and only the feasible options will be applied in the final proposal.[19]

| | |
|---|---|
| Development of new concepts | **Dematerialisation** |
| | Include an application within the headset (combine the headset with the mobile phone) to reduce the amount of materials used and the size of the final product. |
| | Integrate the subjection system within the headset itself. |
| | Remove the protective foam that makes the headset more comfortable and improve ergonomics by redesigning the headset, to eliminate unnecessary elements from the design. |
| | **Shared use** |
| | Share the headset by replacing the mobile phone placed within the device with another one, making the product fully customisable. |
| | **Integration of functions** |
| | Make the lenses interchangeable to allow the use of the headset as everyday glasses (sunglasses or reading glasses). |
| | Include headphones in the headset to have a more realistic experience when using VR technology. |
| Consumption reduction and diversity of materials | **Minimise components that don't add value** |
| | Reduce the layers of material to reduce the size of the final product. |
| | Reduce the size of the headset to make it look more natural. |
| | **Optimise wall thickness and material density** |
| | Reduce wall thickness without harming the structure of the design to save materials. |
| | **Part re-utilisation** |
| | Re-use the lenses if the main body breaks. |
| | Re-use the main body if the lenses break. |
| | **Avoid superficial treatments** |
| | Do not include paint or any other superficial treatments. |
| | **Consult suppliers on optimisation** |
| | Not applicable. |
| | **Consider the environmental impact of the material** |
| | The main material of the current product is cardboard. Offer material alternatives considering their environmental impact. |

Table 5. Eco-design brainstorming

[19] CIDEM, Generalitat de Catalunya. *Eines de Progrés: Ecodisseny*. 1st edition. Barcelona, Spain: April 2005.

| | |
|---|---|
| Material selection for a minor environmental impact | **Derived from natural resources** |
| | The main material of the current product is cardboard. Offer material alternatives derived from natural resources. |
| | **High recycled material content** |
| | Make the main body recyclable so that most of the headset is recyclable. |
| | Make the subjection system recyclable. |
| | **No dangerous substances** |
| | Check whether the parts of the final product are made of dangerous materials. If so, consider different environmentally friendly alternatives. |
| | **Environmentally friendly** |
| | Check which of the processes are environmentally friendly within the production of the parts of the product. Consider different options if any processes may harm the environment. |
| | **Low energetic intensity** |
| | Check the energetic intensity used to create the final product. |
| | **Easily recyclable** |
| | The main material of the current product is cardboard. Offer other recyclable material alternatives. |
| Reduction of environmental impact in productive processes | **Reduce amount of productive stages** |
| | Minimise the variety of materials used in the final product. |
| | Minimise the amount of components used in the final product. |
| | Minimise any unavoidable superficial treatments. |
| | **Process and material selection that allows to recycle production waste** |
| | Recycle production waste (cuts). |
| | Check the production procedure for standardised parts. Consider offering alternatives. |
| | **Environmentally friendly processes** |
| | Check the production systems to ensure that the making of the final product is as environmentally friendly as possible. |
| Distribution optimisation | **Minimise the use of packaging** |
| | Make the packaging integrated in the final product. |
| | **Packaging materials with the lowest environmental impact** |
| | Consider the use of paper bags to pack the loose parts. |
| Distribution optimisation | **Mark materials with identifying symbols** |
| | Mark the final product with a sticker or paint to identify the materials. |
| | Mark the final product by cutting it into the main body. |
| | **Lowest volume possible in transportation and storage** |
| | Transport a disassembled product to reduce the taken space for transportation. |

Table 6. Eco-design brainstorming (continued)

| | |
|---|---|
| Distribution optimisation | **Reduce the product's weight to use less energy to transport the product** |
| | Take into account the weight of the product in the design process to minimise energy consumption and to improve ergonomics. |
| | Make the packaging as light as possible. |
| Reduction of environmental impact during its use | **Reduce water and energy consumption per unit of service offered by the product** |
| | Not applicable. |
| | **Introduce the use of renewable energy** |
| | Charge the mobile phone placed within the headset during its use, by means of solar energy or using the movement of the user. |
| Increase of product life | **Allow and promote the re-utilisation of the product** |
| | The device may be used by more than one person by changing the mobile phone placed within the headset. |
| | **Identify and try to eliminate the weak spots of the product to prevent it from breaking and having to be repaired or replaced** |
| | Test the product with prototypes to identify the weak spots and fix the design before production. |
| | Test the product with users to identify the weak spots and fix the design. |
| | **Choose the correct materials and thickness to ensure good product resistance to continuous use** |
| | Test the product with different materials before choosing the final one to ensure that the product is resistant enough. |
| | **Design the product in modules that can be updated to adapt to the changing needs of the user** |
| | Not applicable. |
| | **Make repairing and maintenance easy** |
| | Allow the headset to be disassembled to change any of the elements of the final product in case they break. |
| | **Provide spare parts for repairing** |
| | Add a second set of lenses to the pack. |
| | Add a second subjection system to the pack. |
| Optimisation and waste management | **Use recyclable or biodegradable materials keeping in mind the recycling systems for the country in which the product will be used** |
| | The main material of the current product is cardboard. Offer other recyclable material alternatives. |
| | Check the materials for the standardised parts. |
| | **Use the lowest amount of different materials possible** |

Table 7. Eco-design brainstorming (continued)

| | |
|---|---|
| Optimisation and waste management | Consider material options before the final product is made. |
| | **Use materials that allow the product to be recycled as a whole** |
| | Design an integrated subjection system that allows the final product to be recycled without the need of disassembly. |
| | **Minimise the use of superficial treatment that make it difficult for the product to be recycled** |
| | Avoid paints or other superficial treatments. |
| | Any marks that need to be made can be done by cutting them into the final product. |
| | **Simplify the disassembly of the product** |
| | Combine the headset with the subjection system. |
| | Avoid sticking the lenses to the main body. |

Table 8. Eco-design brainstorming (continued)

## 3.3. CONTEXT OF USE

The last aspect to be considered is the context of use of the device. This will affect the way in which the user interacts with the product and the expected functions of the headset.

The physical scenario in which the low-cost VR headset will be used depends on the user's available space or will to walk around while experiencing VR technology. For those wanting to walk around and immerse in the VR world, they will require a radius of approximately 1.5 metres to walk around. Those apps that do not require movement other than head rotation may be used by sitting on a chair, preferably one that allows the user to look around without moving their neck. [20]

The target user profile, as seen on the user analysis, is a young person of up to 25 years old, with some interest in ages up to 59 years old. The gender of the user, in this case, is irrelevant, and they tend to have an interest in using VR technology for learning (40% in children from 0 to 12 years old and 74% in young people aged 13 to 25) and gaming (100% in children and 59% in youngsters). There is also an interest in watching films (80% in children and 56% in youngsters), and people aged 13 to 25 are also keen on live events (50%). The target user would not have any impairment in the use of VR headsets or VR technology.

[20] *HTC Vive VR: How much room space do I really need?* [Consulted: 03 Jan 2017]. Available at: <http://www.ibtimes.co.uk/htc-vive-vr-how-much-room-space-do-i-really-need-1558494>
*How much space do you need for your HTC Vive?* [Consulted: 03 Jan 2017]. Available at: <https://www.vrheads.com/how-much-space-do-you-need-your-htc-vive>
*How to prepare your PC and room for VR.* [Consulted: 03 Jan 2017]. Available at: <http://www.pcgamer.com/how-to-prepare-your-pc-and-room-for-vr/>

## 3.4. SWOT ANALYSIS

The aim of this SWOT analysis (Strengths-Weaknesses-Opportunities-Threats) is to assess the state in which the current Easy Phone Cardboard device is at the moment, compared to its competitors. It will show the positive and negative internal aspects, as well as the external (Table 9. SWOT analysis).

| | Positive | Negative |
|---|---|---|
| Internal | STRENGTHS | WEAKNESSES |
| | • Inexpensive<br>• Light<br>• Easy to build<br>• Compatibility with most (if not all) mobile phones | • Poor ergonomic design<br>  ○ Pain on nose<br>  ○ Pain on cheekbones<br>  ○ Pain on forehead<br>• Subjection system not adjustable<br>• Need of the use of foam to avoid pain<br>• Poor subjection system for the phone<br>• Incompatible with the use of glasses<br>• Use of superficial treatments<br>• Fixed focal length<br>• Low budget |
| External | OPPORTUNITIES | THREATS |
| | • Expensive competitors<br>• Heavy competitors<br>• Competitors with large headsets<br>• Most headsets are incompatible with the use of glasses<br>• Open/Shared designs on the Internet<br>• Re-design allows the headset to become more competitive<br>• Re-design allows the headset to become more ergonomic<br>• Increased interest in VR technologies<br>• Non-recyclable competitors | • Ergonomic competitors<br>• Competitors with more resistant materials<br>• Competitors with instant connection to a VR app on the phone<br>• Competitors with touch panels and other electronic parts<br>• New cardboard models |

**Table 9. SWOT analysis**

This information is useful for the re-design stage. Finding the weaknesses and strengths of the product early on in the project helps establish new design strategies. The knowledge of the opportunities and threats of the market may also affect the final product and the way it develops. In this case, the weaknesses will be improved and the opportunities will be reinforced to offer the best product possible.

## 3.5. DESIGN BRIEF

The design brief of a project includes all of the requirements of a design process to set a clear base from which to develop any product or service. Its first step is to create a framework, which, in the case of a design process, is a sentence that clearly describes the designed product, allowing for no mistakes or confusion.

"A light headset costing less than €100.00 with lenses for 3D viewing that serves as a support for mobile phones with VR apps."

Attributes are the characteristics that the product must have in order to achieve its goals. In this case, the attributes have been organised into five categories: related to comfort, related to norm, related to use, related to the user and related to materials (Table 10. Design brief: Attributes).

| Related to comfort |
|---|
| No pain on the nose |
| No pain on the forehead |
| No pain on the cheekbones |
| No pain on the head through the subjection system |
| Reduce the size to make the product more comfortable |
| Use of a groove for heat dissipation |
| **Related to norm** |
| Distance between the mobile phone screen and the face of the user |
| **Related to use** |
| Adequate subjection of the mobile phone |
| Design compatible with the use of glasses |
| Reduce the size to make the product more attractive |
| Good subjection system to prevent unwanted movements of the headset during its use |
| Prevent light from coming into the headset |
| **Related to the user** |
| Easily understandable design |
| Easily built headset |
| Adjustable focal length |
| Adjustable subjection system |
| Results of anthropology studies |
| **Related to materials** |
| Use of ecological materials |
| Use of recyclable materials |
| Use of low-density materials to reduce weight |
| Use of resistant materials to hold the lenses and the mobile phone |
| No superficial treatments |
| Low-cost materials (total cost has to be under €100.00) |

Table 10. Design brief: Attributes

For design inspiration, it is important to understand the precedents and the referents of the products. The first are other products in the market, the competition, while the latter are those products or services that solve the need of the studied object. In this case, the studied precedents are the four VR headsets that have been compared in the first test. The referents are the following:

- Different kinds of goggles, with which to analyse different subjection systems and the contact of the product with the user's face.
- Video game consoles, with which to check the impact of a screen on the user's eyes.
- Glasses, with which to study the design of temples and nose pads.
- Tablet supports, with which to study how to hold a device.
- 4D cinemas, with which to study the movements required for VR movie immersion.

The strategy for this product will be a poetic design, which focuses on the utility, functionality and beauty of the product. In this case, it is more important than emotion, the wow factor or innovation.

# 4. DESIGN

## 4.1. FAULT ANALYSIS

After establishing the design brief and the requirements of both the user and the product, an analysis of the initial product (Easy Phone's Cardboard Black) was made, to check how it related to these requirements and see how it could be improved. Figure 16. Fault analysis shows the 2D plan of this headset. Marked in blue are the problem areas which should be fixed.

