DESIGN OF ADJUSTABLE MEASURING TOOL FOR POSTERIOR AURICULAR AREA

Master Thesis Integrated Product Design

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TU Delft

M!

CONTACT INFORMATION

MASTER THESIS INTEGRATED PRODUCT DESIGN

This thesis is written in the context of the master program Integrated Product Design at the faculty Industrial Design Engineering TU Delft, University of Technology.

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I want to thank all the people that stood by me during the entire length of the project and believed in me even when I didn't. A Special thanks to my parents, that allowed this to be possible.

ABSTRACT

This research project is a collaboration between TUDelft, UPPS Fieldlab, and Made4eyes, a company that produces made-to-fit eyewear.
In order to design a frame correctly, it is essential having a 3D head scan upon which the frame can be molded. The temple tips are crucial components that contribute to the frame's comfort and stability. Therefore it is fundamental to identify the curvature of the head behind the ear to model the temple tips accordingly.

This area resulted difficult to 3D scan due to its position, the projected shadow of the ear, the limitations of the technology currently in use (occipital sensor scanner II), and the occasional involuntary movements of the subjects during the scan.
Several methods have been tested to retrieve the posterior auricular area's curvature, including 3D scanning (using Artec Eva lite, Artec Spider, and 3Shape's Intraoral scanner Mark II), taking silicone molds, and combining both methods.

The 3D scan results were either not accurate enough or presented problems during the elaboration phase (misalignment between the surfaces). The area corresponding to the attachment between the ear and the skull was not captured by any of the scanners.
It was concluded that the most effective way to retrieve data would be by creating a mold with an embedded reference system that could later be 3D scanned.

The developed solution is "flex" an adjustable frame that functions as a measuring tool due to the flexibility of its temple tips. The adjustability features (360° hinge and extendable temple tips) make this tool adaptable to a diverse user group.
Once the temple tips curvature mold has been taken, the frame can be removed, and 3D scanned. The information retrieved is necessary to design comfortable and functional temples.

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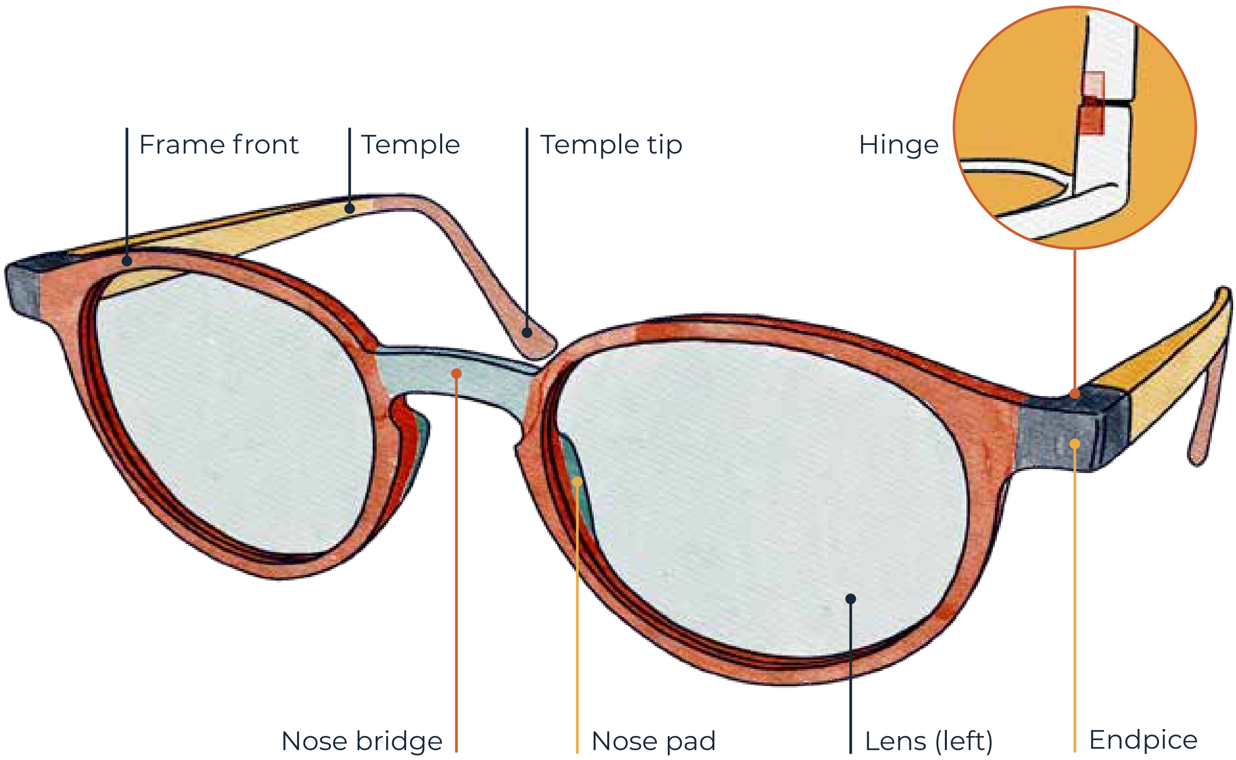
GLOSSARY

GLOSSARY OF GLASSES



DEFINITIONS[7]

- **Frame front** - The main part of the glasses frame which holds the lenses.
- **Temple / Sides** - The arms of a glasses frame, the temples are the thin protrusions that help secure the glasses to the head by resting and hooking behind the ears. They can also be called “sides”.
- **Temple tip**- The end-point of the temple, furthest away from the frame front.
- **Hinge** - This is the moving part with conjoins the frame front and the temple.

- **Nose bridge** - The crossbar section in the middle of a glasses frame which overhangs the nose.

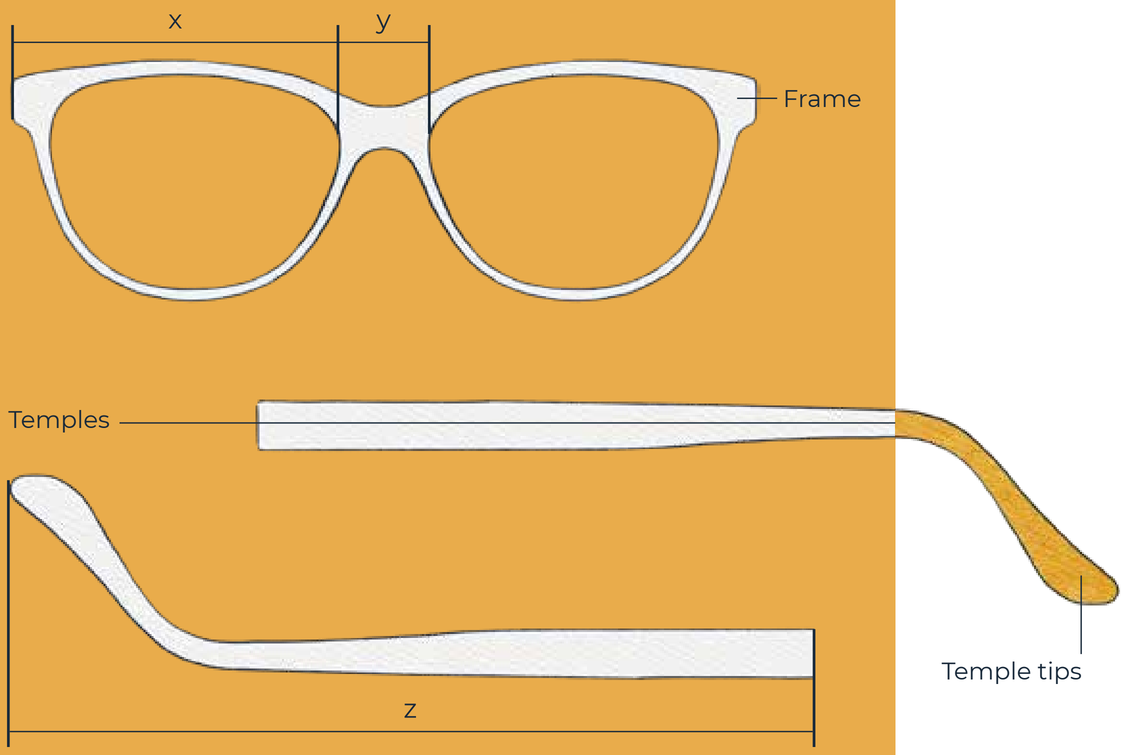
- **Nose pad** - Small sections of glasses that rest on the nose for comfort and to secure the glasses on the face. The pads are either inbuilt as part of an acetate frame front or pushed-in as a separate piece. Push in pads have the ability to be bent and adjusted whilst acetate pads can not be adjusted.

- **Lens** - A transmissive solid used to focus or disperse light via refraction.

- **Endpice** - The outermost edges of your glasses frame where the temples connect to the frame front. The endpieces make room at the upper outside edges of each lens to make room for the hinges.

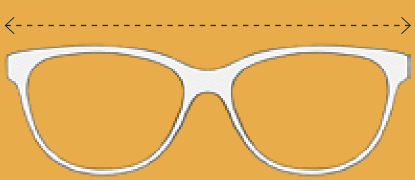
SIZING REFERENCE

x y z
54- 20- 140

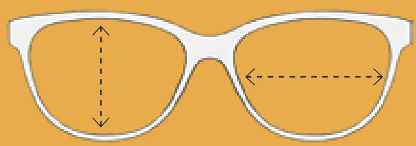


SIZING FACTORS

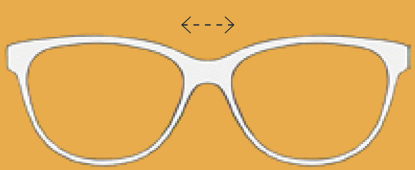
Frame width



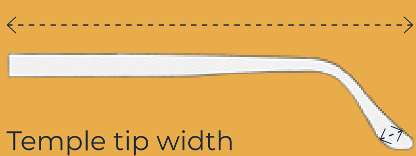
Lense height and width



Nose bridge width



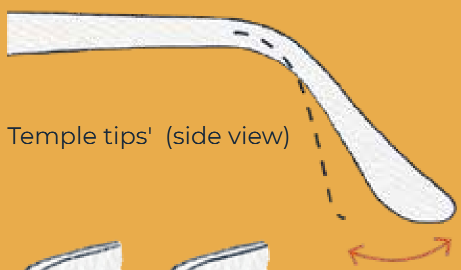
Temples length



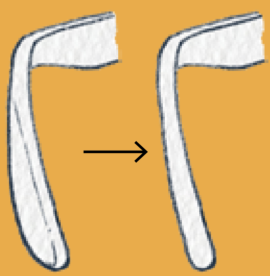
Temple tip width

MANUAL ADJUSTMENTS

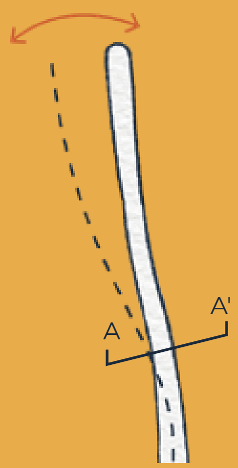
ADJUST TEMPLE TIP CURVATURE with heating device



Temple tips' (side view)

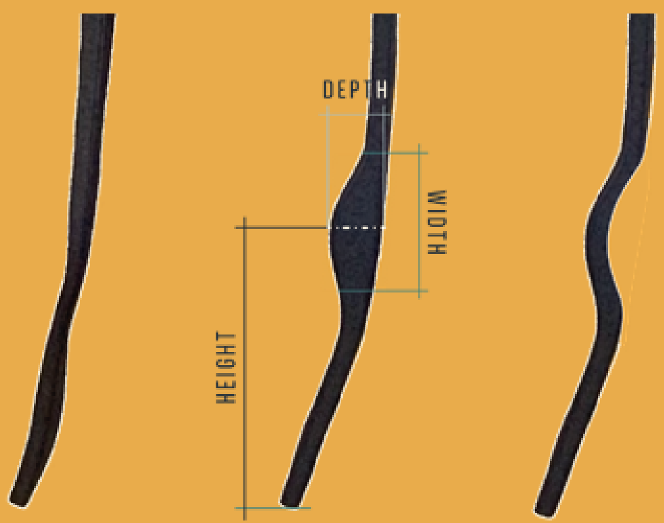


Twist of temple tips



Temple's tip (Top view)

TEMPLE TIP MODELS (TOP VIEW)



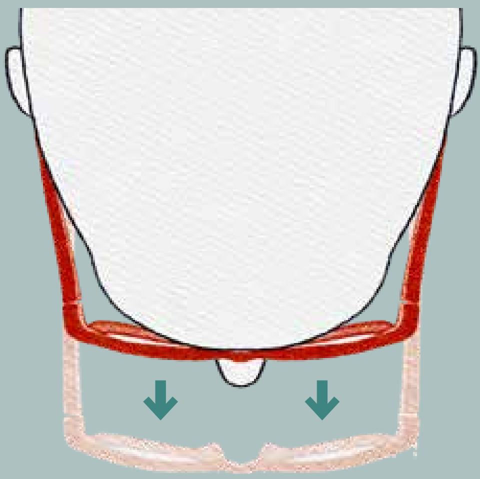
Regular model "Bone" model "S Shape" model

REFERENCE FOR SILICONE ANALYSIS

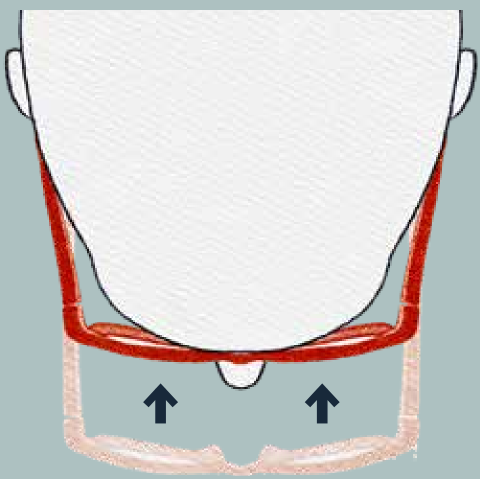
Bump

Fossa / Dip

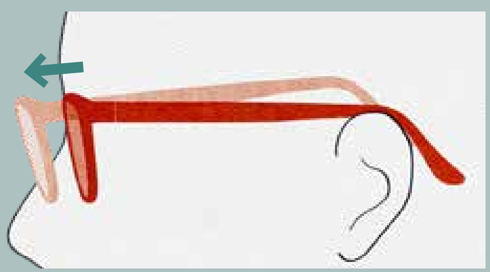
MOVEMENT REFERENCE



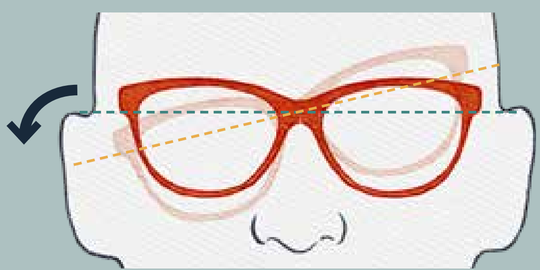
Pushing forward



Pushing Backwards

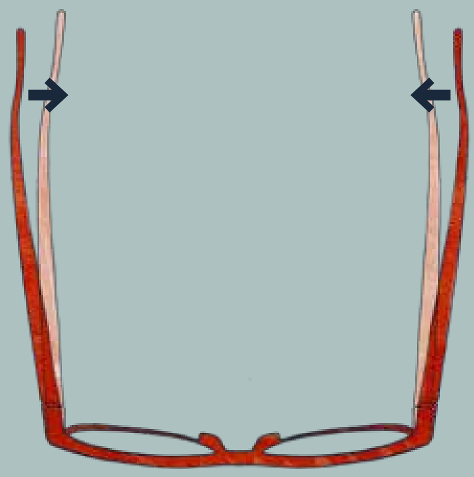


Sliding forward

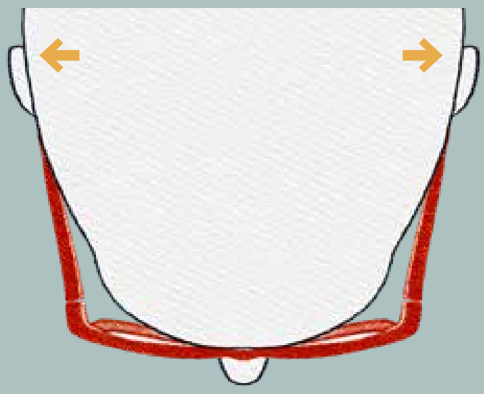


Tilting sideways

FORCE REFERENCE



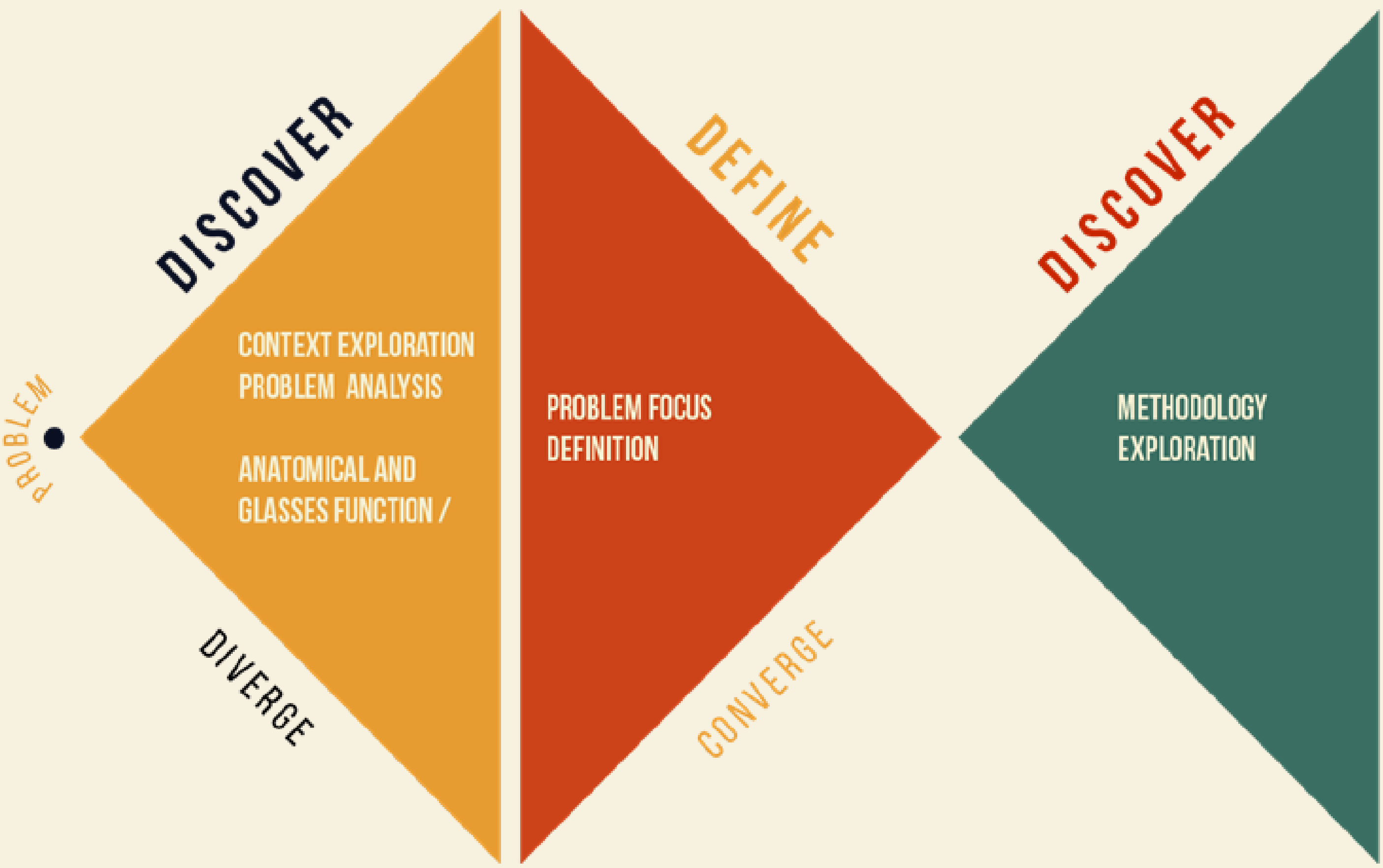
Spring force

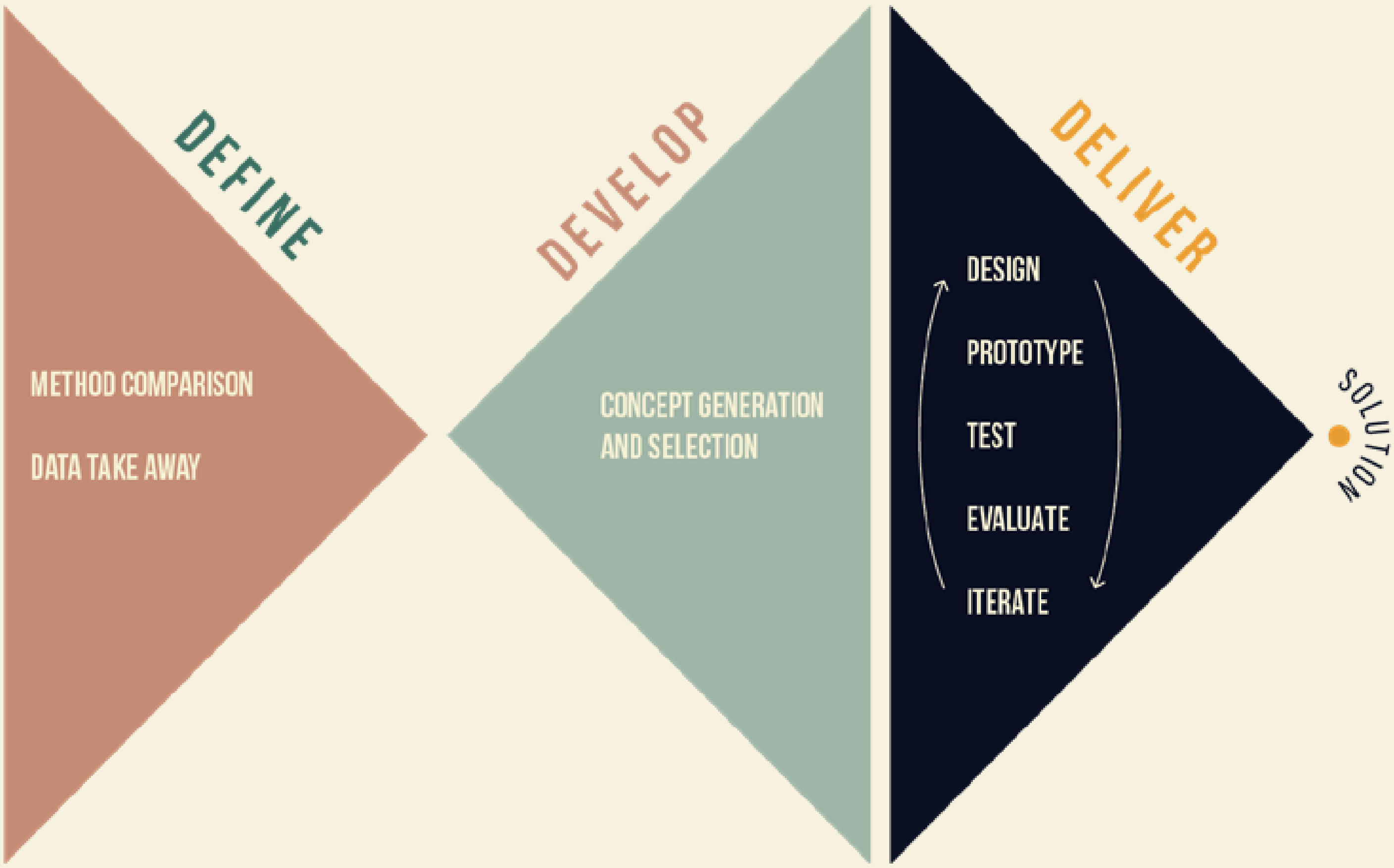


Displacement force

Normal force

REPORT STRUCTURE




DEFINE
METHOD COMPARISON
DATA TAKE AWAY
DEVELOP
CONCEPT GENERATION
AND SELECTION
DELIVER
DESIGN
PROTOTYPE
TEST
EVALUATE
ITERATE
SOLUTION

1 INTRODUCTION

This chapter includes the Introduction to the project partners and a description of the problem and research approach.

1 INTRODUCTION

1. ABOUT THE PROJECT

In the world of made-to-fit eyewear, it is essential having a 3D head scan upon which the frame can be molded.

The temple tips are crucial components of the frame in terms of comfort and stability. Currently, the 3D scans obtained using the Occipital sensor scanner do not depict the area behind the ear correctly. After profuse research, it was found that it is not possible to obtain such data through direct 3D scanning.

It is necessary to create a mold of the area that includes a reference system. The developed solution is "flex" an adjustable frame that functions as a measuring tool due to the flexibility of its temple tips that can be molded to detect the head's curvature. Once the mold has been taken, the frame can be moved and 3D scanned on its own. The information retrieved from the 3D scan of the temple tips allowed the design of comfortable and functional temples.

PROJECT PARTNERS

This project is a collaboration between TUDELFT, MAAT! And Fieldlab UPPS.

2.1 MAAT!

Maat! is an Amsterdam-based MedTech startup company specializing in customized eyewear tailored to the Medical Sector. They use a combination of 3D-scanning and 3D-printing technology to produce glasses made-to-measure with the perfect fit.

Maat developed an algorithm that allows designing frames based on a 3D scan of the client to compensate for any facial asymmetry leading to perfectly fitted eyewear. For this reason, the startup works in close cooperation with hospitals, ophthalmologists, and other medical professionals.

Maatbril's team designs and produces eyewear for children and adults with particular pathologies such as Down syndrome, Goldenhar which often lead to craniofacial anomalie (See image 1.1_ target user chart).

IMAGE 1.1 *Target user chart*

2.2 FIELDLABS UPPS

The graduation project is part of a larger project that falls under the guidance of Fieldlap UPPS, an initiative that stimulates innovations around Ultra Personalized Products and Services[2].

Within the Fieldlab UPPS, it is possible to collect 3D data and subject it to extensive analyses, study parametric design techniques and flexible production techniques, and ultimately evaluate the ultra-personalized products and processes in a lab setting. The Fieldlab UPPS is set up for the top sector Creative Industry and is coordinated by the TU Delft Faculty of Industrial Design Engineering.

2.3 TU DELFT FACULTY OF INDUSTRIAL DESIGN ENGINEERING

This project is carried out within the faculty of Industrial Design Engineering in the master track Integrated Product Design. Both Mentor and Chair are responsible for the guidance of the graduate student by implementing an academic approach.

3. BRIEF

The brief was analyzed to understand and define the stakeholders, the problem the client has encountered, and evaluate the proposed approach to define the project approach. *(See Appendix A).*

3.1 MAATBRIL STAKEHOLDES

The stakeholders mentioned in the Brief document functioned as a starting point for a deeper analysis to define all the parties involved and their relation to the development of Maatbril.

The map (see image 1.2) shows how the stakeholders have been divided into different categories based on the type of involvement towards the company: Production,

Users, Expertise centers Specialized care Providers.
Each stakeholder has been placed on the map based on their interest and influence on Maatbril's development.

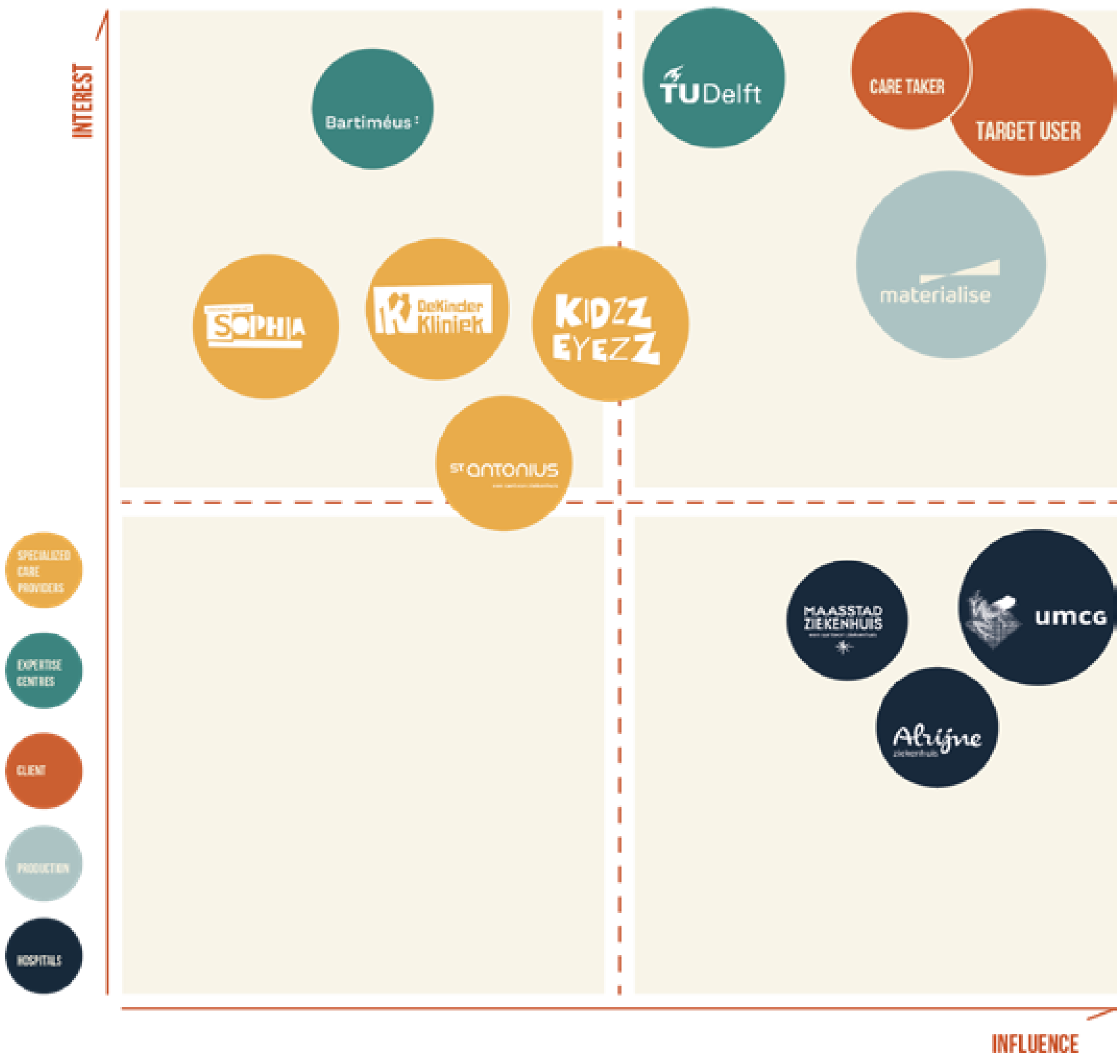


IMAGE 1.2 *Stakeholders map*

3.2 PROBLEM

"Glasses that slide down the nose or hurt behind the ears are very common complaints especially for people with non standard facial dimensions. With our innovative technology we've been able to overcome this problem. Nevertheless the area behind the ear is difficult to reach with a scanner therefore the dimensions and shape of the temple tips are not as accurate as the rest of the frame".

3.3 REQUEST

"Can a common denominator for this area be found for certain target groups (age, needs, characteristics of the head related to medical issues) or can the position and shape of the outer ear predict the shape of the area behind the ears?"

3.4 PROPOSED APPROACH

1. *Gather 3D scans of the area behind the ears of the target group* and do *statistical shape analysis*;
2. *Design temple tips of the frames*, based on the outcome of the analyses, for people in the target groups to test;
3. *Do fit mapping* of the redesigned temple tips. (see image 1.3).

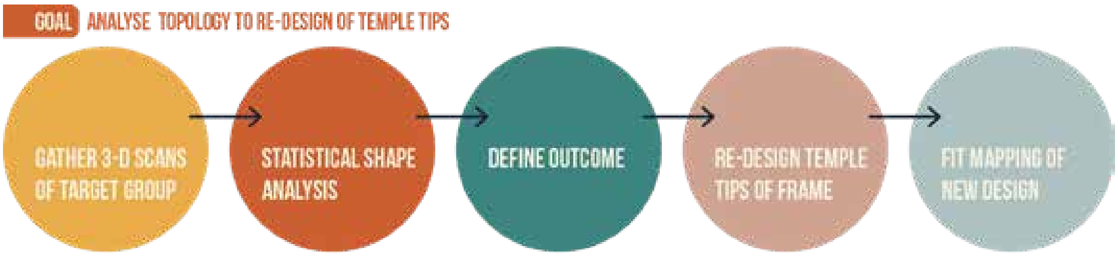


IMAGE 1.3 *Proposed approach*

4. REVISED APPROACH AND GOAL RE-FRAMING

As the project developed the approach and subsequentially, the project's goal has been revised as follows (see image 1.4).

Initially, the project's goal focused on studying the posterior auricular area to redesign the temple tips. To do so, it was first necessary identifying a proper methodology to analyse the curvature. This phase was more complicated than initially expected and required various iterations. At the end of this phase, it emerged that 3D scanning was not as effective as initially anticipated due to limitations involving the current state of the technology and the interaction it implies with the user. It emerged that the more urgent matter involved designing a feasible tool to obtain the data regarding the curvature and integrate it into the glasses' production method. Therefore the goal has been re-defined.

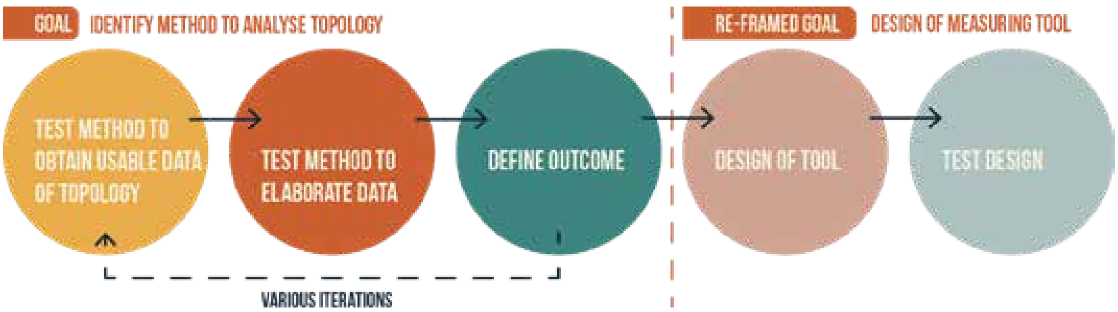


IMAGE 1.4 *Revised approach*

2 CONTEXT ANALYSIS

Gain knowledge of how the company operates and interacts with the clients.
Have a clear view of the type of clients involved.
Analyse and define the problem.

2 CONTEXT ANALYSIS

1. CONTEXT

1.1 MAATBRIL'S CURRENT WORK FLOW

RQ: What is the company's current process to design a pair of glasses?

The following text indicates the steps necessary to design and produce a customized pair of glasses at Maatbril.

3D SCAN COLLECTION

Upon appointment, a specialist of Maatbril performs a 3D biometric scan of the client's face at their home or a healthcare facility.
The scanning is performed with an *Occipital*[3] scanner mounted on a tablet at a distance of around 150 cm.
The measurement takes approximately 10 seconds. The client has to sit on a chair and remain as still as possible while the specialist moves around them, holding the 3D scanner. In this phase, the quality of the scan can be negatively affected by movement and the presence of hair. The scan of the area behind the ears is critical: it is of fundamental importance, but - at the same time - it is very challenging to scan due to the presence of the auricles, which obstruct the camera sight.

MODEL SELECTION

Once the measurements have been taken - in some cases, they may require multiple takes - the specialist and the Caretaker discuss the client's lifestyle and special

request (ex. Hearing aid, a wheelchair with headrest, etc.) to be taken into account while designing the frame.
When ready, the scan is uploaded on the App. It is then shown to the Caretaker and client, who can then virtually try on different frame models in different variations of colours, and easily choose the preferred option, avoiding the hassle of physically trying on the frames.

DESIGN OF FRAME

Starting from the digital mesh of the 3D biometric scan, Maatbril's 3D model expert modifies the frame of choice to the perfect fit: the frame is adjusted in terms of: length, inclination, size, and placement of each of its components.[1]
In some cases, such as in the presence of extreme asymmetries or anomalies (es: missing ear, missing nose), this step is particularly challenging.

PRODUCTION OF FRAME

The final frame 3D model is sent to a specialized 3D printing company (Materialise) for SLA 3D printing in white Polyamide (PA12).
Once Maatbril receives the printed components of the frame, they can colour them according to the client's choice. Once the parts are ready, they are assembled into the final pair of eyeglasses by adding the prescribed lenses provided by the Optician.

DELIVERY AND ADJUSTMENTS

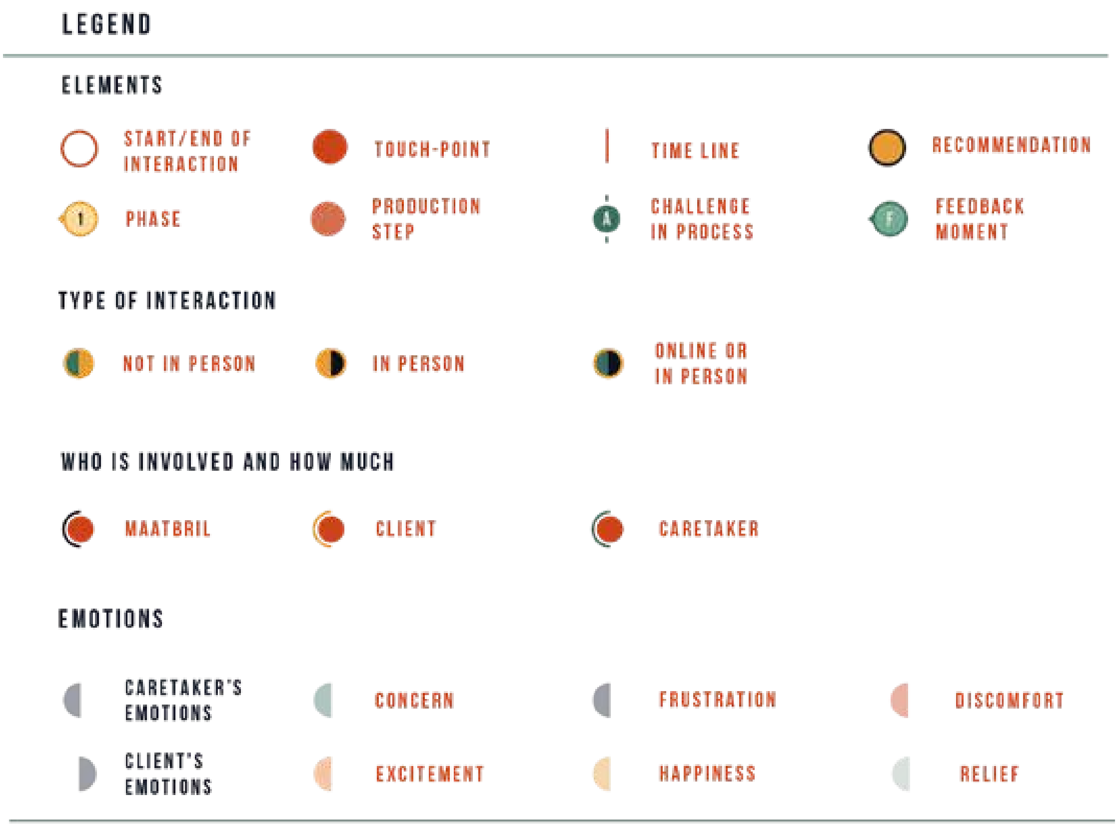
The finished glasses are brought to the client for the fitting test.
This way, if necessary, the temple tips's curvature can be adjusted on the spot.
The adjustment consists in heating up the temple tip using the dedicated heating tool and moulding it manually along the curvature of the head. This step is executed by one of Maatbril's expert and is necessary in order to improve the comfort and grip while wearing the glasses.
In some cases, issues are reported after a period of testing the frame. In these cases, it is often required to reprint components or even the entire frame to solve the problems regarding the fitting.

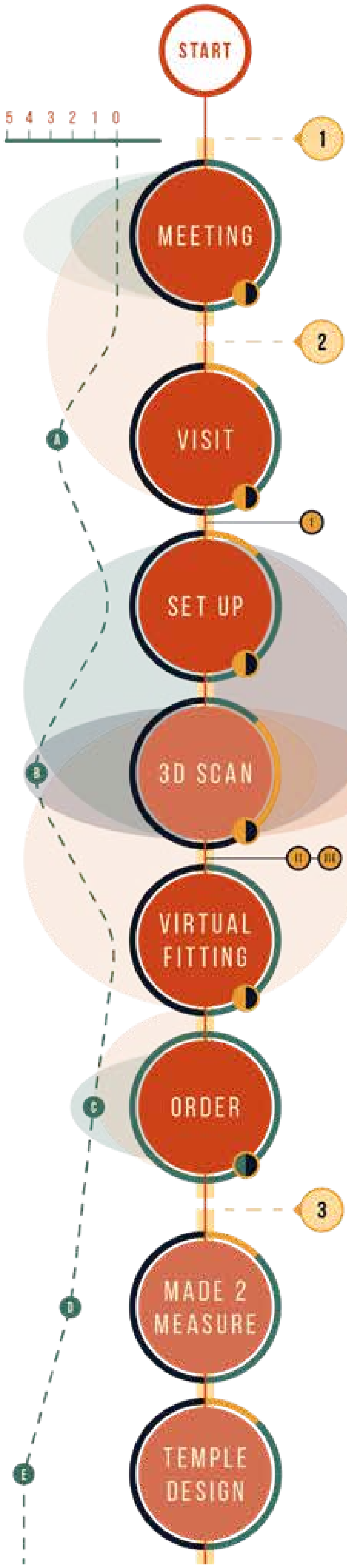
Once the final design of the frame has been approved the users can enjoy their new made-to-measure pair of glasses without having to worry about their comfort. To cite *Orthoptist Wijnanda Asjes*:

"You know glasses are good when you don't even notice you're wearing glasses. That way, you are concerned with the world around you, not with the frame on your nose. "[4]

1 See glossary p.14 : *"Sizing factors"*

The work flow has been analysed in depth and summarised in the following costumer Journey Map (see image 2.1).





1 APPOINTMENT

The caretaker interacts with Maatbril either by booking an appointment online/phone or by meeting them at an organized event.

2 3D SCANNING

Maatbril expert goes to the client's residence to gather the biometric 3D scan of the face.

Maatbril expert explains dynamics of scanning phase and prepares setup for scanning: mounting the occipital scanner on the ipad a clearing out and area to do the scan.

Maatbril expert takes the 3D scan of the client's face. The client might be subject to uncontrollable movement or might be intrigued by the novelty of the situation. In this case, the caretaker's assistance is needed to stabilize the head or help reduce the distraction.

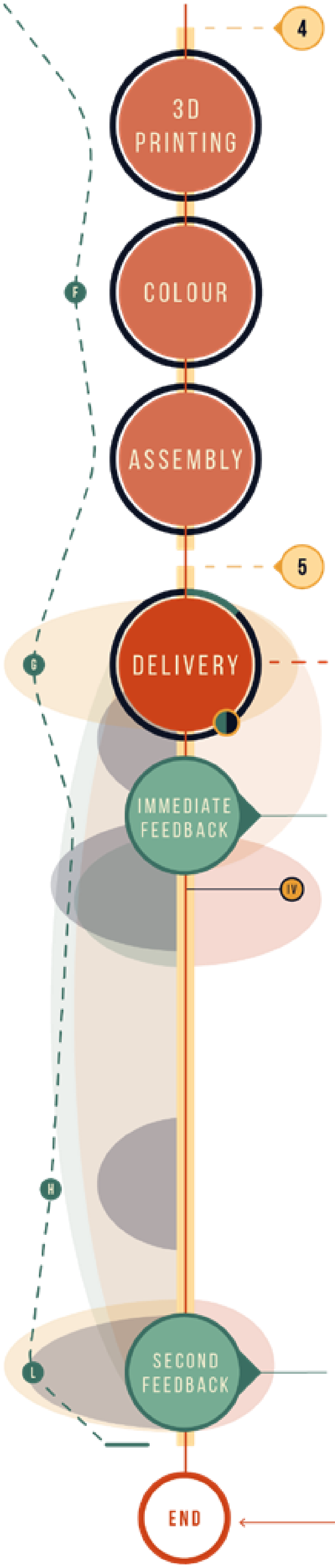
The caretaker can choose the glasses model and color trough the App that allows to virtually try on the diffrent models by placing them on the 3D scan. Avoiding the hassle related to having the client try on the glasses in the store.

Taking the scan does not imply ordering glasses, therefore the order has to be confirmed by the client subsequently.

3 DESIGN

Maatbril's 3D model expert designs the eyewear frame based on the 3D scan obtained during phase 2.

The length of the temples is defined based on the location of the eardrum shadow, if visible in the 3D scan. Otherwise, it is estimated based on the expert's gathered experience while designing similar models.