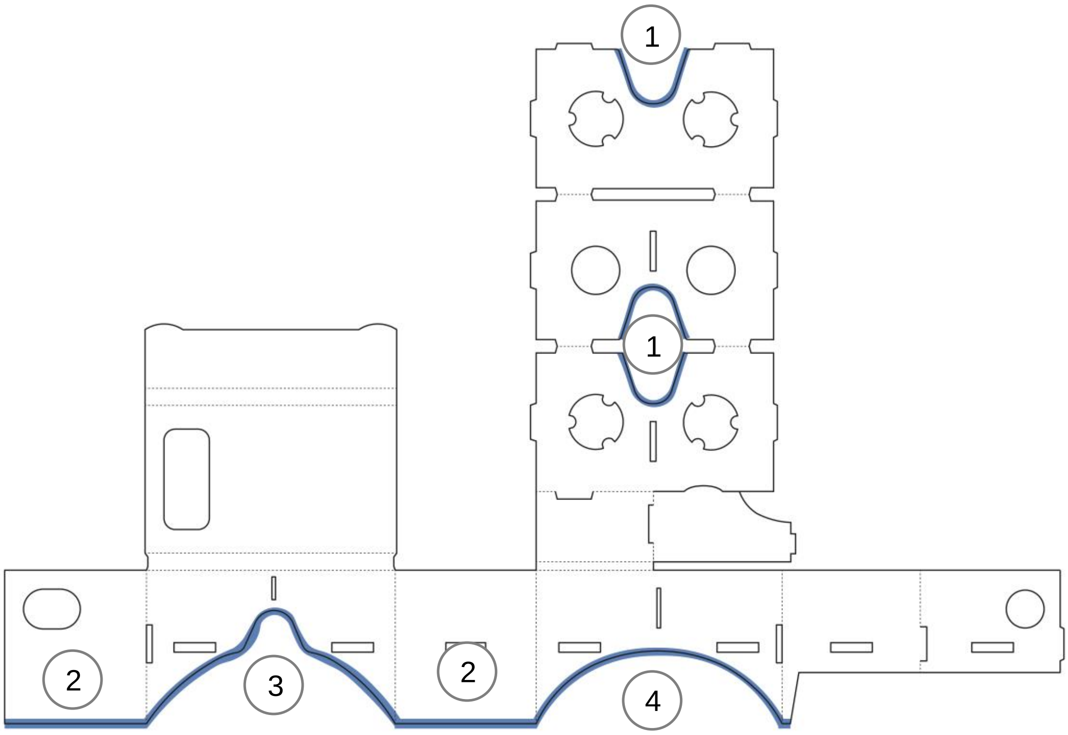



Figure 16. Fault analysis

1. In contact with the nose: The cardboard sinks into the skin. It produces pain and leaves marks on the face.
2. In contact with the sides of the face: Manufacturers have placed foam here to avoid pain.
3. In contact with the cheekbones and the nose: The cardboard sinks into the skin. It produces pain and leaves marks on the face.
4. In contact with the forehead: Manufacturers have placed foam here to avoid pain.

All of these points will have to be revised and improved with new design proposals. Also, the final design has superficial treatments, use of unnecessary elements (foam) and the use of glue to keep it from disassembling.

## 4.2. POKA-YOKE

Poka-Yoke is a tool used to prevent mistakes before they can be made. It is used based on the analysis of the product and its use, and it requires a very thoughtful insight into the device.

The final product is very simple and easy to use. The only poka-yoke needed is for the product assembly. All the instructions are cut out into the main body of the headset. On the one hand, the position of the lenses is indicated (Figure 17. Poka-Yoke: Lenses position). The curved side of the lenses must be placed away from the face.

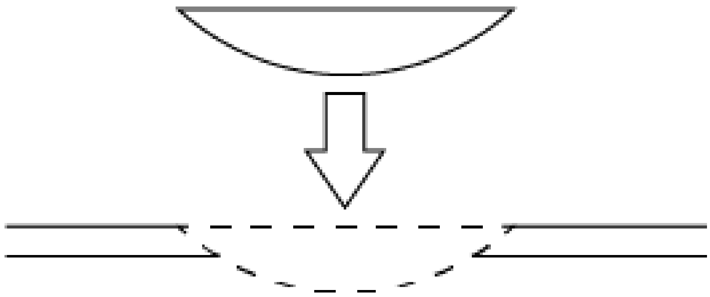


Figure 17. Poka-Yoke: Lenses position

On the other hand, the process to build the headset is indicated with numbers, also cut into it, and an instruction sheet is included. This prevents any mistakes from being made. The building process is very simple so that anybody can do it.

The position of the logo, on the front side of the headset, is important. If placed incorrectly, the logo will be horizontally flipped. The instruction sheet makes the user see the correct position of the headset and the folds.

## 4.3. CONCEPTS AND HYPOTHESIS

Based on this starting point, new proposals were made. Each modification had a hypothesis linked to it, which would later on help assess the validity of each change in the design (Table 11. Changes in the design and their linked hypothesis).

| Change in the design | Hypothesis |
|---|---|
| Increase the space for the nose | This should make the headset less painful on the nose |
| Increase the radius in contact with the forehead | This should help the device adapt to more types of faces and therefore reduce pain |
| Increase the radius in contact with the cheekbones | This should help the device adapt to more types of faces and therefore reduce pain |
| Increase the space between the head and the device | This should allow the user to wear glasses while wearing the headset |
| Increase the space on the sides between the head and the device | |
| Add folds on the forehead | This should reduce pain on the forehead |
| Add folds on the nose | This should reduce pain on the nose |
| Add folds on the cheekbones | This should reduce pain on the cheekbones |

**Table 11. Changes in the design and their linked hypothesis**

Each of the changes made (11 versions of the product in total) can be found in 2D drawings in Annex Q: 2D drawings of proposals.

Other concepts were also explored, such as a system to adjust the focal distance. The first idea was to create a cardboard strap with the lenses placed within (Figure 18. Focal distance adjustment). It would be placed on a guide and the user would pull or push the extremes to place the lenses in the distance that best adapts to their face. It would then be held in position with the help of Velcro on the sides of the headset. The second version of this idea would work the same way, but using an elastic material to make it naturally return to its initial state to pull the lenses together with ease (Figure 18. Focal distance adjustment). This could be applied in further studies on this same subject.

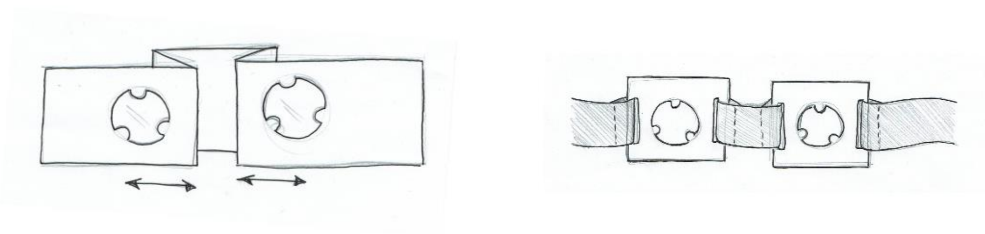


**Figure 18. Focal distance adjustment**

# 5. PROTOTYPING

## 5.1. MOCK-UPS

To test these concepts before prototyping, mock-ups were made (Figure 19. Mock-ups). This models are made of other materials other than the final ones to test quickly and cost-effectively. In this case, mock-ups were made out of paper, where the 2D plan was printed and cut out, stuck with tape and built. If any faults were found in the process, they were marked in red to re-design.

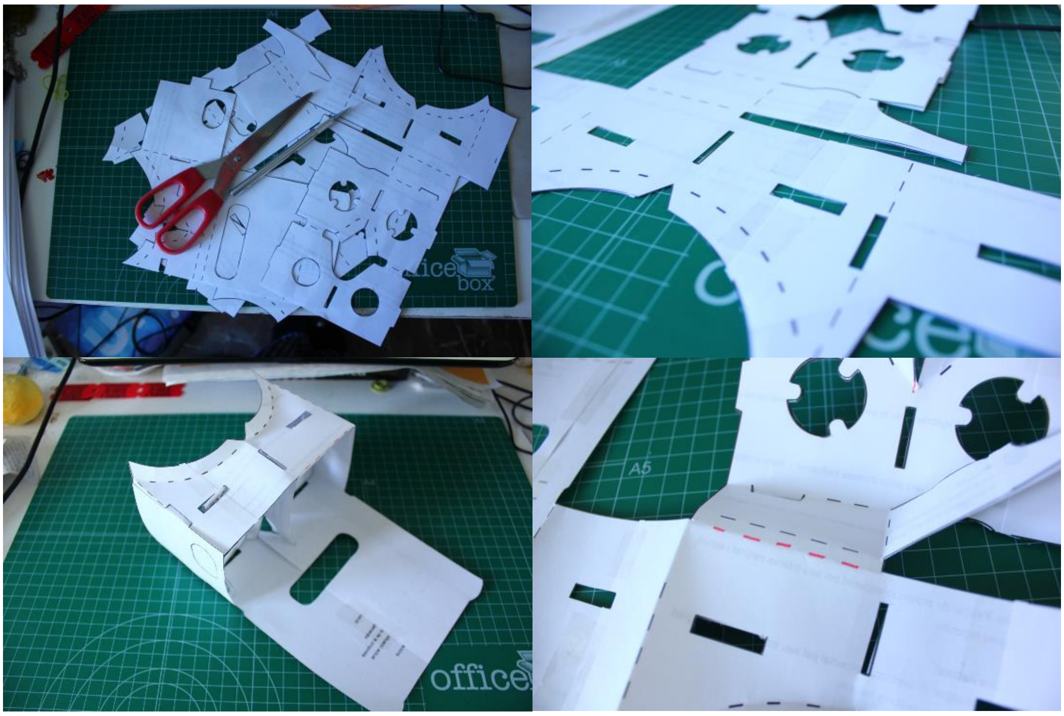



Figure 19. Mock-ups

Some information was drawn from this process, which were missing fold lines, modification of radiuses or elimination of shapes that don't add to the final product.

## 5.2. PROTOTYPES

Once the mock-ups were checked, prototypes were laser cut in cardboard. Two types of cardboard were used, thick (2.0 mm) and thin (0.6 mm). The latter was used for final prototypes given that it is easier to fold than the thicker one, which broke (Figure 20. Thick cardboard faults).

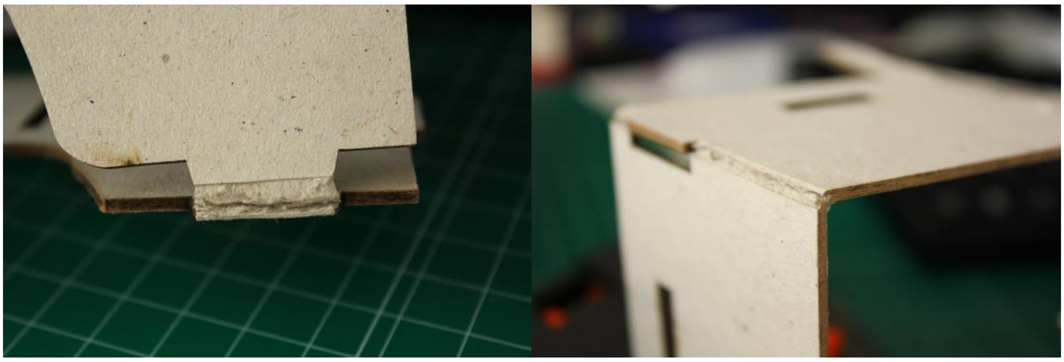


Figure 20. Thick cardboard faults

These prototypes assisted in the evaluation of the designs prior to user testing, as well as allowing to imagine any other design possibilities by seeing the production method. Once it is understood, it is easier to generate new design ideas. As the last step within the project, a final prototype is created with the final design proposal.

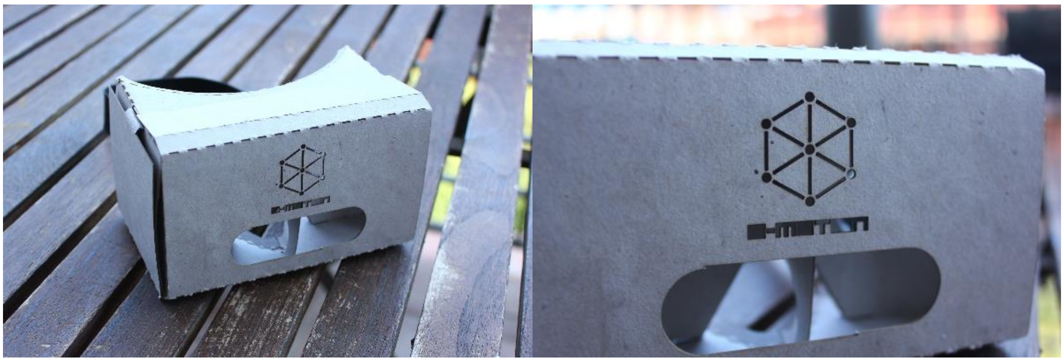


Figure 21. Final prototype

# 6. EVALUATION

In this chapter, different tools for evaluation are presented. These are used for the evaluation of the various design proposals, as well as production processes and the use of the final product.

## 6.1. ERGONOMIC DESIGN GUIDELINE

### 6.1.1. ERGONOMIC DESIGN GUIDELINE

The Ergonomic Design Guideline for VR headsets has been created based on the information obtained by personal experience and, most importantly, by user testing. It helps assess the quality of a headset's ergonomics and offers suggestions to improve the design depending on the faults found. It has been used in various sections throughout the project but has finally been considered an evaluation tool because it allows for the assessment of VR headsets (as well as assisting in the design of these products).

It is divided in four sections: glasses (to assess the compatibility of the headset with the use of glasses), subjection (to evaluate the subjection system), face (the ergonomics themselves of the headset against the user's face) and control (to assess the adjustability and personalisation of the headset). Table 12. Ergonomic Design Guideline for VR headsets shows the questions of the Guideline and the design suggestions for each fault.

<table>
<tr><th>Question</th><th>Suggestion</th></tr>
<tr><td colspan="2">Glasses</td></tr>
<tr><td>1. The device is compatible with the use of glasses.<br>When using glasses, the device can be comfortably placed.</td><td>The designer can vary the VR device design to allow compatibility with glasses. If this is not possible, the user shall change the VR device until they find a compatible model.</td></tr>
<tr><td colspan="2">Subjection</td></tr>
<tr><td>2. After the necessary adjustments, the device is correctly subjected.<br>The device is well subjected if it is not displaced when the user makes different movements while using it after correctly adjusting it.</td><td rowspan="2">The designer must improve the subjection method (straps, Velcro, etc.) to prevent the device from being displaced when the user changes the head's orientation. These should also allow maximum adjustability for different types of people.</td></tr>
<tr><td>3. When adjusting the device, long hair makes subjection difficult.<br>Long hair might get tangled with the subjection elements when making adjustments, making this a difficult procedure.</td></tr>
</table>

**Table 12. Ergonomic Design Guideline for VR headsets**

<table>
<tr><th>Question</th><th>Suggestion</th></tr>
<tr><td colspan="2">Subjection</td></tr>
<tr><td>4. The user needs assistance to adjust the device.<br>If the user needs assistance, they will take longer than what is considered normal when adjusting the device and will be quicker once assistance is given.</td><td>The designer should modify the device so that it is easily adjusted without assistance. If this is not possible, the designer should properly indicate that assistance is necessary when adjusting the VR device.</td></tr>
<tr><td>5. When adjusting the device, there is a considerable change in the user's head orientation.<br>The user might need to adopt an uncomfortable position to adjust the device.</td><td rowspan="2">The designer must check the weight of the VR device if an uncomfortable posture is observed when adjusting or using it.</td></tr>
<tr><td>6. After the necessary adjustments, there is a considerable change in the head's orientation.<br>The user might need to adopt an uncomfortable position when using the device due to its weight or design.</td></tr>
<tr><td colspan="2">Face</td></tr>
<tr><td>7. The device rests comfortably on the nose.<br>The user might report some discomfort on the nose during or after using the device.</td><td rowspan="4">The designer must check the mass distribution between subjection straps and the VR device's chassis to avoid overloading the nose and cheekbones.</td></tr>
<tr><td>8. The device rests comfortably on the cheekbones.<br>The user might report some discomfort on the cheekbones during or after using the device.</td></tr>
<tr><td>9. The device rests comfortably on the forehead.<br>The user might report some discomfort on the forehead during or after using the device.</td></tr>
<tr><td>10. The device leaves marks on the face.<br>The user might have noticeable marks on the face during or after using the device.</td></tr>
<tr><td>11. The device triggers a noticeable increase in sweat.<br>The user might show a noticeable increase in sweat during or after using the device.</td><td>The designer must check the device's materials (heat dissipation, refrigeration).</td></tr>
</table>

**Table 13. Ergonomic Design Guideline for VR headsets (continued)**

| Question | Suggestion |
|---|---|
| Face | |
| 12. The device triggers some kind of pain on the back side of the head.<br>*The user might report some discomfort on the back side of the head during or after using the device.* | The designer must check the adjustment methods to avoid pain. |
| Control | |
| 13. The user can adjust the focal distance.<br>*The device's design allows the user to adjust the focal distance.* | The designer must make control and adjustments easy for the user by the use of an instruction guide or adjustment buttons/mechanisms conveniently indicated. |
| 14. (In the case of headphones) The user can adjust the distance of the device between the face and the ears.<br>*If the device has headphones, they can be adjusted to be comfortably used by the user.* | |

**Table 14. Ergonomic Design Guideline of VR headsets (continued)**

With this Guideline, however, one can find problems while answering the questions. Each of them are accompanied by descriptions of the question, but some can only be answered in special cases. For example, if the user does not usually wear glasses, he or she will not be able to answer the question, and two compared headsets will only be able to be assessed on 13 of the 14 heuristics. This happens again with heuristics 3 (long hair makes subjection difficult) and 14 (only answered in the case that the headset includes headphones). Other heuristics might be assessed differently amongst different users.

This Guideline is version four, meaning that it has evolved from a starting point, but that it can also be re-designed with more (or less) heuristics that can be assessed in an easier way. Table 15. Ergonomic Design Guideline proposal is the proposed fifth version for the Guideline, filtering the problematic heuristics. It has been assessed by a group of Interaction experts from the AIPO community and has been answered correctly by each of these people (section 6.1.3. Guideline validation by experts).

| Question | Suggestion |
|---|---|
| Subjection | |
| 1. After the necessary adjustments, the device is correctly subjected.<br>*The device is well subjected if it is not displaced when the user makes different movements while using it after correctly adjusting it.* | The designer must improve the subjection method (straps, Velcro, etc.) to prevent the device from being displaced when the user changes the head's orientation. These should also allow maximum adjustability for different types of people. |

**Table 15. Ergonomic Design Guideline proposal**

<table>
<tr><th>Question</th><th>Suggestion</th></tr>
<tr><td colspan="2">Subjection</td></tr>
<tr><td>2. The user needs assistance to adjust the device.<br>*If the user needs assistance, they will take longer than what is considered normal when adjusting the device and will be quicker once assistance is given.*</td><td>The designer should modify the device so that it is easily adjusted without assistance. If this is not possible, the designer should properly indicate that assistance is necessary when adjusting the VR device.</td></tr>
<tr><td>3. When adjusting the device, there is a noticeable change in the user's head orientation.<br>*The user might need to adopt an uncomfortable position to adjust the device.*</td><td rowspan="2">The designer must check the weight of the VR device if an uncomfortable posture is observed when adjusting or using it.</td></tr>
<tr><td>4. After the necessary adjustments, there is a noticeable change in the head's orientation.<br>*The user might need to adopt an uncomfortable position when using the device due to its weight or design.*</td></tr>
<tr><td colspan="2">Face</td></tr>
<tr><td>5. The device rests comfortably on the nose.<br>*The user might report some discomfort on the nose during or after using the device.*</td><td rowspan="4">The designer must check the mass distribution between subjection straps and the VR device’s chassis to avoid overloading the nose and cheekbones.</td></tr>
<tr><td>6. The device rests comfortably on the cheekbones.<br>*The user might report some discomfort on the cheekbones during or after using the device.*</td></tr>
<tr><td>7. The device rests comfortably on the forehead.<br>*The user might report some discomfort on the forehead during or after using the device.*</td></tr>
<tr><td>7. The device leaves marks on the face.<br>*The user might have noticeable marks on the face during or after using the device.*</td></tr>
<tr><td>8. The device triggers a noticeable increase in sweat.<br>*The user might show a noticeable increase in sweat during or after using the device.*</td><td>The designer must check the device’s materials (heat dissipation, refrigeration).</td></tr>
<tr><td>9. The device triggers some kind of pain on the back side of the head.<br>*The user might report some discomfort on the back side of the head during or after using the device.*</td><td>The designer must check the adjustment methods to avoid pain.</td></tr>
</table>

**Table 16. Ergonomic Design Guideline proposal (continued)**

| Question | Suggestion |
|---|---|
| Control | |
| 10. The user can adjust the focal distance.<br>*The device's design allows the user to adjust the focal distance.* | The designer must make control and adjustments easy for the user by the use of an instruction guide or adjustment buttons/mechanisms conveniently indicated. |

**Table 17. Ergonomic Design Guideline proposal (continued)**

### 6.1.3. GUIDELINE VALIDATION BY EXPERTS

With the first versions of the Ergonomic Design Guideline (Annex J: Ergonomic Design Guideline) ready, based on the information given by the participants of the first test, it was then used and validated by interaction experts. These members of the *Asociación Interacción Persona-Ordenador* (Person-Computer Interaction Association, AIPO) were asked to use the Guideline to assess different VR headset models. It was remotely filled in through an online questionnaire that allowed the participants to add any comments concerning the use of the headset or the Guideline itself. The questionnaire was answered by nine experts, and 11 headsets were analysed (amongst them, HTC Vive, Oculus Rift and Google Cardboard).

Results showed that even headsets from a higher range of prices than the four tested devices in this project had aspects to be improved, such as the ergonomics related to the nose, the forehead or the cheekbones. This could lead to further investigation in VR headsets and their ergonomic design. The results obtained (full report on Annex R: Guideline validation by experts report (Spanish)) show that these experts were able to fill in the questionnaire correctly and had no problems answering the Guideline with their particular devices. One participant highlighted the importance of stating the difference between VR devices and VR headsets, given that there are other means of experiencing VR technology other than through headsets.

### 6.1.4. FIRST PROTOTYPES COMPARISON TEST

Once design proposals were created, a new test with 13 students from different Engineering studies was carried out on 26$^{th}$ April, 2017. One by one they were taken into a room in EPSEVG, in which an interview was carried out. After filling in a consent form (Annex S: Consent form for first prototypes comparison test (Spanish)), they were asked to assess the prototypes in terms of comfort, weight and aesthetics by answering the Guideline and four final questions that represented each of the blocks of the Guideline.

The information was collected by the use of an online questionnaire, filled in by the test conductor. This allowed the participants to add any other information they considered important in relation to the design or the comfort of the product. The compared headsets were three prototypes (coded as blue, green and red) and the original Easy Phone headset (made of the same material as the others to avoid biases in the comparison, and coded as yellow).

Each of the presented prototypes were designed under different hypothesis. The blue prototype (Figure 22. Blue prototype) was designed to be more compatible with the use of glasses, the green prototype (Figure 23. Green prototype) was designed with a new subjection system (with temples), in an attempt to improve the subjection method, and the red prototype (Figure 24. Red prototype) was designed to reduce the pain on the nose and the cheekbones.