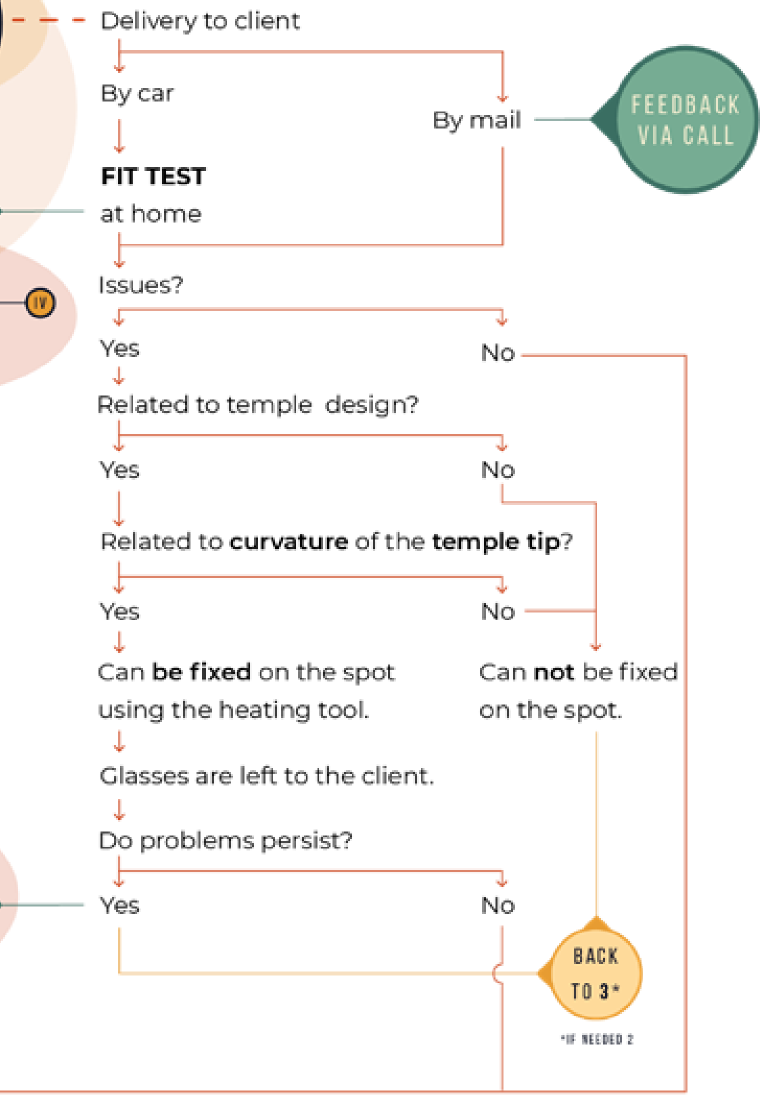
4 PRODUCTION OF GLASSES

The cad models are sent in batch to an external company, responsible for 3D printing the single parts. After aproximatly two weeks the glasses are shipped back to Maatbril.

Each component of the frame is coloured based on the choice of the client.

Once the parts have been coated and are fully dry they can be assemble with the lenses into a functional eyewear frame.

5 DELIVERY & ADJUSTMENTS



CHALLENGES

A Maatbril has to drive to the client’s house to gather the 3D scan without certainty that the client will complete the order.

B 3D scanning can be a complex process if:
- the client has an uncontrollable spasm;
- the client moves following the iPad;
-The client is disturbed by the unfamiliarity of the situation;
- To obtain a scan, the caretaker holds still the client's head.

C A lot of effort and time goes into making a scan, and therefore, it is problematic when the order falls through.

D The quality of the 3D scan is often compromised, affecting the design output.

E The model of the temples is compromised in terms of length and temple tip design if the 3D scan does not include the ears.

F The color does not behave as expected in some cases, and the results might differ from the original request.

G The delivery in person requires time and effort but is necessary for Maatbril's expert to evaluate on the spot the proper fit of the glasses.

H Sometimes, the frame presents issues that can be resolved on the spot using a heating tool to remodel the temple tips' geometry. (Improve grip, reduce pressure on nose-pad and/or posterior auricular area).

I If problems persist, a reprint is necessary (of a single component or complete frame, depending on the case).

RECOMMENDATIONS

I It would be ideal if Maatbril incentivized the clients to reach a designated 3D scanning location while maintaining the home visit option if needed.

II Collect data regarding the posterior auricular area topology to compensate for the missing data in the 3D scan. This step is necessary to improve the temple tip design and reduce reprints.

III Possible improvements that Maatbril can apply during the 3D scanning phase:
- adopt a scanning technology that requires less time (<10 s) to obtain a proper scan;
-Integrate a distraction for the client to fix during the 3D scanning phase to reduce possible head movement.

IV Standardize how feedback is collected based on the requirements given by Maatbril’s model expert to ensure enough data is collected to make the necessary improvements.

1.2 TEMPLE TIPS ANALYSIS

RQ: What are the specifications of the temple tips in Maatbril's catalogue?

The following text illustrates what are the main types and characteristics of the temple tips offered by Maatbril, analyzed based on the user they are often associated with, grip and possibility to vary the design.

Maatbril offers different options of temples, that for each pair of glasses, are chosen and customized based on the client needs. The models' correct use has been analysed to understand to what extent the area behind the ear is involved. The correct fit has been discussed with Maatbril 3D model expert. These are the current models: (see image 2.1_ models of temple tips)

- Model 1 "steekveer" that translates to "Library temple";
- Model 2 "metalen veer" that translates to "metal temple":

  Lightweight model but allows limited adjustment;
- Model 3 "Regular temple":
- Model 4 "krulveer" that translates to "Riding bow temple":
- Model 5 with BCI (Bone Conduction Implant) slot;
- Model 6 with extended arched temple tip.

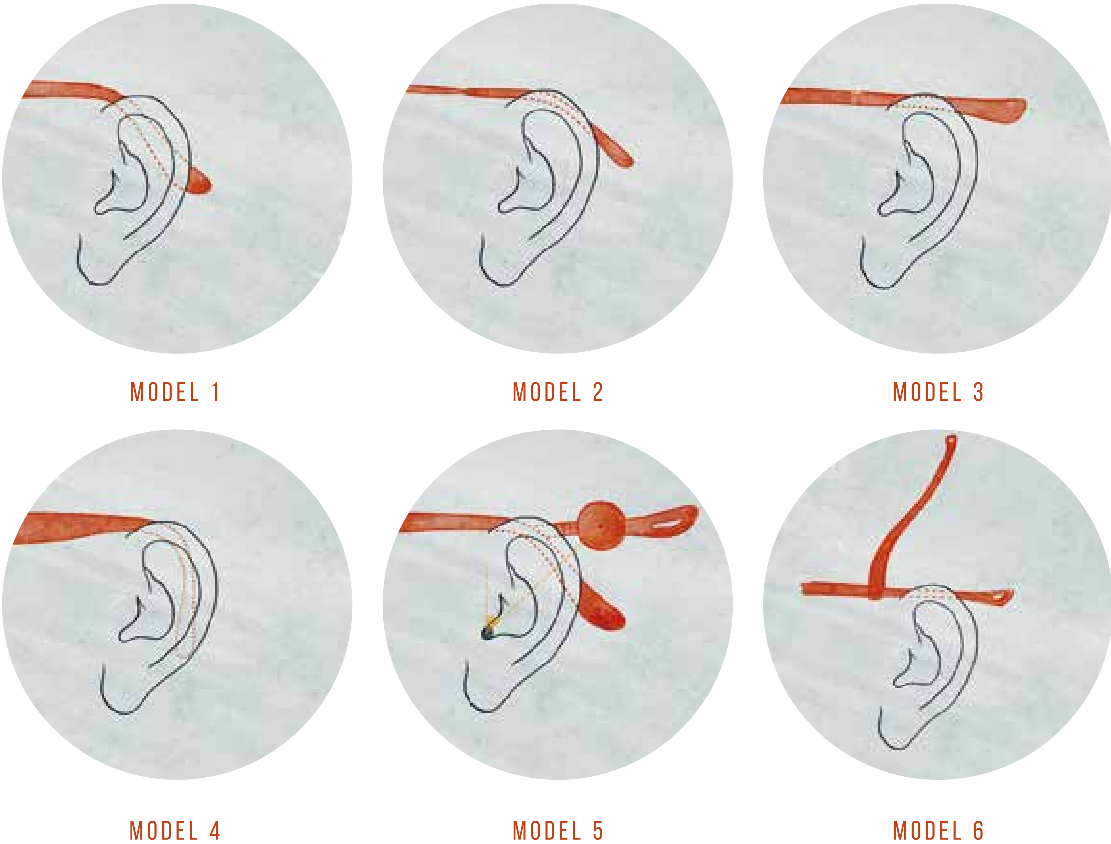


IMAGE 2.1 *Models of Maatbril's temple tips*

The metal temple is being implemented less and less in the current glasses models since it allows inferior freedom of deformation when adjusting it on the clients head.
The “ridging bow temple” has been redesigned recently since the previous design was often reputed unpleasant to wear by the clients. In the new design, the temple is straighter and easier to adjust to fit. (see image 2.2_ Design evolution of "Riding Bow" temple)
The BCI temple is essentially a regular temple with the addition of a flexible strip that has a dedicated slot for a Bone conduction implant(BCI).

IMAGE 2.2 *Design evolution "Riding Bow" temple*

The temple tips characteristics in terms of user, adaptability of design and grip have been summarized in the table "Temple tip analysis" (see APPENDIX B).

KEY FINDINGS

- Maatbril offers 6 different types of temple tip models;
- the temple tip design can be customized based on the clients needs;
- Model 1 is the most popular;
- Model 3 and 6 are suited for user with missing ear(s) or severe asymmetry in ear placement;
- Model 3 is not compatible with user that require a wheelchair headrest;
- Model 4 compensates by providing extra grip for user that have limited or missing nose support;
- Model 4 is best suited for users that require a wheelchair headrest;
- Model 5 is compatible with BCI (Bone conduction Implant);
- Model 6 is used for clients that present the most severe cases of cranial deformation;
- The hole at the extremity of the temple tip is the slot for the headband attachment, that increases greatly the stability of the frame.

1.3 CLIENTELE ANALYSIS

RQ: What are the typical maatbril clients?

The following text indicates the results of the analysis of Maatbril clientele information in terms of: gender, age and affected syndrome.
The findings of this research have been implemented for the development of the Persona sheets, to have a clear definition of the target group for the project.

The information is based on an analysis of the current Maatbril's clientele database from February 25, 2018, to March 8, 2021. Of the retrieved information, only gender and age have been analysed, since no clear indication was found regarding the type of the disease the clients are affected by.
The results indicate that 46% of the clients are under the age of 15, and 55% are women. (see image 2.3- Pie charts of clientele)

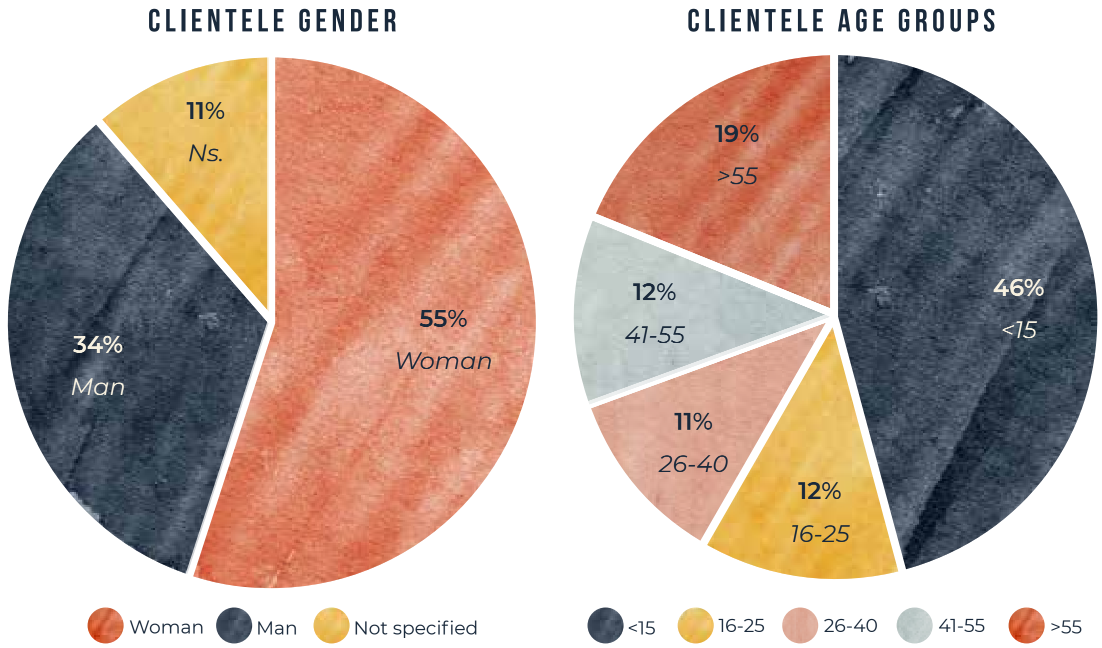


IMAGE 2.3 *Pie chart of clientelle: gender (left) and age group specification (right)*

It has been noticed that each age subgroup covers a varying amount of years (See Appendix C- Age and gender distribution of clients). The first subgroup of "<15" includes the most significant amount of clients and presents a variation issue since it clusters the years of significant development and growth of the cranium into one single group.
Out of 333 clients, only 204 have an age specification, leaving a gap of 129 clients with no age specification, so this is only an indicative evaluation of the actual representation of the client's gender division. The clientele gender division is based on 333 clients, of which 57 have no gender specification.

It was found that statistical information regarding the type of syndrome that the clients were affected by was not mentioned. This type of information is considered relevant to gain a deeper understanding of the potential anatomical effects the syndromes might have on the cranium. Therefore additional research has been conducted, reported in the following chapter.

KEY FINDINGS

- 55% of clients are woman; 34% are men; 11% not disclosed
- There is no specification of age of clients under the age of 15;

- The group of clients under the age of 15 is the most significant (46%)
- The analysis regarding age division is only indicative since the data presents missing information.
- No data regarding the type of syndrome the clients are affected by was found; therefore further research is necessary.

The mentioned syndromes in the *persona sheets* have been chosen based on a statistical study cited in the following chapter.

1.4 PERSONAS

The *persona sheets* summarize the key findings of the context analysis by outlining fictional but realistic clients.

Image 2.3 represents the variation occurring in the target group. In terms of gender, age, type of communication and affected syndrome. These differences have an impact on the interaction and result of the encounter between Maat! and the clients.

The *persona sheets* have been based on the elaboration of information provided by Maatbril's experts in combination with the data retrieved from the client's analysis phase and client's house visits (see image 2.4 and 2.5_ house visits).

IMAGE 2.4_ *Thimo house visit*

IMAGE 2.5_ *Wilmer house visit*

The photos and names reported in the Persona sheets are fictional and do not correspond to actual clients; the 3-d scans do and have been matched to similar photo profile.
See Appendix D_How to read the persona sheet in the appendix for further details.

GERRIT VAN DIJK, 11

Male, Dutch

Down syndrome

Verbal & Non-verbal communication

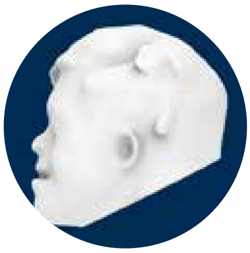
Movement level

3D SCAN WITH MAATBRIL SCANNER

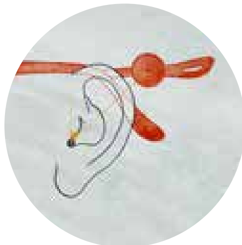
TEMPLE TIP TYPE

Center

Right



Left

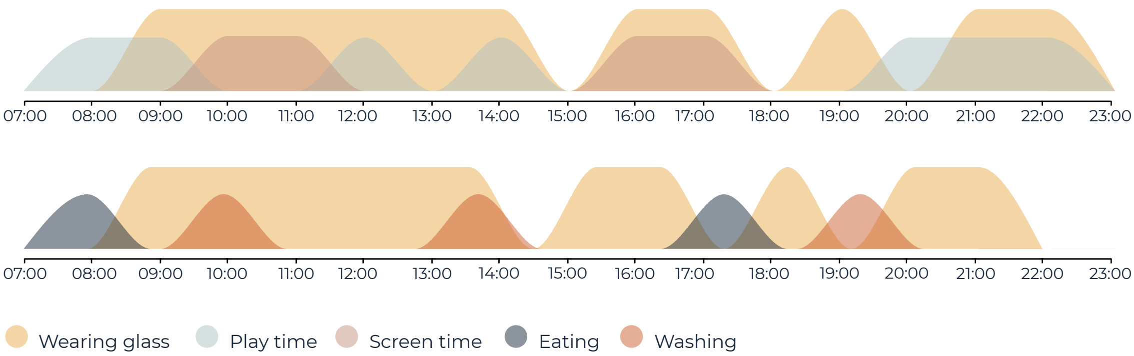


name

Location of scan: **House**

Aid during scan: **Not required**

DAY ACTIVITIES



With these glasses his life has changed, I can see it from his smile how his friends interact with him now.

Lara, Gerrit's mother

LOTTE BAKKER, 67

Female, Dutch

Non-verbal communication

Movement level

3D SCAN WITH MAATBRIL SCANNER

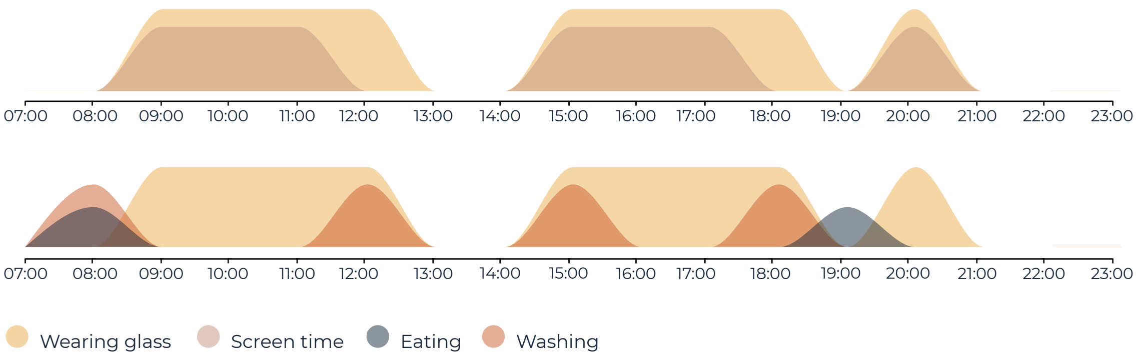
TEMPLE TIP TYPE

Center Right Left name

Location of scan: **House**

Aid during scan: **Required**

DAY ACTIVITIES



Since Lotte has these glasses, it has never happened that she throws them off her face because they are not comfortable. That gives peace of mind; for herself but also for us!

Vera, Lotte's caretaker

2. PROBLEM DEFINITION

RQ: what is the core issue of the project?

The Context analysis allowed to gain a better understanding of the Maatbril's current method and their clientele base in relation to their product line. The main issue, and focus of this project relies in the 3D scanning phase, that currently is unable to detect information of the posterior auricular area.

The main problem regarding 3D scanning of the posterior auricular area is reachability due to the presence of the pinna and, in some cases, hair. (See image 2.6_ Polar diagram of 3d scanning output).
See *image 2.7* to visualize an example of failed scan of the posterior auricular area.

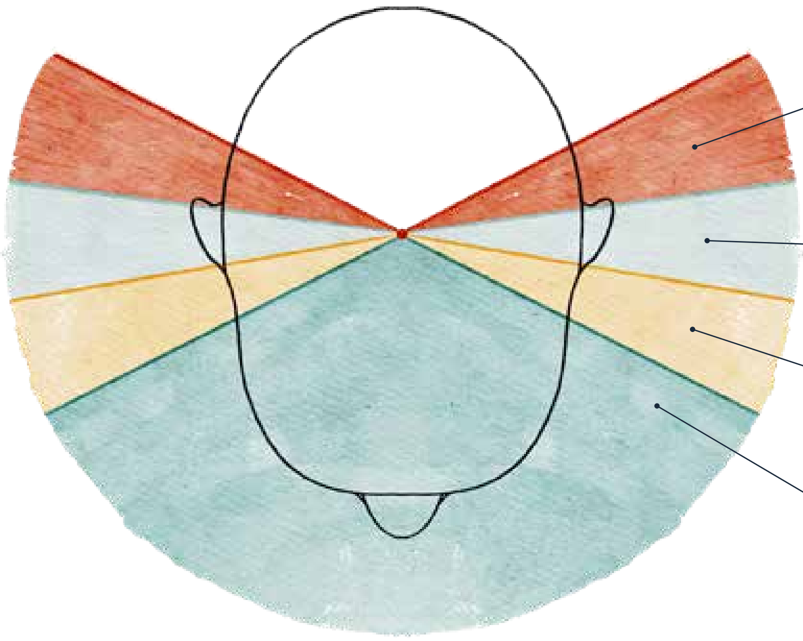


IMAGE 2.6 *Polar Digram of 3D scan output*

AREA 1	Area that includes main facial features (eyes and nose)
QUALITY OF SCAN OUTPUT*	Good
REASON	The area is well lit and clear of obstacles
RELATION OF SCAN TO FRAME	Front component
RELEVANCE FOR PROPER FIT	High

AREA 2	Area between zygomatic bone and attachment of ear
QUALITY OF SCAN OUTPUT*	Acceptable
REASON	The area might be partially covered by hair
RELATION OF SCAN TO FRAME	Temple
RELEVANCE FOR PROPER FIT	Low

AREA 3	Area including ear
QUALITY OF SCAN OUTPUT*	Poor
REASON	The pinna of the ear has a complicated geometry that, to be scanned properly requires: - high fidelity scanner - well lit area - cleared of obstacles (hair)
RELATION OF SCAN TO FRAME	Temple tip
RELEVANCE FOR PROPER FIT	High

AREA 4	Area including ear
QUALITY OF SCAN OUTPUT*	Poor
REASON	The pinna creates an obstacle since it hides and creates a shade of the area that is trying to be reached by the scanner
RELATION OF SCAN TO FRAME	Temple tip
RELEVANCE FOR PROPER FIT	High

* Considering the use of occipital scanner, evaluated in optimal conditions of clients scanning:

- The environment is well lit
- The clients remain still for the entire duration of the scan (10 s.)
- The client does not require head support during the scan

While accurate capturing of this area is of extreme importance to obtain a precise design of the temple tips, which ultimately results in a good fit of the eyeglasses When the temple tips are approximated, it often leads to the need for final manual adjustments and, in some cases, to a partial or complete reprint of the frame.

The current issues have been summarised and divided into three main subgroups depending on the type of the cause:

- TECHNICAL ISSUES
- PHYSICAL ISSUES
- BEHAVIOURAL ISSUES

Image 2.8_ PROBLEM DEFINITION GRAPH illustrates how cause and effects are linked.

KEY FINDINGS

The main Design challenges have been summarised below:

- Variability in the quality of 3D scan depending on area depicted;
- Difficulty in obtaining an accurate 3D scan of the client's head due to movement of the client;
- Challenge in reaching the area behind the ears;
- Missing or reduced information retrieved from scab leads to an approximated design of temple tips*
- Since the temple can't be molded based on a 3D scan; Manual adjustments on temple tips are needed to improve the frame's grip behind the ears, general stability, and comfort;
- The effect that the design of each of the components of the frame has on comfort is still unclear;
- The clientele pool varies greatly
- Interpreting the client's issues concerning the comfort with their pair of glasses might be complicated due to communication differences;

*The temple tips are standard models assigned to the client based on their needs which are manually adjusted, based on the client's skull curvature, after the delivery.

In the case of this graduation project, the focus will be on the issue concerning the posterior auricular area.
This area appears difficult to 3D scan due to its position, the fact that it is low-lit, the subject tends to move during the scan, and the level of accuracy of the scanner in use by Maatbril.
This area needs to be studied to design functional and comfortable temple tips.

Front view

Right view

Left view

IMAGE 2.7 *Example of failed scan of posterior auricular area*

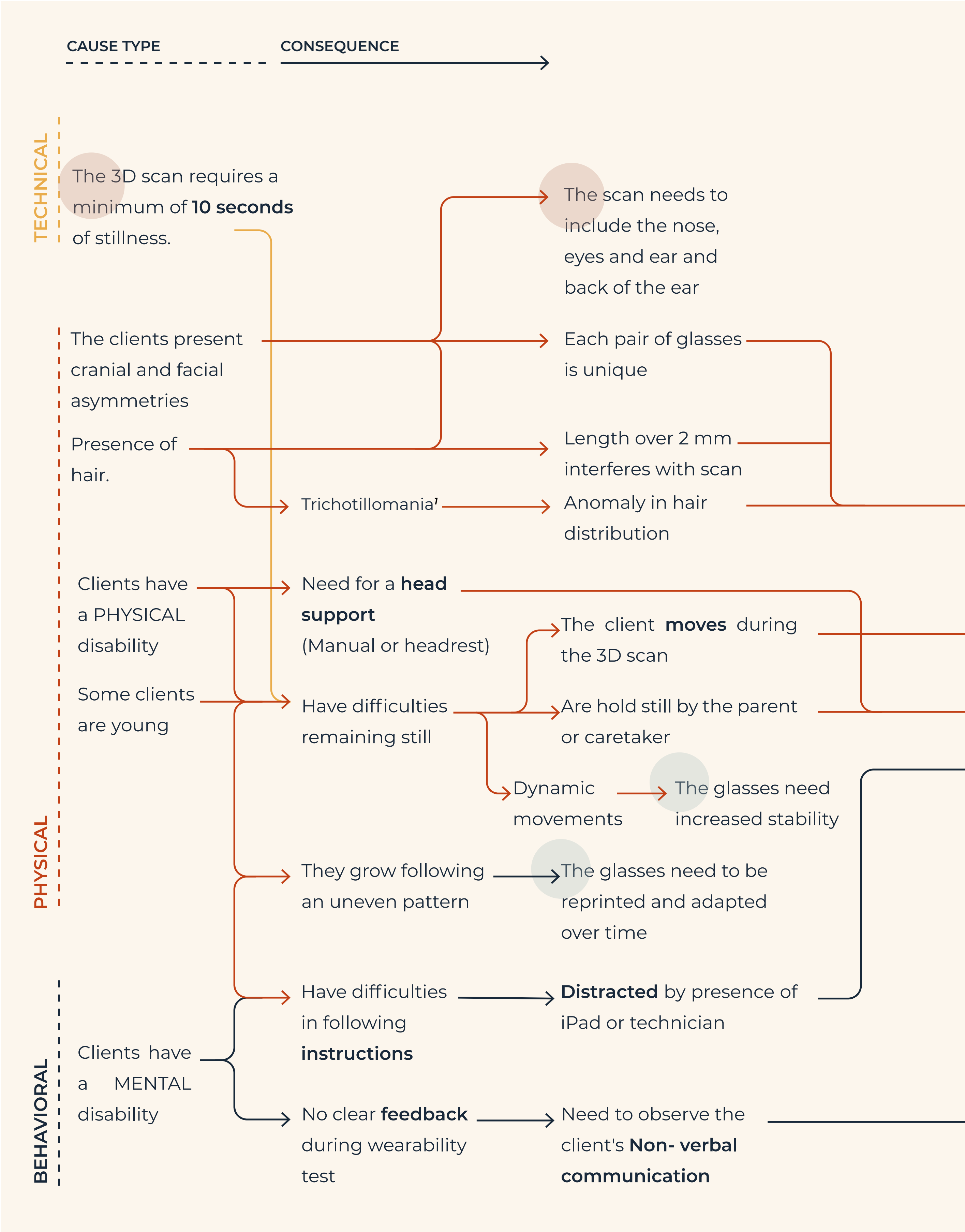
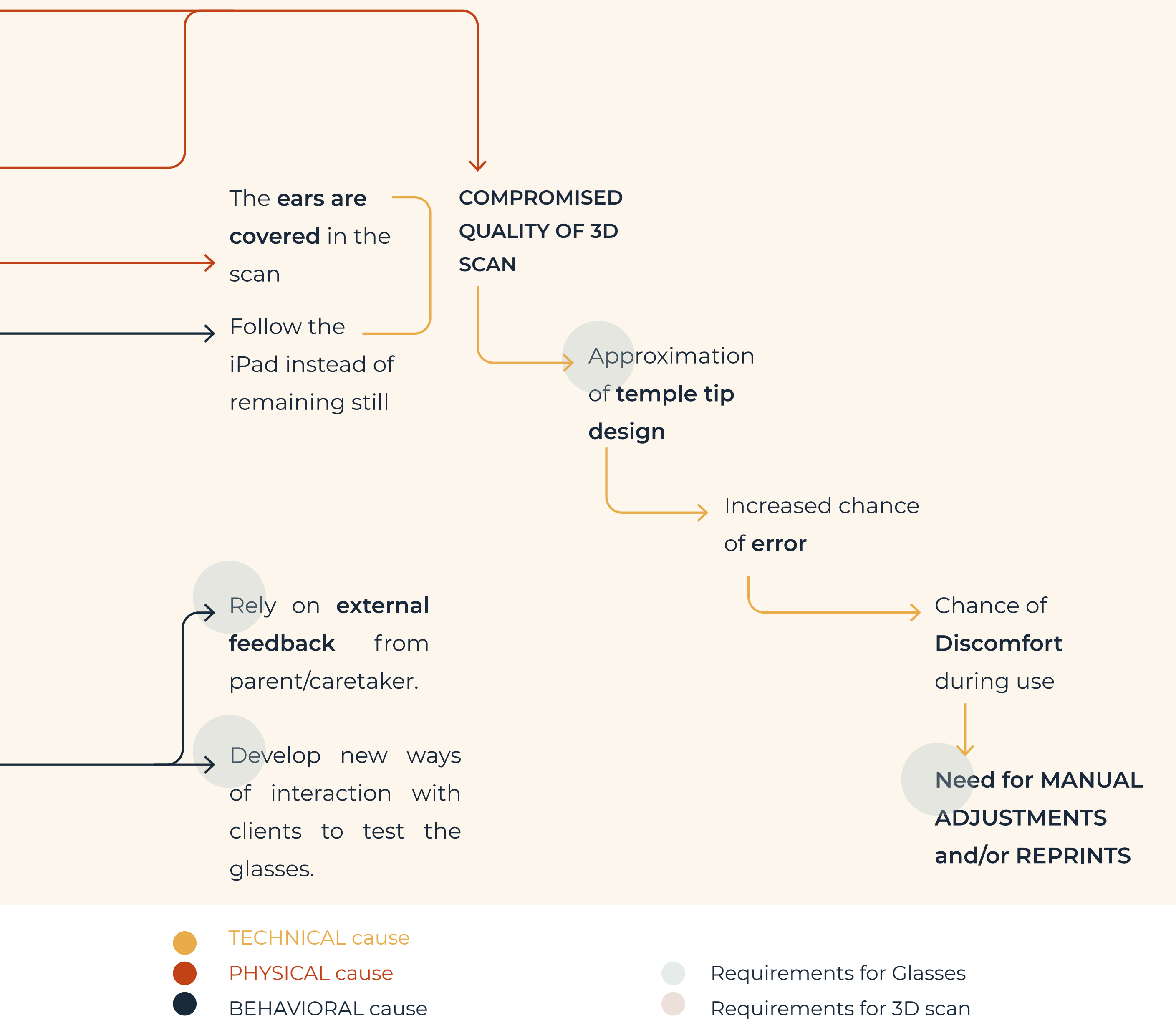


IMAGE 2.8 *Problem definition graph*

1 Trichotillomania an abnormal desire to pull out one's hair [5]


COMPROMISED QUALITY OF 3D SCAN
The **ears are covered** in the scan
Follow the iPad instead of remaining still
Approximation of **temple tip design**
Increased chance of **error**
Chance of **Discomfort** during use
Need for MANUAL ADJUSTMENTS and/or REPRINTS
Rely on **external feedback** from parent/caretaker.
Develop new ways of interaction with clients to test the glasses.
TECHNICAL cause
PHYSICAL cause
BEHAVIORAL cause
Requirements for Glasses
Requirements for 3D scan

3 BACKGROUND RESEARCH

A. The anatomical research focuses on clients often having a unique skull shape. Understanding what these variations imply on a bone level and how often they occur is necessary to define the area on which the study will focus.

B. The second phase of the research focused on understanding how a pair of glasses interact with the skull and how this interaction varies in the case of a head with down syndrome.

3.A ANATOMICAL RESEARCH

1. INTRODUCTION TO MORPHOLOGIC ANOMALIES OF THE HEAD

RQ: What does having a morphologic anomaly of the skull imply?

From a statistical point of view, when designing the clients' eyeglasses, it is crucial to analyse the causes of their head's shape anomalies to try to predict the problems we may face. These anomalies might involve the skull, facial features, or even both.

However, when talking about the "human body," in reality, we are talking about an abstract concept: think about how different a baby, a child, and an adult are to understand that we should always specify -at least- the stage of development (for instance, childhood, puberty, adulthood), sex, ethnicity, and pathologies, which are essential to adapt the model linked to a given pathological anomaly and verify if we can expect that a complete development has already been reached. **Also, symmetry and asymmetry are just statistical concepts, as does not exist a human body that presents a perfect right-left symmetry.**

Focusing on the aspects to be explored for this project, here are the main elements of interest:

- The **skull**, its definition, and morphology, in particular of the braincase;
- The **face,** and its features, like eyes, nose, and ears;
- The **morphological anomalies** of the skull and the face, particularly those of the temporal bone and facial features.

A distinction must be made between the different types of morphological anomalies that may be classified as malformation, deformation, disruption, or dysplasias.

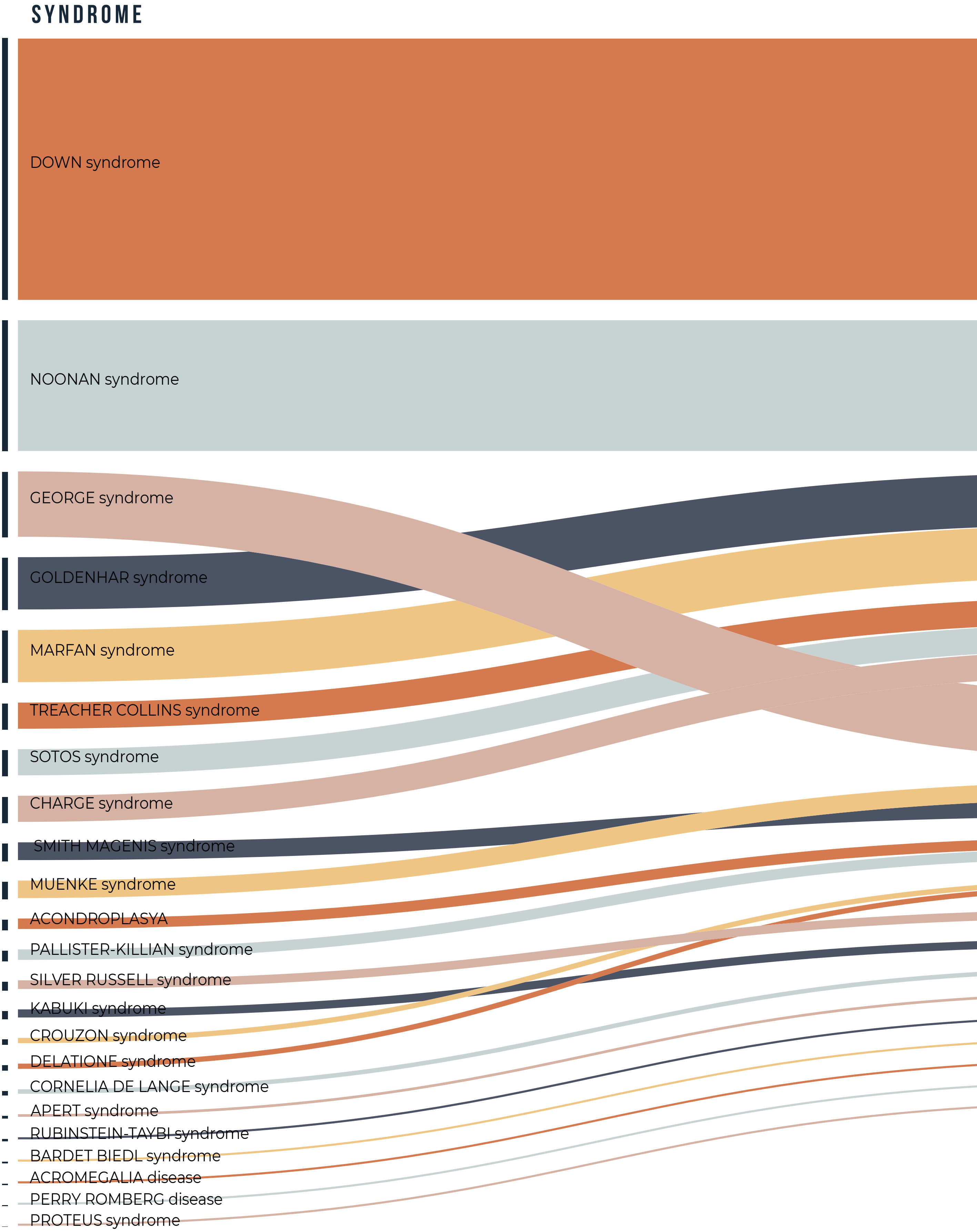
The **main difference is that malformation has common characteristics that allow forecasting of what they might imply**(e.g., down syndrome: flatter nose, lower nose bridge, longer eyelashes, etc.), **while in the case of deformation, disruptions, or dysplasias due to their nature, it not possible to trace them back to standard patterns.**

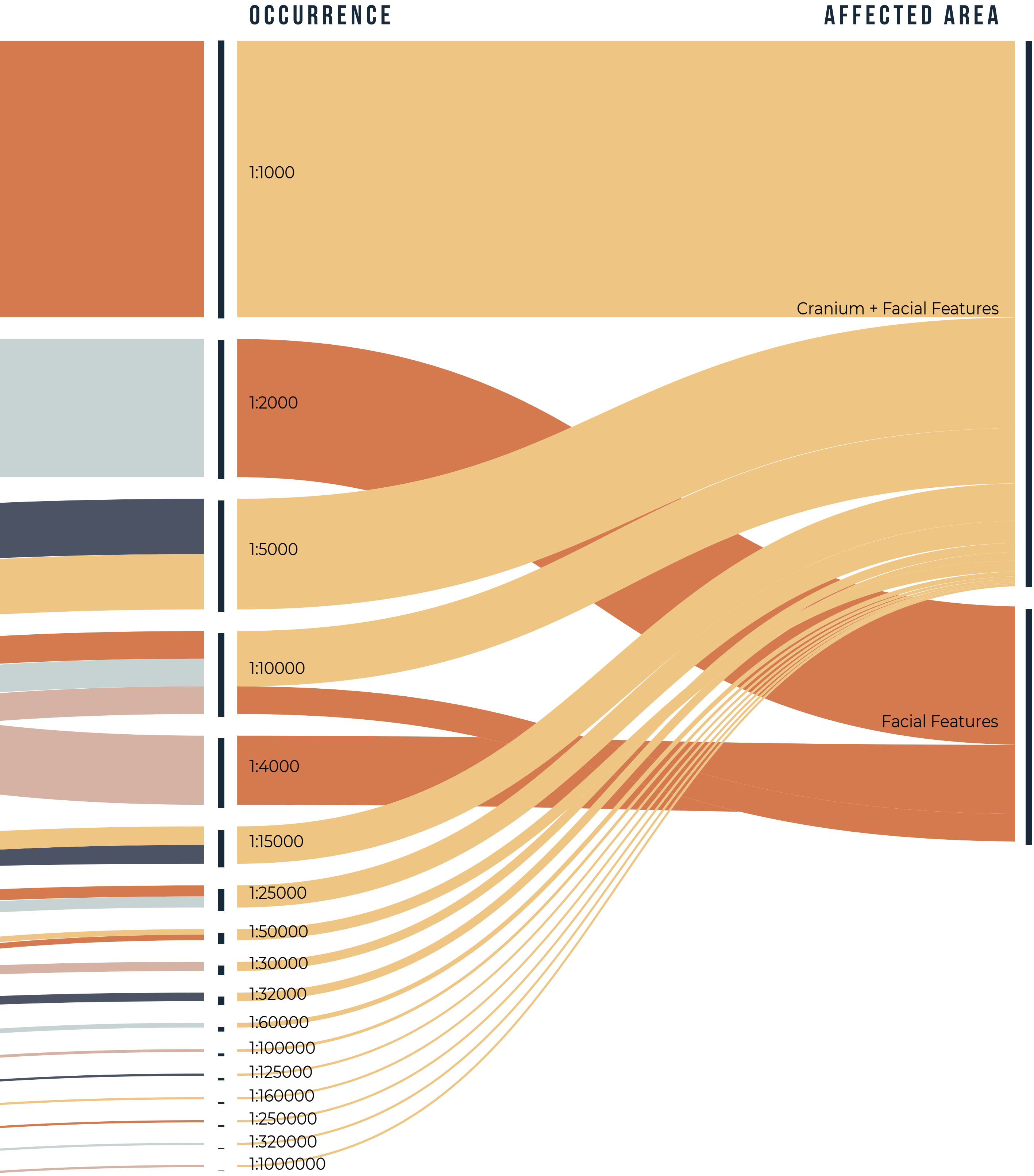
This intrinsic difference implies limiting the statistical study to a group of subjects affected exclusively by malformations if the expected outcome is a pattern.

For further information see *Appendix E*.

Table 3a.1 illustrates a list of the pathologies and syndromes that may affect the shape of a potential client's head. The list was obtained by analyzing the rare genetic diseases mentioned in "Orphanet's" database[6] and what type of effect they caused in cranial malformation and eyesight-related problematics. The list is ordered from most common pathology ("Down syndrome" with 1:1000 cases) to least common ("Proteus syndrome" 1:1000000), mapping out which part of the head is affected by the morphological anomaly.

TABLE 3A.1_ SYNDROME OCCURRENCE AND AFFECTED AREA




OCCURRENCE
AFFECTED AREA
1:1000
1:2000
1:5000
1:10000
1:4000
1:15000
1:25000
1:50000
1:30000
1:32000
1:60000
1:100000
1:125000
1:160000
1:250000
1:320000
1:1000000
Cranium + Facial Features
Facial Features

1.1 SKULL AND FACIAL BONE STRUCTURE

RQ: Which skull bones are relevant for studying the posterior auricular area? How do they align with the exterior features of the head?

Morphological anomalies are also affected by their underlying bone structure, which involves both the skull and the facial bones. The temporal bones are the bones that mainly might influence the shape of the temple tips. Therefore understanding the relation between bone, soft tissue, and the morphological anomaly is fundamental to studying the posterior auricular area, which can lead to an improved design of the temple tips.

Since the brain case is a continuous surface, it is evident that any anomalies of any of its bones reflect and interfere with other skull bones. However, the bones that mainly impact the shape of the temple tips are those situated at the sides and base of the skull, lateral to the temporal lobes of the cerebral cortex, i.e., behind the ears, which are called **temporal bones**[7]**.** (*see image 3a.2*).

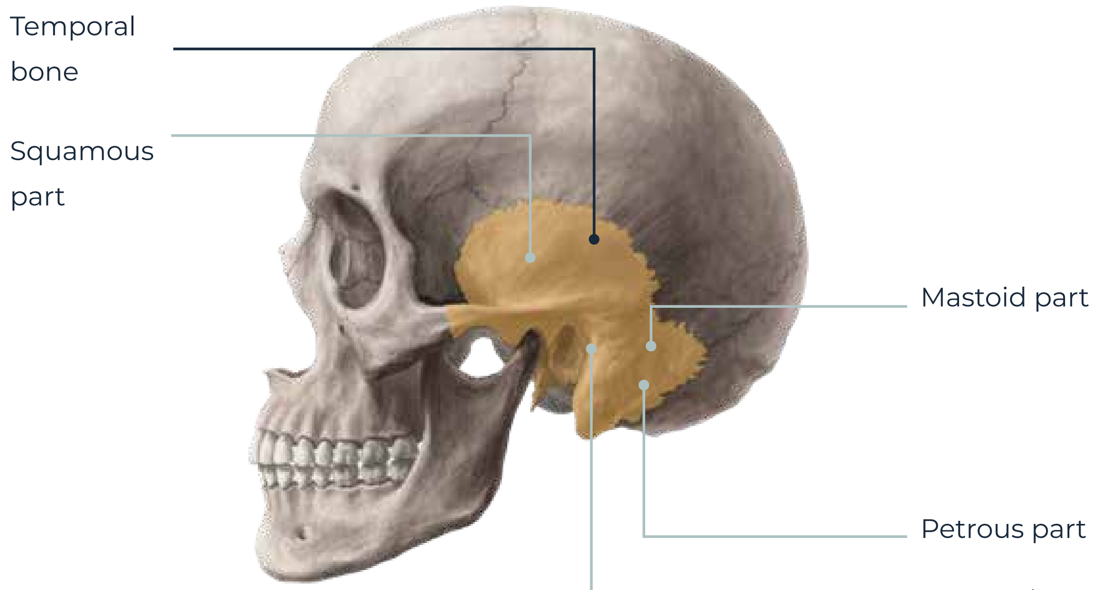


IMAGE 3a.2 *Temporal bone parts*

The bones shaping the face are mainly the maxilla, mandible, nasal, and zygomatic. Also relevant are various soft tissues, including fat, hair, and skin. The alignment between bone and soft tissue has been obtained by aligning screenshots retrieved from "C. Anatomy '22"[8] by marking as reference **Obs**[1] and **Obi**[2] and additional landmarks visible in image 3a.3.

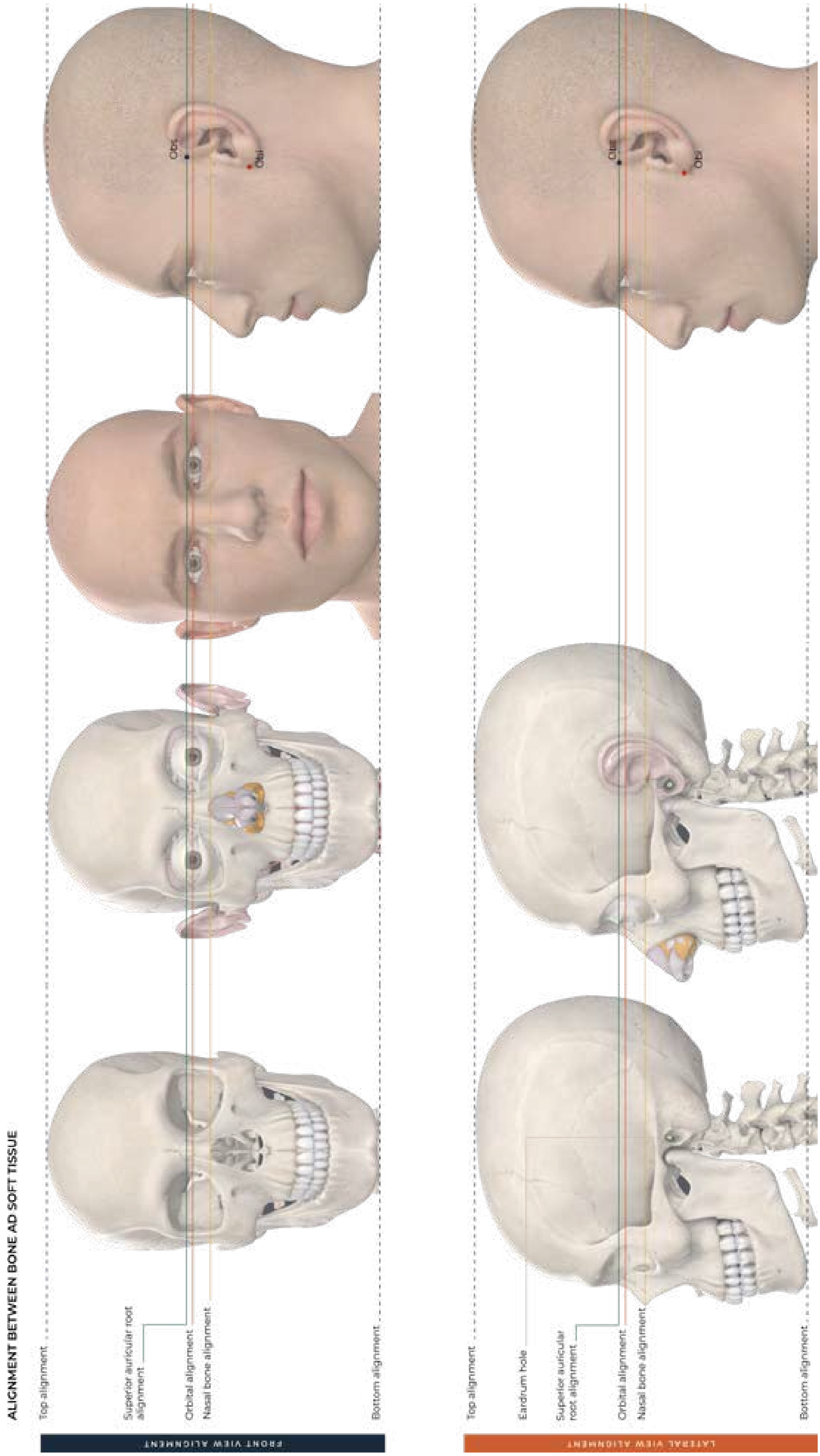
The alignment is necessary to establish a relationship between what is observed on a superficial level and the structural bone level.

For further information see *Appendix F _* Skull and Facial Bone structure study.

1 Otobasion Superius = most superior point of attachment to the ear helix with the temporal region of the head.

2 Otobasion inferius = most inferior point of attachment to the ear lobe with the cheek.

IMAGE 3A.3_ ALIGNMENT BETWEEN BONE AND SOFT TISSUE



1.2 AREA OF INTEREST

RQ: How has the area of interest of the project been identified?

The touch points have been identified based on the contact between the frame on the soft tissue that has been associated with the underlying bone structure. This alignment allows for determining the focus area of the study.

The parts of the head that are in contact with a pair of glasses were used to identify the following touchpoints:

- Posterior auricular area[9], corresponding to the **temporal bone,** in contact with the temple tips[1];
- **Superior auricular root[2]** on the ear(soft tissue), is the touch point of the temple tips on the ear (see image 3a.4_ Ear anatomy);
- Cheekbones corresponding to the **zygomatic bone**, in contact with the front of the frame[3];
- Nose bridge, corresponding to the **nasal bone**, in contact with the nose pad[2].

The precise touch points may vary depending on different glasses models and facial anatomy, but the cranial bones involved remain the same. *(See image 3a.5).*

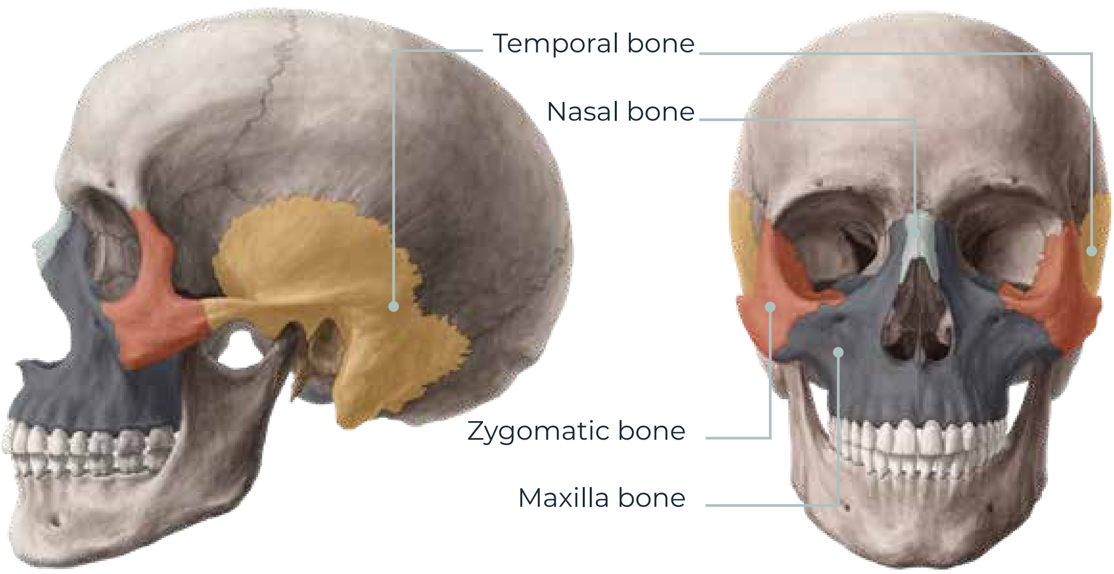


IMAGE 3a.5 *Skull bones corresponding to touch point with glasses in adult.*

In the project brief (Appendix A), the request is to **focus on the temple tips; therefore, the study will focus on the posterior auricular area.**

It is supposed that the remaining ear anatomy does not influence the fit of the glasses since there are no additional touch points; therefore, it will be considered out of scope and excluded from this study.

1 See glossary page 10.

2 The superior auricular root is a landmark of the Pinna, and consists mainly of auricular cartilage and skin and serves as support for the temples.

3 See glossary page 11.

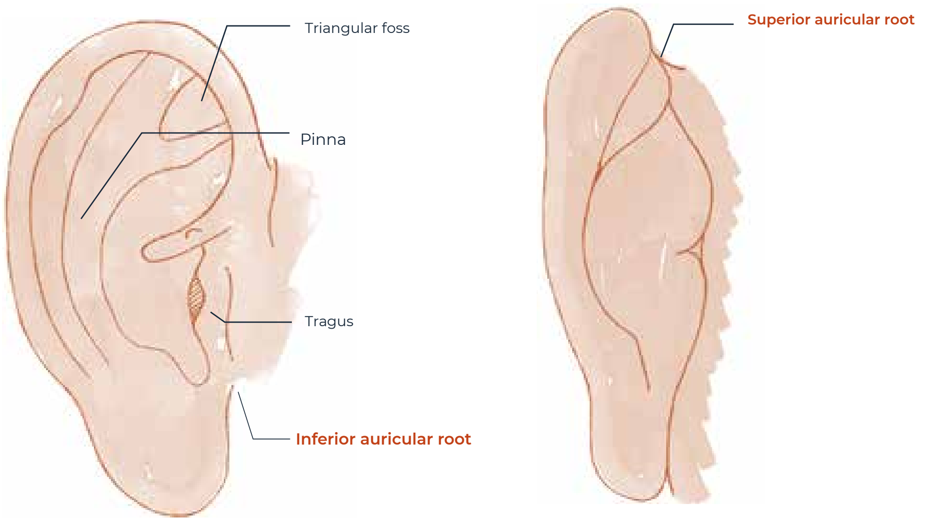


IMAGE 3a.4 *Ear Anatomy side and posterior view.*

1.3 LANDMARK SELECTION

It is necessary to identify reference landmarks to analyse the curvature of the posterior auricular area.

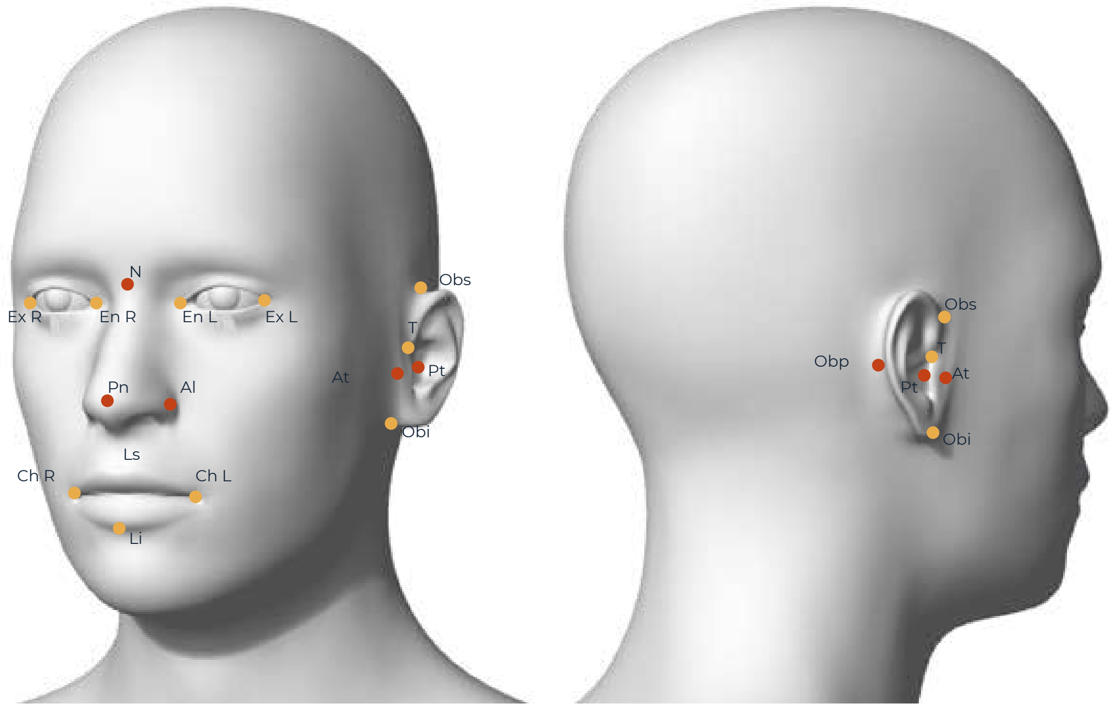
When analysing the subject's anthropometric data, it is not sufficient to consider exclusively two-dimensional measurements since, by doing so, there would be a lack of information regarding the three-dimensional variation of the curvature of this area. Therefore it is necessary to analyse three-dimensional data by identifying specific landmarks and mapping their coordinates (x,y,z) as illustrated in the study (Yan Dong et al., 2010)[10]

The landmarks have been selected based on mainly two factors:

- The area of interest: posterior auricular corresponding to the temporal bone;
- Landmarks needed to generate a consistent coordinate system to align the 3D scans.

The selection is visible in *image 3a.6*. The two different colours indicate the distinct purposes for which the landmarks have been selected. Based on the study Caple, 2015b. [11]

- Orange: landmarks that define the x,y, and z coordinate system.
- Yellow: Landmarks that have been used to align the 3D scan to the base head mesh in WRAP Software from R3DS[12] (see "Method research" chapter).



N Nasion

En Entomion (left and Right)

Ex Exocanthion

Pn Pronasale

Al Alare

Ch Chelion Left and Right

Ls Labiale superius

Li Labiale inferius

Obs Otobasion superius

Obp Otobasion posterius

Obi Otobasion inferius

T Tragion

At Anterotragion

Pt Posterotragion

IMAGE 3a.6 *Base head mesh indicating selected Landmarks*[13]

KEY FINDINGS

The main key finding of the Anatomical research:

- There is a difference between morphological anomalies that classify as "malformation" and "deformation/ disruption and dysplasias;."
- A "malformation" (i.e., *Down syndrome*) may present a pattern in terms of physical anomalies involving the skull and the facial features;
- An unpredictable nature characterizes a "deformation" (i.e. *Petrous syndrome)* and can not be standardized;
- "Down syndrome" has the highest occurrence rate registered (1:1000);
- Not all syndromes affect both skull and facial features;
- None of the analyzed syndromes appear to affect the cranial bones exclusively;

- The study area of interest has been defined by verifying where the temple tips of a generic pair of glasses touch the head. This touchpoint coincides with the "temporal bone" on the bone level and the "posterior auricular area", on the soft tissue level;
- The "Pinna[4]" will be excluded from the study since it does not enter in contact with the frame;
- Several landmarks have been selected both to define a consistent coordinate system needed to align 3D scans and because they correspond to the area of interest;

4 see image 3a.4

3.B TEMPLE TIP FIT

1.GLASSES FIT THEORY

RQ: How does the posterior auricular area influence the proper fit of the frame?

In chapter X, the focus area has been confined to the Posterior auricular area. W. J. Biessels, in his paper[14] theorizes the correlation between the design of the temple tips and the skull's curvature behind the ear.

In the described incorrect wear scenario, the frame touches the temples. Therefore the glasses are pushed off the face, while in the "correct wear" scenario, the touchpoint coincides with the posterior auricular area. Consequently, the so-called "wedge effect" is countered.

In the latter case, the frame tends to move inwards, but this movement is counteracted by the curved temple tips pushing the skull, allowing the frame to stay in place. (Image 3b.1)

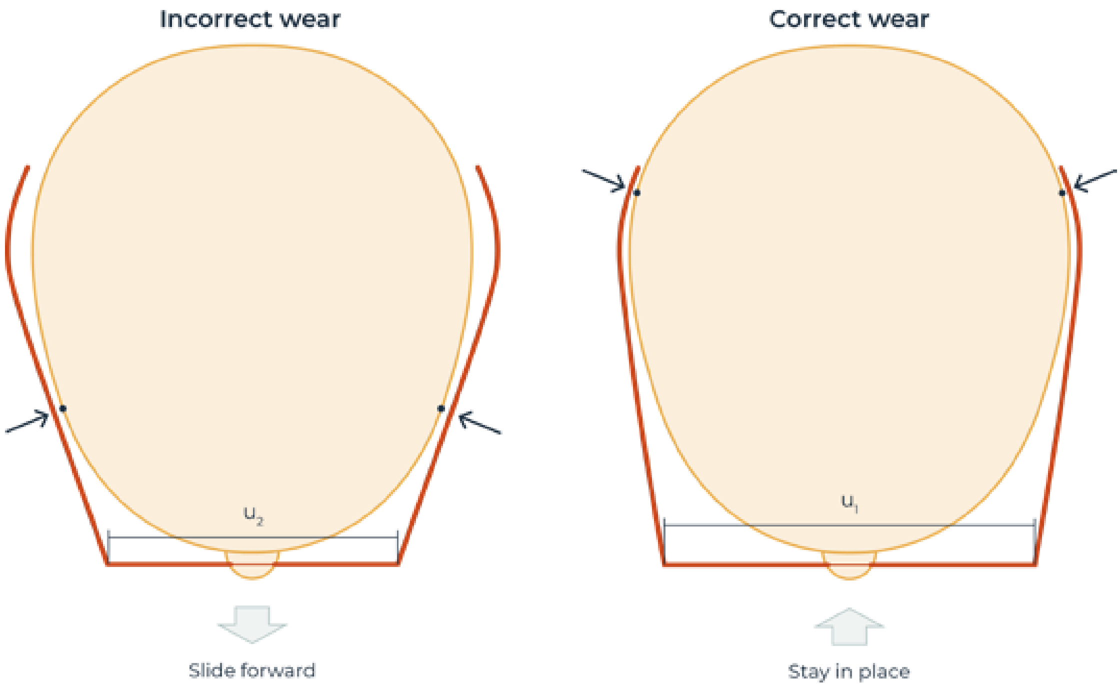


IMAGE 3b.1 *Wedge effect*

For the temple tips to be effective, they have to reflect the shape of the curvature of the head in the rear auricular area.

Biessels theorizes that the temple tips should be curved, and the curvature should reflect the one on the temporal bone.

The simplification of this curvature can be done by identifying the following points:

- Point A coincides with the attachment of the ear to the skull[1], and the start of the temple tip;
- Point B coincides with a dip in the temporal bone[2];
- Point C coincides with a bump of the temporal bone.

IMAGE 3b.2 *Posterior auricular area with highlighted points*

For clarity reasons, Point D has been added, which indicates the end of the temple tip, which may vary based on the model and does not correlate to the skull per se.

See image 3b.3.

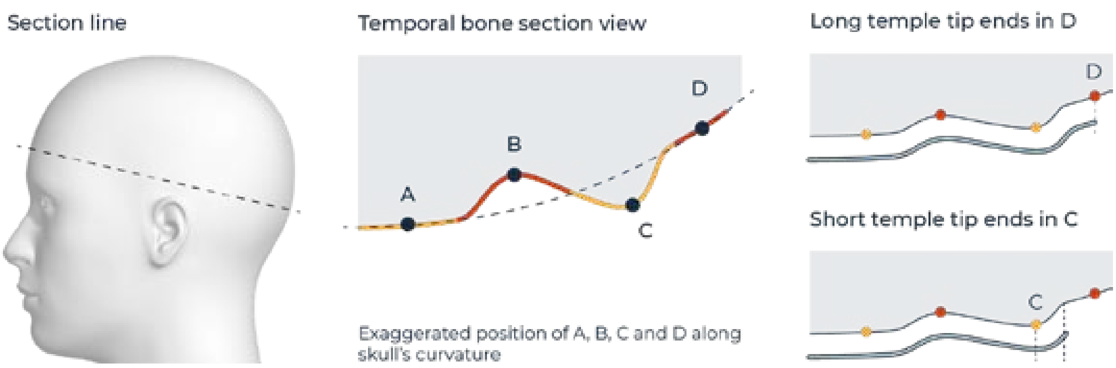


IMAGE 3b.3 *Points identification*

1 Superior auricular root landmark(attachment of the ear to the skull)

2. COMPARISON BETWEEN EUPLOID[1] AND DOWNSYNDROME[2] SKULLS

RQ: What are the differences between a typical skull and the skull of a subject with down syndrome?

It was necessary to establish a reference system on a healthy skull visible in image 3b.4[3] to observe the variation between a typical skull and a skull of a subject with down syndrome.

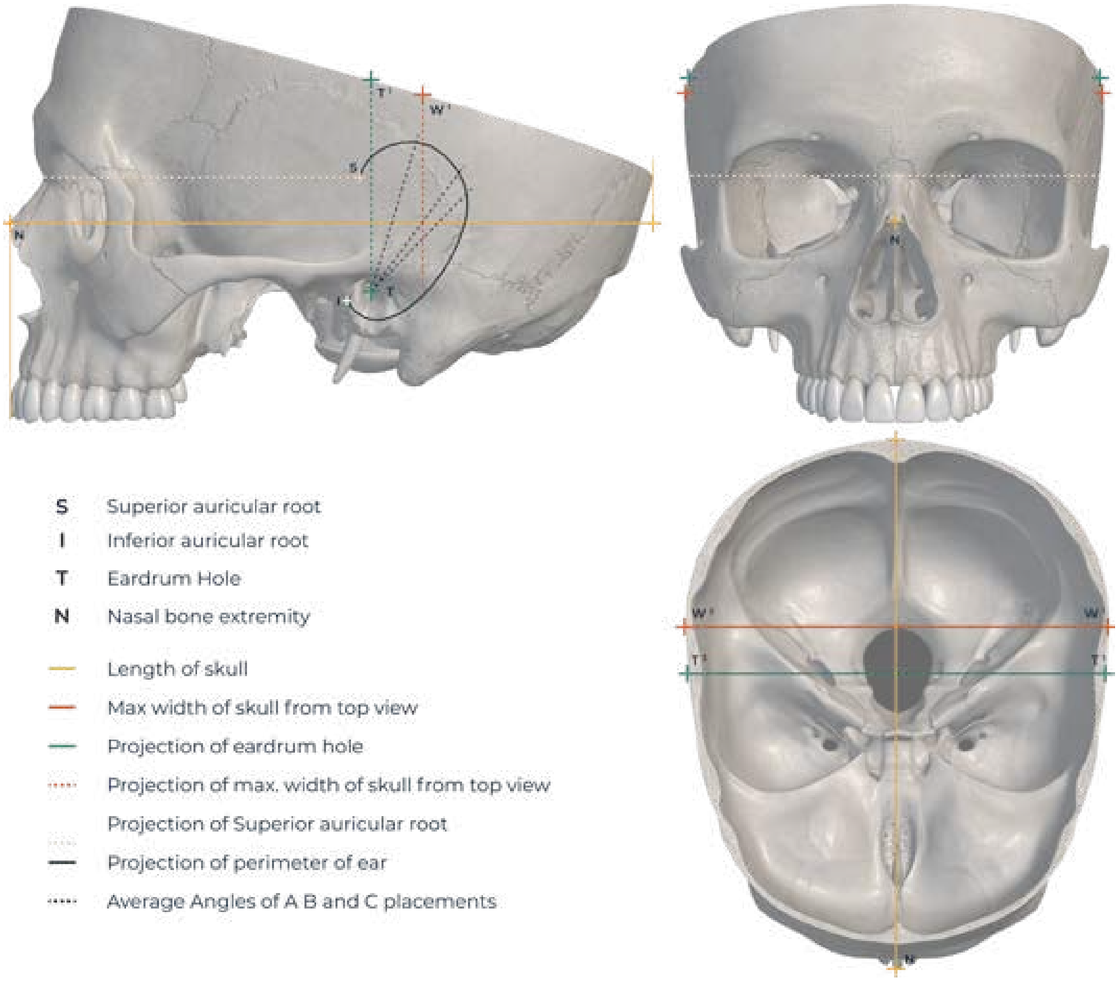


IMAGE 3b.4 *Skull with landmarks alignment*

The main physical features characterizing a subject's head with down syndrome are visible in image 3b.5:

- Hypertelorism[4]

1 Definition of *Euploid*: "having a chromosome number that is an exact multiple of the monoploid number"

2 Definition of *Downsyndrome: " a congenital condition characterized especially by developmental delays, usually mild to moderate impairment in cognitive functioning, short stature, upward slanting eyes, a flattened nasal bridge, broad hands with short fingers, decreased muscle tone, and by trisomy of the human chromosome numbered 21 called also trisomy 21"*

3 The alignments have been defined by comparing soft tissue and bone using the "C. Anatomy '22" images aligned in different views as shown in image 3a.3.

4 Definition of *Hypertelorism:* excessive width between two bodily parts or organs (as the eyes)

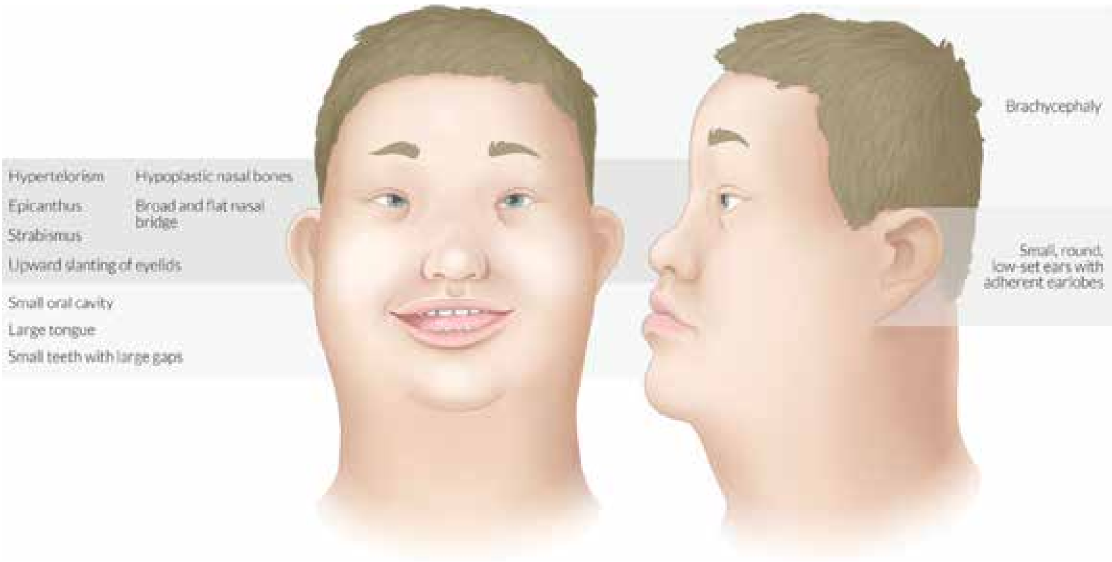


IMAGE 3b.5 *Down syndrome side effects related to the physical facial features*

- Epicanthus[5]
- Strabismus[6]
- Upward slanting of eyelids
- Long eyelashes
- Hypoplastic[7] nasal bones
- Broad and flat nasal bridge
- Small oral cavity
- Large tongue
- Smaller teeth with more significant gaps
- Brachycephaly[8]
- Small, round, low-set ears with adherent earlobes

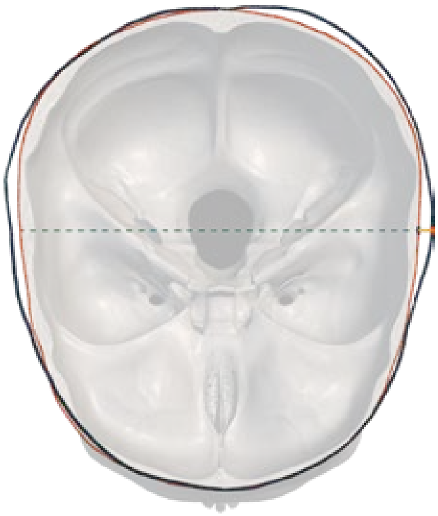


IMAGE 3b.6 *Skull comparison*

Image 3b.6 illustrates the overlap of a top view of a model of a healthy skull and a real down syndrome skull.
The section view used as a reference for the down syndrome skull has been retrieved from an MRI scan[15] and aligned and scaled for comparison.
.The maximum variation between the skulls occurs at the height of the eardrum line and measures 11 mm ca.

5 Definition of *Epicanthus:* a fold of skin extending from the eyelid over the inner canthus of the eye, common among Asian populations.

6 Definition of *Stabismus:* inability of one eye to attain binocular vision with the other because of imbalance of the muscles of the eyeball

7 Definition of *Hypoplastic:* a condition of arrested development in which an organ or part remains below the normal size or in an immature state

8 Definition of *Brachycephaly:* short-headed or broad-headed with a cephalic index of over 80

From this comparison, the cephalic index[9] variation between healthy and deformed skulls does not emerge prominently. In the study, the cephalic index measured in subjects with down syndrome was 84.6%, with a dominance of brachycephalic and hyperbrachycephalic types of head shape registered in 90% of the cases observed in the study. In the case of euploid skulls, the cephalic index is 77,2%

The results of this comparison refer to the adult index since they do not include the ratio variation occurring during the growth development of the subjects.

2.1 HOW DOES THE SKULL VARIATION IMPACT THE FIT OF A FRAME

The wearability of the glasses varies between a subject with down syndrome and a typical subject.

In image 3b.7 the subject with down syndrome (case B) has brachycephaly and, therefore, presents a short-headed or broad-headed, depending on the case, with a cephalic index of over 80.
In the ladder case, the angle measured between the superior auricular root and the hinge, from a top view, is wider than the one measured in case A.
The increased angle implies that the pressure in the posterior auricular root is higher due to the spring effect. In addition, the stress to which the hinge is subject is more significant.

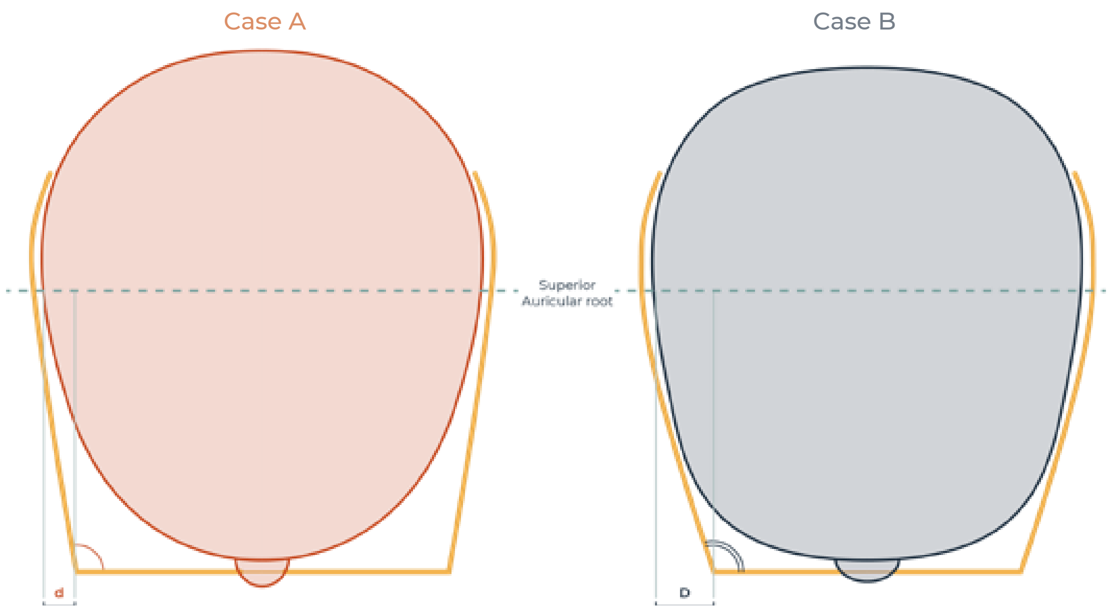


IMAGE 3b.7 *Top view comparison of ear placement (depth) between a Euploid head (case A) and a down syndrome head (case B)*

In subjects with down syndrome, it often occurs that the ears, and therefore the superior auricular root, are located more forward. The depth variation of the ear placement does not drastically affect the angle between the front and the temples (see image 3b.8).

9 Definition of *cephalic index:* the ratio multiplied by 100 of the maximum breadth from side to side of the head to its maximum length from front to back in living individuals

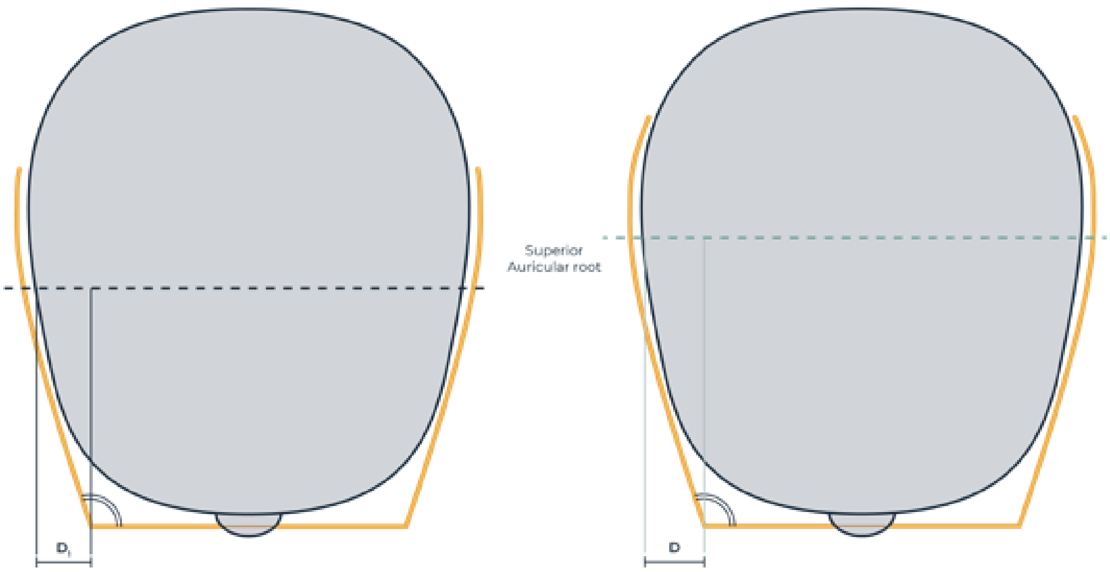


IMAGE 3b.8 *Top view comparison of ear placement in subjects with down syndrome*

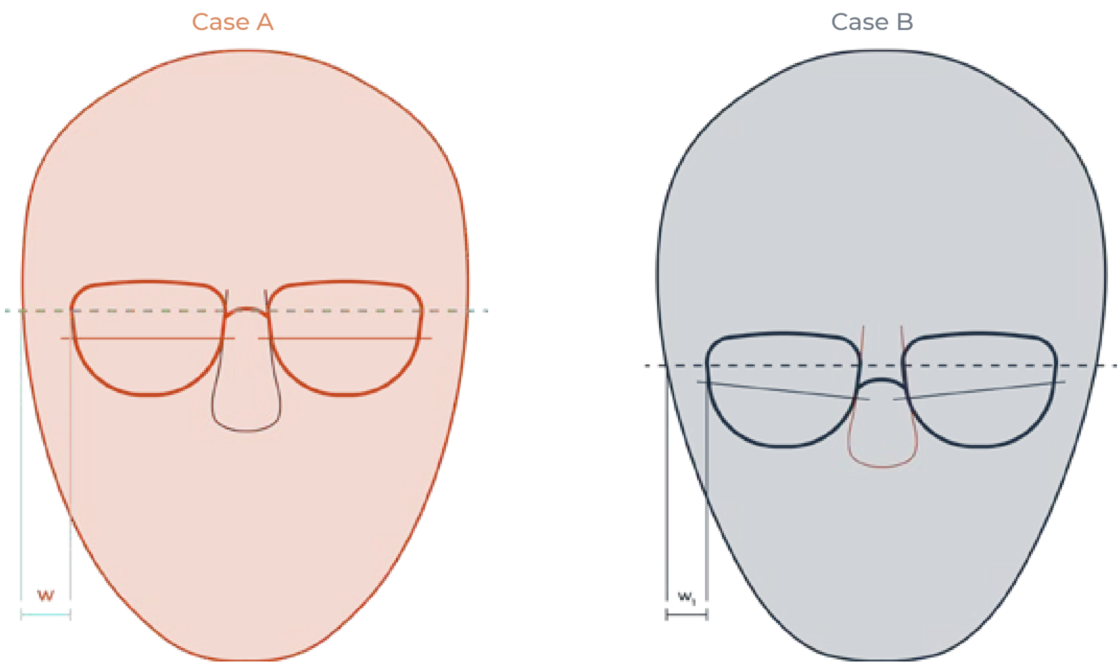
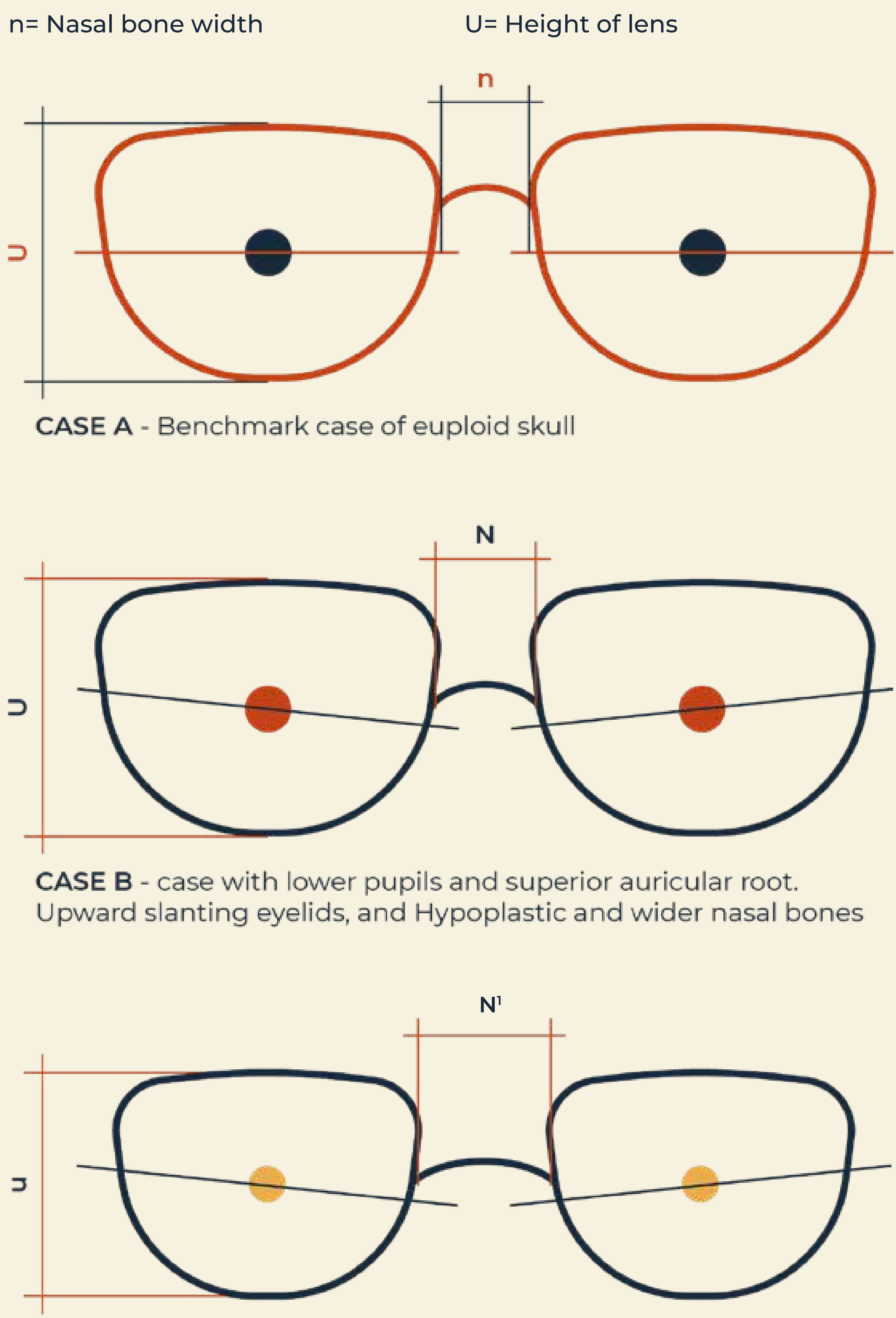


IMAGE 3b.9 *Top view comparison of ear placement (height) between a Euploid head (case A) and a down syndrome head (case B)*

A more significant difference is registered if the variation occurs in terms of height placement of the ear, as shown in 3b.9, which is an accentuated comparison between a typical and a down syndrome head (frontal view).

2.2 DESIGN IMPLICATIONS

The frame needs to be adjusted to accommodate the ear displacement, of which the severity may vary on a case-to-case base (see image 3b.10).



CASE A - Benchmark case of euploid skull

CASE B - case with lower pupils and superior auricular root.
Upward slanting eyelids, and Hypoplastic and wider nasal bones

CASE C - Case B with hypertelorised pupils

$N^1 > N > n \quad U = U > u$

IMAGE 3.b.10 *Relation between nasal bone width and height of lenses in different scenarios*

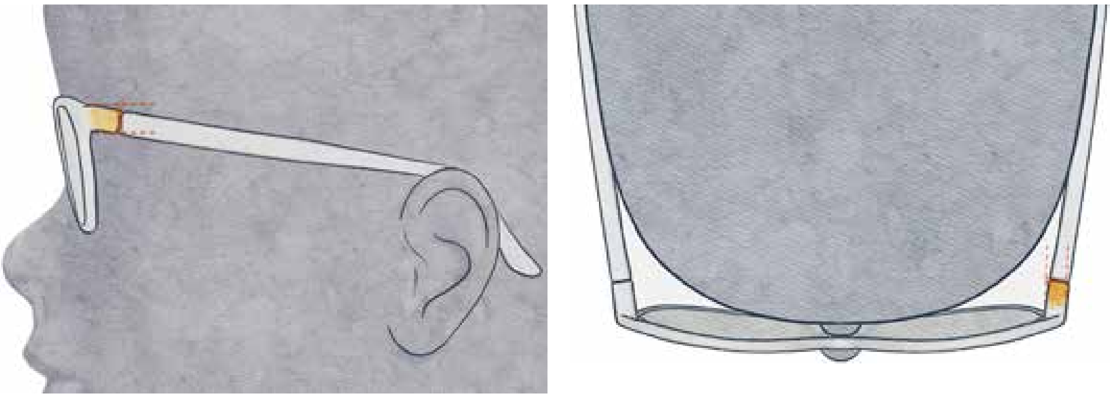


IMAGE 3.b.11 *Endpice design variation*

The main areas involved are the endpieces[10], which can be adjusted in terms of angle and orientation both from a lateral and top view (see image 3b.11), and the nasal bridge[11], which needs to accommodate the variation of nose width.
It is yet unclear how the skull curvature affects the temple tips.

10 See definition of *Enpice* on page 12 of glossary

11 See definition of *Nasal Bridge* on page 13 of glossary

4 METHOD

Description of the methods tested to research the posterior auricular area, which involved testing different 3D scanners (4a); analysing silicone moulds (4b) and finally combining the two methods (4c).

4.A METHOD ANALYSIS
3D SCANNING
1. INTRODUCTION

This chapter focuses on the methods explored to obtain and analyze data regarding the posterior auricular ear curvature.

The choice between adopting Laser scanning (LS) or Stereophotogrammetry (3DSPG) for the research has been discussed with **Bert Nessen**, 3D scanning expert at TU Delft's Body Lab, who suggested that the optimal technique would be LS. Due to the **difficulty in reaching the area and the level of detail required for the research.**

There is *"no significant difference (p>0.05) in the identification of the same parameter on different scans through both instruments and no significant difference between billowing areas, measured through laser scanner or stereophotogrammetry"* (PUCCIARELLI et al., 2016)[16].

Therefore laser scanning has been selected as the primary technique to explore.

The main methods that have been explored can be summarized in three categories (see image 4a.1):

- Method 1: 3D scanning, analyzed in chapter 4a.
- Method 2: Molding, analyzed in chapter 4b.
- Method 3: Hybrid (molding and 3D scanning), analyzed in chapter 4c.

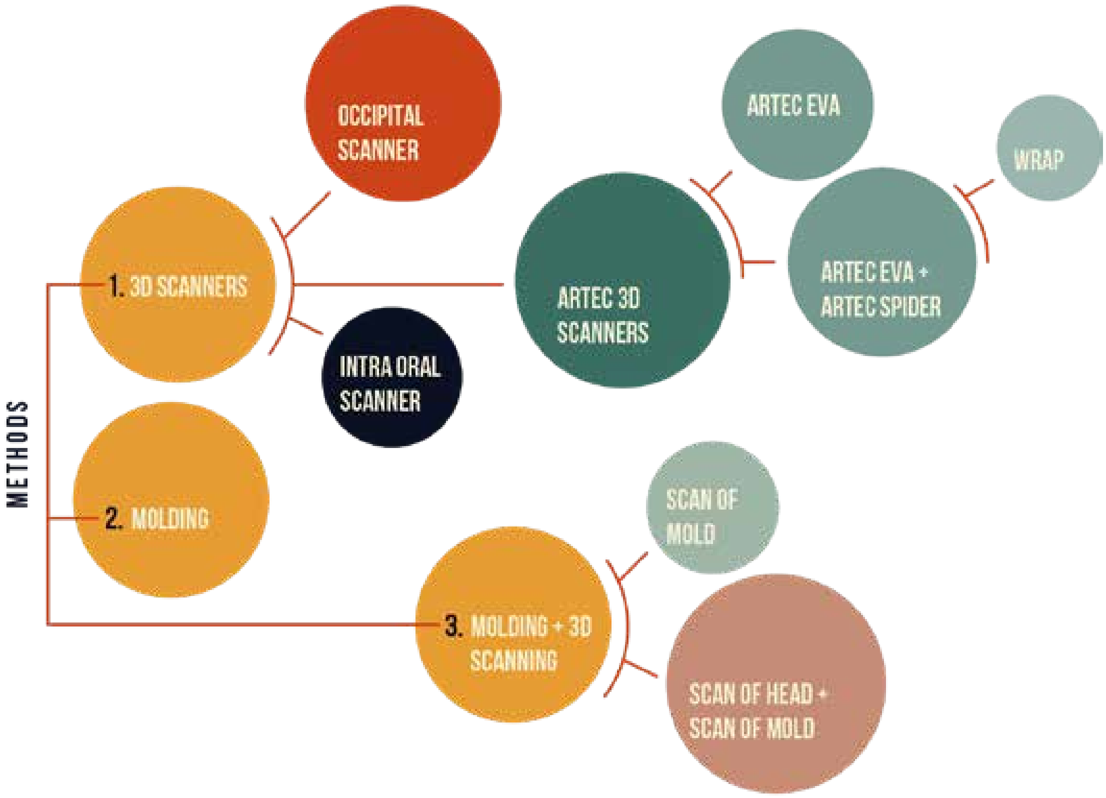


IMAGE 4a.1 *Method overview chart.*

2. METHOD 1: 3D SCANNING

The methodology contemplates:

- Collection of anthropometric data using 3D scanners
- Process of the collected scans using Artec Studio
- Uniforming the scans using Wrap
- Analyzing the collected data

The critical initial focus was identifying which 3D scanner would provide the best output regarding the quality of scans of the posterior auricular area. Several scanners and combinations have been explored. The technical specification of each scanner are in Appendix

2.1 OCCIPITAL STRUCTURE SENSOR

Different subjects[1] were scanned using a "Structure sensor Mark II" to observe and evaluate the quality of the results in the posterior auricular area.