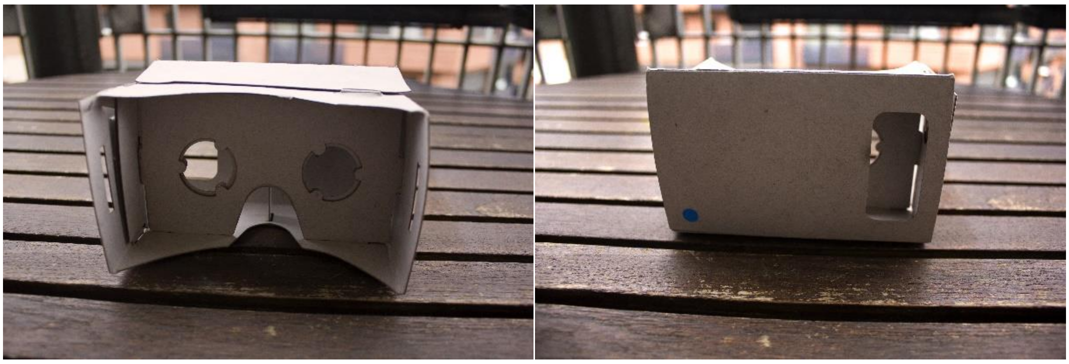


**Figure 22. Blue prototype**

**Figure 23. Green prototype**

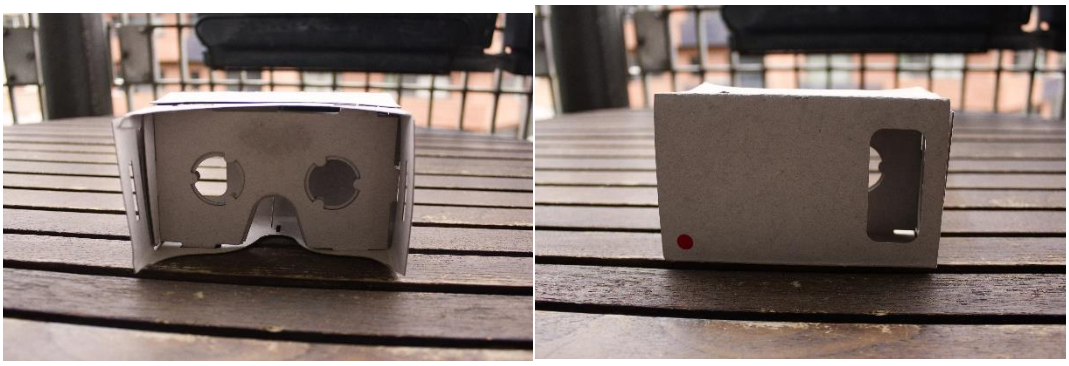


**Figure 24. Red prototype**

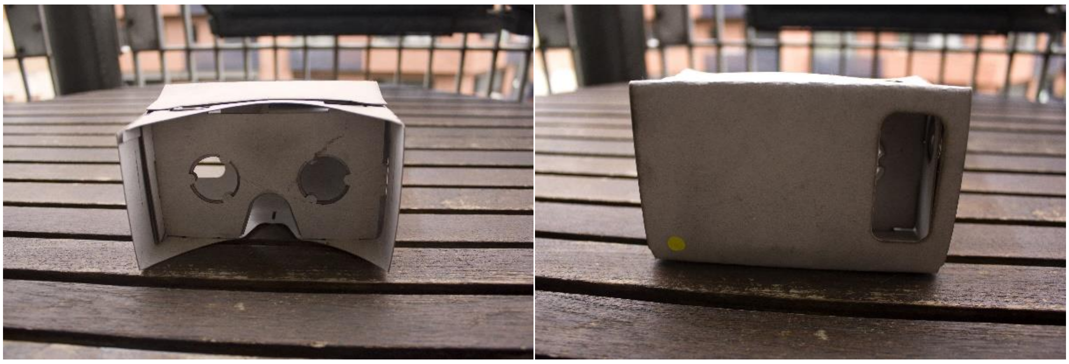


Figure 25. Yellow prototype

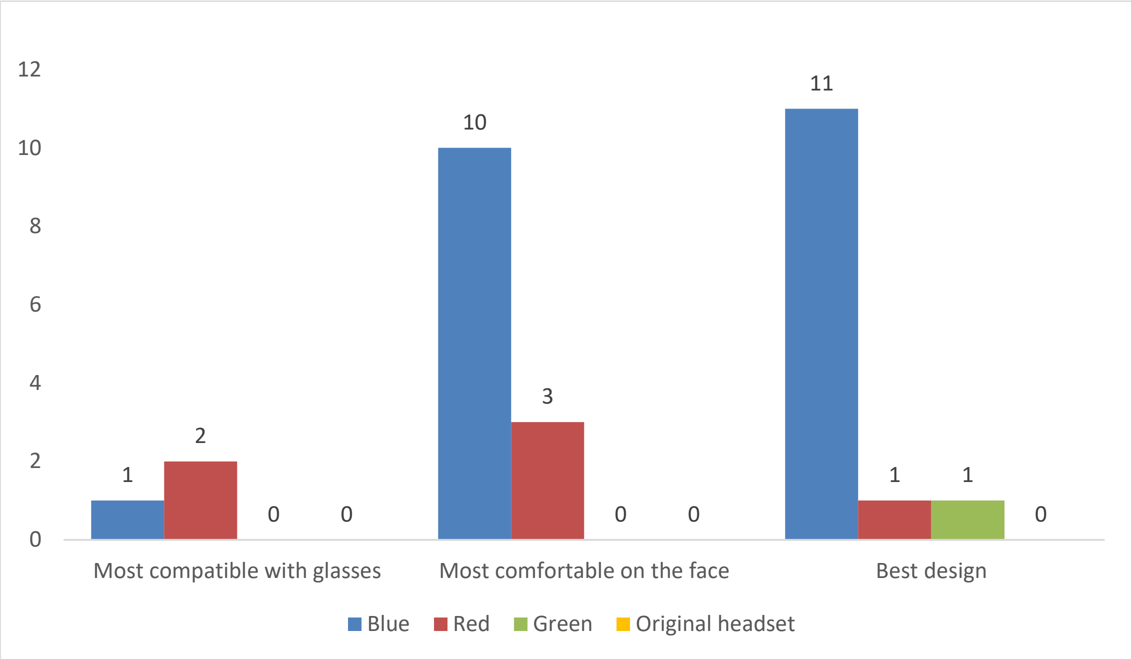



Figure 26. Comparison results

Figure 26. Comparison results shows the answers given by the participants. This results have been statistically analysed by Luis Miguel Muñoz, a member of the AIPO community, by means of a Chi-squared test. This method is used because the results are registered in a binary form (yes/no) and can therefore be compared with this tool to analyse if there is an existing difference amongst the evaluated heuristics (in this case, 7. The device rests comfortably on the nose, and 8. The device rests comfortably on the cheekbones). The results have been organised on Table 18. Organised results of first prototypes comparison test.

| Device | 7. The device rests comfortably on the nose | | | 8. The device rests comfortably on the cheekbones | | |
|---|---|---|---|---|---|---|
| | No | Yes | Total | No | Yes | Total |
| Blue | 5 | 8 | 13 | 3 | 10 | 13 |
| Green | 10 | 3 | 13 | 8 | 5 | 13 |
| Red | 8 | 5 | 13 | 9 | 4 | 13 |
| Yellow | 12 | 1 | 13 | 10 | 3 | 13 |
| Total | 35 | 17 | 52 | 30 | 22 | 52 |

**Table 18. Organised results of first prototypes comparison test**

The null hypothesis $H_0$ considers that there is no significant difference between the observed results for each headset, and the degrees of freedom for the test are *r*-1 (being *r* the amount of compared elements, in this case, the four headsets: 4-1 = 3). This is the sub index given to $X^2$. *k* is the amount of possible outcomes (in this case, yes/no). The degrees of freedom is (*k*-1)(*r*-1), (2-1)(4-1) = 3. *n* is the observed frequency and *e* is the expected frequency.

$$X_3^2 = \sum_{i=1}^{r} \sum_{j=1}^{k} \frac{(n_{ij} - e_{ij})^2}{e_{ij}}$$

The larger the difference between *n* and *e*, the larger the value of $X^2$ will be, and thus the higher the possibility of rejecting $H_0$. To calculate *e*, the following formula is used, obtaining that for heuristic 7, $e_{11} = 8.75$ and $e_{12} = 4.25$.

$$e_{ij} = \frac{n_i n_j}{n}$$

$$e_{11} = \frac{35 * 13}{52} = 8.75$$

$$e_{12} = \frac{17 * 13}{52} = 4.25$$

$$X_3^2 = \frac{(5-8.75)^2}{8.75} + \frac{(8-4.25)^2}{4.25} + \frac{(10-8.75)^2}{8.75} + \frac{(3-4.25)^2}{4.25} + \frac{(8-8.75)^2}{8.75} + \frac{(5-4.25)^2}{4.25} + \frac{(12-8.75)^2}{8.75} + \frac{(1-4.25)^2}{4.25} = 9.35$$

Taking this result and applying it in a Chi-squared table[21], the obtained p-value for heuristic 7 is 0.025, and p-value = 0.027 for heuristic 8. This indicates statistical difference amongst the compared headsets, rejecting the $H_0$.

Comparing the devices with the best results, blue and red for heuristic 7 and blue and green for heuristic 8, a new test was carried out.

---

[21] Instituto de Física, Facultad de Ciencias. *Tabla 3-Distribución Chi Cuadrado $X^2$*. [Consulted: 28 Jun 2017] Available at: <http://labrad.fisica.edu.uy/docs/tabla_chi_cuadrado.pdf>

For heuristic 7, $X_1^2 = 1.38$ was obtained, with p-value = 0.24. This means that no statistical difference is found between the two compared devices in nose comfort. A larger sample should be taken to check whether the difference is significant or not.

For heuristic 8, the result obtained is $X_1^2 = 3.93$, with p-value = 0.047. This indicates a significant difference between the blue and the green prototype in cheekbone comfort.[22]

In both cases, one of the prototypes (blue) scored better than the original headset, clearly showing that there was an improvement made through testing and by using the design Guideline. Participants also made comments to further improve the designs, namely the use of foam or nose pads, and the revision of the subjection system. The Guideline was also improved derived from the results obtained. A full report can be found on Annex T: First prototypes comparison test report and the full results on Annex U: First prototypes comparison test results.

### 6.1.5. FINAL PROTOTYPES COMPARISON TEST

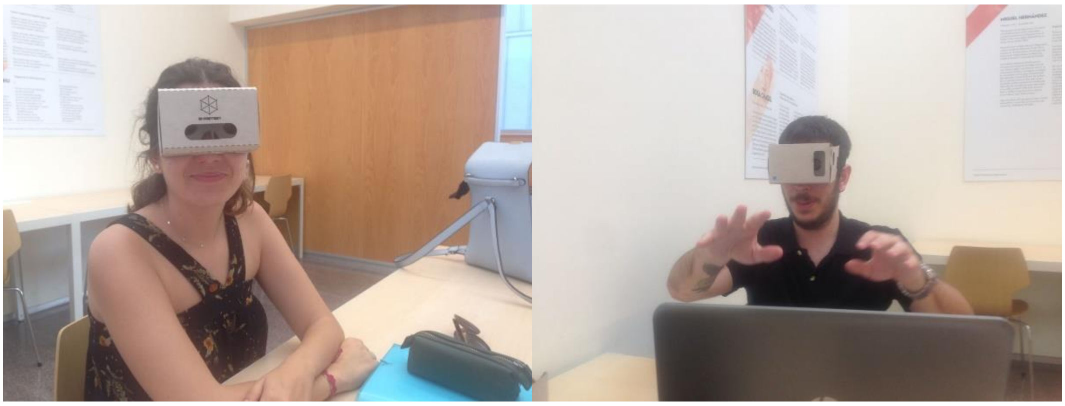


Figure 27. Final prototypes comparison test

The third and final test (Figure 27. Final prototypes comparison test) was done with nine engineering students, mostly from the Industrial Design studies, on 17th of June, 2017 in El Prat's public library. They were asked, one by one, to fill in a consent form (Annex V: Consent form for final prototypes comparison test (Spanish)) and then compare the two final prototypes built on an online questionnaire. One was the best scored on the first comparison test (Figure 22. Blue prototype), and the second one, a new version with folds and other changes based on the first test's comments and suggestions (Figure 28. Prototype with folds). The original product was not compared in this test because it scored lower than the prototype in the previous comparison.

[22] WikiLibros. *Tablas estadísticas/Distribución chi-cuadrado.* June 2017. [Consulted: 28 Jun 2017] Available at:
<https://es.wikibooks.org/wiki/Tablas_estad%C3%ADsticas/Distribuci%C3%B3n_chi-cuadrado>

Figure 28. Prototype with folds

Participants were asked to take the first prototype, try it on and answer the Guideline in the form of an online questionnaire. Then, they repeated the process with the second prototype. Once this was done, they were asked to answer a comparative questionnaire, which asked questions corresponding to each of the sections of the Guideline. This allows the user to assess which of the headsets is better designed and they could then add any comment they considered necessary in regards to the design of the product. They were also asked to fill in the System Usability Scale (SUS)[23]. A full report of results can be found on Annex W: Final prototypes comparison test report and Annex X: final prototypes comparison test results.

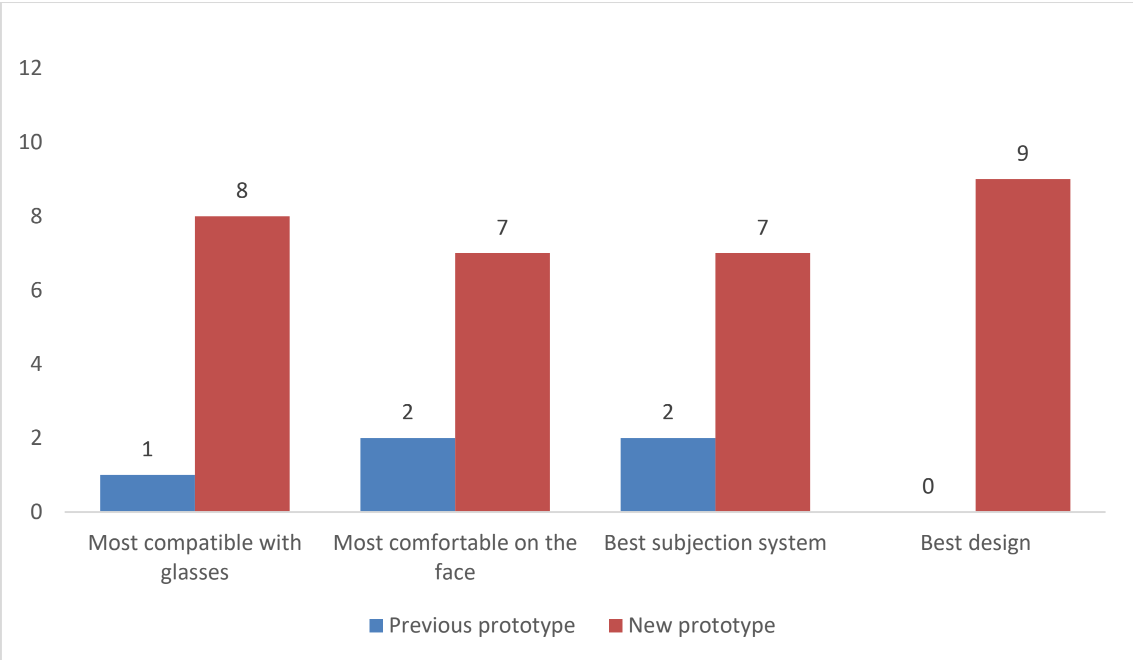



Figure 29. Comparison results

Out of the two headsets, the new version of the prototype scored better in every category (Figure 29. Comparison results). It is considered the most compatible with the use of glasses, the most comfortable on the nose, cheekbones and forehead, with the best subjection system and with the best overall design.

[23] Usability.org. *System Usability Scale (SUS)*. [Consulted: 20 Jun 2017] Available at: <https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html>

## 6.1.6. DESIGN HYPOTHESIS AND RESULTS

As seen on Table 11. Changes in the design and their linked hypothesis, different hypothesis were linked to the changes made in the design. With the tests that have taken place, it is now time to analyse which of these hypothesis were validated and which were rejected. Table 19. Design hypothesis and results

<table>
<tr><th>Change in the design</th><th>Hypothesis</th><th>Validation</th></tr>
<tr><td>Increase the space for the nose</td><td>This should make the headset less painful on the nose</td><td>It has improved the ergonomics of the nose (red prototype), but other methods are more effective (blue prototype: increase the general space for the face in the headset)</td></tr>
<tr><td>Increase the radius in contact with the forehead</td><td>This should help the device adapt to more types of faces and therefore reduce pain</td><td rowspan="2">It has slightly improved the ergonomics of the headset, but it is not a key change</td></tr>
<tr><td>Increase the radius in contact with the cheekbones</td><td>This should help the device adapt to more types of faces and therefore reduce pain</td></tr>
<tr><td>Increase the space between the head and the device</td><td rowspan="2">This should allow the user to wear glasses while wearing the headset</td><td rowspan="2">This makes the headset slightly more compatible with glasses (blue prototype), but the space should be greatly increased to be compatible with all glasses. Another option would be to make the sides of the headset of an elastic material to keep light from coming into the device but adapt to the use of glasses</td></tr>
<tr><td>Increase the space on the sides between the head and the device</td></tr>
<tr><td>Add folds on the forehead</td><td>This should reduce pain on the forehead</td><td rowspan="3">This has improved the ergonomics (the final prototype compared to the blue prototype)</td></tr>
<tr><td>Add folds on the nose</td><td>This should reduce pain on the nose</td></tr>
<tr><td>Add folds on the cheekbones</td><td>This should reduce pain on the cheekbones</td></tr>
</table>

Table 19. Design hypothesis and results

## 6.2. STORYBOARD

To finish the evaluation of the project, a storyboard has been created. It shows the final state of the product with the modifications made.

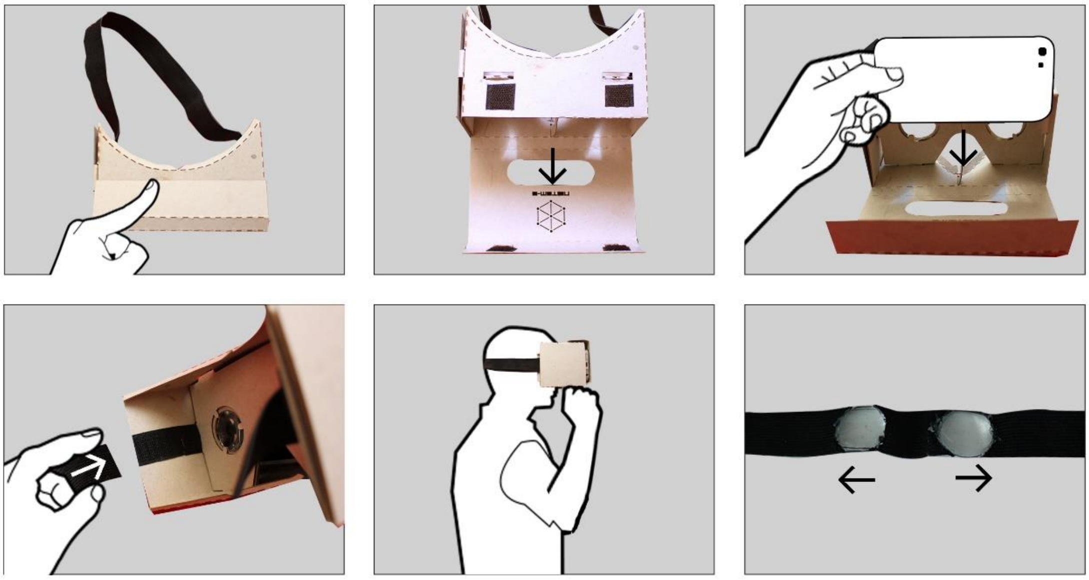


Figure 30. Storyboard of final version

As shown on Figure 30. Storyboard of final version, the headset is opened by pulling from the cover, held in place by Velcro. Once opened, the mobile phone (ready for use) is placed horizontally, with the screen facing the inside of the headset, and the compartment is closed by sticking the Velcro together. It is possible to adjust the subjection of the mobile phone by pulling the compartment lid further into the headset or closer to the edge. The strap is then adjusted to the size of the user's head by using the same method as the one for the compartment. The Velcro, in this case, is placed on the inside of the headset to prevent it from coming off with its use. The headset is then placed against the user's face by placing the strap around the head. The distance between the lenses can then be adjusted by pulling from the extremes of the elastic band holding them in place. The extremes can then be placed on the Velcro to make them maintain their position.

# 7. IMPLEMENTATION

## 7.1. ECO-DESIGN

Table 20. Eco-design decisions includes each of the decisions made after the previous phases of the project and based on the initial brainstorming in section 3.2.4. Eco-design. This decisions are based on ease of design, compatibility amongst them and user assessment.[24]

| | |
|---|---|
| Development of new concepts | **Dematerialisation** |
| | Remove the protective foam that makes the headset more comfortable and improve ergonomics by redesigning the headset, to eliminate unnecessary elements from the design. |
| | **Shared use** |
| | Share the headset by replacing the mobile phone placed within the device with another one, making the product fully customisable. |
| Consumption reduction and diversity of materials | **Minimise components that don't add value** |
| | Reduce the layers of material to reduce the size of the final product. |
| | **Optimise wall thickness and material density** |
| | Reduce wall thickness without harming the structure of the design to save materials. |
| | **Part re-utilisation** |
| | Re-use the lenses if the main body breaks. |
| | Re-use the main body if the lenses break. |
| | **Avoid superficial treatments** |
| | Do not include paint or any other superficial treatments. |
| | **Consider the environmental impact of the material** |
| | The main material of the current product is cardboard. Offer material alternatives considering their environmental impact. |
| Material selection for a minor environmental impact | **Derived from natural resources** |
| | The main material of the current product is cardboard. Offer material alternatives derived from natural resources. |
| | **High recycled material content** |
| | Make the main body recyclable so that most of the headset is recyclable. |
| | Make the subjection system recyclable. |
| | **No dangerous substances** |
| | Check whether the parts of the final product are made of dangerous materials. If so, consider different environmentally friendly alternatives. |

Table 20. Eco-design decisions

[24] CIDEM, Generalitat de Catalunya. *Eines de Progrés: Ecodisseny*. 1st edition. Barcelona, Spain: April 2005.

| | |
|---|---|
| Material selection for a minor environmental impact | **Environmentally friendly** |
| | Check which of the processes are environmentally friendly within the production of the parts of the product. Consider different options if any processes may harm the environment. |
| | **Low energetic intensity** |
| | Check the energetic intensity used to create the final product. |
| | **Easily recyclable** |
| | The main material of the current product is cardboard. Offer other recyclable material alternatives. |
| Reduction of environmental impact in productive processes | **Reduce amount of productive stages** |
| | Minimise the variety of materials used in the final product. |
| | Minimise the amount of components used in the final product. |
| | Minimise any unavoidable superficial treatments. |
| | **Process and material selection that allows to recycle production waste** |
| | Recycle production waste (cuts). |
| | **Environmentally friendly processes** |
| | Check the production systems to ensure that the making of the final product is as environmentally friendly as possible. |
| Distribution optimisation | **Minimise the use of packaging** |
| | Make the packaging integrated in the final product. |
| | **Packaging materials with the lowest environmental impact** |
| | Consider the use of paper bags to pack the loose parts. |
| Distribution optimisation | **Mark materials with identifying symbols** |
| | Mark the final product by cutting it into the main body. |
| | **Lowest volume possible in transportation and storage** |
| | Transport a disassembled product to reduce the taken space for transportation. |
| | **Reduce the product's weight to use less energy to transport the product** |
| | Take into account the weight of the product in the design process to minimise energy consumption and to improve ergonomics. |
| | Make the packaging as light as possible. |
| | **Introduce the use of renewable energy** |
| | Charge the mobile phone placed within the headset during its use, by means of solar energy or using the movement of the user. |

Table 21. Eco-design decisions (continued)

| | |
|---|---|
| Increase of product life | **Allow and promote the re-utilisation of the product** |
| | The device may be used by more than one person by changing the mobile phone placed within the headset. |
| | **Identify and try to eliminate the weak spots of the product to prevent it from breaking and having to be repaired or replaced** |
| | Test the product with prototypes to identify the weak spots and fix the design before production. |
| | Test the product with users to identify the weak spots and fix the design. |
| | **Choose the correct materials and thickness to ensure good product resistance to continuous use** |
| | Test the product with different materials before choosing the final one to ensure that the product is resistant enough. |
| | **Make repairing and maintenance easy** |
| | Allow the headset to be disassembled to change any of the elements of the final product in case they break. |
| | **Provide spare parts for repairing** |
| | Add a second set of lenses to the pack. |
| | Add a second subjection system to the pack. |
| Optimisation and waste management | **Use recyclable or biodegradable materials keeping in mind the recycling systems for the country in which the product will be used** |
| | The main material of the current product is cardboard. Offer other recyclable material alternatives. |
| | Check the materials for the standardised parts. |
| | **Use the lowest amount of different materials possible** |
| | Consider material options before the final product is made. |
| | **Minimise the use of superficial treatment that make it difficult for the product to be recycled** |
| | Avoid paints or other superficial treatments. |
| | Any marks that need to be made can be done by cutting them into the final product. |
| | **Simplify the disassembly of the product** |
| | Avoid sticking the lenses to the main body. |

Table 22. Eco-design decisions (continued)

## 7.2. MATERIALS

To choose the most appropriate material for the proposed design, CES Edupack 2016 software was used. This tool is a reliable material database used for educational purposes. It contains the most used materials for different purposes, comparing up to 39 properties amongst 100 materials.

The chosen material has to satisfy the needs of the design. Each part of the final product has to use a different material due to the different requirements of their use. These requirements have been divided into three topics: function (what the material is designed to do), constraints (criteria the material must meet for the product to work properly) and objectives (what is desired from the material).[25] The following table (Table 23. Material requirements) establishes the different requirements for each part of the design.

| | Main body | Strap |
|---|---|---|
| Function | Plasticity / Yield strength (the material must be folded and it must maintain its position) | Elasticity (it must adapt to the user's head and return to its normal state when taken off) |
| Constraints | Density (it must be light enough for the user to hold the device with the head) | Density (it must be light enough for the user to hold the device with the head) |
| Objectives | Ecological (the final product must be environmentally friendly) | Ecological (the final product must be environmentally friendly) |

Table 23. Material requirements

For the main body, the first selection is made through the yield strength (its elastic limit) to discard any materials that cannot be folded. Figure 31. Yield strength of materials (MPa) shows the acceptable materials.