METHOD

1 See Appendix K for more information regarding the subjects

IMAGE 4a.2 *Testing the Occipital Structure Scanner Mark II*

The "Structure sensor Mark II" by Occipital[17], used by Maatbrill, is a device that can be strapped to an iPad, turning it into a portable optical 3D scanner.
The setup in which it is used implies that the subject is scanned sitting upright in a well-lit environment, and the 3d scanning expert has to be able to freely move around the subject at about a 1.5 meter distance.
The scanner was tested on four subjects with no cranial deformations to observe the scan's quality in the area of interest: the region behind the ear.
On average, the maatbril scans take about 10 seconds. During the test, multiple scans were taken per subject, with a time frame ranging from 10 to 60 seconds.

OBSERVATION

It was noticed that the scanning quality is adversely affected by many factors, such as:

- The presence of the subject's hair;
- The shadows projected by the subject's ear (even with improved lighting);
- The sensibility of the scanner
- The subject's movements

DISCUSSION

Even in scans that took up to 60 seconds, the results did not show Biessles's [18]points A-B-C with sufficient accuracy. The temporal bone to which those points belong is covered by soft tissues that often make those points almost invisible to the scanner since they are less accentuated.
This issue occurred even in the case of a bald subject with no hair, that might have negatively influenced the results.

CONCLUSION

The 3D surface resulting from the scanning process is not accurate enough to mold precise temple tips.
The obtained results demonstrated that this low-cost, portable optical scanner is not the proper tool to get relevant data on the posterior auricular area

2.2 ARTEC EVA LITE AND ARTEC SPIDER

Both scanners, developed by Artec3D[19], are hand-held, stand alone, scanners that support different object sizes:

- Artec Eva Lite= medium size objects (Accuracy up to: 0.1 mm; Resolution up to: 0.5 mm)
- Artec Space Spider = small size objects (Accuracy up to: 0.05 mm; Resolution up to: 0.1 mm)

This characteristic implies that the scanners are best suited to scan different-sized objects and, therefore, different head parts.
Artec Eva works best at around a 1.5 m distance and is well suited to scan the entire

MODE A

PROCESSING IN ARTEC

EVA 3D SCAN

360° of head

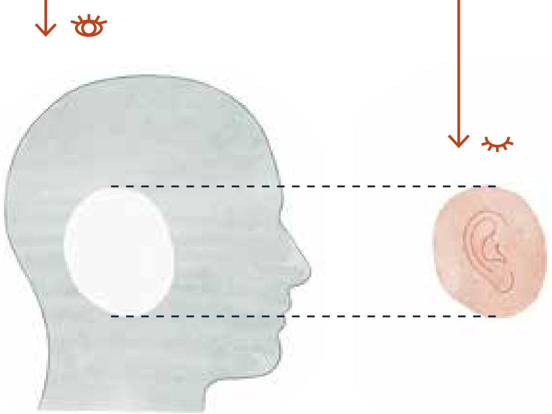
No tape

SPIDER 3D SCAN

Focus on ear and temporal bone

ALIGN SCANS

Use the Landmarks to align Spider scan to Eva Scanner. The landmarks are marked prior to both scans therefor they match. The scans are on different layers but the ears are aligned.



DELETE AREA

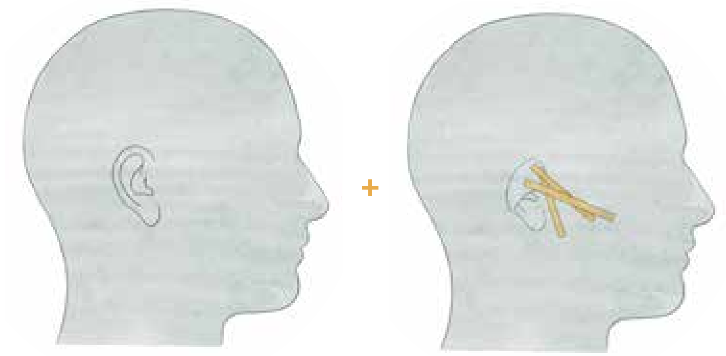
From the Eva scan (visible layer) delete the area that corresponds to the surface covered in the spider scan (non visible layer) .

EXPORT

Make both layers visible and export file in **.obj** for compatibility with Wrap

IMAGE 4a.3 *Mode A of collecting 3D scan data*

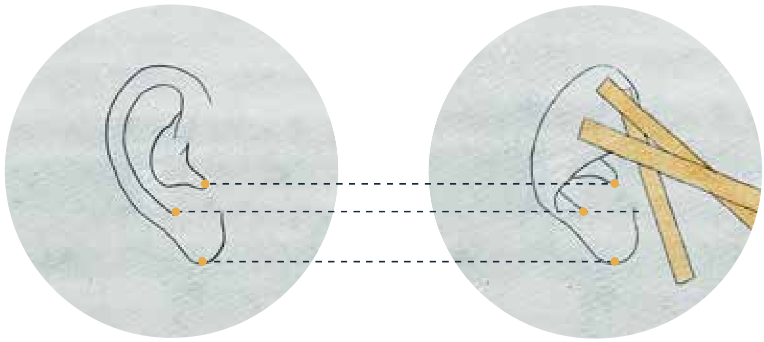
MODE B



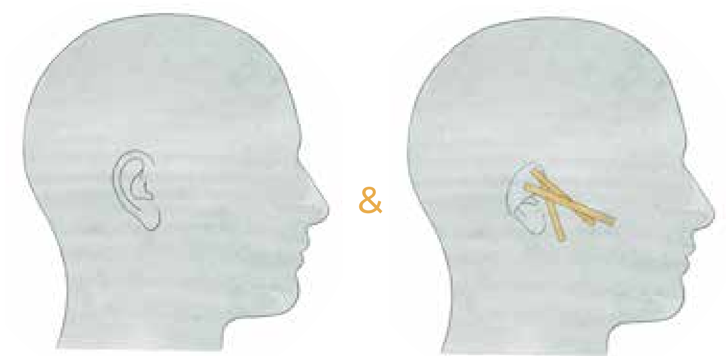
EVA 3D SCAN
360° of head
No tape

EVA 3D SCAN
360° of head
Tape to fold "Pinna"

PROCESSING IN ARTEC



ALIGN SCANS
Use the Landmarks to align the two Eva scans. Since T, Ta and Pt are covered by the tape, the new landmarks, used to align, rely on the visible shared texture.



EXPORT
Export the two files separately as obj.

IMAGE 4a.4 *Mode B of collecting 3D scan data*

head (360°).
Artec Spider scanner works best at a 30 cm distance and is well suited to scan the focus area accurately (i.e.: the posterior auricular area).

METHOD

These scanners are significantly bigger and more expensive than the "Structure sensor Mark II" seen before but are used similarly: the subject shall be sitting upright, in an area that allows free range movement around him/her and is well lit.

The scan is obtained by moving around the subject at different distances based on the scanning tool used. The procedure may require multiple takes, the aim consisting in getting a proper result in the least number of takes possible, as this number affects the accuracy and time of processing.

The data was processed in two distinct modes:

- MODE A: using the Artec Eva to scan the head in combination with Artec Spider to scan the focus area, with a higher resolution (see image 4a.3).
- MODE B: taking two scans using the Artec Eva, one in standard conditions and one with the subject's pinnas[2] folded and held in place with adhesive tape (to remove the optical obstacle represented by the auricle). See image 4a.4.

The scans have been process using ***Artec Studio***[3] following the steps illustrated in Appendix L.

RESULTS

MODE A

The result of mode A is a combination of two aligned meshes. Comprised of a 360° head scan obtained using Artec Eva aligned to an ear cutout on both the left and right sides, the detail was obtained using Artec Spider scanner. The mesh surfaces do not align and result in an "open mesh."

MODE B

The result of mode B consists of two aligned closed mesh, obtained with Artec Eva scanner, in one of which the subject's eras are taped down to increase the reachability of scanning the area behind the pinna.
When taped down, the soft tissue of the area is slightly altered and, in some spots, still cannot be scanned correctly.

OBSERVATION

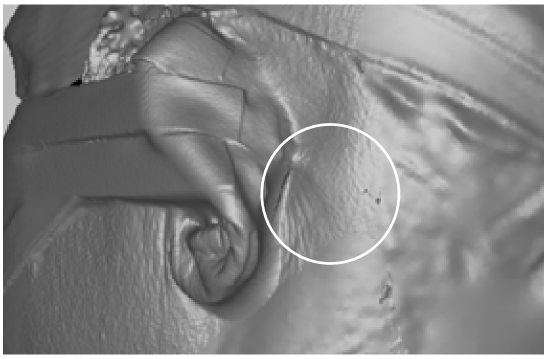
MODE A

The head scan, obtained using Artec Eva, is necessary to acquire landmarks on the face, which are essential to align the scans to each other.

2 Refermce the pinna anatomy page

3 Artec Stido xxxx

The ear scan, obtained using Artec Spider, has a high-quality and detailed texture but still presents an issue in the area of interest.
In image 4a.5 it is possible to observe the texture variation occurring between the two different scanners.



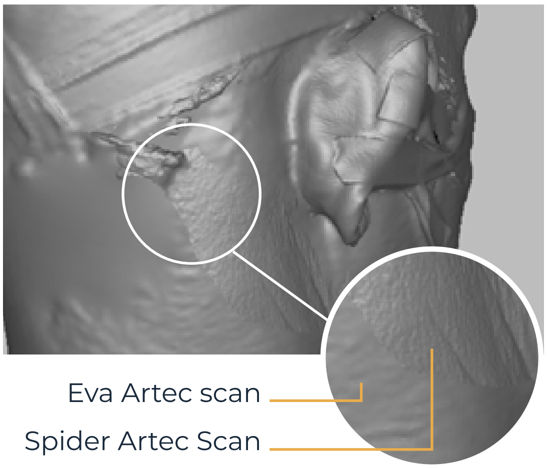


IMAGE 4a.5 *Example of texture variation in scans obtained with Artec Spider and Eva.*

The example shows how, even in a subject with no hair, it was impossible to scan the area where the ear connects to the head, which coincides with the superior auricular root landmark. The result is a hole in the exported mesh visible in image 4a.6.

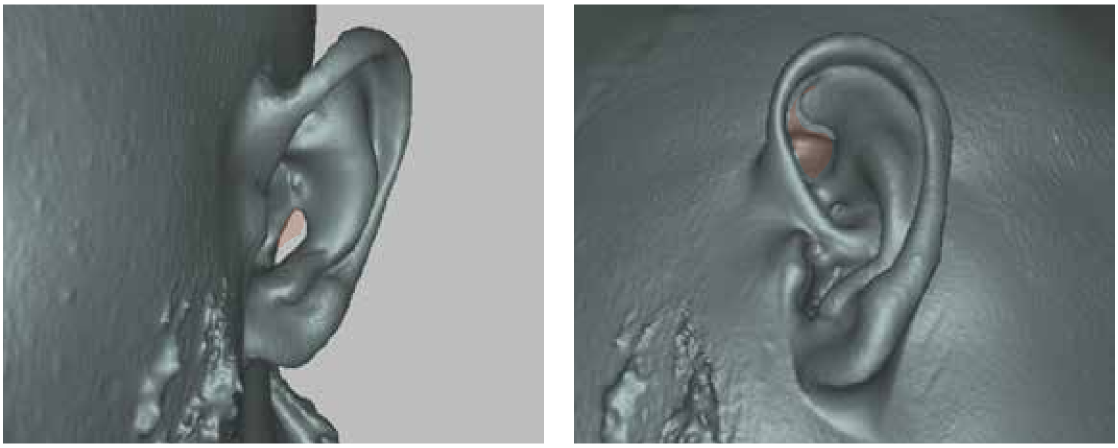


IMAGE 4a.6 *Examples of holes in mesh obtained with Spider Artec 3D scanner*

The subject is unlikely to remain perfectly still between the first and second scans. This slight variation in position causes a **mismatch between the surfaces**, even after aligning the scans based on the landmarks. See image 4a.7.
The compromised mesh quality causes issues when importing it into programs such as Wrap[20],that require closed mesh, making it incompatible for subsequent surface analysis.
The quality of the output is compromised by the presence of the subject's hair, even in placed under a cap.

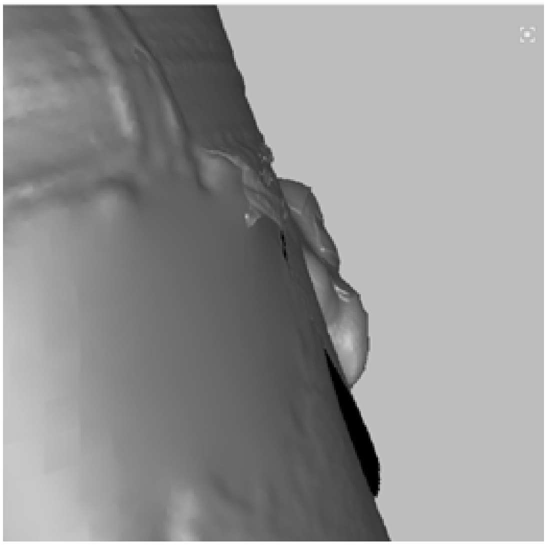


IMAGE 4a.7 *Surface mismatch*

MODE B

The meshes are aligned based on the landmarks visible in image 4a.8.
This methodology does not require scans to be cut out, so there is no risk of exporting open meshes and are therefore compatible with the software Wrap.

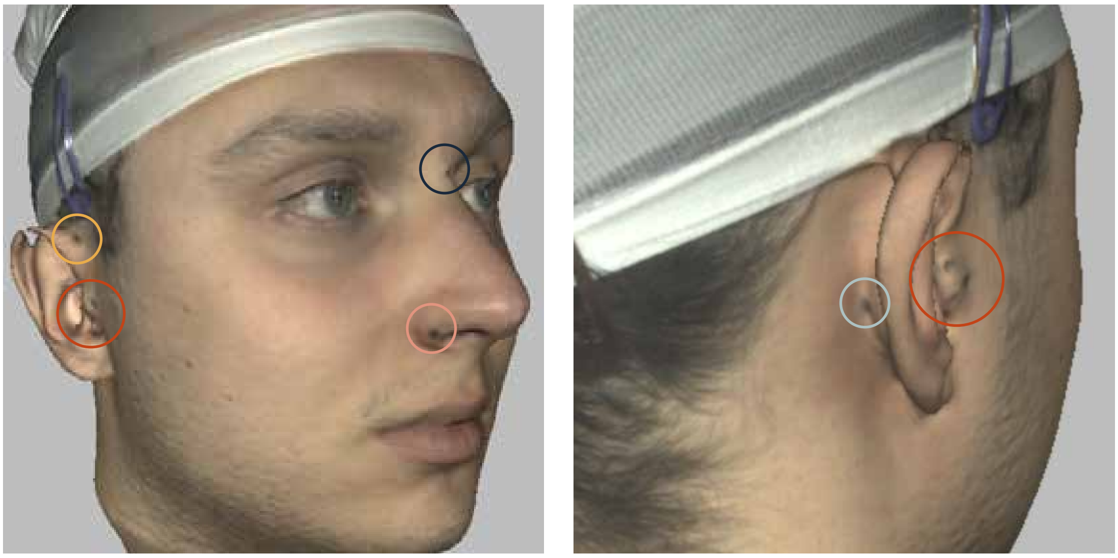


IMAGE 4a.8 *Landmark placement on subject*

The curvature of the area of interest appears to be altered when the Pinna is bent down. Image 4a.9 illustrates the comparison between the output of the different scanners.

IMAGE 4a.9 *Comparison between right ear scans. From left to right: Artec Spider, Artec Eva and Artec Eva with tape*

DISCUSSION

MODE A

- This method implies the collage of a scan of the head, to have landmarks necessary for alignment made one that depict the ear in detail.

- Even with the spider scanner it is not possible to accurately capture the superior auricular root;
- The mesh presents holes in the area behind the ear;
- The surfaces do not match after being collaged together
- The mismatch results in an open mesh that can not be used in Wrap, so it is not useful for subsequent surface analysis
- The presence of hair compromised the reachability of the area behind the ear and therefore impacts the quality of the output.

MODE B

- Once the auricle is bent, the position of the tendon is altered, modifying the shape of the soft tissue behind the ear, therefore giving inaccurate results.
- Due to the taping there are several landmarks (T, Ta and Pt) that are not visible in the scan;
- The alignment points are defined based on the visible landmarks of the ear. The situation varies case to case based on the ear shape when folded and tape placement, even if standardized (see Appendix M for tape placement sequence);
- The focus area is still not scanned precisely;

CONCLUSION

MODE A

This method results in an open mesh that can not be analyzed further, and the output still does not accurately depict the area behind the ear in the correspondace of the superior auricular root. The recommendation is to avoid using this method for future research.

MODE B

Taping the pinna creates some discomfort for the subject, therefore it is a process that can be applied only on voluntary study cases and is not advised for subjects with mental illness.

It has been evaluated that both the Artec scanners, even if more accurate than the “Structure sensor Mark II” by Occipital, are not suited for Maatbrill clients due to:

- Implication for the subject to be still for the entire duration of the scan. (About 2-3 minutes, depending on the ability of the technician to scan).
- Require a well-lit environment (at clients’ houses, the environment is not controlled)
- Require an elaborated and lengthy post-processing phase that must be

conducted using the Artec 3D proprietary software.

Plan B is preferable to Plan A since it does not compromise the quality of the mesh. Therefore, it does not influence the external use of programs such as Wrap, which are necessary for the second phase of the analysis.

2.3 WRAP

The result from the previous phases (collection and processing phase) required an additional step to make them uniform. The scans were elaborated using 3DRS Wrap.

METHOD

Create a node graph map that defines the elaboration process of a single scan. Step followed by the uniform application of the same method to the entire batch of scans. See Appendix N for additional detail regarding the map.

The process consists of taking an existing basemesh and non-rigidly fitting it to the batch of scans, which are made uniformly and prepared for the following analysis phases.
The steps have been illustrated in Appendix O.

RESULTS

The wrapping process's output consists of a batch of uniform scans (see image 4a.10).

OBSERVATION

The process provides smoothening of the surface, which is helpful in terms of cleaning the scan for bumps and improves the overall surface quality. In the case of this research, it has undesired side effects since it overly smooths out the area behind the ear, even if the mesh is subdivided into a denser mesh.

DISCUSSION

This excessive "smoothening effect" contrasts the initial goal of obtaining a detailed site curvature, including mapping bumps[4] and fossas[5] in this area.
Unfortunately, this step can not be avoided since it is necessary to properly align the scans to each other and correctly import them into Paraview[21] for further analysis.

The wrapping phase is fundamental for making the batch of scans uniform and comparable to each other. This step overly smooths the area of interest but can not be avoided since it is required for processing in Paraview. Therefore further model development in Paraview will not provide indicative information regarding the posterior auricular area curvature.

4 See glossary page 15

5 See glossary page 15

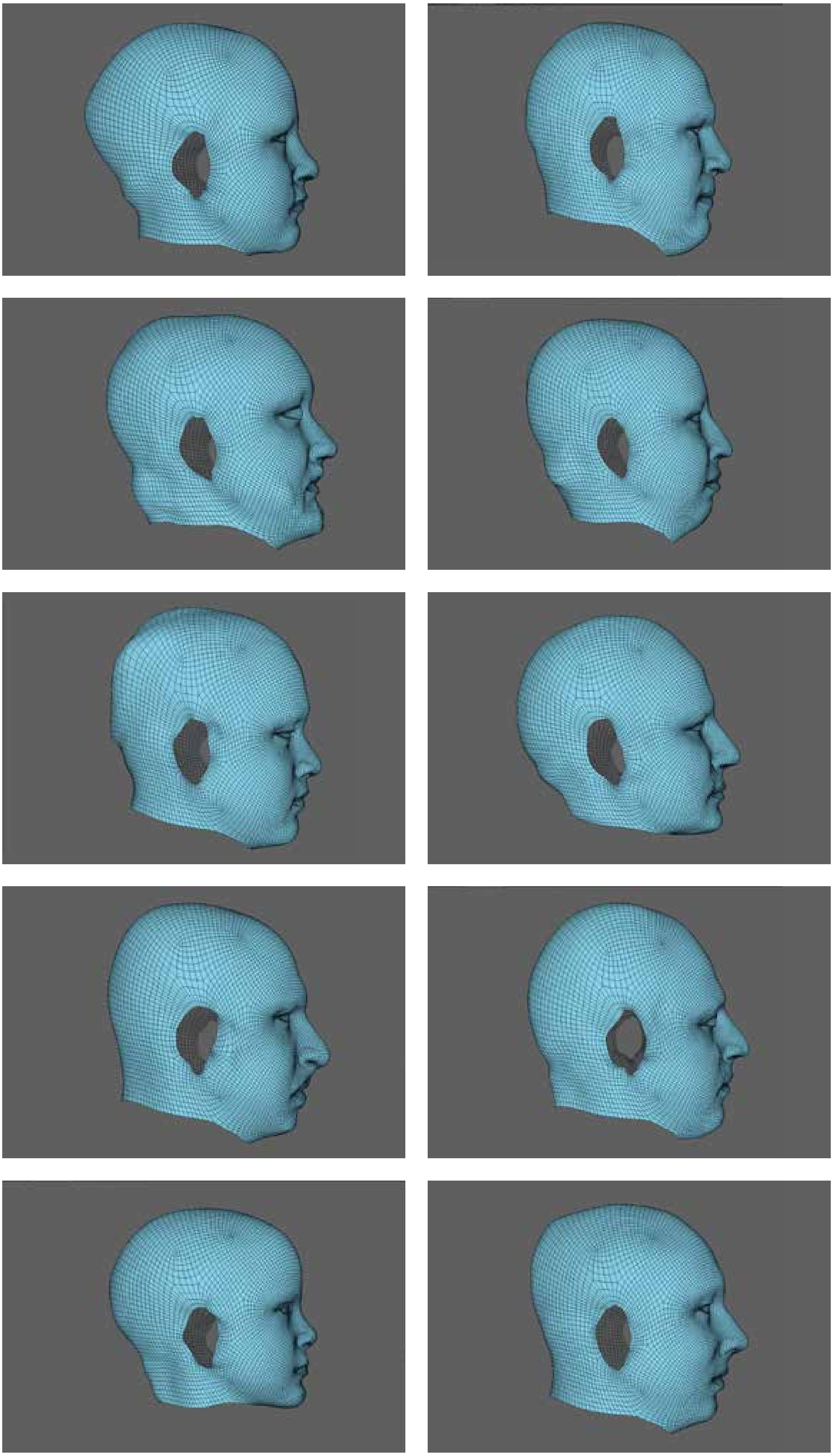


IMAGE 4a.10 *Results of wrapping process*

2.4 INTRA-ORAL SCANNER

The third tested tool was the intraoral scanner *"TRIOS 3 BASIC"* developed by *3Shape*. This tool has been tested in the dental studio of Dr. David Smitz, who has kindly illustrated how it should be used in the scenario for which it was designed, dental scanning.

METHOD

The Ai has been developed and optimized for the dental industry. The scanning phase has been standardized to obtain a superior quality mesh, thus reducing the chance of inducing errors[22].

Hence, the scanner must be used with dedicated software to improve and simplify the scanning operation, including the post-processing phase.

The test conducted in the studio aimed to evaluate if the tool could be used to scan the area behind the pinna.

For testing purposes, since we were using the scanner in a different environment for which it had been designed initially, it was necessary to define a different scanning sequence.

The modified sequence was obtained by comparing the results of the 3D scan (mesh) to videos taken of the process.

RESULTS

The sequence result is illustrated in image 4a.11.

The orange dots indicate the landmarks that should be marked down before scanning, and the arrows indicate the movement that needs to be made with the scanner. A complete scan requires about three scans. The starting point of each scan corresponds to the number placement.

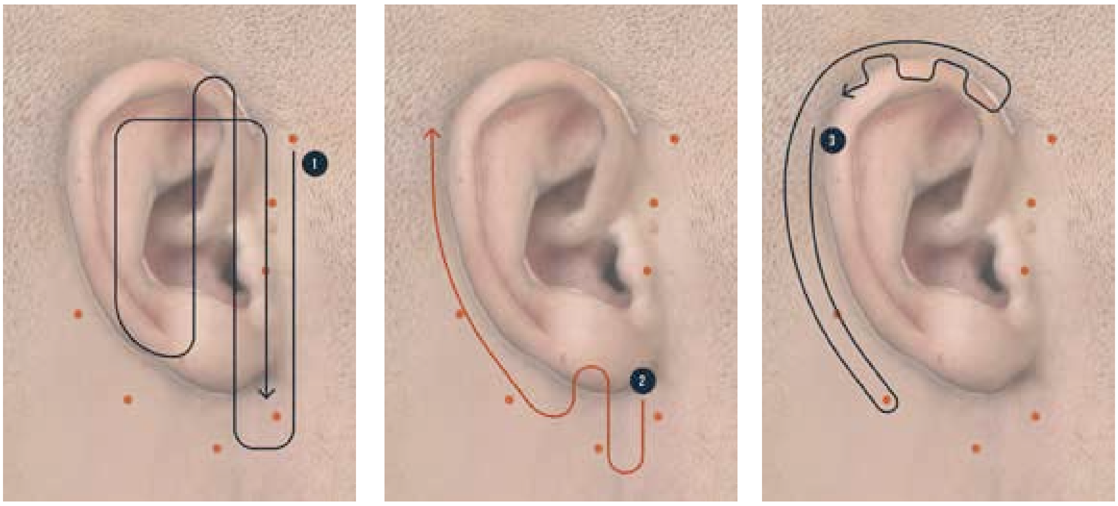


IMAGE 4a.11 *Sequence of steps defined to*

The final mesh result is visible in image 4a.12, and the error area is defined by the blue dashed line.

IMAGE 4a.12 *Intra -oral scanner result*

OBSERVATION

The Trios scanner operates at a closer distance (3 cm ca.[6]) if compared to the Occipital and Artec scanners. Initializing the scan requires direct contact with the surface being scanned.

The results were promising in terms of accuracy, speed scanning, facility, and speed of processing of the final mesh. It was noticed that the results improved by turning off the Ai system based on dental scan calculation.

However, there were some issues concerning scanning the area near the superior auricular root because the scanner's head was wider than the space between the skull and the pinna. It was necessary to bend the pinna slightly. Unfortunately, the movement of the pinna caused a stitching error, and the surface meshes did not match. (See image 4a.12).

DISCUSSION

This issue could be solved by designing a smaller scanner's head and creating a telescopic extension that would allow easier reachability of the area, avoiding the movement of the pinna and, therefore, the stitching issues in the final mesh output. Image 4a.13 illustrates an indicative redesign proposition variation of this component.

6 See *Appendix J* for technical detail specifications regarding the "Trios 3 basic" 3D scanner

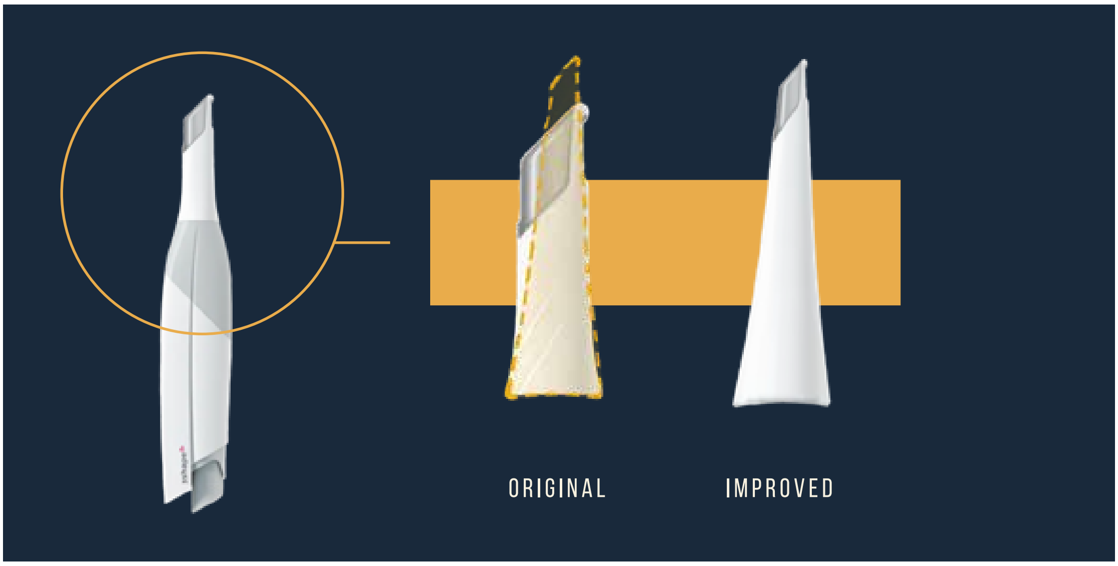


IMAGE 4a.13 *Re-design proposition of head component of Intra-oral scanner*

CONCLUSION

The “TRIOS 3 BASIC” overall performed better than the previously examined scanners and has the potential of obtaining satisfactory results if modified with the proper technical adjustments.

4.B METHOD 2 ANALYSIS
MOLDING

1. INTRODUCTION

A relatively easy and inexpensive way of obtaining a copy of an object is by using the traditional manufacturing process of molding.
In this case, the parts are obtained by applying a proper quantity of fast-curing silicone** around the rear part of the subject's ear, thus obtaining the mold. For a thorough guide regarding selecting silicone as the appropriate material, consult the material selection Appendix P.

The concepts expressed by Biessels *(see chapter 3)* help describes how the temple tips should be designed. Still, there is a lack of information regarding the statistical occurrence of placement of the points mentioned above.
Therefore, it was necessary to understand how this placement appears in the specific case that reflects Maatbrils most common potential customer: subjects with down syndrome.

RQ: Identify points (A, B, and C) on the silicone molds to observe the variation between the samples collected from subjects with down syndrome.

2. METHOD

The samples have been retrieved from **7 subjects** affected by Down syndrome, for a total of **14 molds** (left and right side).
The subject's age variation is from 4 to 56, of which five were females and two males;
The sampling strategy consisted of taking the silicone and applying it to the subjects' posterior auricular area, (see image 4b.1). For the molding process to be successful, it was necessary applying slight pressure on the silicone during the curing phase to ensure that the curvature would be successfully recreated.

IMAGE 4b.1 *Mould sampling*

It was necessary to **wrap the silicone around the superior (Sup Ar.) and inferior auricular root (Inf Ar.)**[1] as a reference to identify the points A, B, and C on the silicone mold surface (see image 4b.2). For further details on applying the silicone mold, consult *Appendix Q*.

1 See appendix G for additional information regarding landmarks.

The molds have been analyzed by visual and identifying and marking the exact position of points A-B-C.
Each mold has been photographed along three perpendicular planes.
The images were then scaled for normalization and aligned to measure the distance between the reference points from a common origin on each plane.

IMAGE 4b.2 *Silicone mold application*

The molds have been analyzed mainly from the two views:

- Lateral view: to observe the position of A, B, and C
- Front view: to measure the depth of the visible points in relation to the superior-inferior auricular root axis.

3. RESULTS

Identifying the points heavily relied on tactile exploration and visual analysis of the silicone surface on the side in contact with the head of the subject. This method has not always been sufficient; therefore, some points were not identified correctly.
The overview of the identified points is illustrated in *Appendix R.*

3.1 LATERAL VIEW ANALYSIS

The points were identified on the molds and mapped on the axis (see image 4b.3).

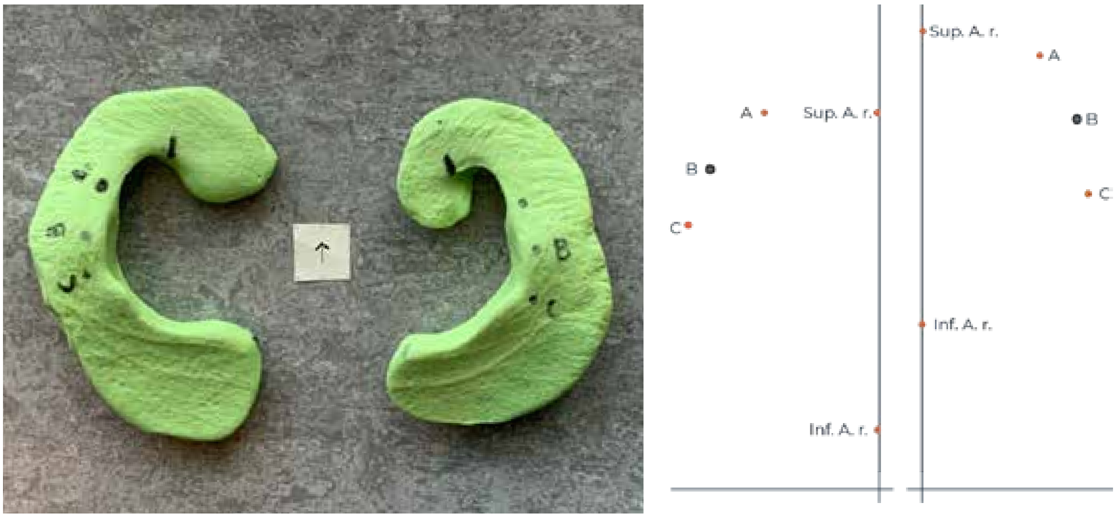


IMAGE 4b. 3 *Example of mold 1 (left) and the point map (right)*

Each mold point cloud has been aligned to the superior auricular root point as a standardized comparison.

Due to the high variation between the subjects, the samples have been normalized. Subsequently, the clusters of points A, B, and C were obtained for the lateral view analysis (image 4b.4).
The continuous blu line connects the average points of each point cloud. The dashed lines indicate the angles measured in relation to the axis between inferior and superior auricular root.

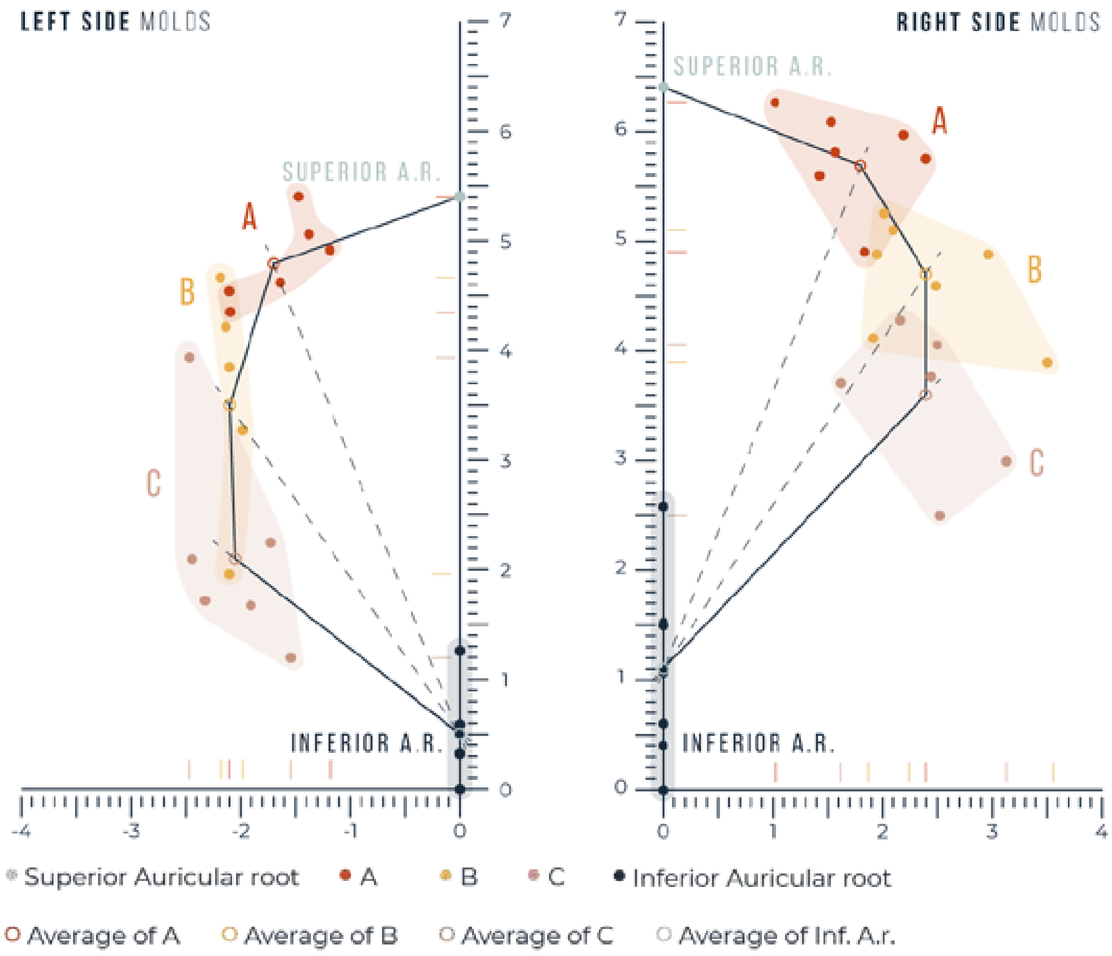


IMAGE 4b.4 *Results of Lateral view Analysis*

3.2 FRONT VIEW ANALYSIS

The points were mapped on the Lateral view and aligned to the front view photo to map their placement on this view, as shown in image 4b.5. (See *Appendix S* for an overview of "front view" mold point mapping).
Subsequently, the clusters of points A, B, and C were obtained for the front view analysis. The normalized results are shown in image 4b.6.
The frontal view analysis results are in image 4b.7.

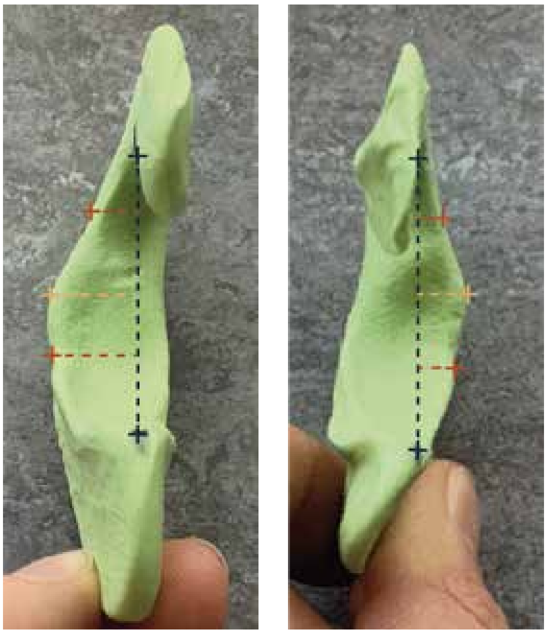


IMAGE 4b.5 *Mold 1, Front view point placement*

LEFT SIDE MOLDS   RIGHT SIDE MOLDS

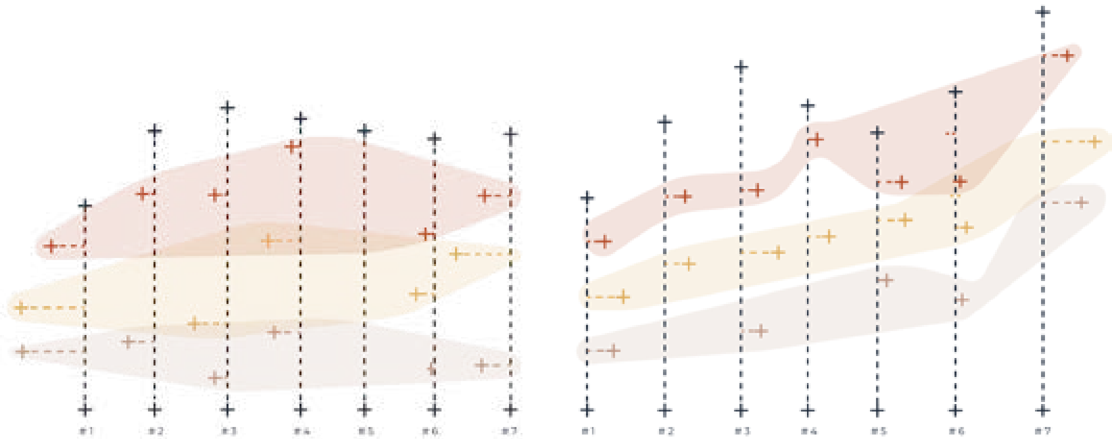


IMAGE 4b.6 *Front view point map of molds*

4. CONCLUSION

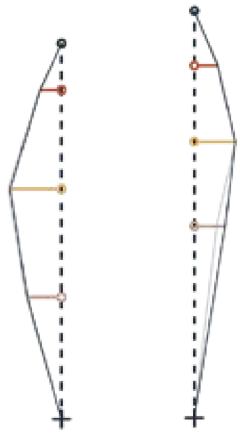


IMAGE 4b.7 *Front view Analysis results*

- Angles measured from the axis Sup. A.r. to Inf. A. R. are quite symmetrical, with a maximum deviation of 6° (c-Inf.) (See image 4b.8).
- Between A, B, and C, are the significant difference between the Left and the Right side is measured in C;
- Left- Right mold average variation:
    - Height: R is 8.8% higher
    - Max Width: R is 14.5%wider
    - Max Width does not always align with B
- Left- Right mold average variation of depth:
    - The Right mold is less deep than the left mold
    - A depth: R 10.3% smaller
    - B depth: R 19% smaller
    - C depth: R 1.8% smaller
    - The Major variation is registered in correspondence of B
    - On both sides, the max depth is registered in correspondence of point B

Calculations in *Appendix R1*.

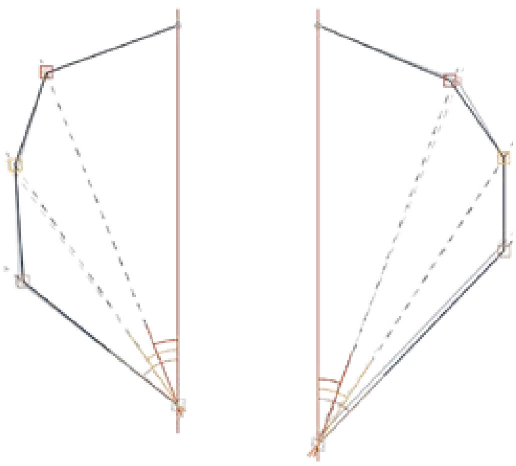


IMAGE 4b.8 *Lateral view angles*

5. DISCUSSION

The principal boundary of the study lies in the limited number of samples. Therefore the comparison between the left and right sides has to be considered with the proper reappraisal.

In the front view analysis, the alignment of the various points has been compromised by the error caused by the different perspectives occurring between the multiple photos. In addition, points that coincide with a "fossa" remain not visible due to their placement.

6. LIMITATIONS

The method is relatively simple and does not require any expensive tools, nor the knowledge of any dedicated software, it has some weaknesses:

- The process for obtaining the molds may create some discomfort in some subjects;
- The identification of the Biessels reference points is operator-dependent, and may need to rely heavily on the touch exploration of the mold;
- Measurements are approximate, then the margin of error may be significant;
- The images of the molds may be affected by distortion due to misalignments, prospective, parallax, distance from the lenses, etc.
- There is no practical method for verifying that the mold replays the area of interest with sufficient accuracy (this specific issue will be further explored ahead in this document);
- The age variation in the subject is significant and there is no equal gender distribution;
- The number of samples is limited.

7. DESIGN IMPLICATIONS

In the case of this study, the points S (superior auricular root) and I (Inferior auricular root) have been aligned on an axis. This step was necessary to create a reference system for the various silicone samples comparison.

It would be interesting exploring the correlation between the ears position by measuring (see image 4b.9):

- The angle between Sup. A.r. and Inf. a. r.
- The distance and angle between Sup. A.r an the eye level to observe the ear placement in correspondence to the rest of the head.