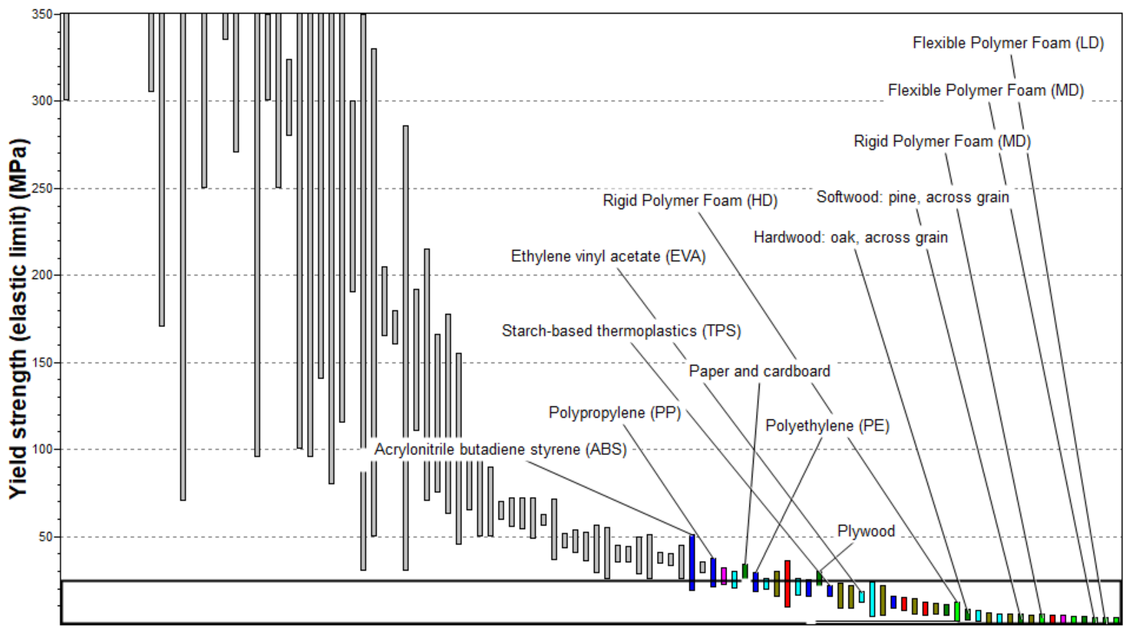



Figure 31. Yield strength of materials (MPa)

The density of these materials is then tested. It should be a light material, and so, the lightest materials are selected. These are shown in Figure 32. Density of materials.

[25] Puddlesden. *Material Selection: Using CES Edupack.* [Consulted: 02 Jun 2017] Available at: <https://www.youtube.com/watch?v=tr3aO2TZrmo>

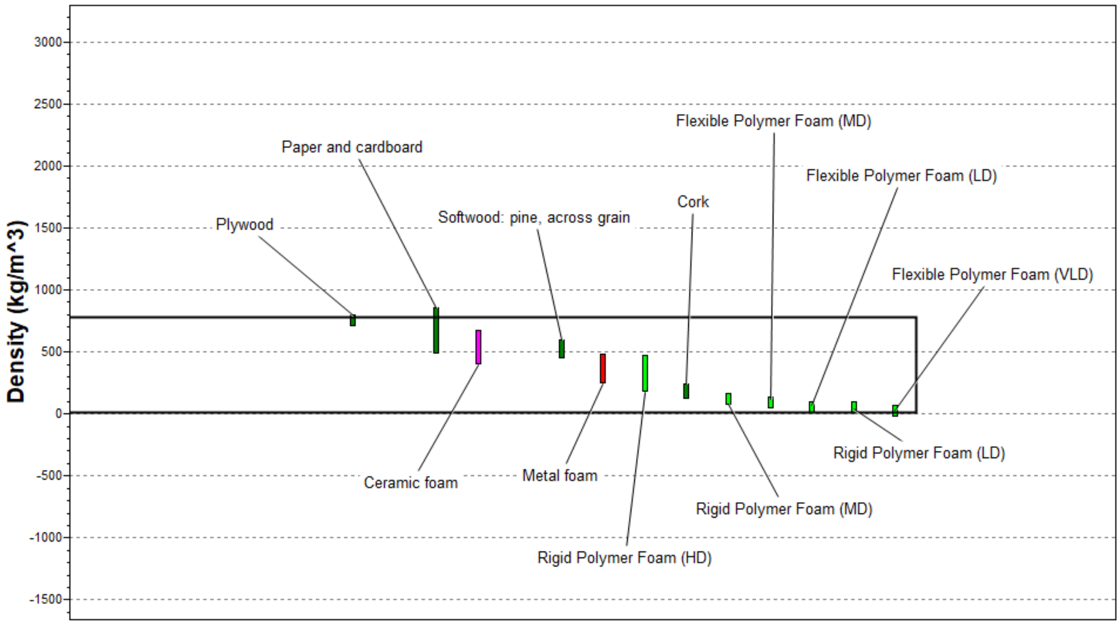



Figure 32. Density of materials

Now, the final material is chosen based on their environmental impact. This is done by checking its $CO_2$ footprint and the energy required for its production (Figure 33. $CO_2$ footprint and energy for production of materials). Then, only recyclable materials are selected.

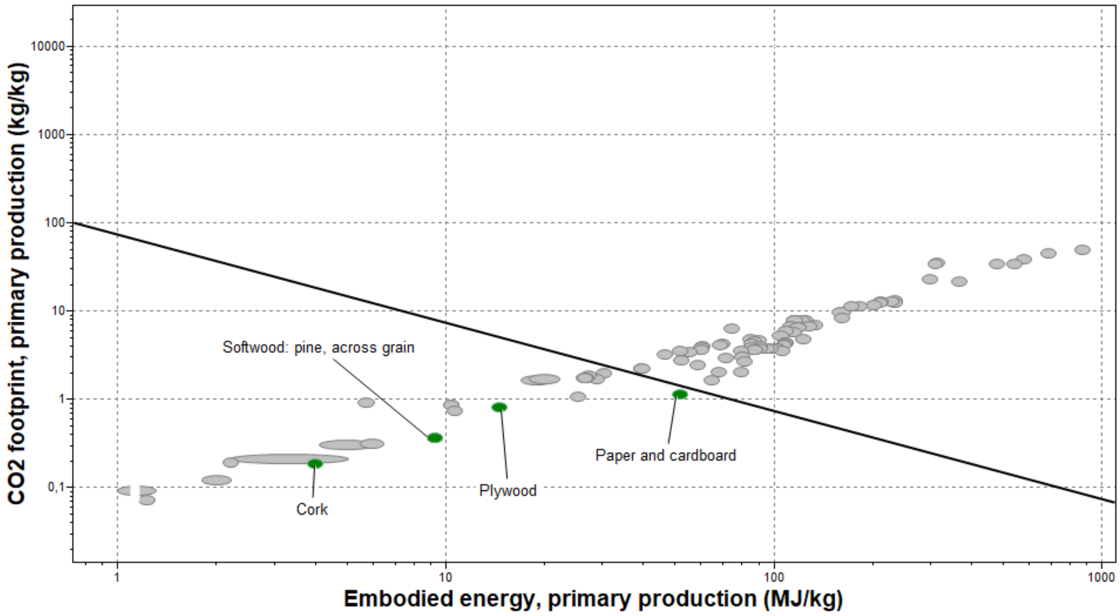



Figure 33. $CO_2$ footprint and energy for production of materials

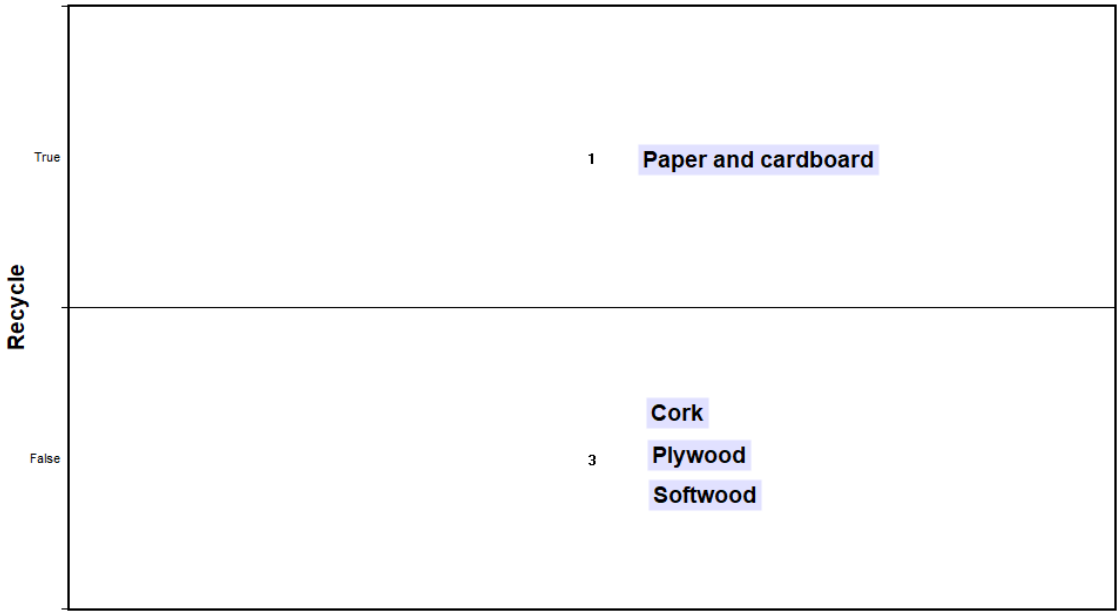



Figure 34. Recyclable materials

The only material that passes all of these tests is paper/cardboard, so this is the selected material for the main body of the headset.

The strap is then analysed. The first step is to compare the Young's modulus of the material against its density. The materials that pass the requirements are marked in Figure 35. Young's modulus versus density of materials.

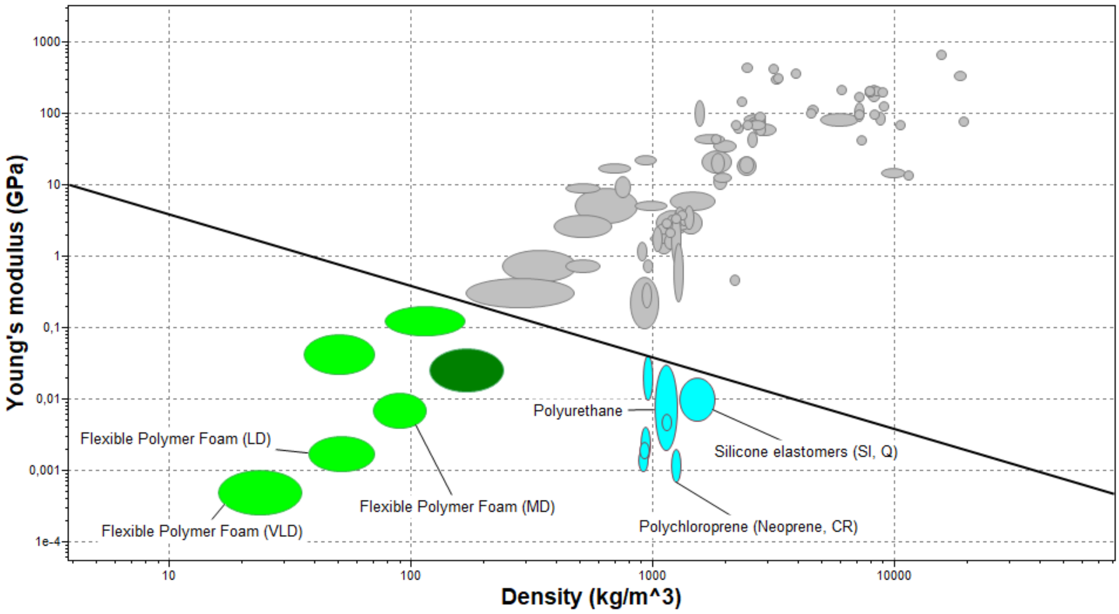



Figure 35. Young's modulus versus density of materials

Out of the analysed materials, none of them are recyclable (Figure 36. Recyclable materials), so the $CO_2$ footprintversus the energy required to produce the materials (Figure 37. $CO_2$ footprind and energy for production of materials) is studied.


Figure 36. Recyclable materials

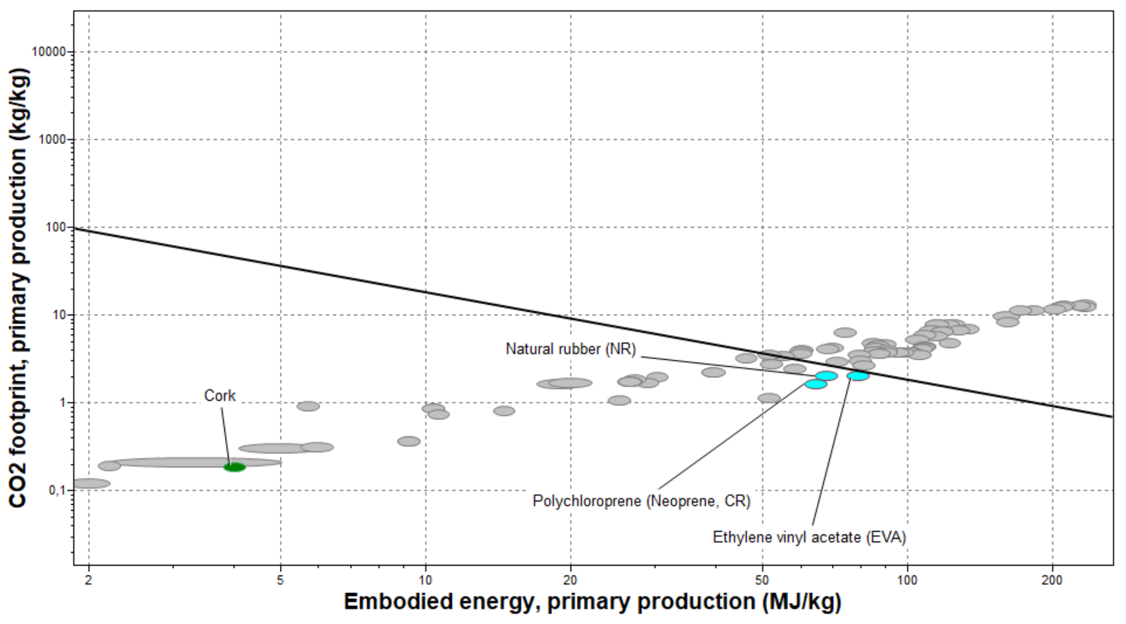



Figure 37. $CO_2$ footprind and energy for production of materials

The material that seems most suitable for the straps out of the four possible materials is polychloroprene, due to its elastic nature. This is the chosen material.

## 7.3. DESIGN FOR MANUFACTURE AND ASSEMBLY

Design for Manufacture and Assembly (DFMA) is a tool used for the justification of the pieces included in the final product. It helps consider alternatives with the aim of reducing costs and to generate an efficient and effective solution. It is usually applied in fabrication and assembly stages, but it can also be applied in any other phase of the design process.

The first step is to identify the specifications that the design must achieve and generate alternatives to each of these points. These alternatives are then assessed to see if they really fulfil the requirements and the cost of implementation is calculated. The options that are not rejected are then compared to the initial design and the best options are chosen. With this analysis, an optimal product is created for fabrication and assembly.[26]

The chosen steps are the following:

- Minimise the amount of parts: The magnet is removed from the final product. It does not add enough value to the final product for it to be included in the design. The parts of the final product are the main body, the lenses and the strap to adjust the headset against the face.
- Develop a modular design: Different signs and symbols are carved into the final headset. These can be added if the product is commercialised, but it can also be built without the logo on the front side of the headset.
- Design the parts to facilitate the assembly: The main body of the headset is easy to build. If it is not understood, an instruction sheet helps to build it.
- Avoid separate fixers: No external parts are used to hold the headset in place. It is built with folds that hold by pressure.

## 7.4. VISUAL IDENTITY

A visual identity is created for the product. To do this, the following steps are completed:

1. Establish the values of the product's brand
2. Create a symbol that represents these values
3. Geometrise the symbol
4. Choose a name based on the brand's values
5. Choose a typography based on the brand's values
6. Choose the colours based on the brand's values

The values of the brand, keeping in mind that it is focused on the creation of low-cost VR headsets and VR technology, are the following:

[26] CIDEM, Generalitat de Catalunya. *Eines de Progrés: DFMA*. 1st edition. Barcelona, Spain: September 2005.

- Technology
- Innovation
- Vision
- Imagination
- Action
- Movement
- Attention
- Creativity
- Informatics
- Videogames
- Videos
- Learning
- Youth
- Modern
- Three dimensions
- Virtual space
- Travel
- Illusion

These values are then attached to different symbols, as shown in table Table 24. Visual Identity: Symbols.

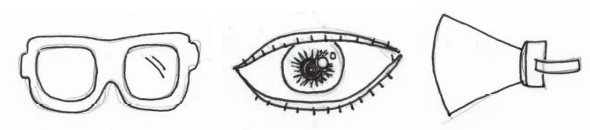
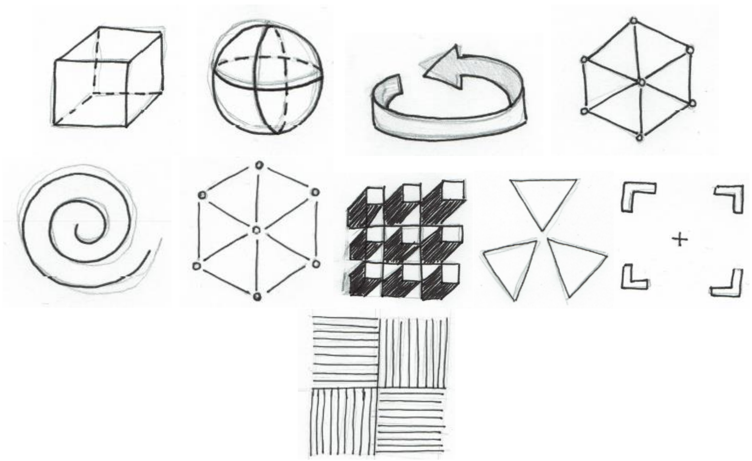
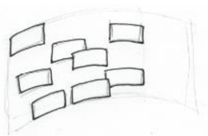
| Value | Symbol |
|---|---|
| Vision, attention |  |
| Imagination, three dimensions, virtual space, illusion |  |
| Technology, innovation, modern, informatics |  |
| Videogames, videos, learning, travel |   |

Table 24. Visual Identity: Symbols

The chosen symbol is shown in Figure 38. First version of the chosen symbol. It is a cube in three dimensions, which can also be interpreted as a hexagon. This double interpretation represents the visual illusion and a closed space, such as the virtual space in which VR is experienced.

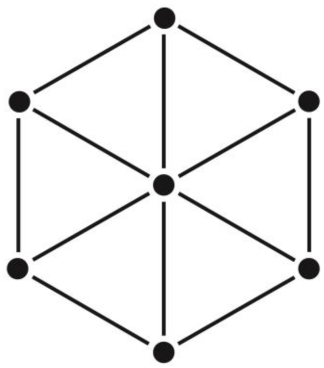


Figure 38. First version of the chosen symbol

It was then geometrised (Figure 39. Geometrisation of the chosen symbol), and the final version has larger circumferences and shorter lines, to help see the visual illusion.

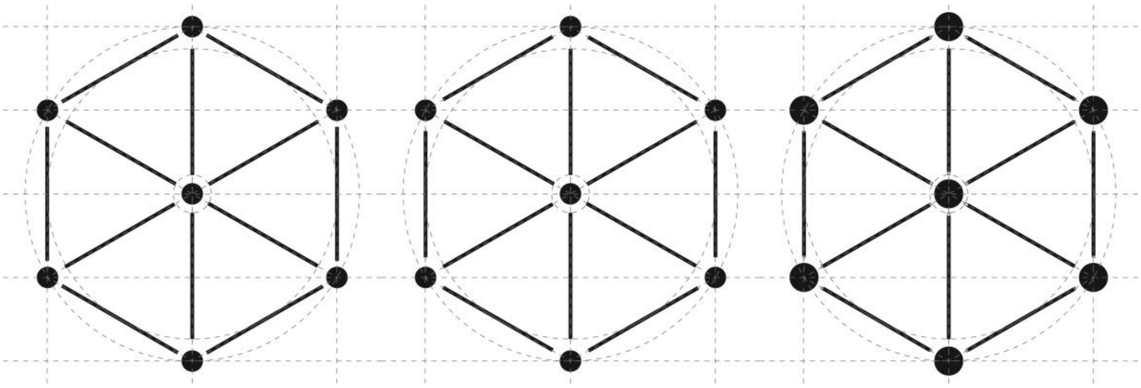


Figure 39. Geometrisation of the chosen symbol

The name for the brand is E-Motion. It is based on the combination of emotion and movement (motion), while adding an element of electronics/informatics by separating the E at the beginning.

Many typographies were studied (Table 25. Typographies), also based on the values of the product. The chosen families were script, decorative and geometric. The first one is a typography with personal style, but it also gives a message of informality. Decorative typographies have the same characteristics, and can be adapted to a wide range of situations. Geometric typographies are the most formal of the three, and they fit perfectly with the symbol of the brand. They represent correctness and trust.

| | | | |
|---|---|---|---|
| **Script** | **TT Masters** | **Carybe** | **Knewave** |
| | E-MOTION<br>E-MOTION<br>E-MOTION | E-MOTION<br>E-MOTION<br>E-MOTION | e-MOTION<br>e-Motion<br>e-motion |
| **Decorative** | **HFF Clip Hanger** | **Nimrodel FS** | **Arual** |
| | E- MOTION<br>E- MOTION<br>E- MOTION | e-MOTION<br>e-Motion<br>e-motion | e-MOTION<br>e-Motion<br>e-motion |
| **Geometric** | **Accidental Presidency** | **Champagne and Limousines** | **Gayatri** |
| | e-MOTION<br>e-Motion<br>e-motion | e-MOTION<br>e-Motion<br>e-motion | e-MOTION<br>e-Motion<br>e-motion |
| | **Avenger** | **Dark Forest** | **Digit LCD** |
| | E-MOTION<br>E-MOTION<br>E-MOTION | e-MOTION<br>e-MOTION<br>e-MOTION | e-motion<br>e-motion<br>e-motion |
| | **Grapple** | **Meek** | **Northwest** |
| | e-MOTION<br>e-Motion<br>e-motion | E-MOTION<br>E-MOTION<br>E-MOTION | E-MOTION<br>E-MOTION<br>E-MOTION |
| | **Simply Square JL** | **Square Deal** | **Supreme** |
| | E-MOTION<br>E-MOTION<br>E-MOTION | e- motion<br>e- motion<br>e- motion | e=MOTION<br>e=motion<br>e=motion |

Table 25. Typographies

Finally, the Avenger typography was chosen because it fit perfectly with the symbol of the brand. The geometric design of the symbol requires geometric typography.

The chosen colours are red, green and black (Figure 40. Chosen Pantone). This selection has been done by listing the colours available and their characteristics. The positive characteristics have been added and the negative (those that do not represent the product) have been subtracted. The colours with the highest score have been taken.

The colour red represents courage, strength, energy, stimulation, excitement and passion, all of those related to movement. It also represents friendliness and it attracts attention. Green, on the other hand, is a symbol for ecology, a very important factor for this project. It also represents balance, refreshment, equilibrium and sincerity. Black is the colour of elegance, safety, efficiency, power, strength and prestige.

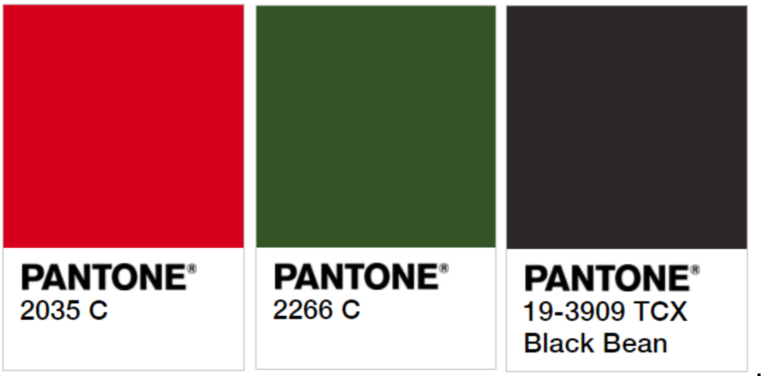



**Figure 40. Chosen Pantone**

A series of colour combinations (Figure 41. Colour combinations) were studied until a choice was made. The final logo is shown in Figure 42. Final logo. Green, the colour of nature, was placed defining the 3D space of the logo, combined with red spots. Motion is the word in red, which represents passion and movement, as well as energy. Black has only been used for the hyphen, as it represents, as well as elegance and safety, heaviness, and it is the opposite message as the product wants to send.