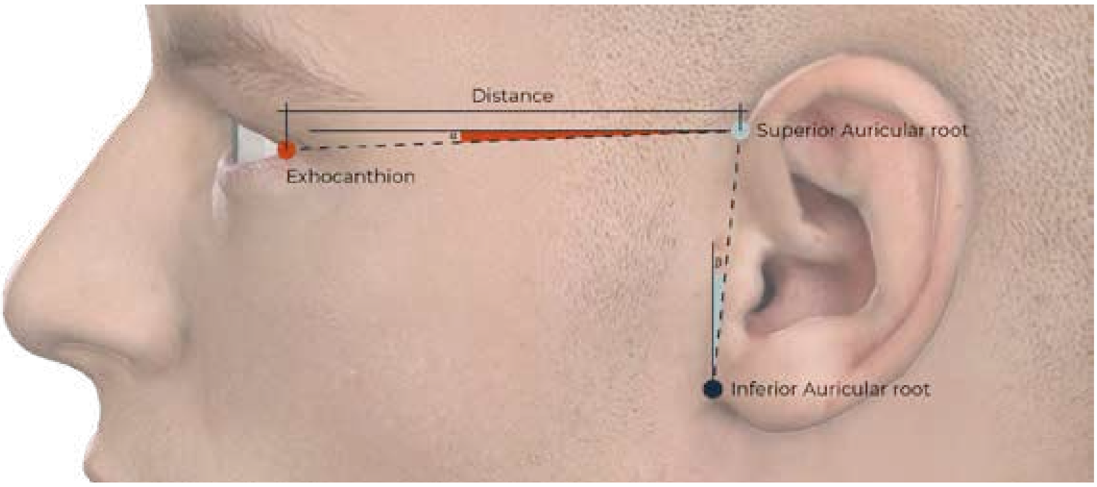


IMAGE 4b.9 *Mold 1, Front view point placement*

4.c METHOD 3 ANALYSIS

HYBRID (MOLDING AND 3D SCANNING)

1. INTRODUCTION

An alternative approach to collecting data of t consists of taking a direct mold of the site, as seen previously in method 2,
The "hybrid method" implies taking a mold of the skull's curvature in the posterior auricular area, just like in method 2, with the addition of taking a 3D scan of:
The silicone molds (left and right side);
The subject's head with the silicone mold in the correct placement behind the ear;
The subject's head, without the silicone mold.

The goal is to obtain a head mesh with a relatively accurate negative corresponding to the area behind the ear by subtracting the silicone mold scan from the head scan (boolean difference in Rhino).

2. DISCUSSION

This method has multiple limitations, such as difficulty obtaining an accurate mold 3D scan or a reliable alignment between head scans and molds.

SILICONE MOLDS LIMITATIONS:

The silicone molds must be scanned in multiple takes, affecting the final result's accuracy.
The molds, during the scan, are turned 360°. When there is a shift between one side to the other, the scanner loses track of the object. (See image 4c.1).
Therefore to adequately capture the geometry of a single mold, it is necessary to take and align about 3 to 5 scans. During this phase, it is likely to have misaligned between the surfaces, so the final result is inaccurate.

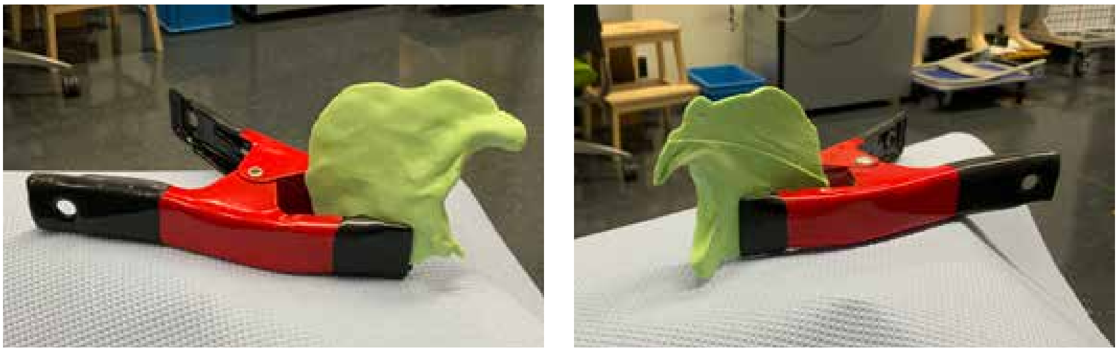


IMAGE 4c.1 *Mould samples: exterior (left image) and interior side, in contact with head (right image).*

The issue could be solved by utilizing a 3D scanner designed for smaller-size objects, but there were cases where the mold did not fit in the scanner's plate and had to be cut down to fit accurately.

An alternative to the abovementioned problem was scanning the molds only on one side, the one in contact with the head. (See image 4c.1)
The scans were uniformed using a custom base mesh in Wrap[1].(see Appendix T for additional detail regarding the steps applied in "Wrap").
The output of the process, due to the nature of the 3D scan, resulted in a surface as visible in image 4c.2

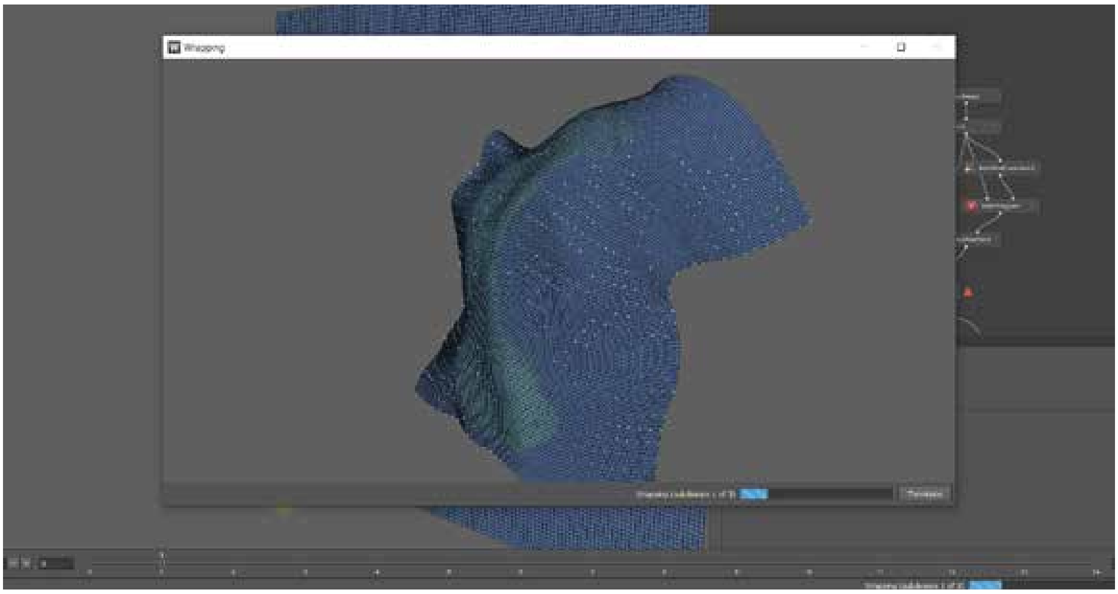


IMAGE 4c.2 Wrapping of surface: result of 3D scan of mold;

ALIGNMENT ISSUES:

It resulted in relatively inaccurate aligning of the surface of the scanned mold with the head scans.
The limitation lies in the fact that when the head mesh has a low resolution in the area to which the ear needs to be aligned, the alignment is necessarily estimated, and the outcome is not sufficiently accurate. (See image 4c.3)

1 square surface, created using Rhino, with a density subdivision of 7

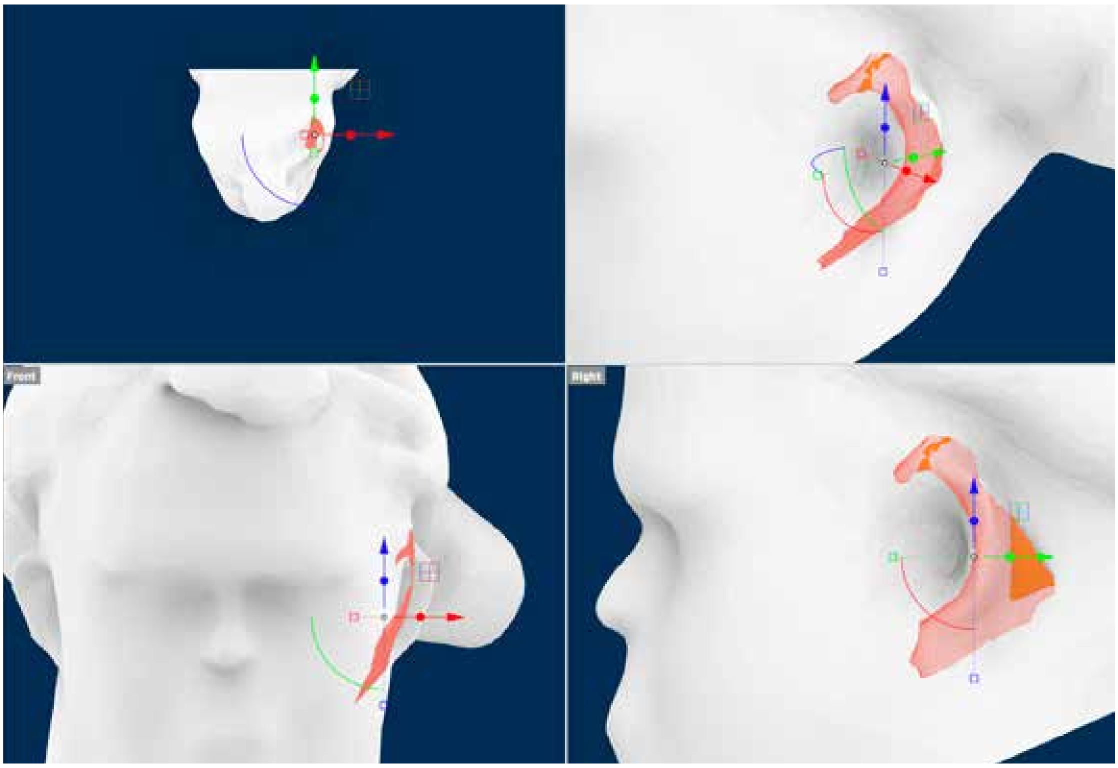


IMAGE 4c.3 Results of alignment of mould onto head scan;

The alignment process is illustrated in Appendix U. Therefore, a high-quality head mesh is crucial, but – as seen before – this is far from achievable with the available scanners.

Moreover, if we obtain a high-quality head mesh, we may need not compensate for the missing data by combining it with the mold scan.

3. CONCLUSIONS OF METHOD COMPARISON

Methods that include the combination of scans or aligning them to each other have a high margin of inaccuracy.

Out of all the methods that have been explored, 3D scanning using the Intraoral tool has shown the most potential while presenting some technical limitations. However, they could be potentially overcome by redesigning the head of the tool;

The methods that require silicone molds are quite long to process and present issues regarding alignment accuracy.

Identifying points A-B-C heavily relies on applying physical pressure to the soft tissues of the temporal area, which reduces the effectiveness of all methods based solely on 3D scanning;

5 SYNTHESIS

This chapter incorporates the concept generation process, including a sprint and a creative session.
The next phase consisted of the selection phase, which led to the further development of concept 4: "The measuring tool."

5 SYNTHESIS

1. CONCEPT GENERATION

RQ: Generate concepts of a measuring tool for the posterior auricular area

The generation of concepts phase started with a Sprint session to fast prototype designs of inclusive frames for subjects with head deformations.

In image 5.1, it is possible to observe some examples of the results of the Sprint session. The output of the session contributed to the idea t the final design should be able to capture the information that could not be retrieved through 3D scanning and adapt to different users. For further information, consult *Appendix V.*
The additional concepts were generated during a creative session, of which the starting point term was: "measuring tool."

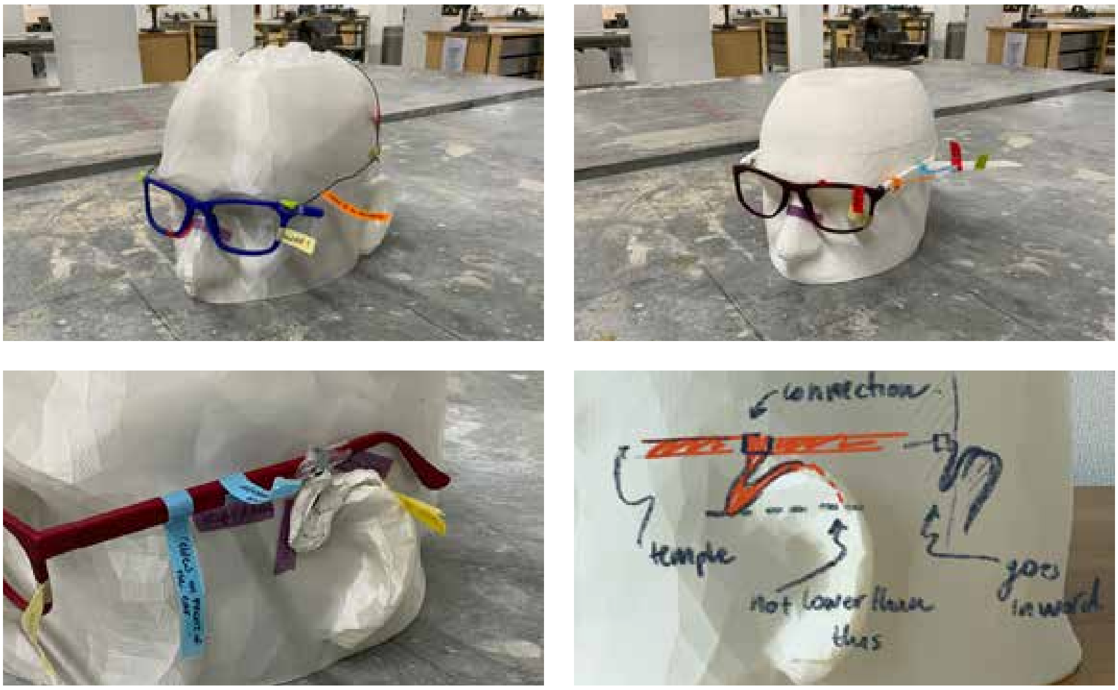


IMAGE 5.1 *Partial result examples of the Sprint session*

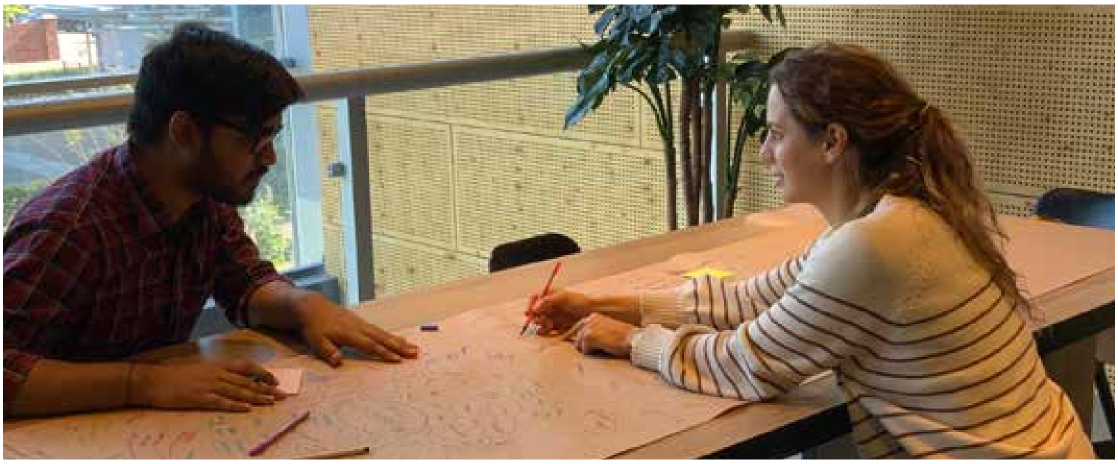


IMAGE 5.2 *Creative facilitation session for concept generation*

The creative session was planned accordingly to the creative session principles *(Meer & van der Meer, 2019)*[23] and involved four product designers, one of which is Maatbril's product designer.
The designers were briefed on the problem and focus of the research concerning the difficulty of measuring the posterior auricular area.
In image 5.2 Manfredi is explaining what type of information he needs to design the glasses correctly.

The result of the creative session consisted in the generation of three concepts:

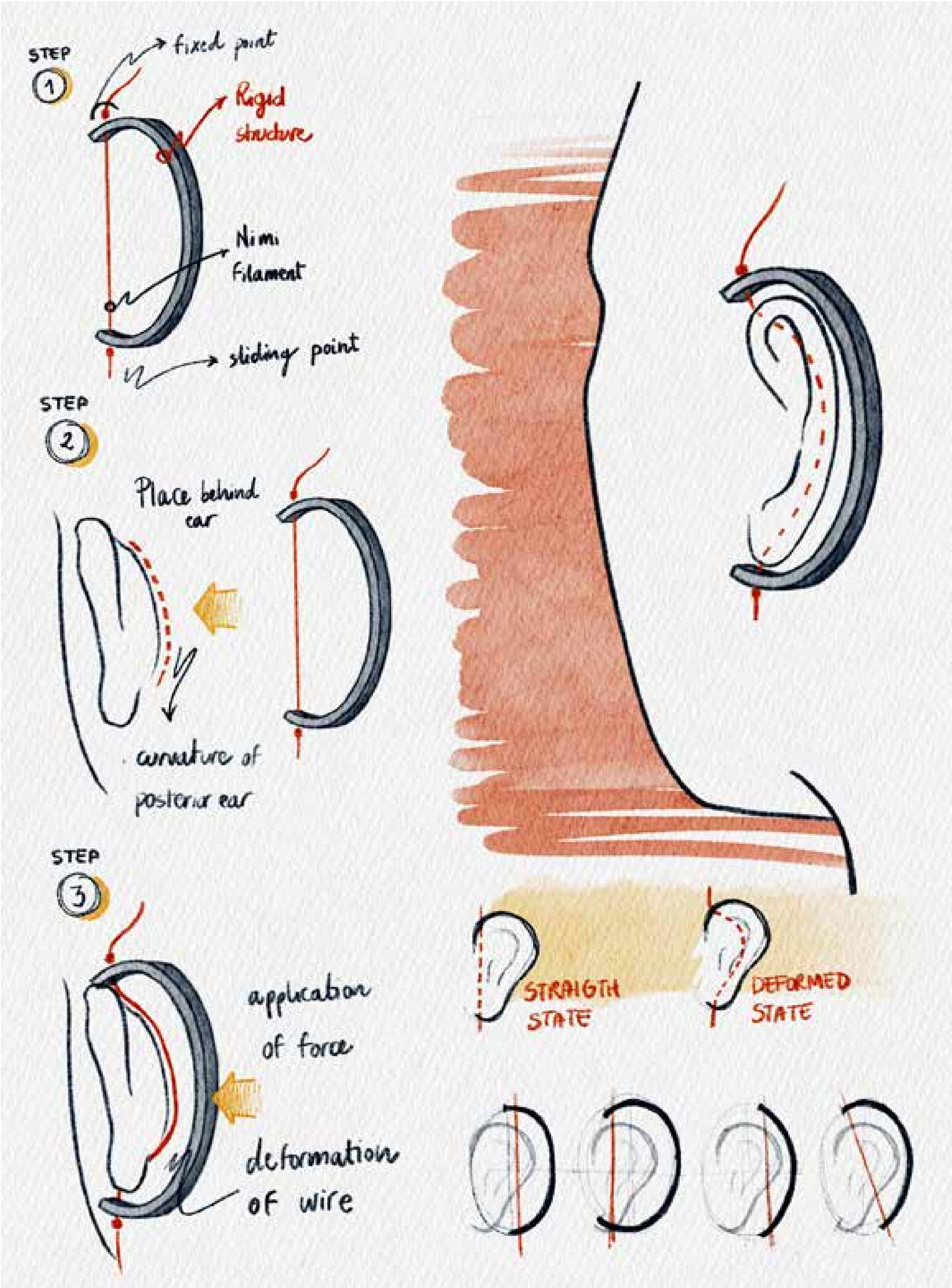
- ***The inflatable cushion;***
- ***The integrated measuring tool;***
- ***The arch with wire;***

The concepts generated during the creative facilitation served as a starting point for additional iteration necessary yo reach the final result.

2. CONCEPTS

The "Inflatable cushion concept" ,after a session with the graduation team, evolved into an additional concept: ***"Vacuum cushion concept"***.
At the end of the creative session the "Measuring tool concept" was still not clearly envisioned and required further design development.

The final concepts have been sketched and described below.



CONCEPT 1. "THE ARCH WITH WIRE"

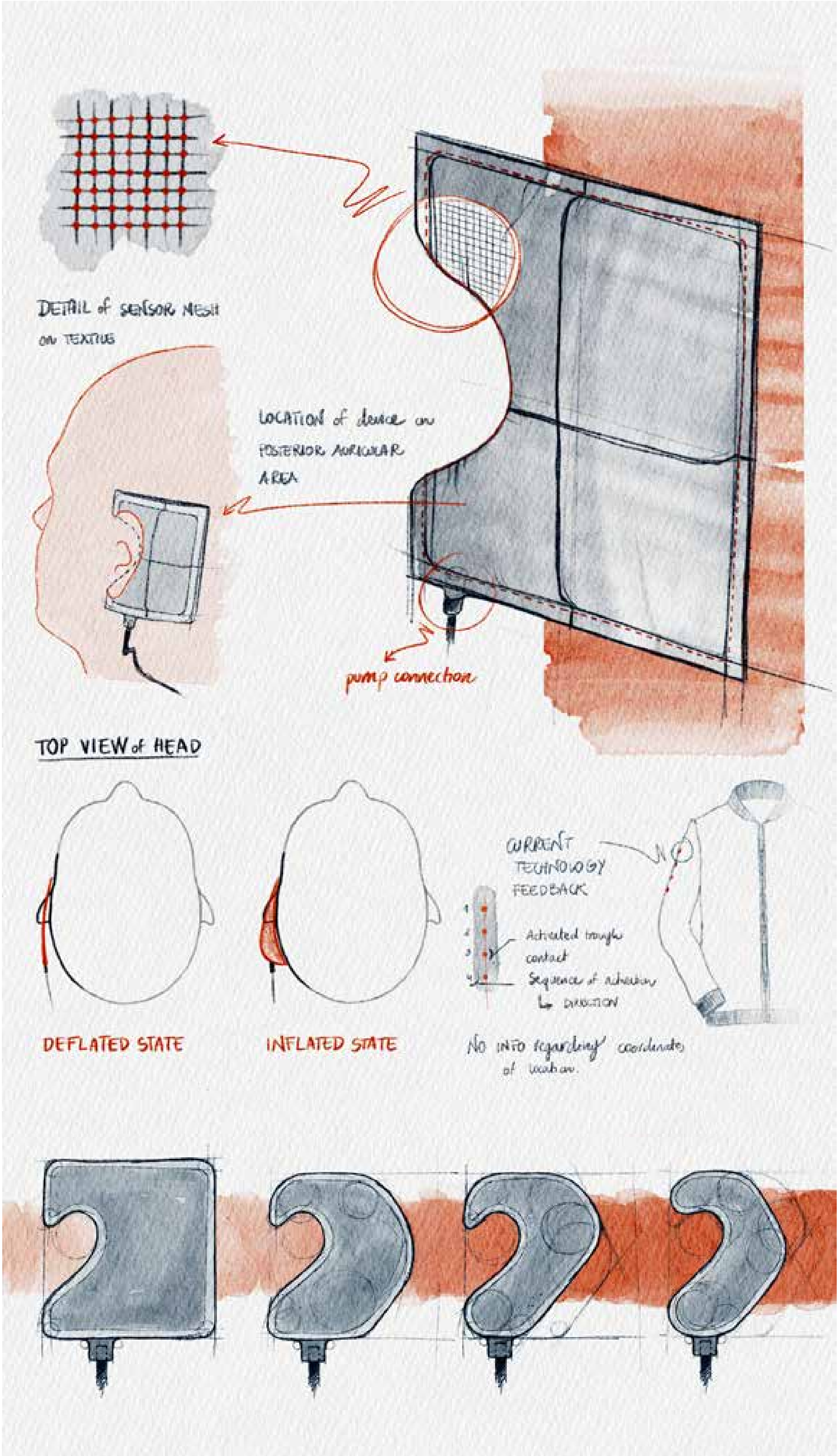
The arch with wire concept consists of a c-shaped 3d printed arch, which supports a shape memory alloy.
The arch is pressed against the connection between the ear and the skull in the posterior auricular area. This way, the alloy wire takes the shape of the curvature in this area.
The alloy has the property of retrieving its original programmed shape when heated up.
Once the arch is removed from the ear, it can be easily traced on a sheet of paper.
Once traced, the wire can be heated back up and reused on the next client.
Unfortunately, the data collected is limited to the 2-D curvature of the ear, excluding the data regarding curvature of the surface behind the ear.

ADVANTAGES

- Reusable device
- Provides information on the posterior auricular area in terms of:
    - The 2-D curvature of ear-skull connection;

DISADVANTAGES

- Does not provide information on the posterior auricular area in terms of:
    - Location of dips and bumps of the surface;
    - Depth of dips and bumps of the surface;
- Requires to be heated up in order to be reused


DETAIL of SENSOR MESH
ON TEXTILE
LOCATION of device on
POSTERIOR AURICULAR
AREA
pump connection
TOP VIEW of HEAD
DEFLATED STATE
INFLATED STATE
CURRENT
TECHNOLOGY
FEEDBACK
Activated trough
contact
Sequence of activation
DIRECTION
No INFO regarding coordinates
of location.

CONCEPT 2. "THE INFLATABLE CUSHION"

As the name suggests, the "Inflatable cushion" concept consists of a cushion placed in the posterior auricular area and inflated and deflated through the connection with a motor.
It simulates the principle of taking a mould with silicone but with an improved and more sustainable interaction since it does not require additional 3D scanning and is not a single-use product.

The textile of the cushion is embedded with sensors that track x,y, and z coordinates in space.
The idea is that the cushion is initially placed in a deflated state behind the area. Once in position, the product can be inflated, and the textile adapts to the skull's surface.
The output of the sensors is a surface map that coincides with the surface of the head.
Once the map is created, the device can be deflated and reused with another subject.
Unfortunately, the currently available technology regarding sensors on textiles is limited.
The sensors can be activated through touch, and the only output is if the sensor has been activated or not. The output does not include data regarding placement in space.

ADVANTAGES

- Reusable device
- Provides information on the posterior auricular area in terms of:
  - The curvature of ear-skull connection;
  - Placement and depth of eventual dips and bumps of the surface.

DISADVANTAGES

- Technology Readiness Level still in early stage.

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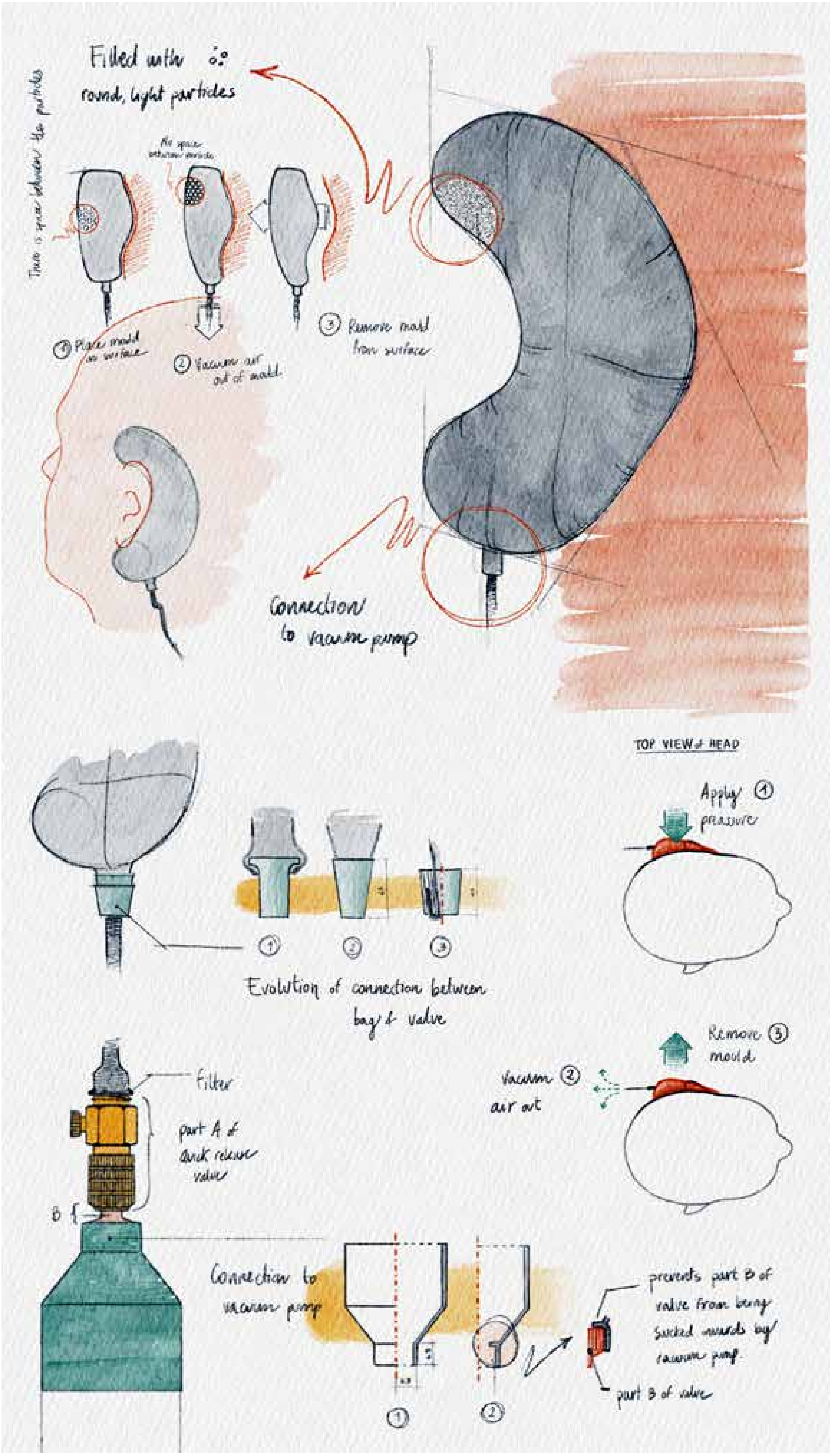

Filled with
round, light particles
There is space between the particles
No space between particles
① Place mould on surface
② Vacuum air out of mould
③ Remove mould from surface
Connection to vacuum pump
TOP VIEW of HEAD
Apply ① pressure
Evolution of connection between bag & valve
Remove ③ mould
Vacuum ② air out
Filter
part A of quick release valve
B
Connection to vacuum pump
prevents part B of valve from being sucked inwards by vacuum pump
part B of valve

CONCEPT 3. "THE VACUUM CUSHION"

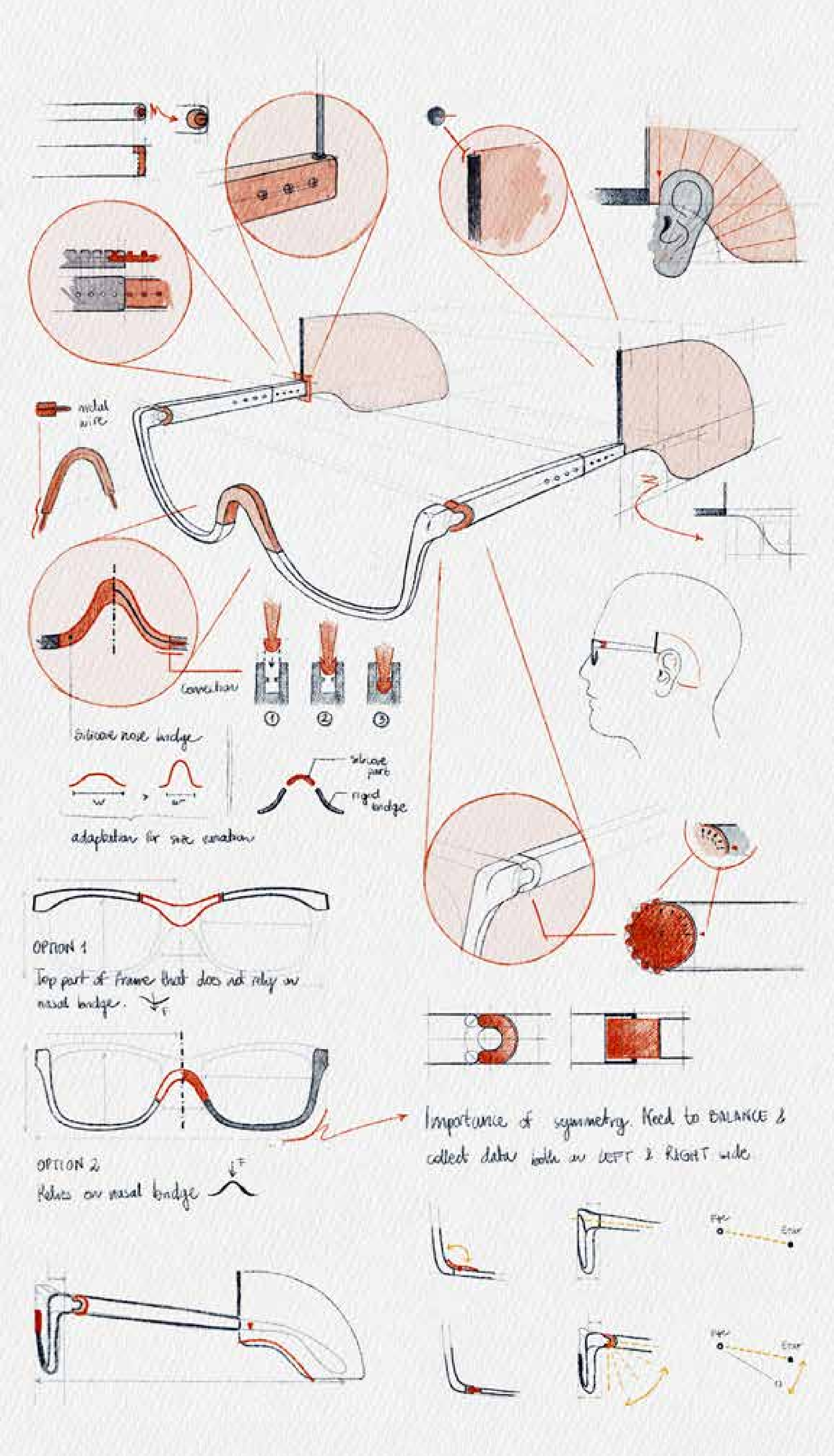
The "Vacuum cushion" is a simplified version of Concept 2.
It maintains the principle of deflating and inflating, but the initial state is inflated, and it is filled with lightweight sand-like material with a small grain.
The principle consists of taking a mould of the posterior auricular area by vacuuming the air from the cushion pressed against it.
The lightweight facilitates the vacuuming process, while the small grain allows obtaining a high surface definition of the moulded surface.
The obtained deflated cushion functions as a reusable mould, that has to be detached from the vacuum and appropriately stored. Later, the mould must be 3D scanned to obtain the data regarding the moulded surface.

ADVANTAGES

- Reusable device;
- The technology readiness level is compatible with prototyping phase;
- Provides information on the posterior auricular area in terms of:
    - The curvature of ear-skull connection;
    - Placement and depth of eventual dips and bumps of the surface.

DISADVANTAGES

- The process is lengthy;
- The device requires the application of force to obtain an accurate mould;
- High risk of losing information since the cushion needs to be detached from the vacuum motor and stored properly;
- There is no alignment reference included in the output;
- Wrinkles on the surface after shrinking will compromise the accuracy of the output.


metal wire
Correction
Silicone nose bridge
adaptation for size variation
silicone part
rigid bridge
OPTION 1
Top part of frame that does not rely on nasal bridge.
OPTION 2
Relies on nasal bridge
Importance of symmetry. Need to BALANCE & collect data both on LEFT & RIGHT side

CONCEPT 4. "THE INTEGRATED MEASURING TOOL"

Concept 4 consists of an adjustable frame that is a measuring tool for the posterior auricular area.
The adjustability of the prototype is obtained through:

- Mobile hinges;
- Extendable temple tips;
- Flexible nosepad.

The mobile hinges compensate for the ear placement asymmetries relative to the y axis.
The extendable temple tip mechanism allows the prototype to fit multiple users and adjust in case of asymmetries along the x-axis.

The flexible nosepad, which consists of wire covered by silicone, allows adjusting the frame size for multiple users by creating a grip on the nose.
The posterior auricular area information is partial since it is limited to the placement of dips and bumps but not to their depth.
No information regarding the curvature of the ear-skull connection is retrieved.

ADVANTAGES

- Reusable product;
- The technology readiness level is compatible with prototyping phase;
- There is an alignment reference included in the output, facilitating design phase.
- The frame fits a wide range of users

DISADVANTAGES

- Limited information regarding the posterior auricular area;

3. PROGRAM OF REQUIREMENTS

The list of requirements refers to the "measuring tool" concept development and not to the requirement regarding the 3D scanning environment, and tools.

The list of requirements has been defined by re-adapting the guidelines provided by the "Delft design guide."[24]

List of requirements referring to ***Measuring tool prototype***:

1. PERFORMANCE: The main function is to mould the posterior auricular area to model comfortable temple tips
2. ENVIRONMENT: The tool should be able to withstand transportation in car, be able to be 3D scanned easily and will be subject to frequent assembly and disassembly;
3. LIFE IN SERVICE: The product should be used on a weekly basis for about 10-15 times a week.
4. MAINTENANCE: Maintenance should be possible and accessible for all components.
5. TARGET PRODUCT COST: The target product cost should be around 50€ per unit, excluding labour costs.
6. TRANSPORT: The product will be transported by car to the location of use.
7. PACKAGING: The packaging of the product should protect against impacts that might occur during standard car transportation. The case is used throughout the lifespan of the product to store the product while not in use and it has to fit all the components neatly, ready for use.
8. QUANTITY: The number of units produced is limited to 3, one unit per size: S, M and L.
9. PRODUCTION FACILITIES: The product has been designed to be compatible with SLA 3D printing, which is outsourced, while silicone moulding, colour, finish and assembly are conducted within the company.
10. SIZE AND WEIGHT: Size and weight influence the transportability of the product, therefore it should not be larger than a 25X40X15 box, with a weight lower or equal to 5Kg.
11. AESTHETICS APPEARANCE AND FINISH: The aesthetic should be not intimidating and friendly. The finish is defined by the use of Maatbril's current top coat.
12. MATERIALS: The tool should be 3D printed with PA12 filament and coloured with Maatbril's current pigment methodology. All materials, including the silicone of the flexible components, should be safe to use on the skin.
13. PRODUCT LIFE SPAN: Not defined
14. STANDARDS RULES AND REGULATIONS: ***Not sure here what to put***

15. ERGONOMICS: The tool should be easily assembled and disassembled. Since it is an adjustable product it has to be easily brought back to the "original state" and the flexible components need to be straighten out. While the user is wearing it should not feel excessively intrusive or cause discomfort.
16. RELIABILITY: The chance of failure should be limited to the assembly. The components should not break while being used.
17. STORAGE: There are no long periods of storage which require specific measures.
18. TESTING: none
19. SAFETY: The product should be used under adult supervision due to the sizing of its components.
20. PRODUCT POLICY: There are no specific requirements given from the company.
21. SOCIETAL AND POLITICAL IMPLICATIONS: None
22. PRODUCT LIABILITY: none
23. INSTALLATION AND INITIATION OF USE: The user must be aware of how the components need to be assembled and disassembled correctly.
24. REUSE, RECYCLING: The front components are separable, with the exception of the temples which need additional steps to be separated from the metal wire and silicone.

4. CONCEPT SELECTION

RQ: Compare and select the concept to be developed

The concepts have been evaluated using two methodologies: *"Harris profile"*[25] and *"Weighted Objectives"*[26].

4.1 "HARRIS PROFILE" METHOD

"Harris Profile" shows each concept's strengths and weaknesses based on the requirements list. All concepts were evaluated and compared with each other.
The table 5.3 that follows is an example of an evaluation table. The rest of the evaluation tables can be found in *Appendix W*.

4.2 WEIGHTED OBJECTIVES METHOD

The *"Weighted Objectives"* method was used to facilitate the selection by multiplying the ***"weight"*** and the "score" per each concept.
The **weight** is a value assigned from 1 to 5 that determines the importance of the requirement.
The **score** value, going from 1 to 4, reflects the *"Harris profile"* evaluation where one is *"bad,"* and four is *"excellent." See* table 5.4.

4.3 DISCUSSION

The following results were discussed with Maatbril product design expert and both parties agreed that the most interesting and promising concept to develop would be Concept 4: **The integrated measuring tool.**

4.4 KEY FINDINGS

- The results of the *Harris profile* show that the ranking of the concepts from high to low are:
  - Concept 4
  - Concept 1
  - Concept 2
  - Concept 3
- The results of the "*Weighted objectives calculation"* show that **Concept 4** had the best overall result;
- **Concept 2** scored the best after having excluded the requirements regarding the prototyping phase. Promising result to take into account for further development but not at this moment.
- **Concept 4 was selected for future development.**

TABLE 5.3_ HARRIS PROFILE CONCEPT 4_ INTEGRATED MEASURING TOOL

	REQUIREMENTS	-- (BAD)	- (MODERATE)	+ (GOOD)	++(EXCELLENT)
PROCESS	User friendliness*				
	Ease of application/ removal				
	Comfort for user				
	Potential accuracy of collected data**				
	Risk of compromising data				
PROTOTYPE	Feasibility of prototype				
	Compactness				
	TRL				
	TOT.	26			

TABLE 5.4_ WEIGHTED OBJECTIVES CALCULATION

	REQUIREMENTS	WEIGHT	CONCEPT 1		CONCEPT 2		CONCEPT 3		CONCEPT 4	
			SCORE	TOT.	SCORE	TOT.	SCORE	TOT.	SCORE	TOT.
PROCESS	User friendliness*	2	4	8	3	6	1	2	2	4
	Ease of application / removal	3	4	12	2	6	1	3	3	9
	Comfort for user	5	1	5	3	15	2	10	4	20
	Potential accuracy of collected data*	5	1	5	3	15	2	10	3	15
	Risk of compromising data	4	1	4	4	16	2	8	2	8
PROTOTYPE	Feasibility of prototype	5	4	20	1	5	3	15	4	20
	Compactness	3	4	12	2	6	2	6	4	12
	TRL	4	4	16	1	4	5	20	4	16
	Total Process			34		58		33		56
	Total Process + Prototype			82		73		74		104

** Quantity of steps required to obtain data*

*** Based on an estimation since this requirement can't be verified until prototyped and tested*

6 EMBODIMENT

This chapter describes the embodiment phase: designing, prototyping, observing, testing, and iterating upon the various prototypes and repeating the process.
The prototype was assembled to obtain a final model that could be used for a user test, focused on evaluating functionality and interaction. Lastly, the inclusivity test was necessary to determine how and if it would fit subjects with specific head deformations.

6 EMBODIMENT

1. ITERATIONS AND PROTOTYPE

RQ: Design and create a functional and operational model of the selected concept

The embodiment phase involves designing, prototyping, observing, testing, and iterating upon the various prototypes and repeating. The product has been broken down into single parts that have been iterated several times. In the last stages, the product is assembled to obtain the final model used for the user test.

1.1 OVERVIEW OF ITERATIONS

The initial concept sketch was iterated and resulted in the final **functional[1] and operational[2]** model illustrated in Image 6.1. The main differences between the two concepts consist in:

PART OF FRAME	OLD CONCEPT	ITERATED CONCEPT
Temple Tips	Plastic sheet with a ruler	Flexible silicone tips with an aluminum wire core
Temples	Extendable temples with slot mechanism	Extendable sliding temples
Hinges	PLA hinge that allowed rotation along only one axis	Ball joint hinge with 360° movement and TPU socket
Connection of Nosepad to frame	Silicone extremity with arrow stop that inserted into the front	Metal wire was inserted into the front and silicone around it

TABLE 6.2 *Iteration differences from initial concept to Final proposal*

1.2 PROCESS

The concept was divided into components, and each component was subjected to several design iterations.

The objective of the component's iterations consisted in reaching a satisfactory level of a **"functional model,"** consisting in capturing functional features and underlying operating principles.

Once this level was reached, the frame was assembled to create an **"operational model"** necessary for the user test.[27]

TEMPLE TIPS

There are **20 iterations of temple tips** visible in image 6.3.

They went from an "insert and lock" mechanism to a flexible silicone temple with an aluminum core.

1 Definitions of *Functional model* from ID cards: "captures the key functional features and underlying operating principles. Has limited or no association with the product's final appearance."

2 Definitions of *Operational model* from ID cards:" Communicates how the product is used with the potential for ergonomic evaluation".

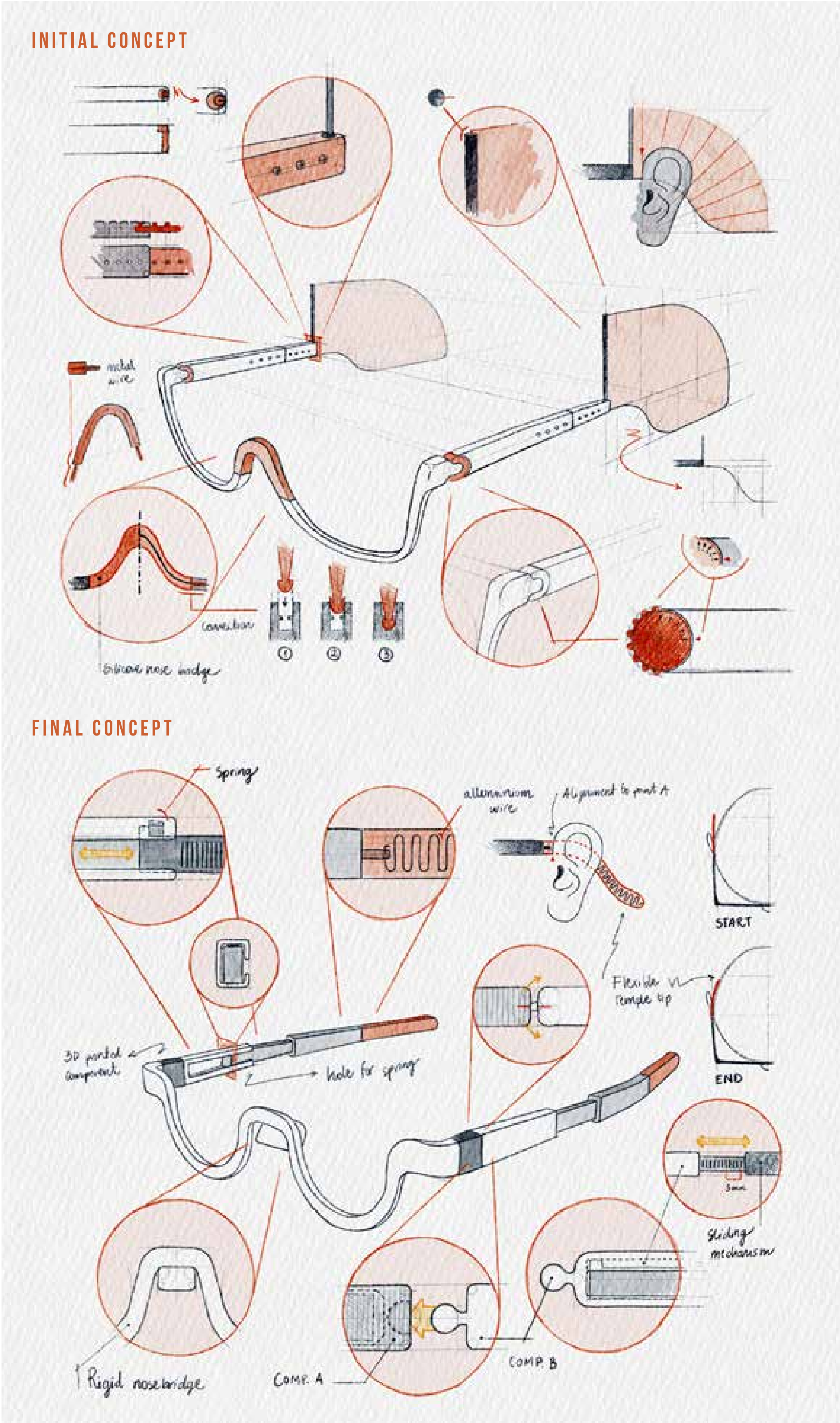


IMAGE 6.1 *Comparison between Initial concept and Final concept*

The main focus was **designing a mold for the temple tips** that would:

- Allow for the silicone to be poured in correctly;
- For the temple to be easily extracted once the silicone is cured;
- Let the correct placement of a wire inside it;
- Have the correct ratio between ease in being molded and maintaining the given shape;
- Find the right balance between thickness of silicone and the wire enclosure;
- Define a stable connection between the wire, silicone and temple;
- Reduce the quantity of material and time required to 3D print the mold;
- Identify the right shape of the temple tip to ensure that it covers enough surface in the posterior auricular area.

It is overall the component that requires the most number of design iterations. The **silicone** used is a bi-component[3] with a hardness of 20Shore since the other tested options were either too flexible or rigid.

Wire flexibility and thickness have also been explored. The tested options included: Iron (Ø0.65mm and Ø1.2mm), tin (Ø0.8mm), and aluminum (Ø1 mm). The best results were given by the aluminum wire.

NOSEPAD

The flexible nosepad has been iterated upon **15** times (see image 6.4) . The main focus was identifying how to connect it to the front, compatible with the wire placement inside.

FRONT

The front only required **7 iterations** which primarily focused on identifying the proper connection between the flexible nosepad and the rigid front by designing the connection between the wire to keep in place and the silicone to be connected to the frame (see image 6.5).

HINGE & SLIDING TEMPLE

The front and the temples connect through a **ball joint hinge** (see images 6.6 and 6.7). One component, the sleeve, is connected to the front and printed in flexible TPU. This way, it can hold the other hinge component, the ball, printed PA11. The iterations mainly focused on identifying the right proportions between the diameter of the ball and the connection to the sliding mechanism without excessively compromising the solidarity of the component. The edges have been rounded off to **facilitate the 360° rotation of the temples**.

The sliding mechanism has been designed keeping in mind the correct sequence of assembly which implies first the positioning of the spring, which is necessary for the sliding mechanism to function, then the temple placement, which acts as a lever by compressing the spring and allowing the sliding movement. The spring, when extended, keeps the temple in place. The section of the mechanism is a sort of "C," of which the top part is lower so that the spring does not slip out once it has gone tough the hole on the bottom for its insertion. The hole is placed at the end of the mechanism to allow as much extendable length as possible.

3 Reschimica R pro 30

IMAGE 6.3 *Temple tip iterations*

IMAGE 6.4 *Nosepad iterations*

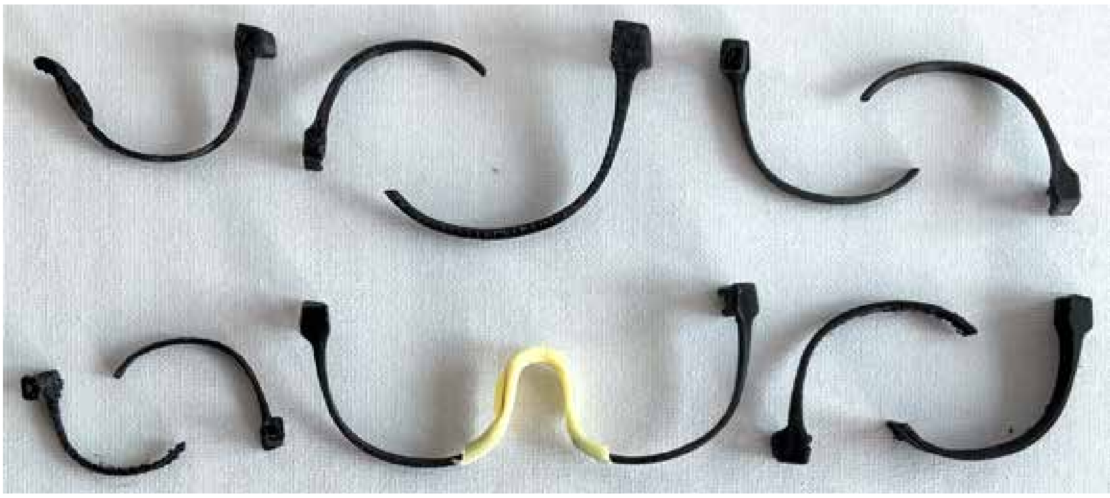


IMAGE 6.5 *Front iterations*

IMAGE 6.6 *Hinge iterations*

IMAGE 6.7 *Sliding temple iterations*

1.3 RESULT: OPERATIONAL MODEL

The assembled model is illustrated below.

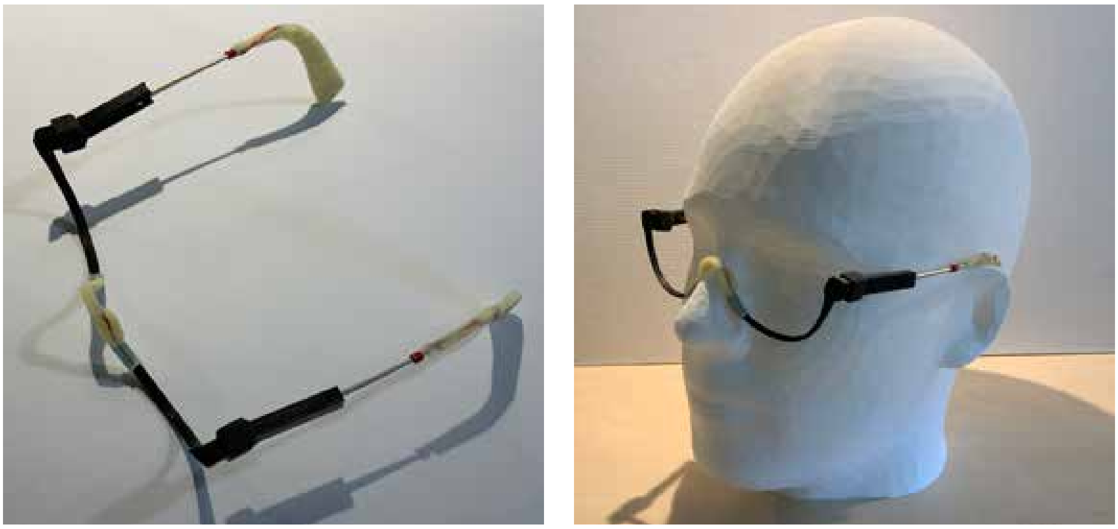


IMAGE 6.8 *Operational Model prospective view*

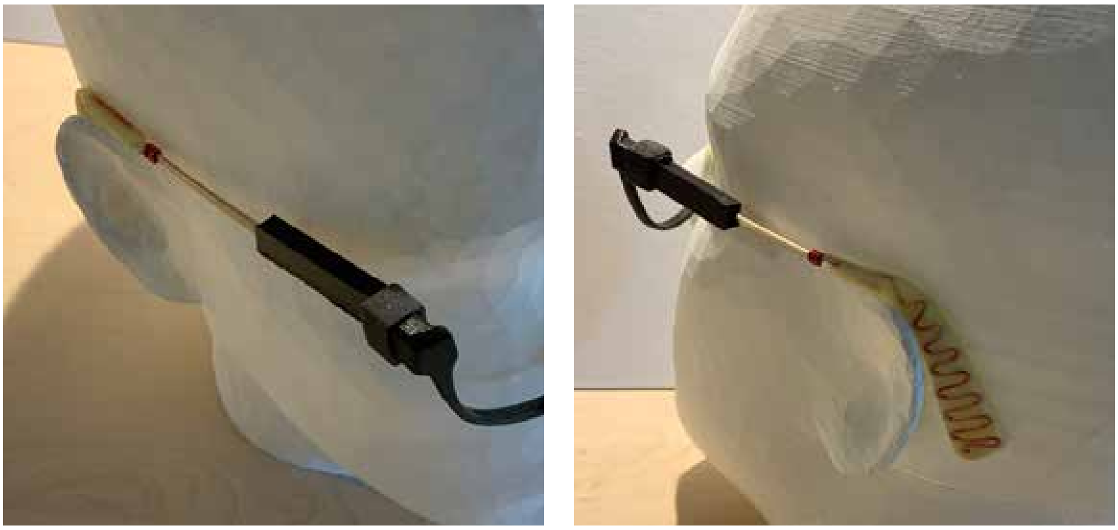


IMAGE 6.9 *Hinge and Flexible temple tip detail*

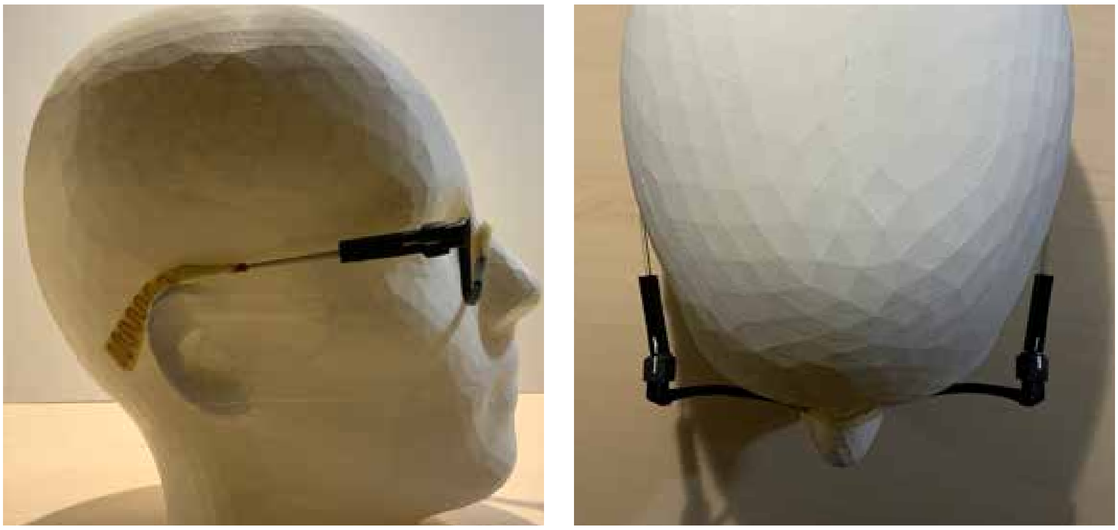


IMAGE 6.10 *Lateral and Top view*

2. TEST OF OPERATIONAL MODEL

Once the model was assembled and each component worked on its own, it was necessary **investigating if the assembly was functional in the context of use**. For this reason, **two tests were conducted**: the first to **evaluate the model's functionality and interaction with the subject**; the second to **verify the prototype's inclusivity in terms of fit.**

2.1 FUNCTIONALITY AND INTERACTION EVALUATION

RQ: Does the model work in the simulated context of use?

METHOD

The prototype was placed on the subject, and pictures were taken from the top, left, right, and front views to evaluate if the prototype captured the data correctly.

RESULT

IMAGE 6.11 *Left and Right view*

IMAGE 6.12 *Side and Top view*

OBSERVATION

Overall, the prototype correctly functions since it adapts to the subject's facial features and the temple tips mould along the subject's head.
The **flexibility of temple tips** bend accurately enough to mould the subject's head but present a reduced accuracy if compared to silicone mould samples *(see chapter 4)*. The temple tip's extremity did not shape the head properly.

The temple tip slides out from the metal temple. The **spring** of the sliding mechanism, when the temple was excessively extended, escaped from its lodging.
The alignment marks are a reference, but **the structure is not rigid enough to be considered as accurate** (see image 6.11).

The flexible nosepad allows adjustability in terms of fit but causes an excessive bent into the front component.
Regarding interaction, there is a need to introduce support for the frame after the measurement has been taken. The **stand is required for the 3D scanning** phase of the temple tips.
When taking the photos, there is a risk of not being constant in terms of inclination and distance.

CONCLUSION

The **surface of the temple tips should be reduced** to avoid the detachment of the extremities from the head's curvature. Better to have less surface covered but with higher accuracy.
The connection between temple tip and temple should be improved because it slides out.

Additional improvements to the sliding temple mechanism are necessary to **prevent the spring from slipping out when adjusting the temples**.
The excessive bent of the front, due to the flexible nosepad, leads to an **alteration of the alignment** (see 6.12), and therefore the markings placed on the hinges are not as effective as they would be if the front didn't bend.
The metal frames are not compatible with 3D scanning. Therefore the material has to be changed.

It is necessary to introduce a **reference system** that can not be altered to compensate for the deformation occurring in the photos.
It would be helpful to **3D scan the head of the subjects while still wearing the frame.** After these steps, the frame can be removed, even taken apart, as long as the temple tips' curvature is not altered. The phase of 3D scanning the temple tips needs to happen right after the measuring step, or they must be stored away correctly to **prevent data loss.**

DESIGN IMPLICATION

FUNCTIONALITY CHANGES:

- Reduce the temple tip's width[1] to reduce the chance of deformation (detachment from the curvature of head);
- Maintain sliding temple but introduce a stop mechanism to prevent the temple from sliding out;
- Introduce a rigid nosepad to avoid bending the front part;
- The nosepad requires a design that can fit multiple subjects;
- The metal of the temples clashes with 3D scanning phase;
- Introduce a reference system on the frame to compensate for the photo distortion;

INTERACTION CHANGES:

- Introduce support for the 3D scanning phase;
- Introduce a reference system on the frame to compensate for the photo distortion;
- Take a 3D scan of the subject while wearing the frame instead of taking only photos;
- To reduce the risk of losing data, the 3D scanning of the temple tips step must happen right after the mold has been taken. As an alternative, the temples need to be adequately stored and scanned afterward.

2.2 FIT INCLUSIVITY EVALUATION

RQ: How inclusive is the prototype in terms of fit, for subjects with head deformations?

METHOD

The prototype was placed on the three different 3D printed heads.
Each head simulated a specific scenario of possible users:

- Scenario 1: User with missing ear on left side (image 6.
- Scenario 2: User with flatter nose bridge and asymmetrical ear placement, both in terms of height and depth;
- Scenario 3: User with missing ears on both sides

1 Temple tip width see page 12 of glossary

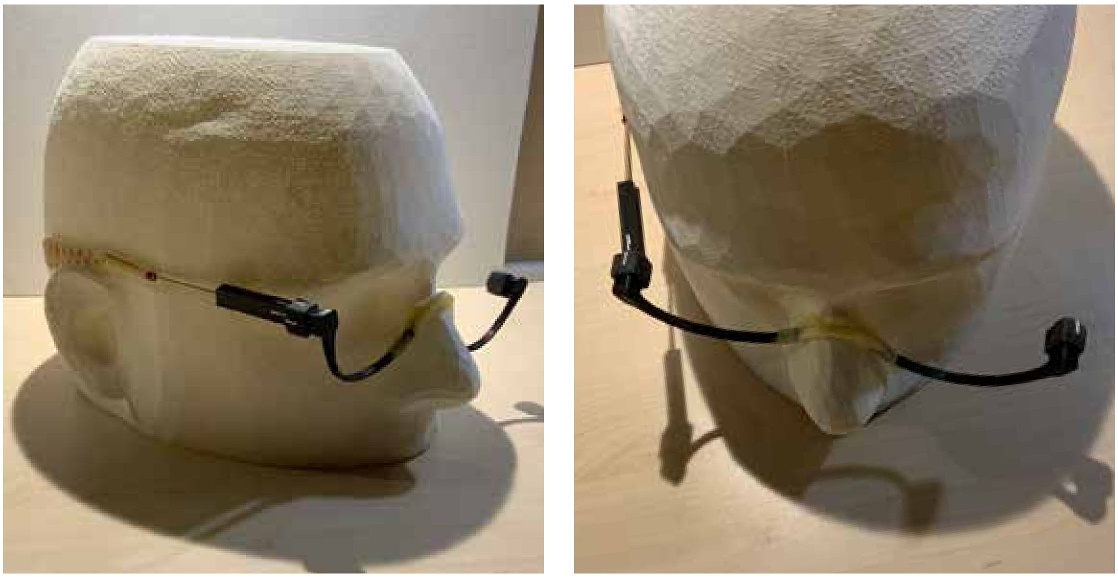


IMAGE 6.13 *Scenario 1: User with missing ear on left side*

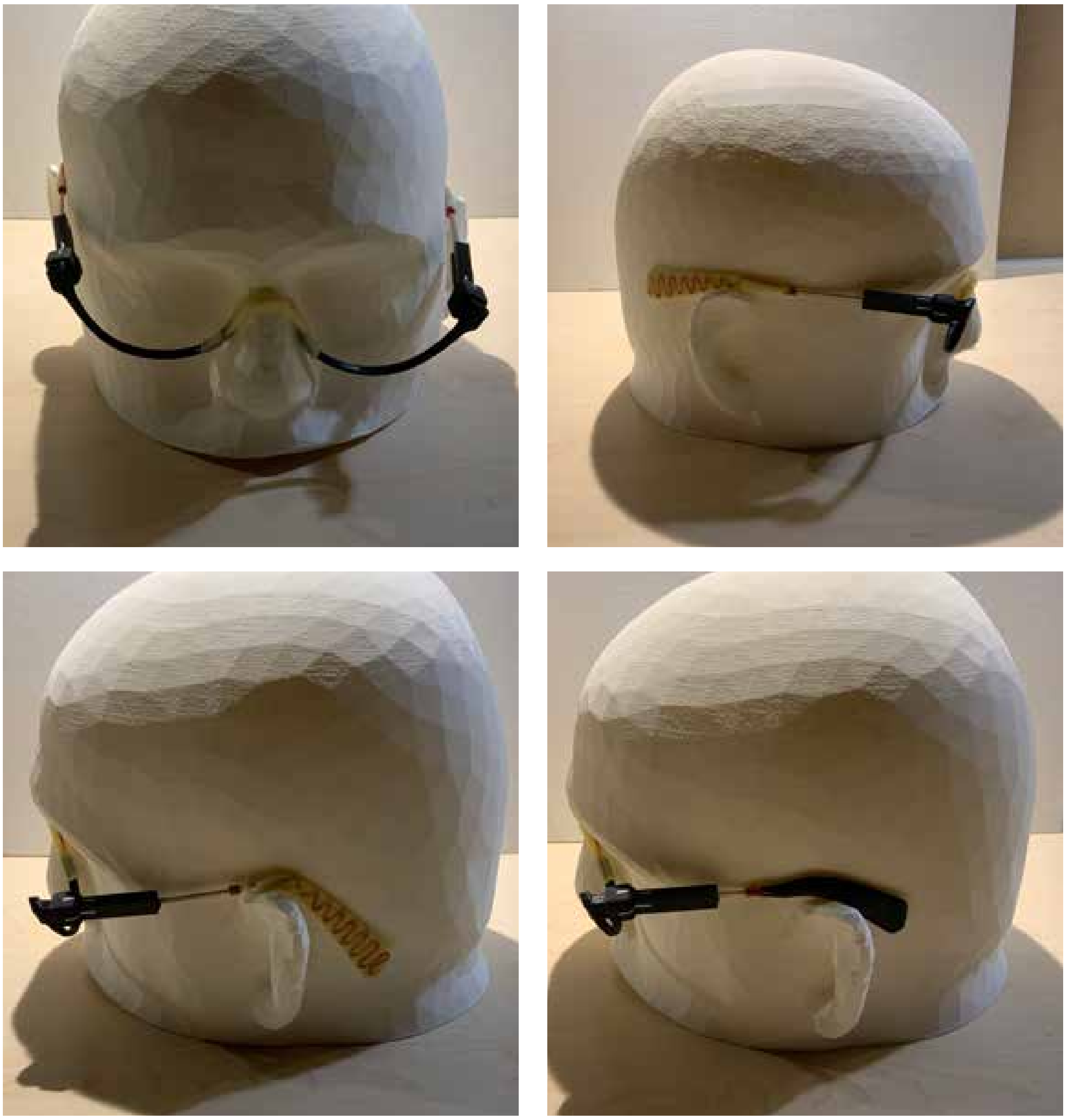


IMAGE 6.14 *Scenario 2: Flatter nose bridge and asymmetrical ear placement;*


IMAGE 6.15 *Scenario 3: User with missing ears;*

OBSERVATION

SCENARIO 1

Image 6.13. The mould is required only on one side.

The front is bent and inclined. The angle information measurable on the hinge is not reliable.

SCENARIO 2

Image 6.14. The frame adapts to the head's facial features, but the front appears too wide, even after adjusting the flexible nosepad. The hinges allow the temples to stand on both ears. The left temple is too wide and detaches from the head, but the smaller version fits appropriately.

SCENARIO 3

Image 6.15. The flexible nosepad is not sufficient to keep the frame in place.

CONCLUSION

SCENARIO 1

The mold is necessary only on one side. The front is bent and deformed due to the missing stand on the left side. Therefore the front does not provide additional information regarding the correct placement of the temple or facilitate the balance of the right side temple. Using only the right temple to take the mold would make more sense..

SCENARIO 2

It would be advised to use a smaller frame. The 360° hinges allow the temples to stand on both ears, even with different placements. The size variation between the temple tips appears to work correctly.

SCENARIO 3

The flexible nosepad is not sufficient to keep the frame in place. Therefore it is not possible to take molds in this scenario.

DESIGN IMPLICATION

- Include different frame sizes;
- Have additional temple tips sizes.

7 FINAL PROPOSAL

Description of the design inspiration and details of the final result.

7 FINAL PROPOSAL

1. AESTHETICS AND MATERIAL INSPIRATION

A Moodboard was created as an inspiration source for the final design to design a tool that expresses certain qualities, such as friendliness, simplicity, and reliability. This moodboard inspired the selection of specific colours, shapes, and materials while designing the product.

Maatbril's navy blue was used as a starting point. Still, since this product also targets kids, often intimidated by measuring eyewear tools, the idea was to create a friendly product. Therefore a warm orange was associated with the blue.
The colour contrast highlights the shift in the use of materials, from blue PA12 to orange silicone.

The goal was to integrate the components that required to be 3D printed in FDM as accent elements.
All edges have been rounded and filleted to increase the sense of friendliness.

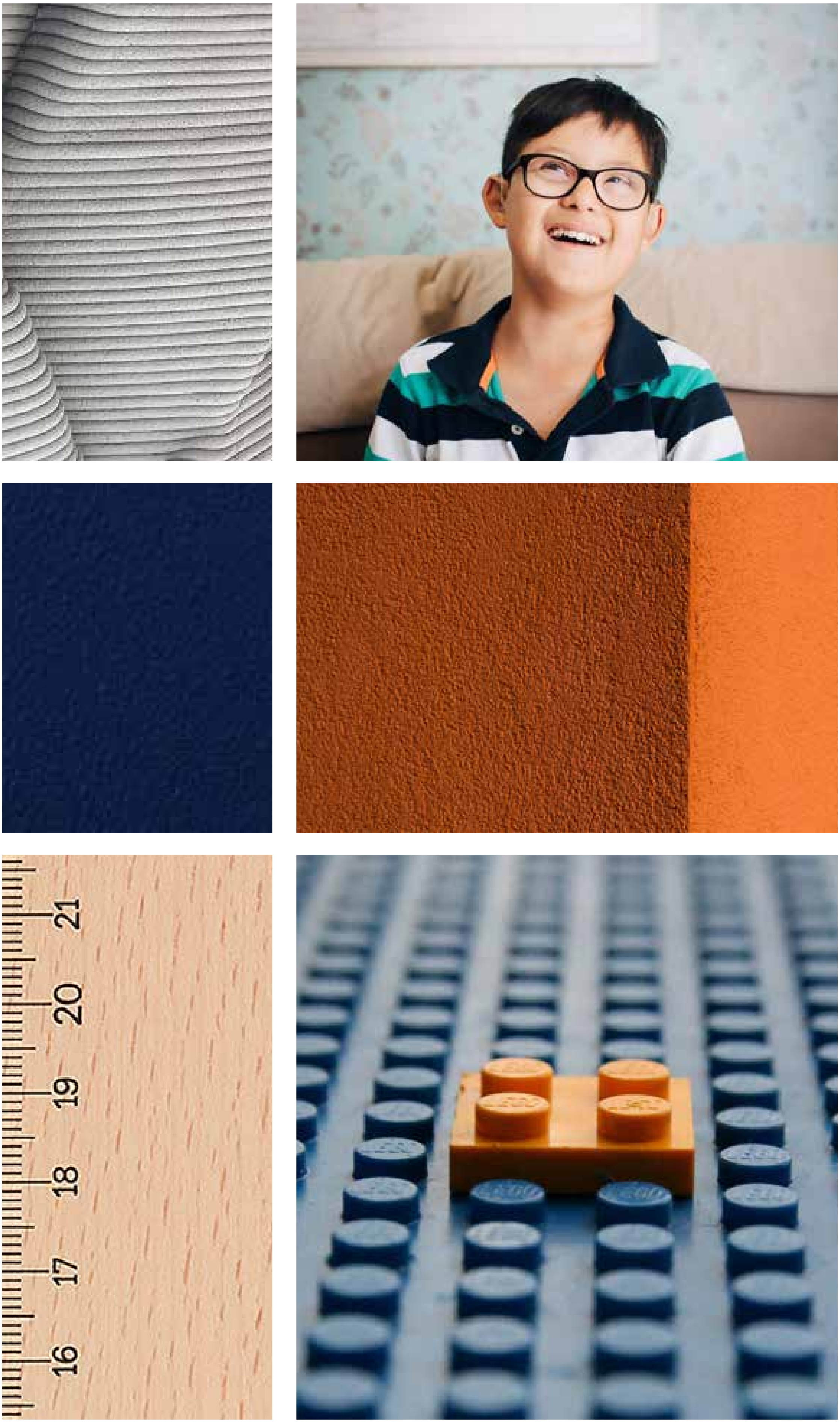


IMAGE 7.1 *Moodboard*

2. FLEX

After extensive research and iterative processes, a final design is created: "**Flex**". This adjustable frame functions as a measuring tool to model the head's curvature in the posterior auricular area. (see image 7.2)

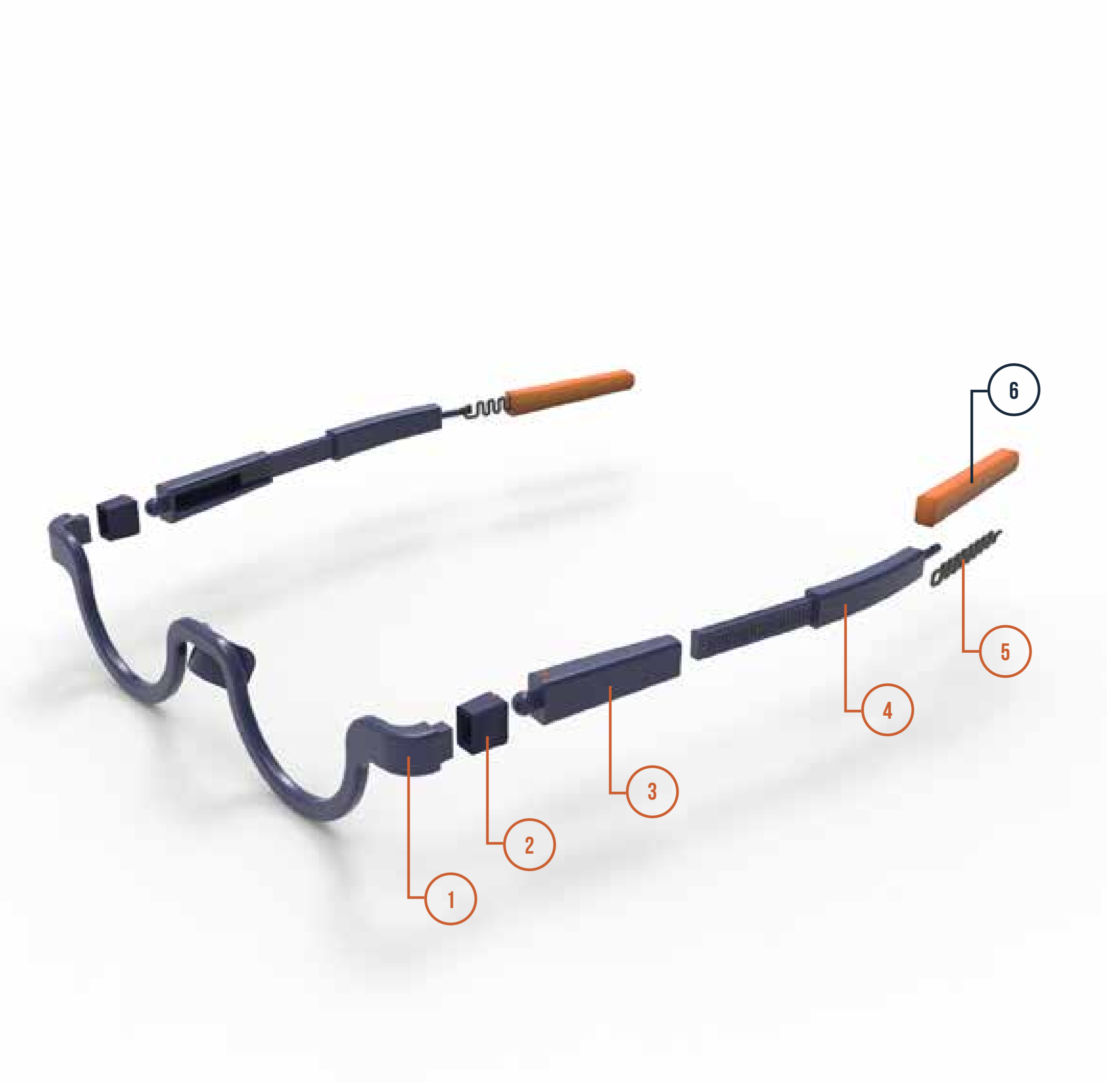
This product is designed to be **adaptable to multiple clients** and be **efficiently reused**.
Its goal is to **gain access to data that is not visible** and can't be easily retrieved during the 3D scanning process of the client's head.

The silicone **temple tips with the aluminium core** can be easily bent and retain the moulded shape. While the client wears the frame, it has to be photographed for reference. Once it is accurately removed, the **temples can be 3D scanned**. The obtained data is used during the glasses' design phase to **increase the output frame's accuracy.**

The tool can be later **easily stored away** and used for the next client.

IMAGE 7.2 *Rendering of "Flex"*

3. MAIN COMPONENTS



COMPONENT LIST

- **1.** Front, 3-D printed in P12;
- **2.** Socket of joint, 3-D printed in TPU;
- **3.** Ball and stud of joint, 3-D printed in P12;
- **4.** Sliding temple, 3-D printed in P12;
- **5.** Aluminum wire, 1mm diameter;
- **6.** Silicone temple tips, shore 30.

4. PRODUCT DETAILING

Details illustrated in image 7.3

FRONT:

Single piece front with a rigid nose pad prevents this component from bending. The rigidity of the component does not compromise the angle measurement between the frame and the temples.

According to the width of the nose, the nosepad will be positioned at different heights.

BALL JOINT:

The hinge is a ball joint that allows a 360° movement of the temple. It is composed of two parts:

- The socket: 3D printed in TPU to allow the ball joint to enter the socket, but keep it in place when the prototype is assembled;
- The ball and stud: which function as the sliding temple's sleeve and serve as a connection between the joint and the temple.

The two components are marked on the top view to visualize the angle between the front and the temple.

SLIDING TEMPLES:

The temple is straight in the part that has to slide inside the stud of the joint and curved in the second half to follow the head's curvature.

The top and external surfaces of the straight part are engraved with lines at a 1mm distance from each other, creating a ruler. The rulers can be observed both from the side and top view as a reference for the 3D scan.

Due to the lack of space, no numerical reference could be added.

TEMPLE TIPS:

The flexible temple tips are composed of an aluminum core bent into a serpentine shape to cover as much surface possible within a silicone involucre.

The silicone has a shore of 20 and a thickness of 4mm. These values were defined to compromise the flexibility and rigidity required for temple tips to mould accurately but without excessive deformation. *(See Appendix X).*

5. COST ESTIMATION

The cost estimation regarding exclusively material cost is of 0.7 €.

The cost estimation is based on material prices in October 2022 and does not include additional costs. See *Appendix Y* for the cost break down.

6. STORYBOARD

IMAGE 7.3 *Product's details*

IMAGE 7.4_ STORYBOARD OF MEASURING PHASE

1. Choose the correct size option between S, M, and L based on the client's facial dimension;

2. Assemble measuring tool during the appointment;

3. Place on the client's face, like glasses;

4. Regulate the temple's length and angle;

5. Align line present on temple tip to superior Auricular root landmark.

6. Take mould of temple tips by gently pressing the silicone temple along the skull's curvature.

7. Take 3D scan of the client while they are wearing the measuring tool;

8. Remove temples gently. Do not modify the curvature of the tips. Detach from the front part if needed.

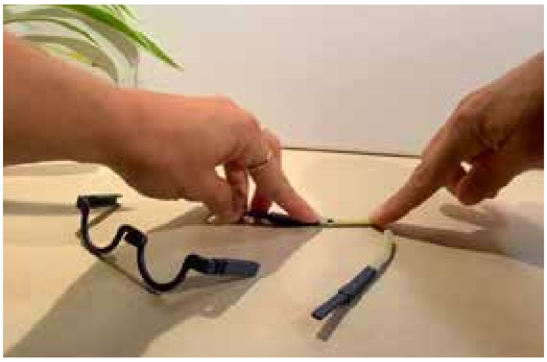
IMAGE 7.5_ STORYBOARD OF 3D SCANNING PHASE OF MEASURING TOOL

1. Assemble stand and reassemble frame, if it has been taken apart during removal from client's head;

2. Place tool on stand;

3. 3D scan the temples using a portable 3D scanner;

4. Remove *Flex* from the stand and disassemble it;



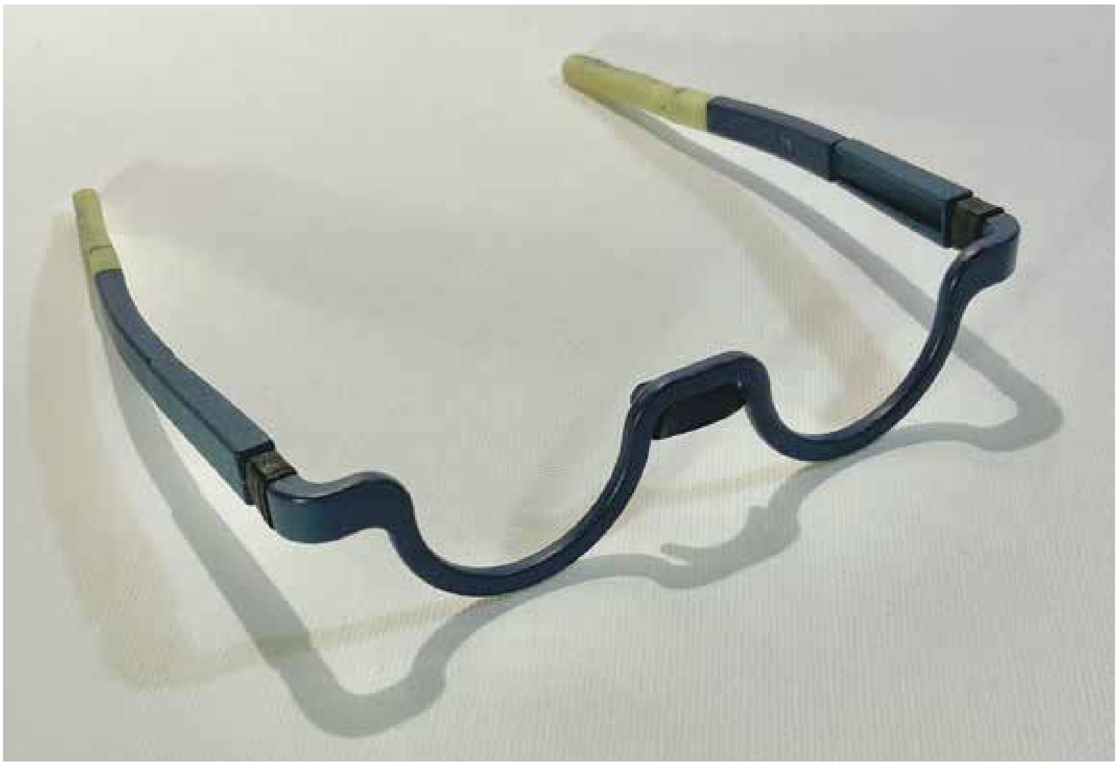
5. Straighten the temple tips by pressing against a flat surface;

6. Store away neatly, ready for the next client;

The modeling phase of the glasses for the client implies:

1. Importing the 3D scan of the temples in rhino on a separate layer;
2. Align the scan of flex's temples with the new model of temple that is being designed
3. Model the new temple's CURVATURE, WIDTH and LENGTH accordingly to the Flex temple 3D scan.
4. Send result for 3D print.

7. FINAL PROTOTYPE



In these photos, the final prototype was placed on 3D printed heads of a child (2.5 years old) and an adult.

It is possible to view the detail of the curved temple tip behind the ear.
The prototype's temple, placed on the adult head, is extended to fit correctly.

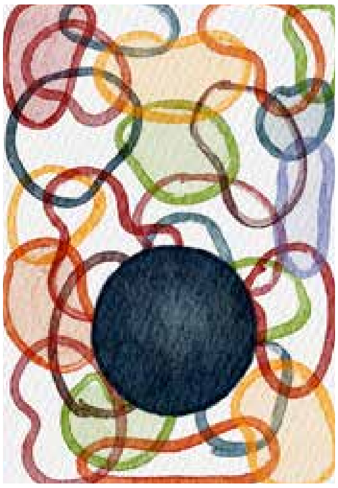
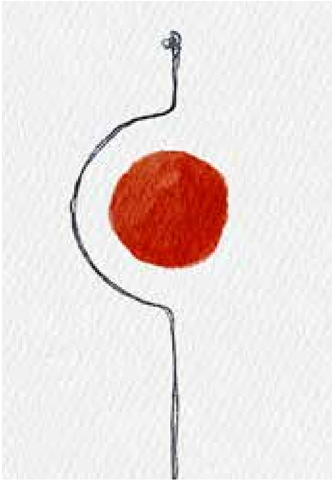
8 RECOMMENDATION & REFLECTION

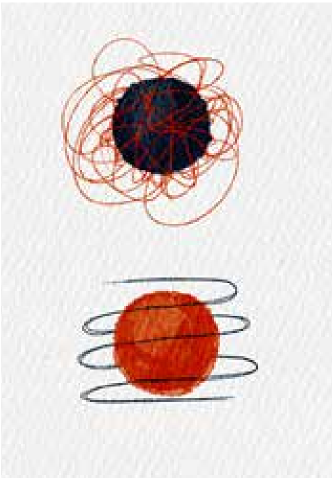
8 RECOMMENDATION & REFLECTION

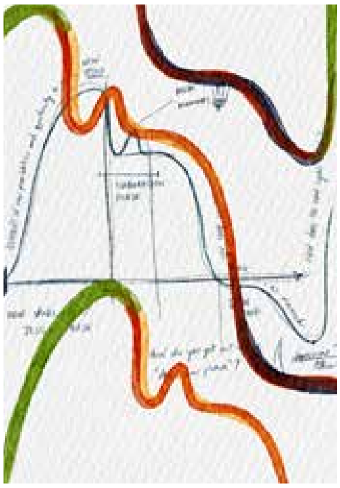
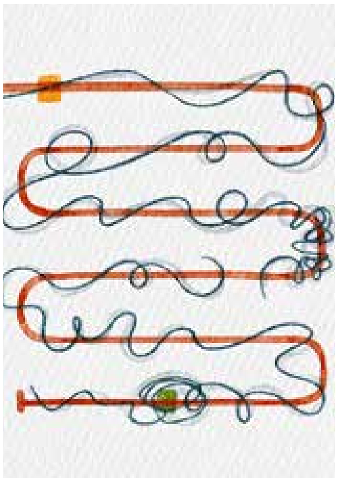
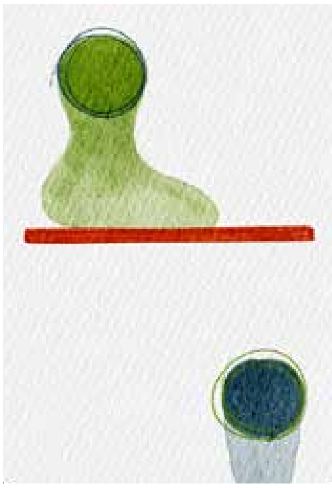
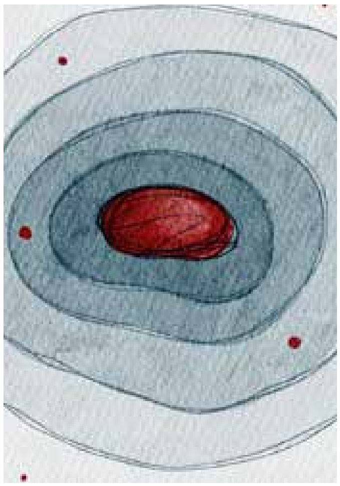
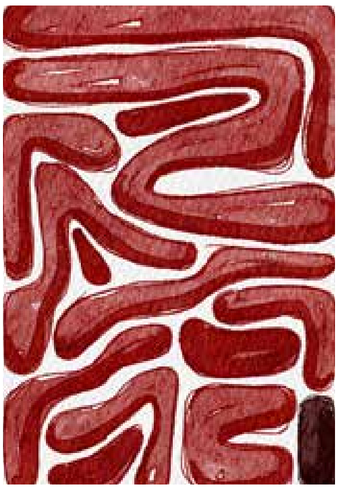
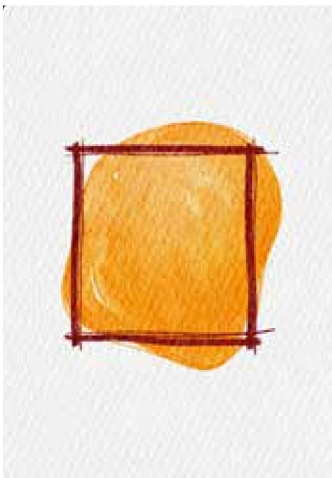
1. RECOMMENDATION

To the person who might use this research as a starting point for another project, I would recommend the following:

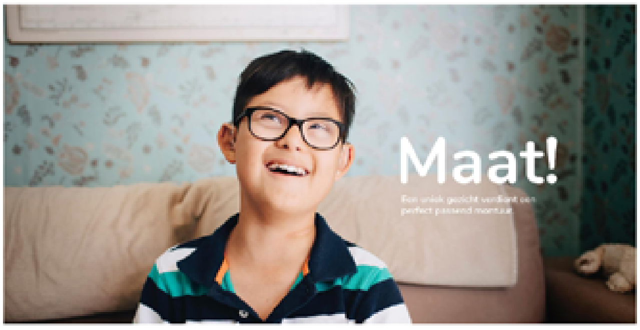
- Define a 3D scan setup and plan prior to taking any scans;
- Processing and taking scans requires quite a lot of time; do not underestimate this aspect;
- The subject variety has a great influence on the results of the research, so select subjects that fit the scope of the research;
- When taking mold samples, includes a physical landmark system;
- Prototyping in SLA has a higher definition, but it was quite time-consuming, so I would advise printing in FDM during the proof of concept phase;
- Testing using 3D-printed heads allows one to simulate a variety of situations, but it does not substitute testing with the actual subject.




APPENDIX



Graduation Project for IPD specialisation

Improved personalized design of temple tips for optimal comfort and grip

STAKEHOLDERS

Maat!

Maat! is an Amsterdam-based MedTech start-up company specialized in customized eyewear tailored to the Medical Sector. We use a combination of 3D-scanning and 3D-printing technology to produce glasses made-to-measure with the perfect fit. In close cooperation with hospitals, ophthalmologists and other medical professionals we design and produce eyewear for children and adults with a special pathology such as Down syndrome, Goldenhar or craniofacial anomalies. Maat! developed a patented technology to compensate for any asymmetry leading to perfectly fitted eyewear.