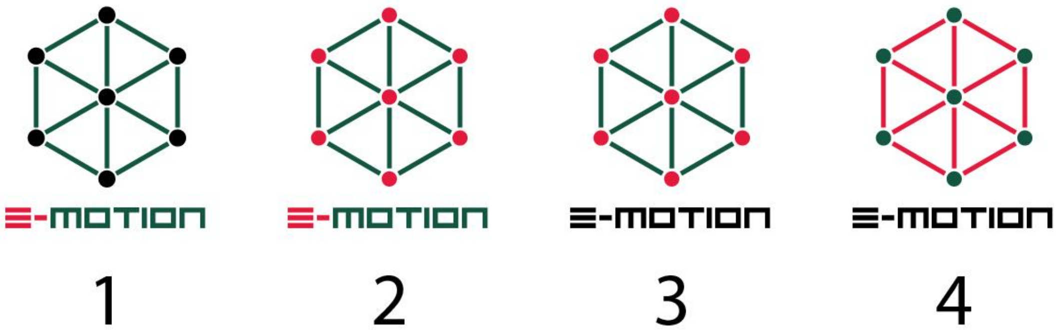



**Figure 41. Colour combinations**


**Figure 42. Final logo**

## 7.5. INSTRUCTION SHEET

For the use of this headset it is necessary to build it first, as it is be purchased disassembled. To avoid unnecessary use of paper, it has been decided that the assembly instructions will be given online, by means of a QR code (Figure 43. QR code). It can be easily read by any mobile phone with the appropriate app, and given that the user will need to have this device to use the headset, one can assume it will be easy for them to access this information. Also, the target group of this project is young people with knowledge of new technologies, who will most likely have used QR codes in the past.

**Figure 43. QR code**

This code will be printed on a small piece of paper that will be placed within the packaging. The user will then scan it and he or she will be redirected to a website (Figure 44. Website proposal) in which two options will be given: on the one hand, the user will be able to see step by step photos on how to assemble the product, and on the other hand, if they prefer so, a video will be presented showing how to build the headset. Both methods will rely solely on visual techniques to avoid the need of translations in text or spoken language.

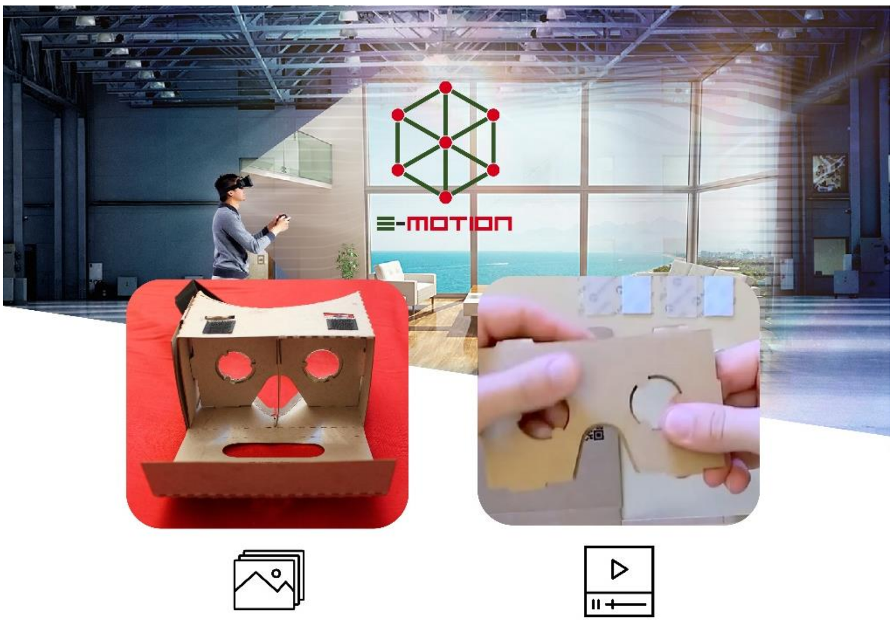



**Figure 44. Website proposal**

The photos for the instructions can be found in Annex Y: Step-by-step product build photographies.

## 7.6. VALUE ANALYSIS

Value analysis is a tool used to reorganise the design process of a product to increase its value. The main competition is identified and compared to the initial product, keeping in mind the pondered factors. This way, it is easy to understand which product is best designed and why. Then, each part is identified and their functions listed, indicating whether they are primary or secondary, and the importance that the user gives to it. After this step, the first phase of the value analysis is carried out: an analysis of the real cost of each part and distribute it amongst its different functions. By means of a graph, the disparities are shown between the user's needs and an improvement plan is done. The process is done again to check if the modifications have a better result.[27]

On the first phase, four characteristics are studied: weight (pondered 30%), comfort (40%), compatibility with different mobile phones (10%) and adjustability (20%). Comparing the four compared headsets, Easy Phone's Cardboard Black is the one with the best price-quality ratio.

After the value analysis (Annex Z: Value analysis), two decisions were made: in the first place, the magnet was removed from the final product because it did not add enough value to the headset. Secondly, the design of the straps is now more focused on the ergonomics for the user rather than holding the headset.

## 7.7. COSTS

The costs for both the product and the project have been studied. The product includes the materials and the process they have to go through. The costs of the project are the engineering budget, which is made up of the hours of work invested in the project.

### 7.7.1. PRODUCT COSTS

Table 26. Product costs shows the cost of each of the parts of the final product.

| | | Cost |
|---|---|---|
| **Material** | Cardboard (0.6 mm) - 700 x 500 mm | € 1.80 |
| **Process** | Laser cut (130 W) - 1 hour[28] | € 0.00026 |
| **Finished product** | 2 VR lenses | € 1.00 |
| | Velcro - 100 x 20 mm | € 0.20 |
| | Neoprene - 400 x 25 mm[29] | € 0.06 |
| **TOTAL** | | € 3.07 |

[27] CIDEM, Generalitat de Catalunya. *Eines de Progrés: Anàlisi de Valor*. 2nd edition. Barcelona, Spain: September 2004.
[28] Perez Camps. *Parámetros de corte y grabado con láser.* [Consulted: 22 Jun 2017] Available at: <http://www.perezcamps.com/es/strong-parametros-de-corte-y-grabado-con-laser-strong_8249>
[29] Alibaba. *Customized elastic Velcro strap.* [Consulted: 22 Jun 2017] Available at: <https://www.alibaba.com/product-detail/Customized-elastic-velcro-strap_60429434104.html?s=p>

Table 26. Product costs

### 7.7.2. ENGINEERING COSTS

Table 27. Engineering costs shows the costs of the development of the project, based on the hours of dedication. The salaries are based on TuSalario website, backed by the Worker's Commissions (CCOO), the General Union of Workers (UGT) and the University of Salamanca.[30]

| Activity | Price / hour | Hours | Cost |
|---|---|---|---|
| **Framework studies**<br>Statistic technician | € 15.95 | 35 h | € 558.25 |
| **Requirement analysis**<br>Market consultant | € 12.50 | 45 h | € 562.50 |
| **Design development**<br>Industrial designer | € 9.85 | 25 h | € 246.25 |
| **Prototyping**<br>Industrial designer / Technician | € 9.85 | 30 h | € 295.50 |
| **Material selection**<br>Production engineer | € 15.15 | 10 h | € 151.50 |
| **Graphic design**<br>Graphic designer | € 8.15 | 24 h | € 195.60 |
| **Design evaluation**<br>Industrial designer with experience | € 11.15 | 62 h | € 691.30 |
| **Cost analysis**<br>Accounting manager | € 9.30 | 5 h | € 46.50 |
| **Technical documentation**<br>Industrial engineer | € 15.15 | 94 h | € 1,424.10 |
| **TOTAL** | | 330 h | € 4,171.50 |

Table 27. Engineering costs

[30] WageIndicator. *Función y Sueldo.* TuSalario. [Consulted: 22 Jun 2017] Available at: <http://www.tusalario.es/main/carrera/funcion-y-sueldo>

# 8. LAUNCH

## 8.1. SINGLE-MINUTE EXCHANGE OF DIES

Single-Minute Exchange of Dies (SMED) is a tool used with the goal of reducing machine preparation time. This helps reduce costs and time of production. It is used in three phases: managing operations of machine preparing, turning unproductive operations into productive ones and improving all of the preparation operations.[31] [32] The chosen steps are the following:

- **Managing operations of machine preparing:** Using a checklist to ensure that all the steps are followed completely as well as keeping a correct maintenance of the machines will keep all of the operations in check and will prevent mistakes from being made.
- **Improving all of the preparation operations:** The parts have standardised sizes, avoiding production time-consuming problems. All of the parts can be fabricated in parallel and then put together at the end of the process. The final product is not built before being sold. Adjustment time can also be reduced by placing centring pieces on the laser cutter that keep the cardboard in place.

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[31] CIDEM, Generalitat de Catalunya. *Eines de Progrés: Canvi Ràpid d'Utillatges (SMED)*. 1st edition. Barcelona, Spain: October 2004.
[32] Shingo Shigeo. *Una Revolución en la Producción: El Sistema SMED*. Madrid, Spain: TGP Hoshin-Productivity Press, 1993.

# 9. CONCLUSIONS

## 9.1. CONCLUSIONS

The objectives of this project have been achieved, both primary and secondary goals. In the following list, the solution to each of the objectives stated at the beginning of the dissertation are explained.

- **Choose a VR headset to modify:** Easy Phone's Cardboard Black headset was chosen due to its low score in the benchmark and in user tests. It provoked pain on the nose, the forehead and the cheekbones, and was perceived as inexpensive and poorly designed. This was the right product to work on and improve.
- **Create a design Guideline:** The Ergonomic Design Guideline for VR headsets has been a critical aspect of this work. It is the interpretation of user comments through testing, and it analyses many aspects related to the ergonomics of these headsets. It has also provided information to re-design the chosen device with the right criteria and has helped in the assessment of different VR headsets. As a result, a preliminary version of this project has been accepted at the 8$^{th}$ International Conference on Applied Human Factors and Ergonomics (AHFE) 2017.[33]
- **Re-design that scores better than the original headset:** The re-design of the headset has scored significantly better in comparison tests with users, without them knowing that they were analysing and commenting on a commercialised product. This assessment has been done through the Ergonomic Design Guideline and through general questions that allowed for a comparison amongst different headsets. The results have been statistically analysed.
- **Include application proposals for VR technology:** Although no formal proposal has been made, user investigation shows that the most interesting applications for VR technology for the target group are education and live events. It is true that simulations of dangerous situations are currently being done to train professionals, but it could be and interesting idea to adapt this to other ways of learning. Live events in VR could make the user feel like he or she is there, and therefore these events could reach a much wider audience by the use of VR technologies.
- **Keep the user at the centre of the design:** One of the most important points of this work has been to keep the user at the centre of the design process at all times. Every change or proposal has been checked with users and are easily justifiable through this information.

## 9.2. FUTURE WORK

Although the idea of this project was to create an investigation framework for ergonomics in VR headsets, many other aspects should be considered in future projects based on the same line of work.

Firstly, the Ergonomic Design Guideline should be revised. Some heuristics cannot be analysed equally by different people (i.e. Does long hair make subjection difficult?) due to physical differences. This makes the comparison of devices slightly biased and

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[33] AHFE. *AHFE 2017 Objective and Areas of Interest*. [Consulted: 28 Jun 2017] Available at: <http://www.ahfe2017.org/>

should be therefore used cautiously. Other questions cannot be answered using the same scale (the answer “yes” can be positive or negative depending on the question). There should be a way to present the different heuristics in a clear manner that still allows for the scale to be equal in each question of the Guideline.

Also, other design proposals should be made. Even though this project is not based on innovation, several improvements have been made on the original product. This, however, does not mean that they are final. Other solutions for adjustments should be discovered, such as the focal distance. The current design proposal for the distance between the lenses can also be further developed.

Finally, it is important for future studies to address the problems regarding the use of VR technologies. The minimum recommended distance between a mobile screen and the user’s eyes is much higher than the one used in these VR headsets. There are problems with dizziness and discomfort. The devices seem to remain uncomfortable for many users. All of these aspects should be analysed and solved for a correct product proposal to be made.

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