The graduation project is part of a larger project that falls under the guidance of Fieldlap UPPS, an initiative that stimulates innovations around Ultra Personalized Products and Services. Within the Fieldlab UPPS it is possible to collect 3D data and subject it to extensive analyses, to study parametric design techniques and flexible production techniques and ultimately also to evaluate the ultra-personalized products and processes in a lab setting. The Fieldlab UPPS is set up for the Topsector Creatieve Industrie and is coordinated by the TU Delft Faculty of Industrial Design Engineering.

ASSIGNMENT

3D-printed eyewear, made to measure

PROBLEM

REQUEST

Glasses that slide down the nose or hurt behind the ears are very common complaints especially for people with non standard facial dimensions. With our innovative technology we've been able to overcome this problem. Nevertheless the area behind the ear is difficult to reach with a scanner therefore the dimensions and shape of the temple tips are not as accurate as the rest of the frame. Can a common denominator for this area be found for certain target groups (age, needs, characteristics of the head related to medical issues) or can the position and shape of the outer ear predict the shape of the area behind the ears?

PROPOSED APPROACH

Challenge

1. Gather 3D scans of the area behind the ears of the target group and do statistical shape analysis;
2. Design temple tips of the frames, based on the outcome of the analyses, for people in the target groups to test;
3. Do fit mapping of the redesigned temple tips.

FOR MORE INFORMATION

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Contact: Jan Berend Zweerts > janberend@maatbril.nl

www.maatbril.nl or www.upps.nl

APPENDIX B_ TEMPLE TIP ANALYSIS TABLE

MODEL	USER[1]	ADAPTABILITY OF DESIGN[2]	GRIP[3]
MODEL 1	No specifications	High	Medium
MODEL 2	No specifications	Low - Material is molded manually and not 3d printed	Low
MODEL 3	User that have missing or severe in ear placement; Not compatible with wheelchair headrest due to push off.	High	Low (Medium if head band is placed)
MODEL 4	User that require extra grip in posterior auricular area to compensate for poor nose support (smaller or missing nose). Compatible with wheel chair head rest.	High	Medium (if curvature of temple is correct)
MODEL5	User with Bone Conduction Implant	Medium- Influenced by positioning of BCI;	High with headband
MODEL 6	User with missing ear(s) and/or severe cranial deformation/asymmetry.	High	3 with headband

1 USER = USER OF MAATBRILL FRAMES
2 ADAPTABILITY OF DESIGN= HOW EASY IT IS TO MODIFY THE TEMPLE TIP DESIGN BASED ON MATERIAL AND PRODUCTION;
3 GRIP= STABILITY THAT THE TEMPLE TIP ENSURES. (FROM 1=LOW TO 3=HIGH

APPENDIX C_ AGE AND GENDER DISTRIBUTION OF CLIENTS

Item #	Geslacht	Leeftijdsgroep
A1583	Vrouw	16-25
A1752	Man	26-40
A2076	Man	<15
A2098	Man	
A2111	Man	
A2115	Man	
A2116	Vrouw	
A2119	Man	
A2123	Man	
A2125	Man	
A2132	Man	
A2133	Vrouw	
A2136	Man	16-25
A2143	Vrouw	
A2150	Vrouw	16-25
A2152	Vrouw	
A2157	Man	
A2158	Man	
A2161	Vrouw	
A2163	Vrouw	
A2170	Man	16-25
A2171	Vrouw	
A2176	Man	
A2181	Man	
A2183	Man	
A2186	Vrouw	
A2187	Man	
A2194	Man	
A2202	Man	
A2203	Man	
A2204	Man	
A2208	Vrouw	
A2210	Man	
A2214	Vrouw	
A2221	Man	
A2231	Vrouw	
A2239	Vrouw	
A2241	Vrouw	
A2243	Man	
A2244	Man	
A2245	Vrouw	
A2246	Vrouw	
A2258	Vrouw	
A2267	Man	
A2268	Vrouw	
A2269	Vrouw	
A2272	Man	
A2274	Man	
A2279	Vrouw	
A2280	Man	
A2288	Man	
A2291	Man	
A2294	Man	
A2299	Man	
A2302	Man	
A2303	Vrouw	
A2306	Man	
A2312	Man	
A2316	Man	
A2319	Man	16-25
A2323	Man	
A2324	Man	
A2328	Vrouw	
A2337	Man	
A2338	Man	
A2341	Vrouw	
A2343	Man	
A2345	Man	
A2351	Man	
A2354	Man	
A2355	Man	
A2358	Vrouw	
A2360	Man	
A2361	Vrouw	
A2365	Man	
A2368	Man	
A2369	Man	
A2370	Man	
A2371	Man	
A2373	Man	
A2374	Man	
A2375	Man	

Item #	Geslacht	Leeftijdsgroep
A2376	Man	
A2377	Man	
A2380	Man	
A2381	Man	
A2382	Vrouw	
A2394	Vrouw	
A2396	Man	
A2397	Man	
A2404	Vrouw	
A2406	Vrouw	
A2407	Vrouw	
A2408	Man	
A2409	Man	
A2410	Man	
A2411		
A2412		
A2417		
A2420	Man	
A2421		
A2422	Vrouw	
A2426	Vrouw	
A2431	Man	
A2432	Vrouw	
A2433		
A2438	Man	
A2439	Man	
A2443		
A2444		
A2446	Vrouw	
A2447	Vrouw	<15
A2448	Vrouw	
A2450	Vrouw	
A2451	Vrouw	
A2452	Man	
A2453	Man	
A2454		
A2455	Man	
A2456		
A2458	Vrouw	
A2459		
A2460	Man	16-25
A2461		
A2463	Man	
A2464	Vrouw	
A2465	Man	<15
A2466	Man	<15
A2467	Vrouw	26-40
A2469		>55
A2470	Man	
A2472	Vrouw	26-40
A2473	Man	>55
A2474	Man	<15
A2475	Man	<15
A2476	Vrouw	<15
A2477	Vrouw	<15
A2479	Man	<15
A2481	Vrouw	16-25
A2485	Vrouw	26-40
A2486	Man	16-25
A2487	Man	>55
A2492	Man	<15
A2493		41-55
A2496	Man	<15
A2497	Man	<15
A2499	Man	26-40
A2500	Man	
A2502		16-25
A2503	Man	26-40
A2504	Man	16-25
A2505		<15
A2506	Man	<15
A2507		>55
A2508		<15
A2510	Man	<15
A2513	Vrouw	<15
A2517	Man	<15
A2518	Vrouw	<15
A2519	Vrouw	>55
A2520	Man	16-25
A2521	Man	>55
A2524		<15
A2525		<15

Item #	Geslacht	Leeftijdsgroep
A2527		16-25
A2528		26-40
A2529	Vrouw	<15
A2534	Man	<15
A2535	Vrouw	<15
A2536	Man	<15
A2537	Man	>55
A2538		<15
A2539	Man	<15
A2540		26-40
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A2542	Vrouw	>55
A2543	Man	<15
A2544	Man	26-40
A2545	Man	41-55
A2546	Vrouw	<15
A2547	Man	>55
A2552	Man	<15
A2558	Vrouw	>55
A2559	Vrouw	16-25
A2560	Man	<15
A2561	Man	>55
A2563	Man	<15
A2564	Vrouw	
A2565	Man	41-55
A2566	Man	<15
A2567	Man	41-55
A2570	Vrouw	16-25
A2571		>55
A2572	Vrouw	41-55
A2578	Vrouw	41-55
A2579		16-25
A2580	Vrouw	<15
A2582	Man	<15
A2583	Vrouw	<15
A2584	Man	26-40
A2586	Man	26-40
A2587	Vrouw	26-40
A2588	Vrouw	16-25
A2589	Man	41-55
A2590		41-55
A2591	Man	<15
A2592	Vrouw	<15
A2593	Vrouw	26-40
A2594		<15
A2596	Man	<15
A2598	Man	<15
A2599	Man	16-25
A2602	Man	16-25
A2603	Man	>55
A2604	Man	41-55
A2606	Vrouw	>55
A2607	Vrouw	>55
A2609	Vrouw	26-40
A2610	Man	<15
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A2619	Man	<15
A2620	Vrouw	<15
A2622	Vrouw	>55
A2624	Vrouw	>55
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A2627	Man	<15
A2628	Man	<15
A2629	Man	>55
A2631	Vrouw	>55
A2635		<15
A2636	Vrouw	>55
A2637		26-40
A2638	Vrouw	41-55
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A2641	Man	<15
A2642	Man	<15
A2643	Vrouw	41-55
A2645	Man	<15
A2647		<15
A2648		<15
A2649		<15

Item #	Geslacht	Leeftijds
A2650	Vrouw	16-25
A2651	Man	<15
A2653		>55
A2654		<15
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A2660	Vrouw	41-55
A2661	Vrouw	<15
A2662		<15
A2663	Vrouw	>55
A2664	Man	<15
A2668	Man	>55
A2669	Man	26-40
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A2674	Man	>55
A2675	Man	<15
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A2678	Vrouw	41-55
A2679	Vrouw	<15
A2680		<15
A2681	Vrouw	26-40
A2684	Vrouw	<15
A2687	Man	<15
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A2690	Man	>55
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A2692	Vrouw	41-55
A2693	Man	41-55
A2694	Vrouw	<15
A2695		
A2696		<15
A2698	Man	<15
A2699		<15
A2700		
A2701	Man	16-25
A2702	Man	16-25
A2703	Man	<15
A2705	Man	<15
A2708	Vrouw	26-40
A2709	Man	41-55
A2710	Man	>55
A2713		<15
A2715	Vrouw	16-25
A2716	Man	
A2717		>55
A2718		>55
A2719	Man	<15
A2720		41-55
A2721		26-40
A2723	Man	<15
A2724	Man	<15
A2725	Man	16-25
A2726	Man	<15
A2728	Vrouw	41-55
A2732		<15
A2733	Vrouw	>55
A2734	Vrouw	26-40
A2740	Man	<15
A2741	Man	<15
A2742	Man	41-55
A2743	Man	<15
A2744	Vrouw	<15
A2745		41-55
A2747		26-40
A2748		<15
A2749	Man	<15
A2750	Vrouw	>55
A2751	Vrouw	16-25
A2752		<15
A2753	Vrouw	>55
A2754	Vrouw	>55
A2756		<15
A2757		>55
A2760		<15
A2761		41-55
A2762	Vrouw	<15
A2764	Vrouw	<15
A2765	Man	<15

APPENDIX D_ HOW TO READ THE "PERSONA" SHEET

*Fictional name

GERRIT VAN DIJK, 11

11 years old since 46% of clients are below the age of 15.

Male, Dutch

Down syndrome

First syndrome in terms of statistical occurrence.

Verbal & Non-verbal communication

Movement level

Refers to the uncontrollable movement that might occur during the scan.

3D SCAN WITH MAATBRIL SCANNER

These are actual scans obtained with the Occipital 3d scanner.

TEMPLE TIP TYPE

The temple tip type has been assigned based on the requirements expressed in the "temple tip analysis" paragraph.

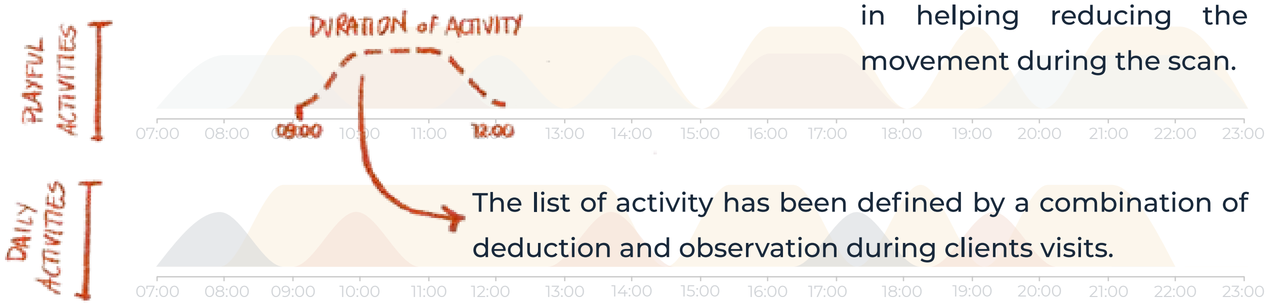
Left Center Right name

Location of scan: **House**

Aid during scan: **Not required**

Refers to the aid given by a parent or caretaker in helping reducing the movement during the scan.

DAY ACTIVITIES



The list of activity has been defined by a combination of deduction and observation during clients visits.

Wearing glass Play time Screen time Eating Washing ACTIVITIES

With these glasses his life has changes, I can see it from his smile how his friends interact with him now.

Lara, Gerrit's mother

The quotes have been cited from previous parents or caretakers feedbacks.

APPENDIX E_ WHAT IS A MORPHOLOGICAL ANOMALY

A morphologic anomaly is an anatomic (microscopic and macroscopic) phenotype that represents a substantial departure from the appropriate reference population[2]. A major morphologic anomaly involves problems of position and shape, therefore also problems related to symmetry or asymmetry, and is often related to pathologies, especially rare diseases, and has a significant consequence for the health or appearance of the individual. **Morphologic anomalies include malformations, deformations, disruptions, dysplasias, or a sequence of the above**:

- *Malformation* is a non-progressive, congenital morphologic anomaly of a single organ or body part (in our case, the head) due to an alteration of the primary developmental program. Malformations typically arise during the embryonic period.
- *Deformation* is an altered shape or position of a body part due to aberrant mechanical force(s) that distorts an otherwise normal structure, which may result in loss of symmetry, altered alignment, abnormal position, or distorted configuration. Deformations can occur at any time in gestation or after birth and are causally heterogeneous: the result is therefore unpredictable and "anarchic".
- *Disruption* is a non-progressive, congenital morphologic anomaly due to the breakdown of a body structure that had a normal developmental potential. The term refers to the "breaking apart" of body structures that are otherwise developing normally. It is a term usually used to describe events happening in utero. As the deformations, disruptions are unpredictable.
- *Dysplasia* is a morphologic anomaly arising either prenatally or postnatally from dynamic or ongoing alteration of cellular constitution, tissue organization or function within a specific organ or a specific tissue type. The defect may involve all of the anatomic sites in which the affected tissue element is present, consequently, there can be widespread involvement, which is not confined to a single organ. Since the tissue itself is intrinsically abnormal, the clinical impact may persist or worsen as long as that tissue continues to grow or function.

With the exception of the latter, the anomalies listed above can occur as an isolated phenomenon or as a component manifestation of broader patterns, including syndromes. As well, the same condition can result in either a malformation or a deformation, depending on the stage when it occurs[1].
Some anomalies affect only the size of the head, but not its shape (scale anomalies). They are neither a real malformation, nor a deformation, as only the dimension of the skull varies, but the proportions remain intact (*microcephaly, macrocephaly*).

When modeling the client's eyeglasses, it is decisive to identify if the results are

1 AS AN EXAMPLE, HYDROCEPHALY, WHEN CAUSED BY MENINGITIS IT IS A DEFORMATION, IF INSTEAD IT IS CAUSED BY A CONGENITAL PATHOLOGY, THEN IT IS A MALFORMATION (I.E.: DIFFERENT CAUSES, BUT SIMILAR EFFECTS).

predictable and under which large scheme they can be included.

As we have seen, in the case of a malformation, **there is a wide range of anomalies that can be forecasted. For instance, in Down syndrome, we usually have: a closer distance of the eyes, longer eyelashes, a flatter nose, lower ears, etc. Consequently, the eyeglasses for a Down patient, shall have lenses closer to each other, give sufficient space to the eyelashes, have specially designed nose pads, etc. It is crucial to know which pathology or syndrome the client is suffering from in order to prepare a model with a correct variability of those parameters.** Therefore, an analytic list of the most common pathologies and syndromes that may affect the shape of the clients' head is included in Table X (disease statistical chart) , along with a description of the most common morphologic anomalies associated with them, focusing on those conditions that are more frequent and that usually involve eyesight problems.

On the contrary, when dealing with clients who live with a **deformation or a disruption, of which morphologic anomalies are unpredictable by definition, it is practically impossible to trace them back to common parameters.**
Also to note, that malformations are usually irreversible, while deformations may be reversible, depending on how longstanding they are and how much growth has occurred subsequent to the initial compressive forces: therefore any forecast models in the case of deformation is even more complex and unpredictable.

The **human skull** (cephalic skeleton) is the bone structure that forms the head in the human skeleton. It is composed of 29 bones, and forms a cavity for the brain, supports the features of the face, and contains the main human sensory organs. Like the skulls of other vertebrates, it protects the brain from injury.
In humans, the braincase, or *neurocranium,* is usually considered to include the following eight bones:

- 1 ethmoid bone
- 1 frontal bone
- 1 occipital bone
- 2 parietal bones
- 1 sphenoid bone
- 2 temporal bones

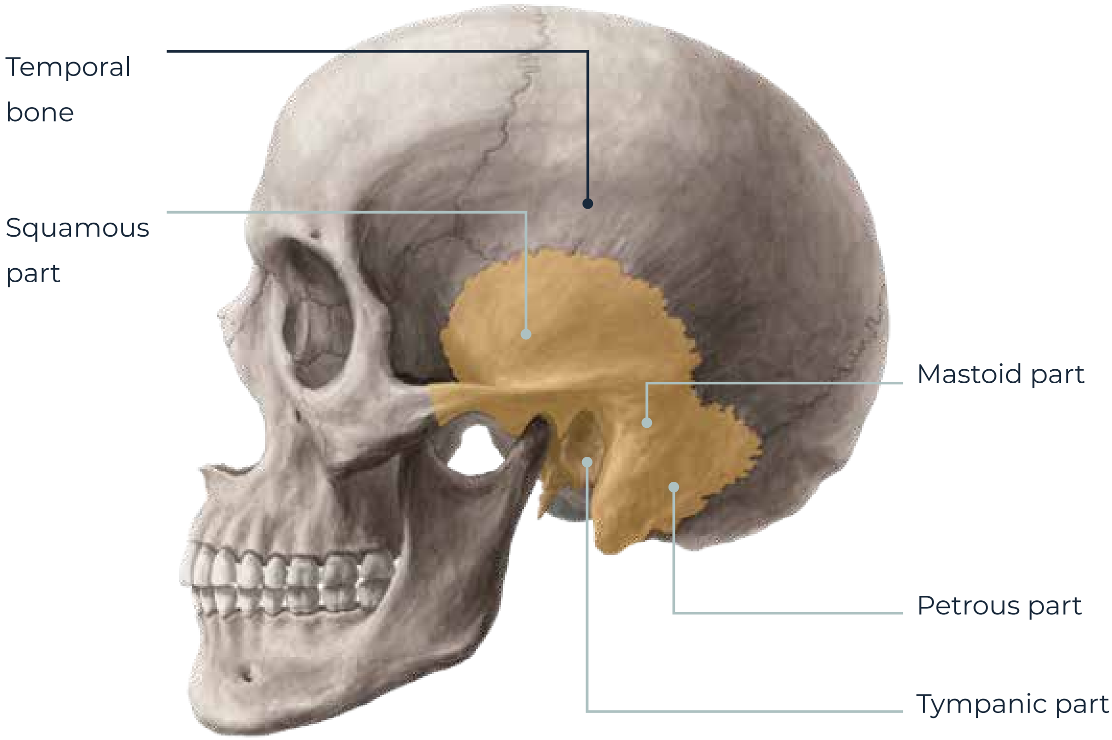


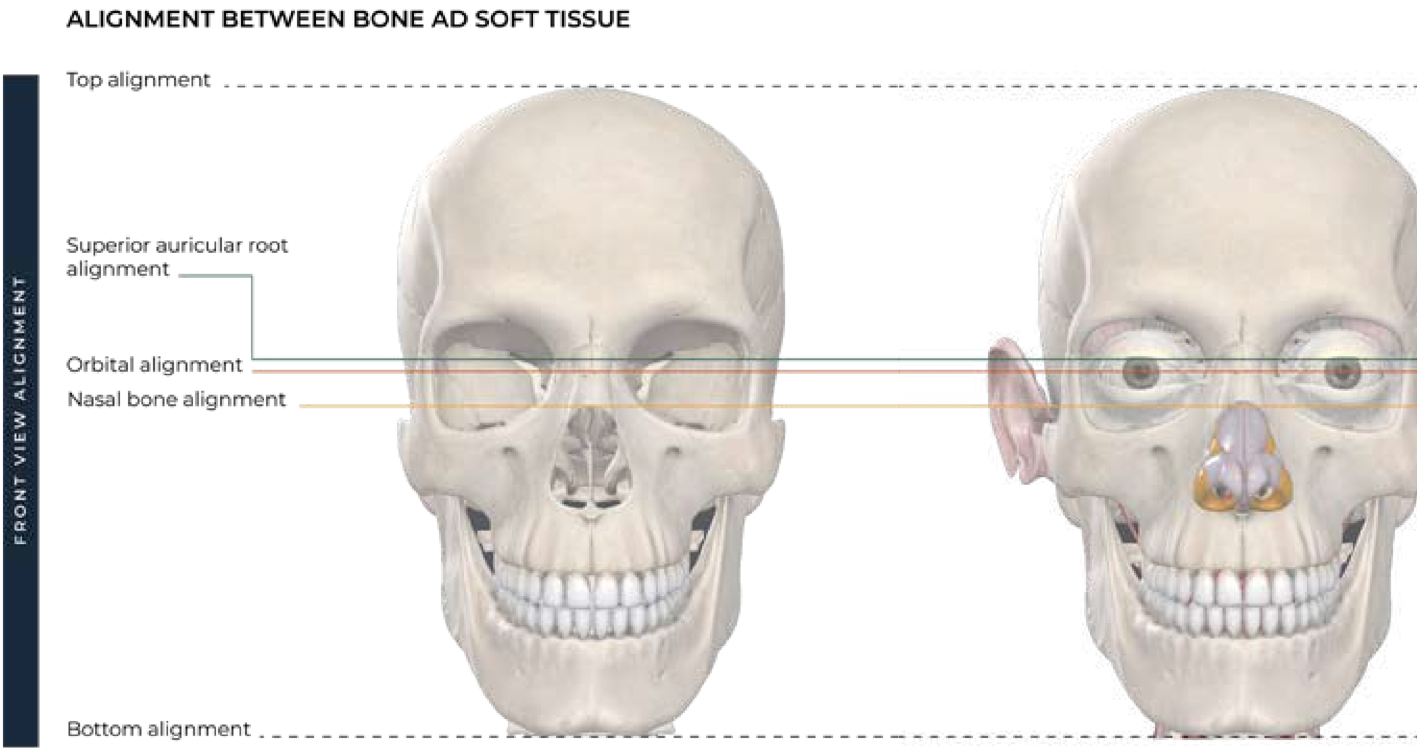
IMAGE X *Temporal bone parts*

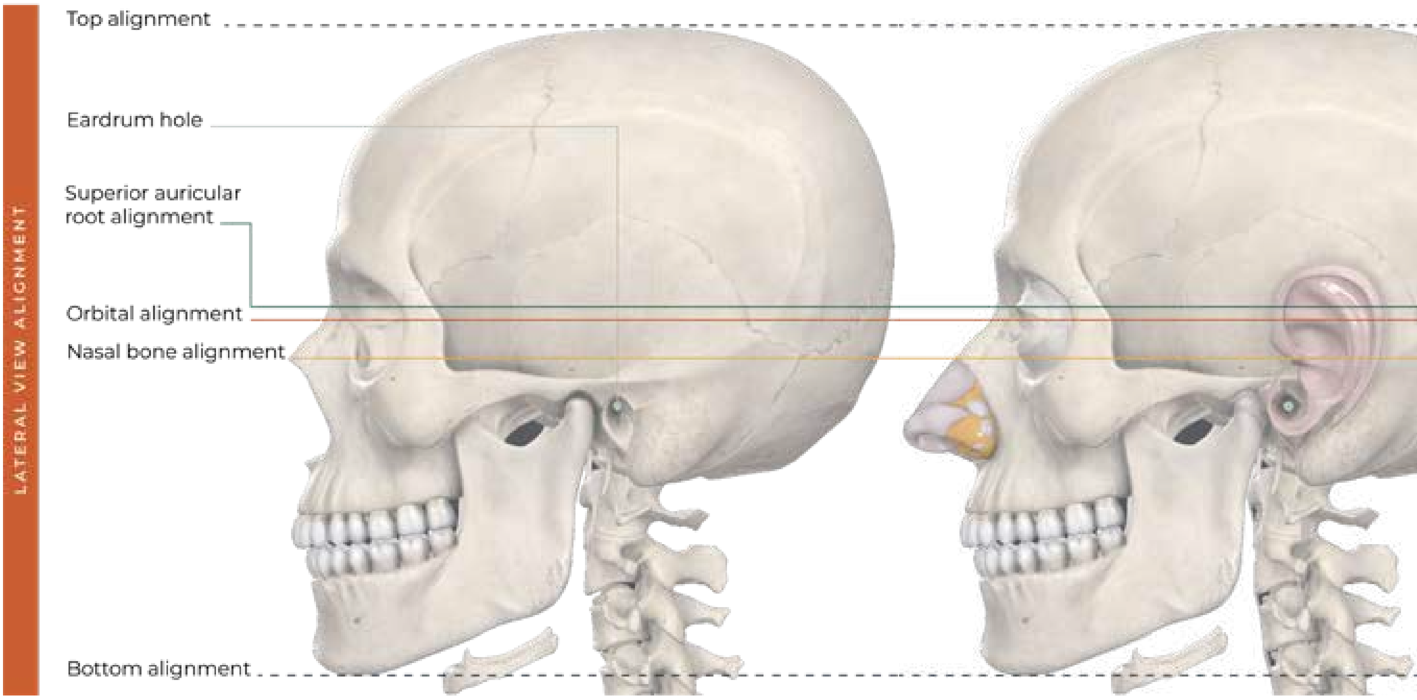
Since the brain case is a continuous surface, it is obvious that any anomalies of any of its bones reflect and interfere with other skull bones. However, the bones that mainly impact on the shape of the temple tips are those situated at the sides and base of the skull, lateral to the temporal lobes of the cerebral cortex, i.e., behind the ears, which are called **temporal bones**[28]**.**

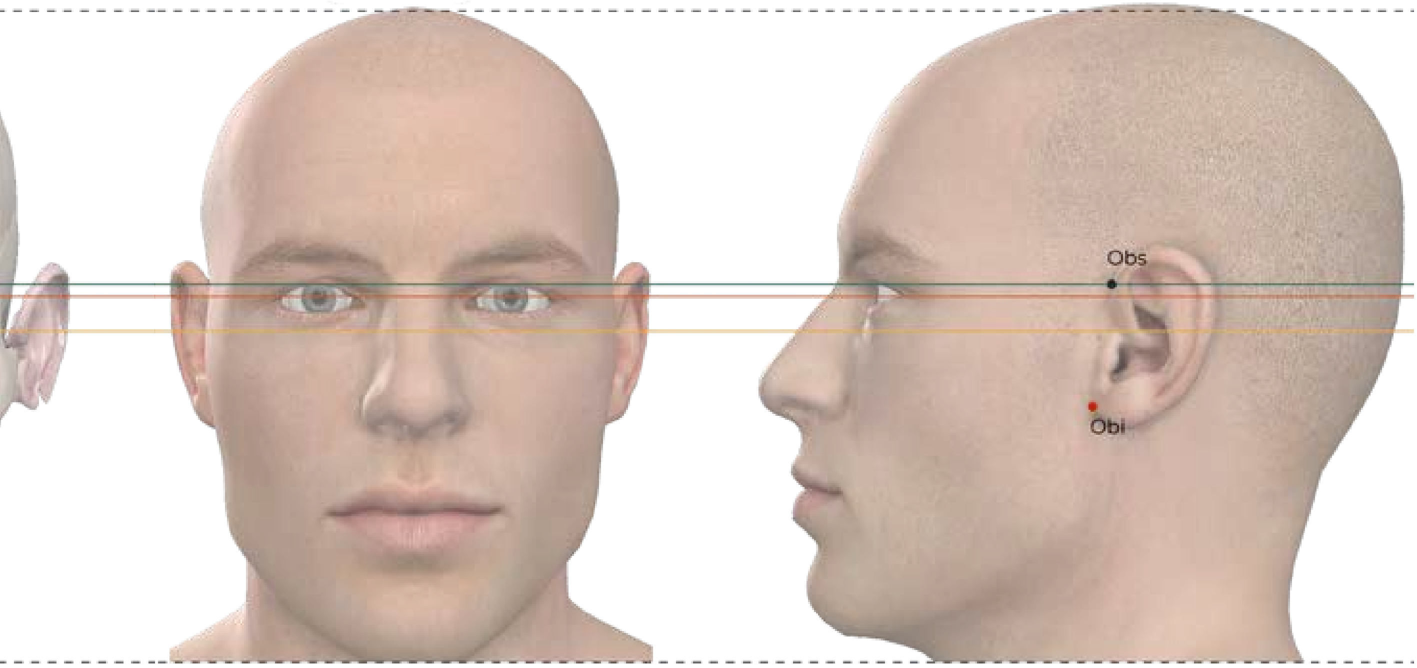
They consist of four parts, the squamous, mastoid, petrous and tympanic parts[1].

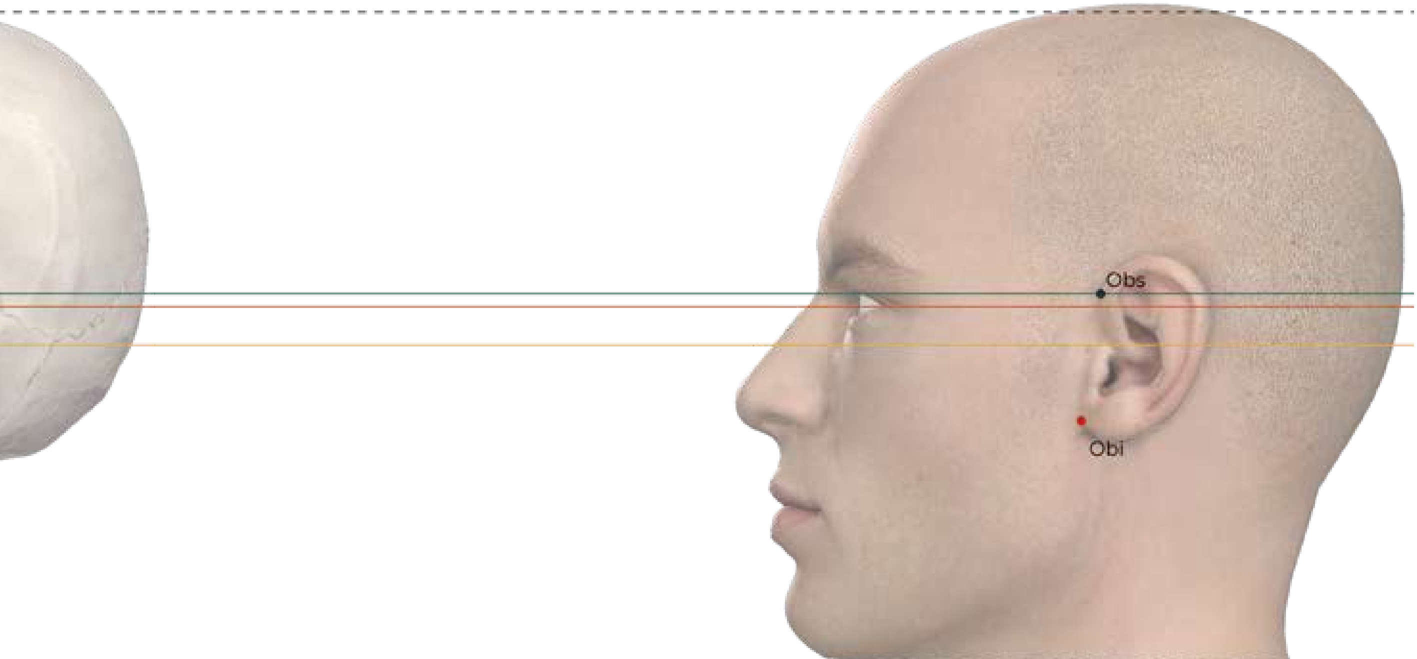
The **face** is the front of a humans head that features three of the head's sense organs, the eyes, nose, and mouth.
The face is crucial for human identity, and developmental malformations or acquired deformations may affect the psyche adversely.
The shape of the face is influenced by the bone structure of the skull, and each face is unique through the anatomical variation present in the bones of the *viscerocranium* (and *neurocranium*). The bones involved in shaping the face are mainly the maxilla, mandible, nasal bone and zygomatic bone. Also important are various soft tissues, such as fat, hair and skin.

1 The squamous part is the largest and most superiorly positioned relative to the rest of the bone. The zygomatic process is a long, arched process projecting from the lower region of the squamous part and it articulates with the zygomatic bone. Posteroinferior to the squamous is the mastoid part. Fused with the squamous and mastoid parts and between the sphenoid and occipital bones lies the petrous part, which is shaped like a pyramid. The tympanic part is relatively small and lies inferior to the squamous part, anterior to the mastoid part, and superior to the styloid process.


ALIGNMENT BETWEEN BONE AD SOFT TISSUE
FRONT VIEW ALIGNMENT
Top alignment
Superior auricular root alignment
Orbital alignment
Nasal bone alignment
Bottom alignment


LATERAL VIEW ALIGNMENT
Top alignment
Eardrum hole
Superior auricular root alignment
Orbital alignment
Nasal bone alignment
Bottom alignment


Obs
Obi


Obs
Obi

APPENDIX G_ CAPULOMETRIC LANDMARKS INCLUDING THEIR ABBREVIATIONS, DEFINITIONS, AND VARIOUS CLASSIFICATIONS[29]

Landmark	3D Notation	Definition
Median Points		
Columella	c'	Midpoint of the nasal columella crest, intersecting a line between the two *cs'* points
Glabella	g'	Most anterior midline point on the forehead, in the region of the superciliary ridges
Gnathion[a]	gn'	Median point halfway between *pg'* and *me'*
Labiale inferius	li'	Midpoint of the vermilion border of the lower lip (identical to labrale inferius)
Labiale superius	ls'	Midpoint of the vermilion border of the upper lip (not identical to and not to be confused for Labrale superius)
Menton[a]	me'	Most inferior median point of the chin
Metopion	m'	Furthest chord length perpendicular to the *n'-b'* chord
Mid-philtrum[b]	mp'	Point midway between *sn'* and *ls'*, in the median plane
Nasion	n'	Point directly anterior to the nasofrontal suture, in the midline, overlying *n*
Nasale inferius[c]	ni'	Most inferior point of the apex nasi. Not locatable on upturned noses
Ophryon	on'	Point, at the mid-plane, of a line tangent to the upper limits of the eyebrows. Can be used as an approximation of glabella when the latter is not clearly identifiable
Opisthocranion	op'	Most prominent posterior point overlying the occipital bone, which produces the greatest head length from glabella
Pogonion[d]	pg'	Most anterior midpoint of the chin, located on the skin surface anterior to the identical bony landmark of the mandible
Pronasale[d]	prn'	The most anteriorly protruded point of the apex nasi. In the case of a bifid nose, the more protruding tip is chosen
Rhinion[b]	rhi'	Point overlying *rhi*, at the end of the internasal suture where bone ends and cartilage begins
Sellion	se'	Deepest midline point of the nasofronal angle; not a substitute for *n'*
Stomion	sto'	Midline point of the labial fissure when the lips are closed naturally, with teeth shut in the natural position; if not in the midline, then below the philtrum
Subnasale	sn'	Median point at the junction between the lower border of the nasal septum and the philtrum area
Supramentale	sm'	Deepest midline point of the mentolabial sulcus
Trichion	tr'	Midpoint of the hairline; determined on a widow's peak as the projection through the midline from both sides
Vertex	v'	Most superior point of the head
Bilateral Points		
Alar curvature point[d]	ac'	The most posterolateral point of the curvature of the base line of each nasal ala
Alare	al'	The most lateral point on the nasal ala
Antitragion[c]	at'	The apex of the antitragus
Corneal apex[c]	ca'	The apex of the cornea. In an anterior view, this landmark is analogous to Farkas' Pupil (p)[d]
Cheilion	ch'	Outer corners of the mouth where the outer edges of the upper and lower vermilions meet
Ciliare lateralis[c]	cl'	Most lateral peak / extent of the eyebrow
Ciliare medialis[c]	cm'	Most medial and inferior corner of the eyebrow (not present when the eyebrows cross glabella)
Columella superius	cs'	Most superior point on each columella crest of the nose, level with the top of the corresponding nostril
Crista philtri landmark[d]	cph'	Point on each elevated margin of the philtrum just before projection to the vermilion line
Endocanthion	en'	Most medial point of the palpebral fissure, at the inner commissure of the eye; best seen when subject is gazing upward
Exocanthion	ex'	Most lateral point of the palpebral fissure, at the outer commissure of the eye; best seen when subject is gazing upward
Euryon	eu'	Most lateral point of the head, located in the parietal region
Frontotemporale[d]	ft'	Point of concavity on each side of the forehead above the supraorbital rim, lateral to the elevation of the linea temporalis
Frontozygomaticus	fz'	Most lateral point on the frontozygomatic suture, identified by palpation of the suture line at the superolateral corner of the orbit
Gonion[d]	go'	Most lateral point on the mandibular angle, adjacent to go, identified by palpation
Inferior lacrimal papilla[c]	ilp'	The apex of the inferior lacrimal papilla
Infra second-molar	iM_2'	Point overlying *ecm* $_2$, the midpoint of the alveolus of the second mandibular molar
Intertragion[c]	it'	Apex of groove between the tragus and antitragus
Maxillofrontale	mf'	Anterior lacrimal crest of the maxilla at the frontomaxillary suture
Mid-alare[d]	ma'	Midpoint on the nasal alar where the ala thickness (not width) is measured
Mid-columella[d]	mc'	Midpoint of the nasal columella crest on either side, where the columella thickness is measured (equivalent to *Subnasale'*)
Mid-infraorbital[b]	mio'	Point anteriorly adjacent to the inferior orbital rim, at a line that vertically bisects the orbit
Mid-mandibular border[b]	mmb'	Point directly overlying *mmb*, midway between *pg'* and *go'*
Mid-ramus[b]	mr'	Point directly overlying *mr*, best determined by X-ray but can be extrapolated from surface anatomy features including the masseter muscle mass, the posterior margin of the mandible and the zygomatic arch
Mid-supraorbital[b]	mso'	Point anteriorly adjacent to the superior orbital rim, at a line that vertically bisects the orbit
Otobasion inferius[d]	obi'	Most inferior point of attachment of the ear lobe with the cheek
Otobasion superius[d]	obs'	Most superior point of attachment of the ear helix to the temporal region of the head
Orbitale	or'	Most inferior point on the lower orbital rim
Origohelixa[c]	oh'	Origin of the helix from the concha
Palpebrale inferius	pi'	Most inferior point on the margin of the lower eyelid
Palpebrale superius	ps'	Most superior point on the margin of the upper eyelid

Postaurale	pa'	Most posterior point on the free margin of the pinna
Posterohelixa interna[c]	phi'	Posterior most aspect of the inner helix margin
Posterotragion[c]	pt'	Most posterior point on the tragus
Preaurale	pra'	Point on the ear insertion line (*obs'-obi'*) opposite postaurale
Subalare[d]	sbal'	Inferior point at the junction of each nasal alar base with the philtrum area
Subanguli conchali[c]	iac'	Inferior angle of the concha
Subaurale	sba'	Most inferior point of the earlobe
Superaurale	sa'	Most superior point of the free margin of the pinna
Superciliare	sci'	Most superior point on the superior margin of the unaltered eyebrow
Superciliare centralis[e]	scc'	Superior most intersection of the eyebrow with a vertical line through *ca'* (originally *Eyebrow central*)
Superciliare lateralis[e]	scl'	Superior most intersection of the eyebrow with a vertical line through *ex'* (originally *Eyebrow lateral*)
Superciliare medialis[c]	scm'	Superior most intersection of the eyebrow with a vertical line through *en'*
Superior lacrimal papilla[c]	slp'	The apex of the superior lacrimal papilla
Supra-anguli conchali[c]	sac'	Superior angle of the concha
Supraconchale[c]	sc'	Most superior point of the conchal rim where it crosses under the helix
Suprahelixa interna[c]	shi'	Superior most aspect of the inner helix margin
Supra second-molar	$sM^{2\prime}$	Point overlying *ecm* ², the midpoint of the alveolus of the second maxillary molar
Tragion	t'	Located at the notch above the tragus of the ear (the cartilaginous projection anterior to the external auditory canal), where the upper edge of the cartilage disappears into the skin of the face
Tuberculare	tu'	Tip of Darwin's tubercle; when present
Vermilion superius[c]	vs'	Most superior point of the vermilion border of the upper lip at its apex on either side (usually also at the junction of each philtral column with the vermilion border). This represents the previously unnamed landmark used by Martin to establish the Labrale superius (midpoint on a line tangent to the two high points in the curves of the upper membranous lip)
Vermilion inferius[c]	vi'	Most inferolateral point of the vermilion border of the lower lip at the maximum curve change on either side
Zygion[d]	zy'	Most lateral point overlying each zygomatic arch, identified as the point of maximum bizygomatic breadth of the face

RQ: What forces act upon a pair of glasses?

What follows is a simplified study of the mechanics of a pair of eyeglasses, starting from analyzing the forces acting on it and including its linear-static Finite Elements Analysis.

The pair taken as an example is a frame in nylon (PA), 3D printed, and 120 mm wide. Its maximum height is 40 mm at each lens, the total length is 145 mm, while the average thickness of the frame is 3,5 mm. The total mass is 11,2 grams (no lenses).

In this example, image 3b.1, the center of gravity of the eyeglasses is placed on their longitudinal axis of symmetry, at 32,9 mm from the front end and 5,4 mm from the top (position calculated using Onshape[30]).

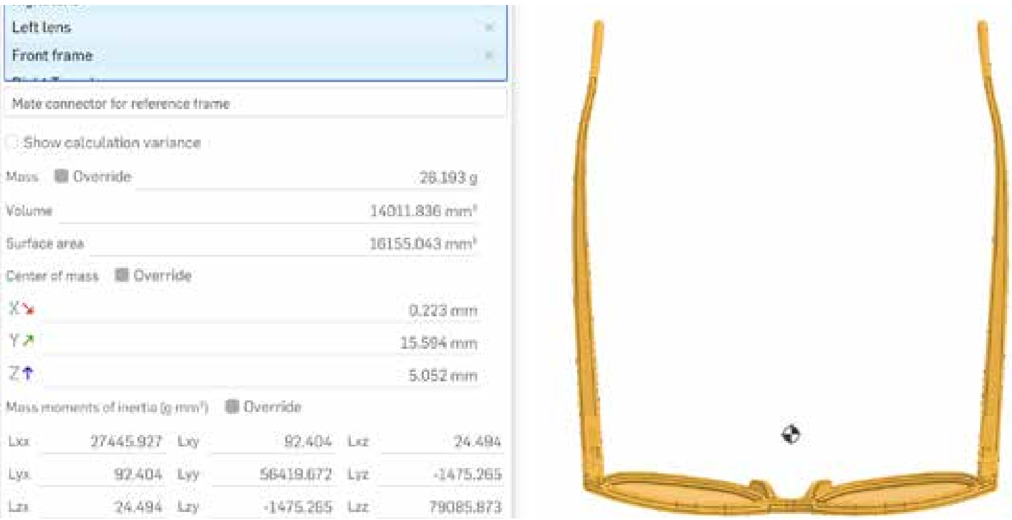


IMAGE 3b.1 *Sample frame with highlighted centre of gravity highlighted*

As for the forces, first, there is a uniform distributed load acting downward upon the whole frame. In the model taken as an example, that load has a value of 0.11 N but may vary to over 100%, depending on the frame's material and lenses' thickness/ material.

The load is balanced by the support force (normal force) acting upward where the eyeglasses are in contact with the face of their bearer: at the nose pads and the temple tips.

Overall, its value equals the load and is distributed as follows: **81,8% on the nosepad, 18,2 % on the tips.** That is because the center of gravity is placed quite forward.

There is also a **spring force acting inward at each temple tip due to the elastic deformation caused by the stretching of the tips exerted by the subject's cranium. The magnitude of the force is**

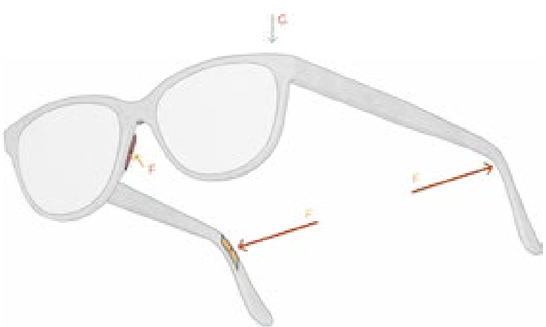
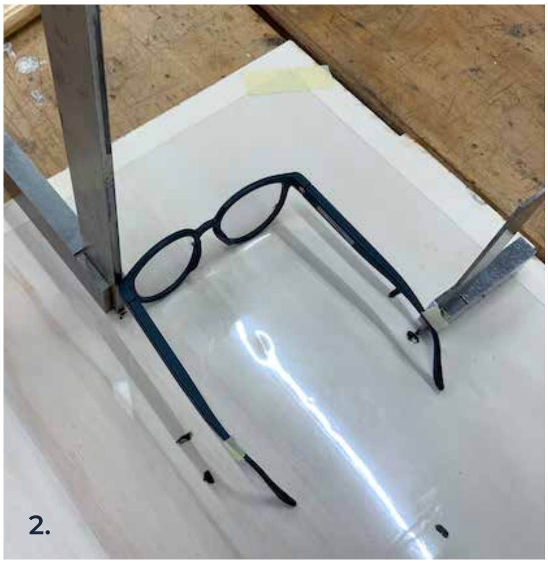


IMAGE 3b.2 *Fixed forces considered for FEA*

directly proportional to the amount of stretch exerted on the tips, depending on the distance between the temple tips when at rest compared to the width of the subject's face at their temporal bones.

For the sake of this research, **the value of that elastic force has been measured with a dynamometer, calculating a deformation of 15 mm on each side** (See image 3b.3). The value measured is 0,3 N.



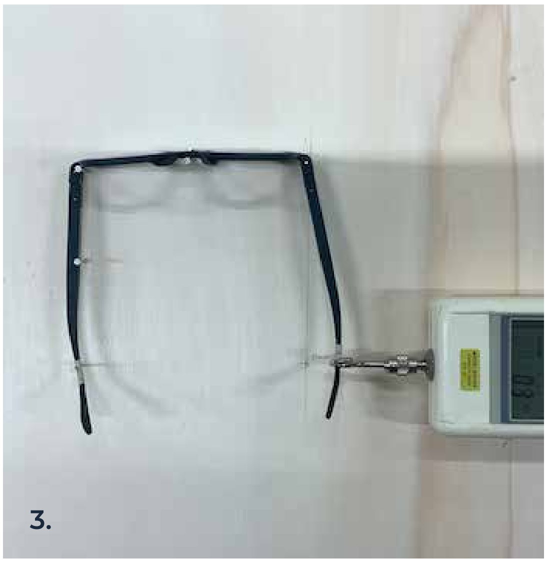


IMAGE 3b.3 *Measurements in the lab to define spring force:*

1. Observation and marking using the frame on a 3D printed head;

2. Aligning frame to markings and tracing displacement;

3. Measuring displacement with a dynamometer.

The detail of the application of forces is as follows:

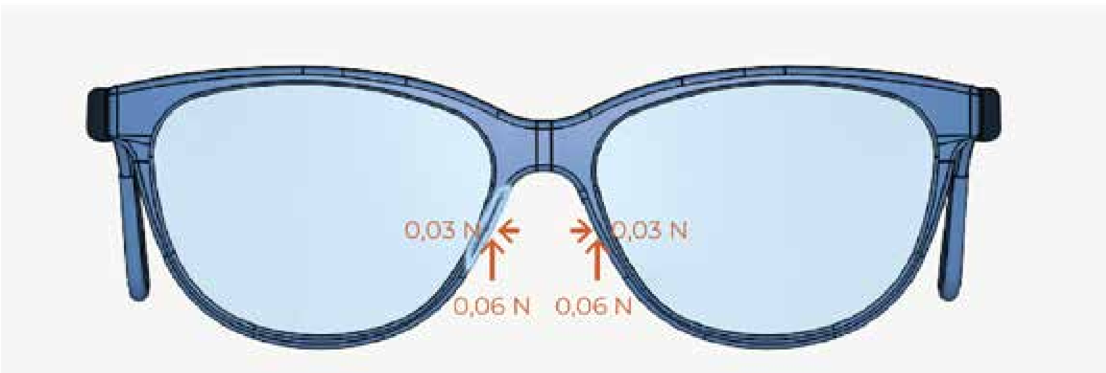


IMAGE 3b.2.1 *Front view of forces application for Finite Element Analysis*

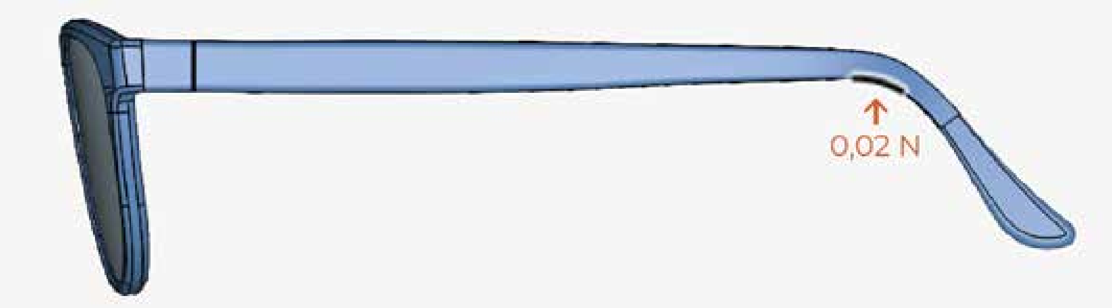


IMAGE 3b.2.2 *Lateral view of forces application for Finite Element Analysis*

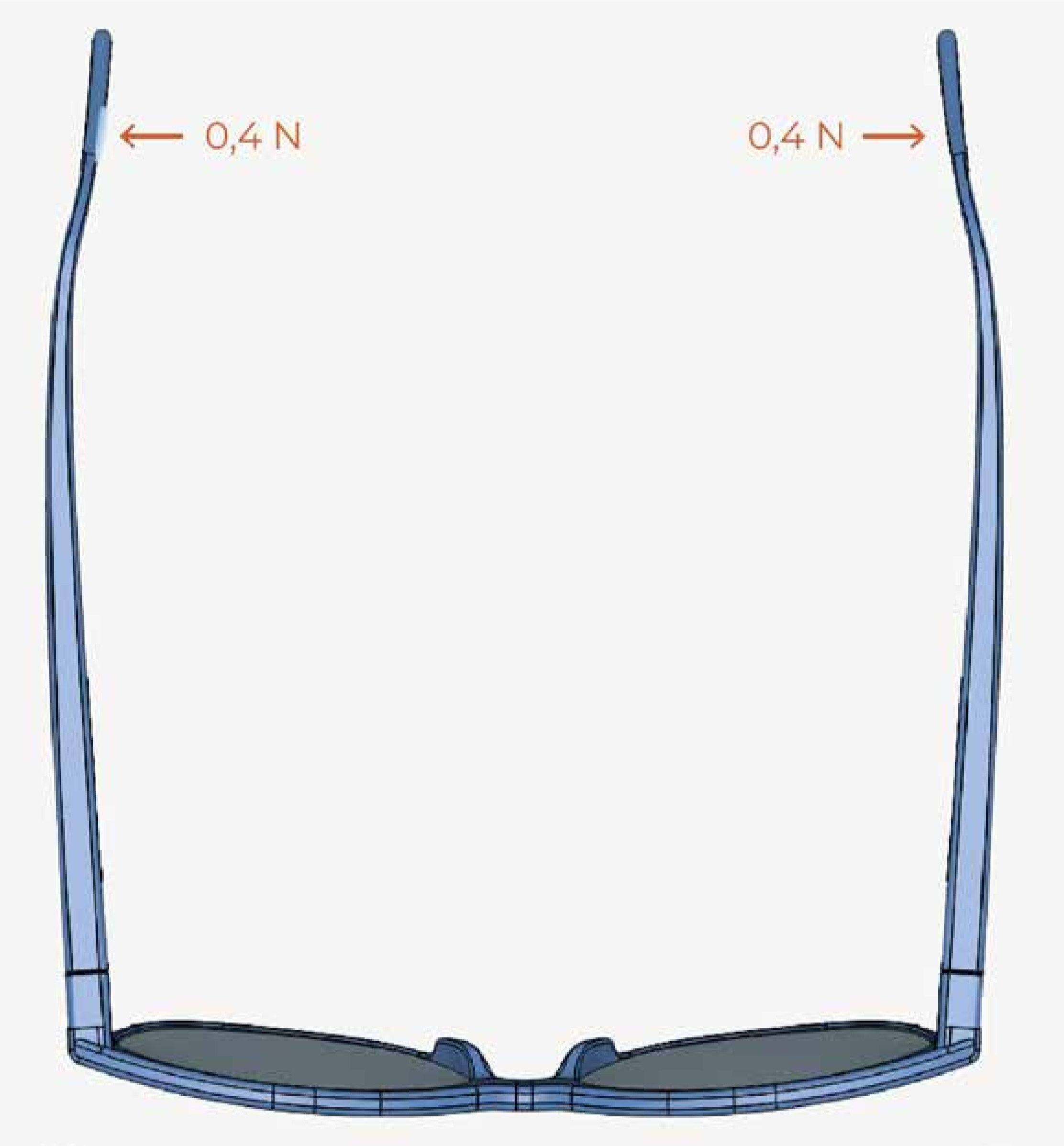


IMAGE 3b.2.3 *Top view of forces application for Finite Element Analysis*

The friction force acts mainly at the inner sides of the temple tips, where they brush against the skin of the subject wearing the glasses. Its value greatly depends on the pressure that the tips exert on the skin as a result of their elastic deformation observed during the measurement using the dynamometer in the lab.

APPENDIX I_ FINITE ELEMENT ANALYSIS

Three Maat! frames (image I.1) were subjected to linear-static Finite Elements Analysis (FEA) to estimate their structural behavior and find eventual weak spots and areas of tension under the foreseeable using conditions.
The models' stress[1] (σ), strain[2] (ε), and displacement[3] (δ) were calculated using SimScale[31].

IMAGE I.1 *From left to right: "Regular" model, "S Shape" model, "Bone" model*

For the simulation, the following parameters have been used:

- Material of the frame: nylon [PA]
- Material of the lenses: crystal (glass, for simplicity)
- Material of the hinges: titanium
- Fixed point under the bridge
- Distributed load due to model's weight: 0,11 N
- Force of 0,4 N at each temple-tip (outward)
- Force of 0,02 N under each temple (upward, vertically)
- Force of 0,09 N under each nosepad (broken down 2/3-1/3 into upward vertical and outward horizontal)

The results can be seen in image I.2-4

"REGULAR" MODEL

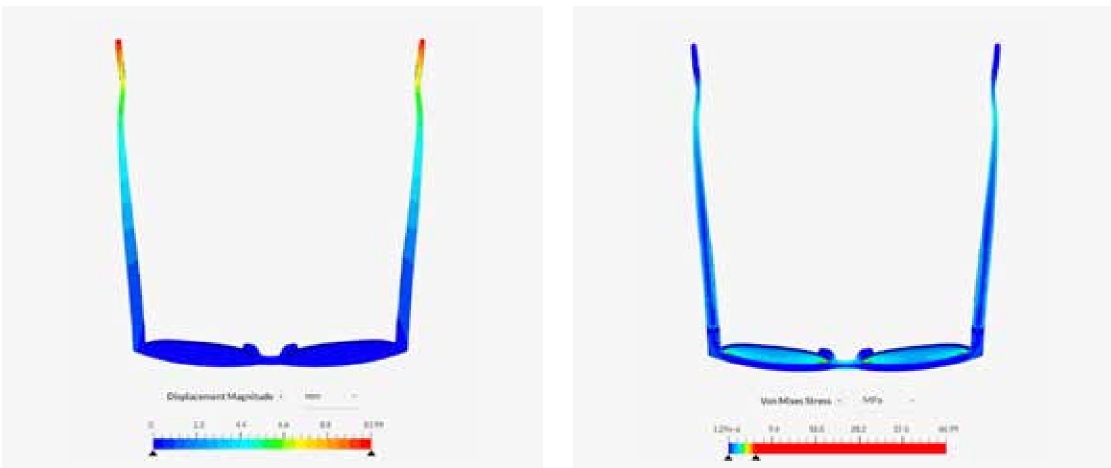


IMAGE I.2 *Left: Displacement 0,4N; Right: Stress 0,4N*

"S SHAPE" MODEL

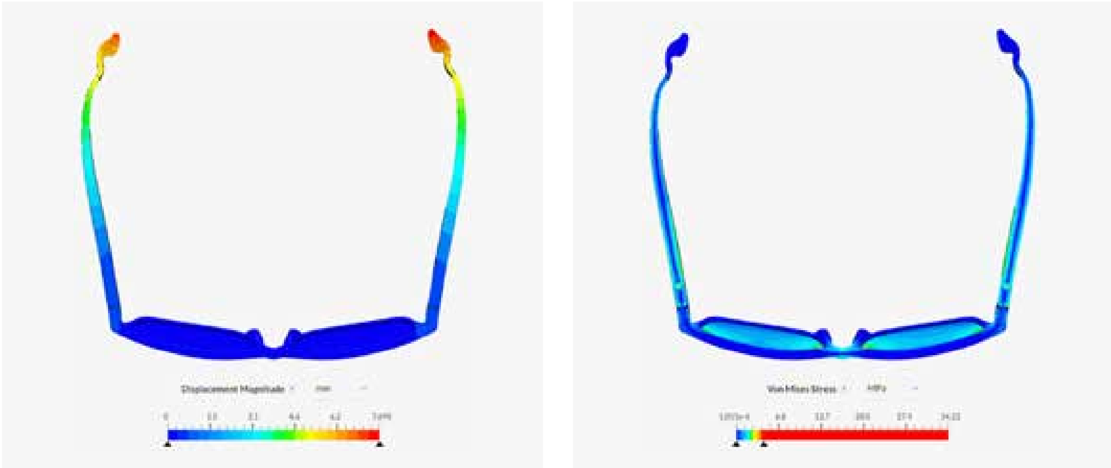


IMAGE I.3 *Left: Displacement 0,4N; Right: Stress 0,4N*

"BONE" MODEL

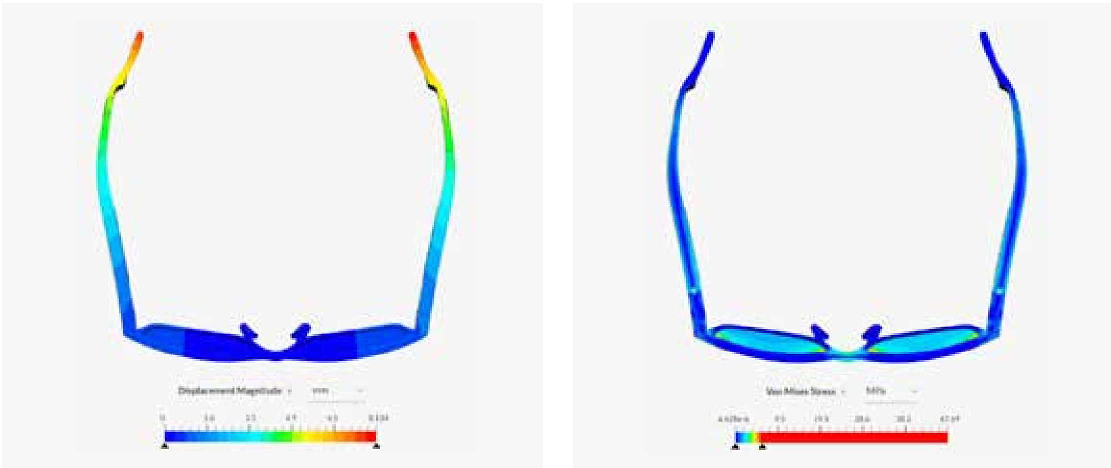


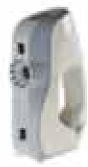
IMAGE I.4 *Left: Displacement 0,4N; Right: Stress 0,4N*

1 Definizione strees:

2 Definizione Strain:

3 Definizione displacement:

APPENDIX J_ 3-D SCANNER TECHNICAL CHARTS OF ARTEC SOIDER & EVA & TRIOS 3

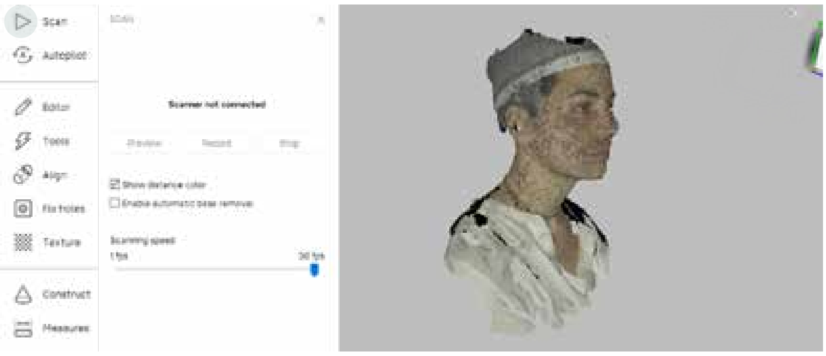
Technical specifications	 Space Spider	 Eva
Scanner type	Handheld	Handheld
3D point accuracy, up to	0.05 mm	0.1 mm
3D resolution, up to	0.1 mm	0.2 mm
3D accuracy over distance, up to	0.05 mm + 0.3 mm/m	0.1 mm + 0.3 mm/m
HD Mode	N/A	Yes
Hybrid geometry and texture tracking	Yes	Yes
Data processing algorithms	Geometry and texture based	Geometry and texture based
Working distance	0.2 – 0.3 m	0.4 – 1 m
Volume capture zone	2,000 cm^3	61,000 cm^3
Linear field of view, H×W @ closest range	90 × 70 mm	214 × 148 mm
Angular field of view, H×W	30 × 21°	30 × 21°
Ability to capture texture	Yes	Yes
Texture resolution	1.3 mp	1.3 mp
Colors	24 bpp	24 bpp
3D reconstruction rate for real-time fusion, up to	7.5 fps	16 fps
3D reconstruction rate for 3D video recording, up to	7.5 fps	16 fps

Data acquisition speed, up to	1 mln points/s	18 mln points/s
3D exposure time	0.0002 s	0.0002 s
2D exposure time	0.0002 s	0.00035 s
3D light source	Blue LED	Flashbulb
2D light source	White 6 LED array	White 12 LED array
Display/touchscreen	USB streaming through external computer	USB streaming through external computer
Multi-core processing	On external computer	On external computer
Interface	1 × USB 2.0, USB 3.0 compatible	1 × USB 2.0, USB 3.0 compatible

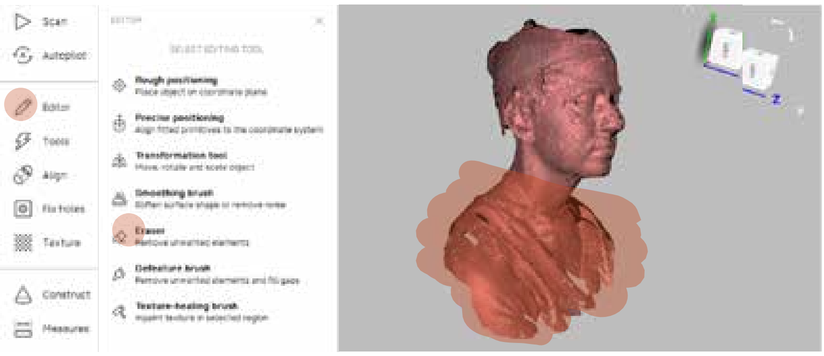
Scanner Features

	TRIOS 3 Basic
Wireless	✗
Trueness (Accuracy)[1]	6.9 ± 0.9 µm
Real Colors & Shade Measurement	✓
Smart Tips	✗
Output Format	PLY, DCM and STL
Send-to-lab	✓
Patient Excitement Apps	✗
In-house apps	Add-on option

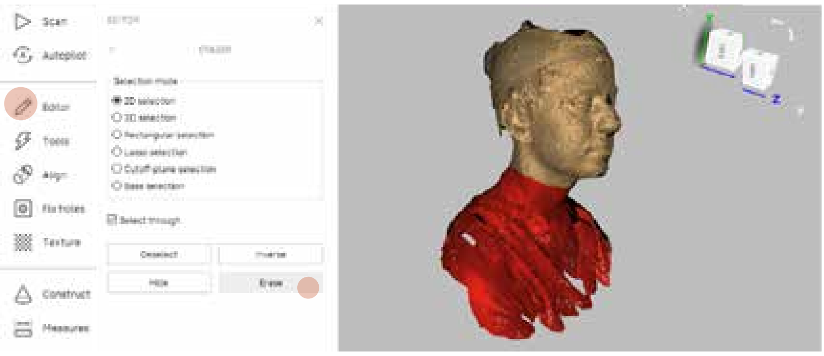
APPENDIX L_ ELABORATION OF 3D SCAN IN ARTEC STUDIO



STEP 1
Complete 3D scan with ***Artec Eva***



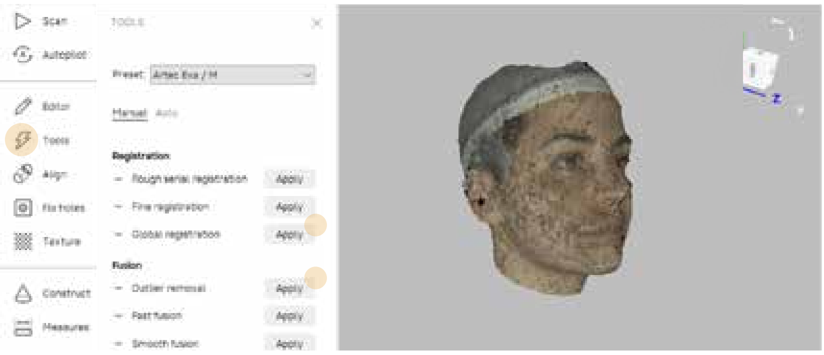
STEP 2
Cnrtl+drag to select area to delete



STEP 3
"Erase" selected area.

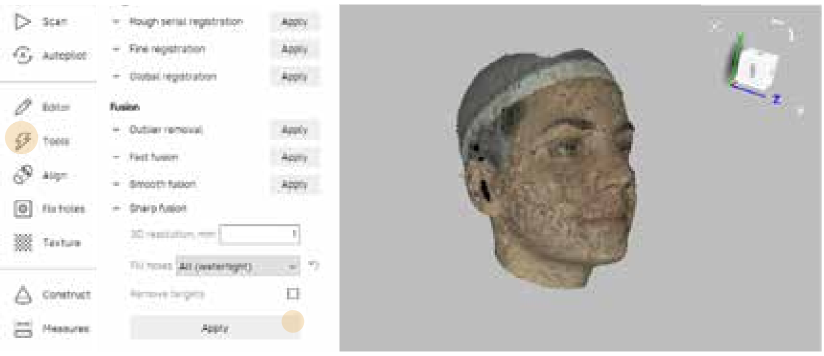
AFTER STEP 3
Results after Step 3

STEP 4
Apply ***"Rough serial registration"*** and ***"Fine registration"***



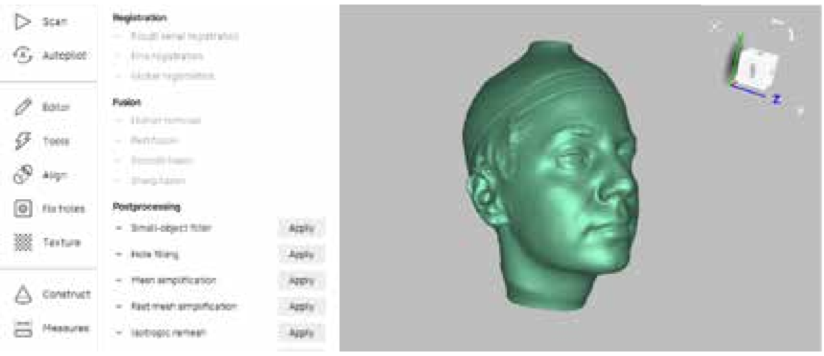
STEP 5

Apply ***"Global registration"*** and ***"Outliner removal"***



STEP 6

Apply ***"Sharp fusion"*** with the fill holes setting as "*watertight*".



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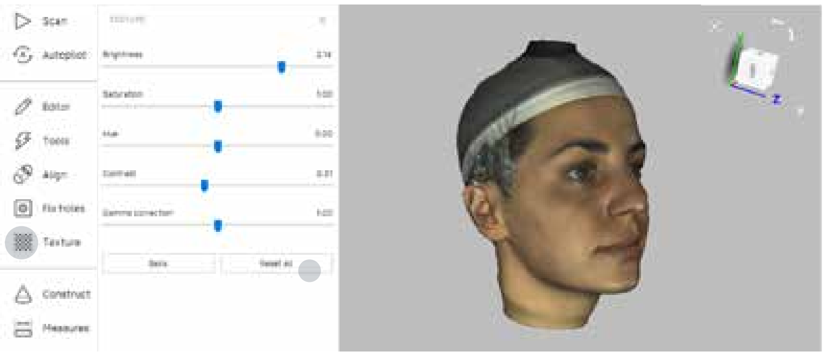
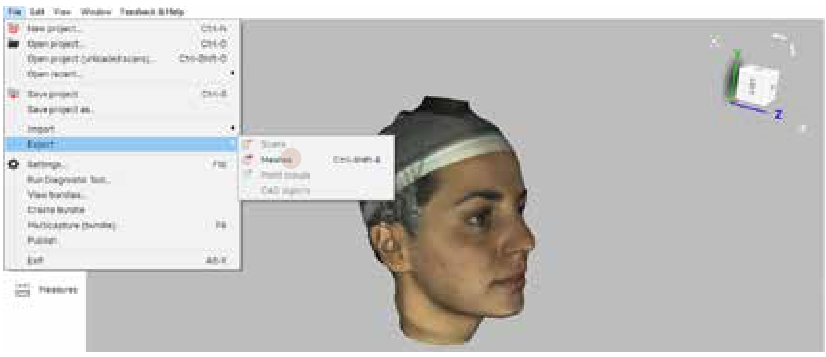
RESULTS OF STEP 6

Results of Fusion.



STEP 7

Final results after the application of texture



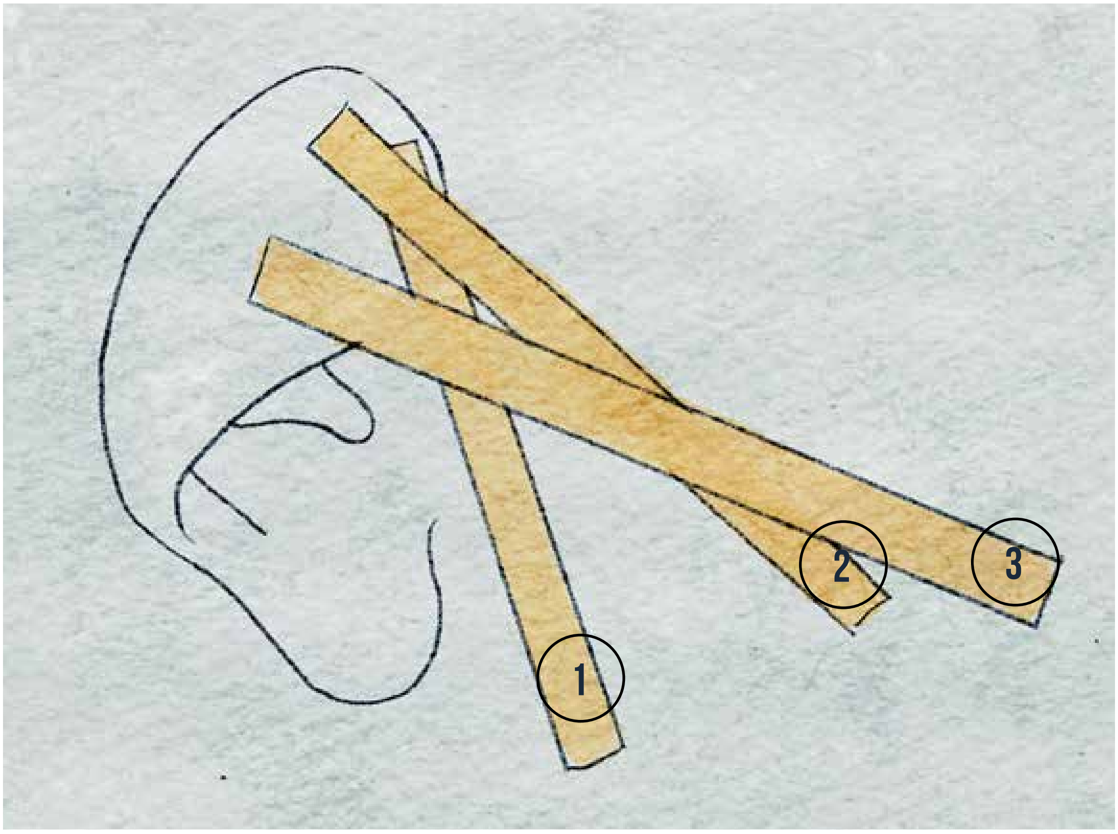
STEP 8

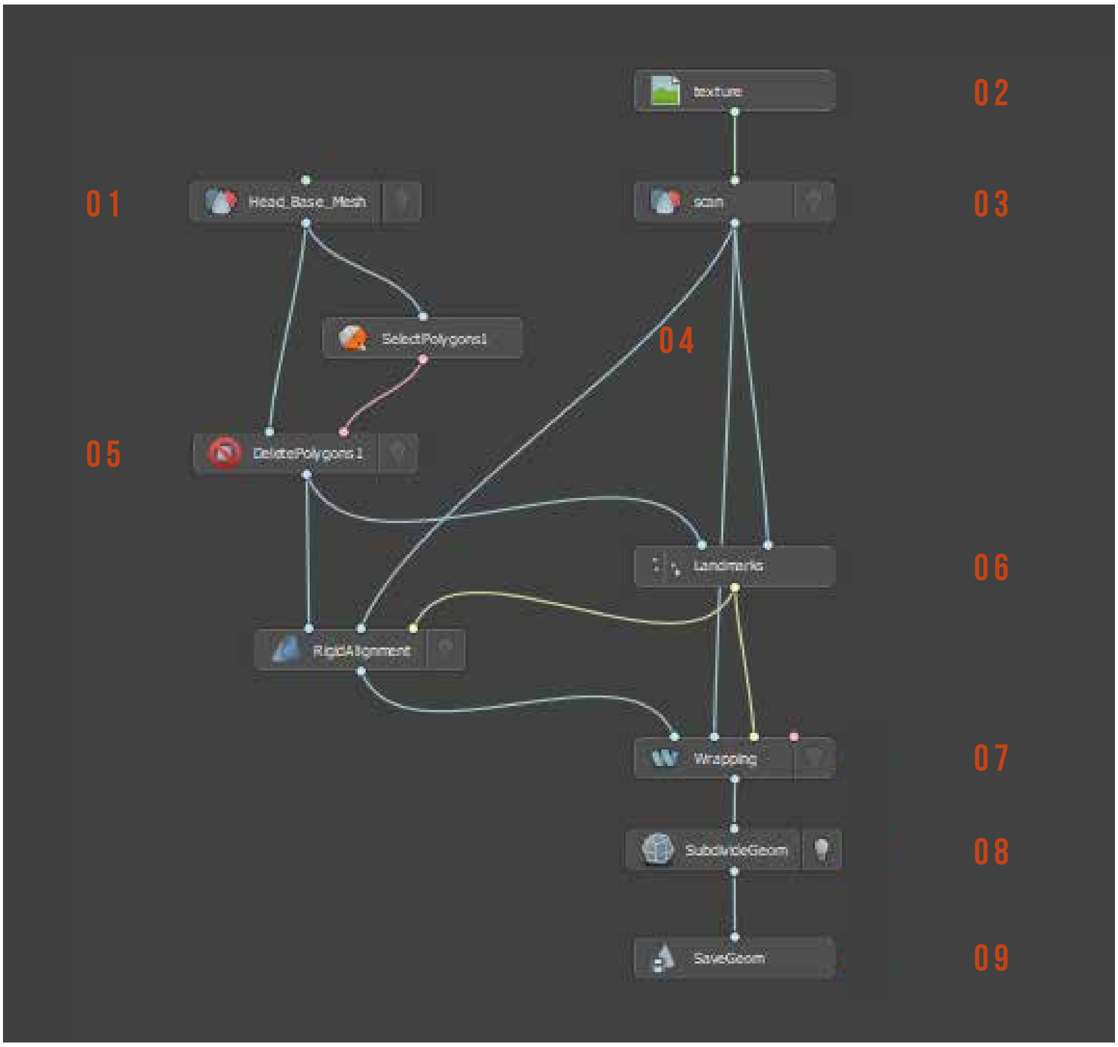
File > Export > Meshes > ***.obj***

APPENDIX K_ DETAILS OF SUBJECTS FROM OCCIPITAL SCANNER TEST

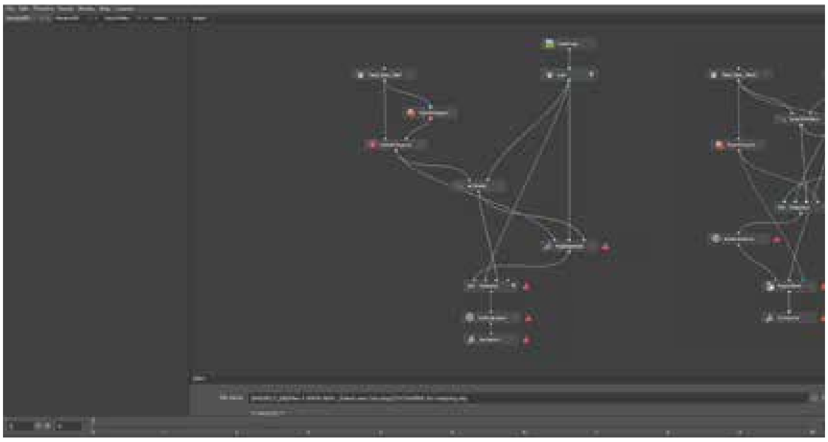
NUMBER	GENDER	AGE	NOTES
1	Male	25	No cranial deformation
2	Male	28	No cranial deformation
3	Female	57	No cranial deformation
4	Male	61	No cranial deformation, bald subject

APPENDIX M_ APPLICATION OF TAPE SEQUENCE



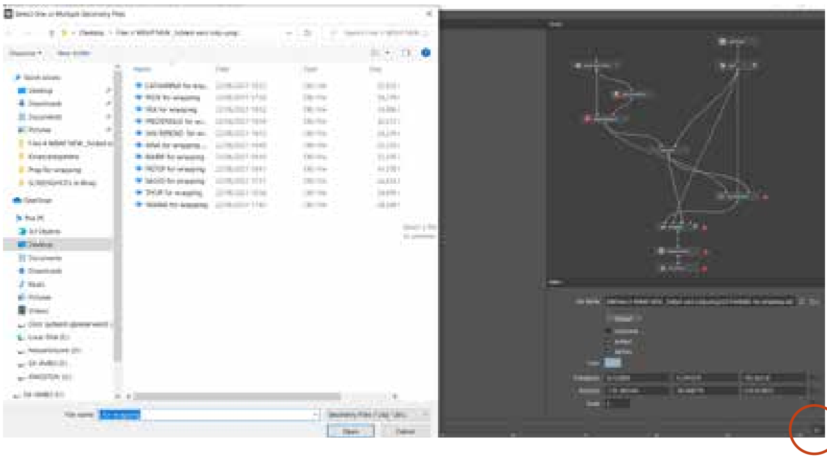


1. Upload ***base mesh***
2. ***Texture*** of scan upload as a .png
3. Upload 3D scan as an ***.obj***
4. ***Select polygons*** from base mesh correspond to area of neck and ear that need to be deleted since in the scans the neck is missing and the ears are folded.
5. Delete selected polygons
6. Selection of 23 ***landmarks***, of which 11 are on the face and 12 behind the ears (6 left and 6 right). Selected both on scan and base head mesh for accurate wrapping.
7. ***Wrapping*** calculation node
8. ***SubdivideGeometry*** node to increase the density of the mesh calculated in the ***Wrap*** node
9. ***Process and save*** geometries in batch mode



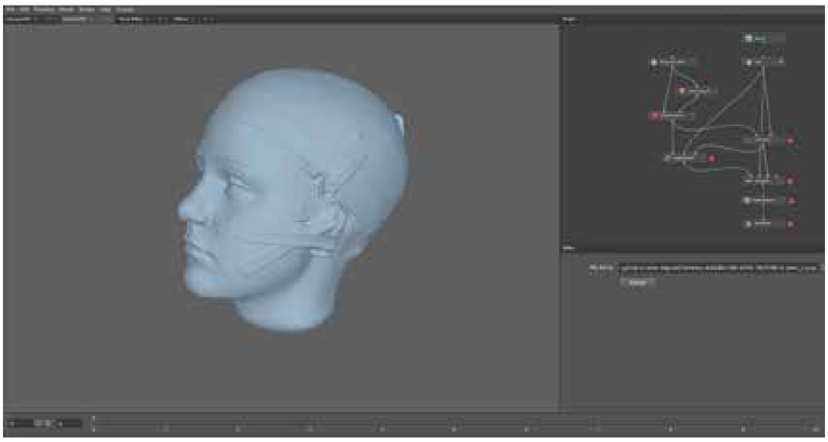
STEP 1

Prepare **node map**



STEP 2

Set **time line** to 10 and import batch of files (11 total scans = from #0-10)

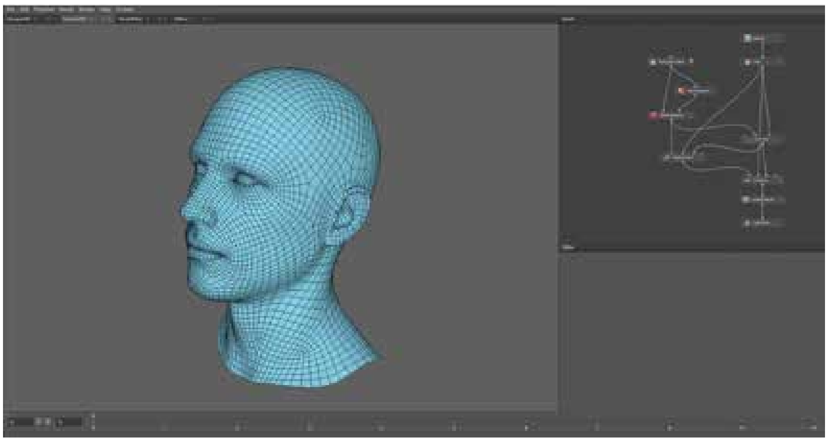


RESULTS OF STEP 2

Results of file import example of scan #0.

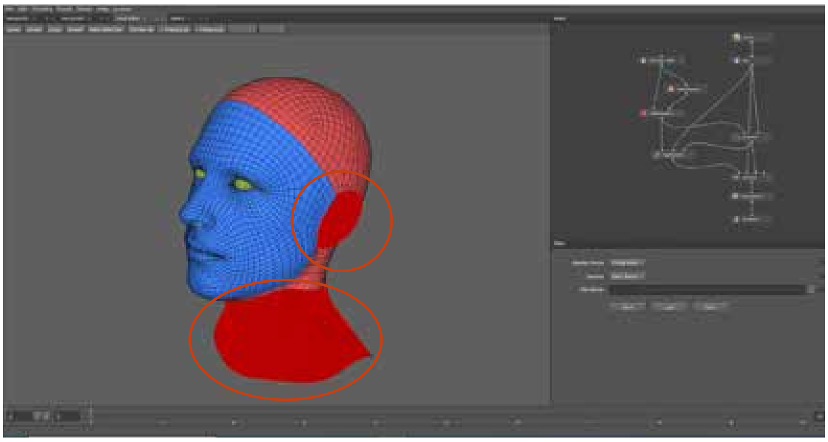
STEP 3

Application of **texture** to scan.



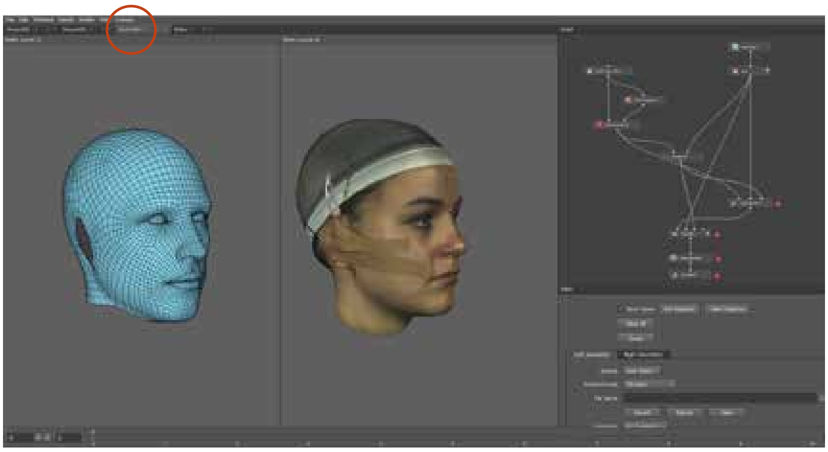
STEP 4

Selection of base head mesh for wrap reference.



STEP 5

Polygon selections of areas to match scans with folded ears.

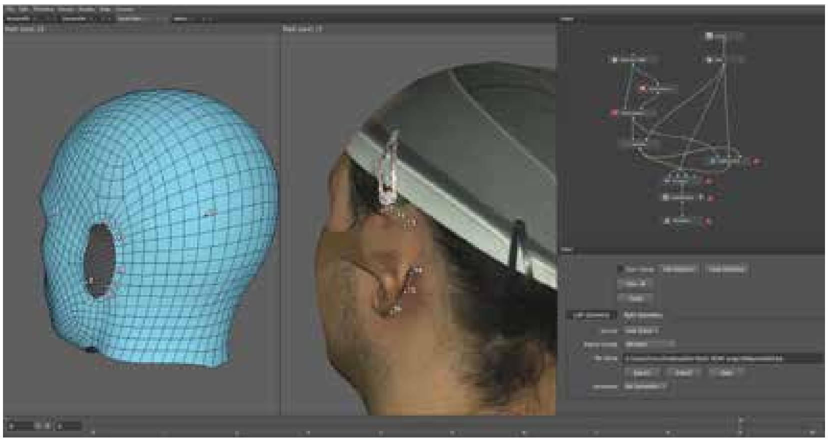


STEP 6

Landmark selection on both meshes in **Virtual editor** panel (sync views)

STEP 7

Select points in **same order and total count** between left and right geometry (tot. 23 ldms)

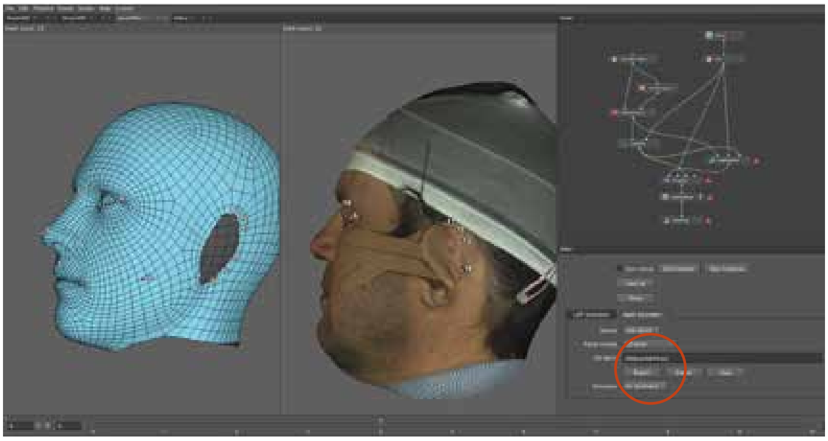


STEP 7 (DETAIL)

Detail of Landmarks placed in the posterior ear area. (6 ldm per side)

STEP 8

Switch from scan #0 to #1. There is a mismatch of landmarks between the scans.

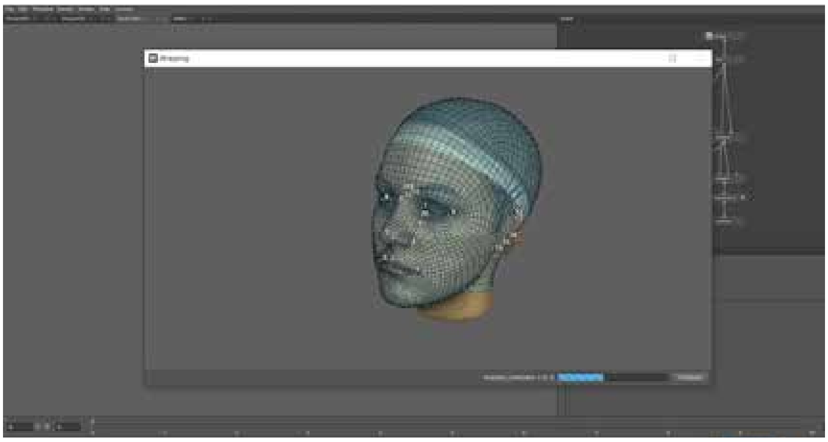


STEP 9

Once the landmarks have been selected export a **.txt** file *(name###.txt)*

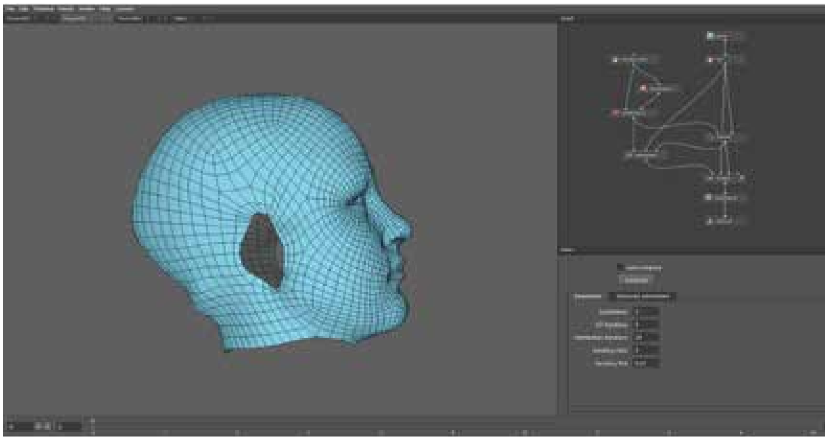
STEP 10

Once the Ldm selection has been completed, select **Source>File**, to match the scan to their own Ldm file.



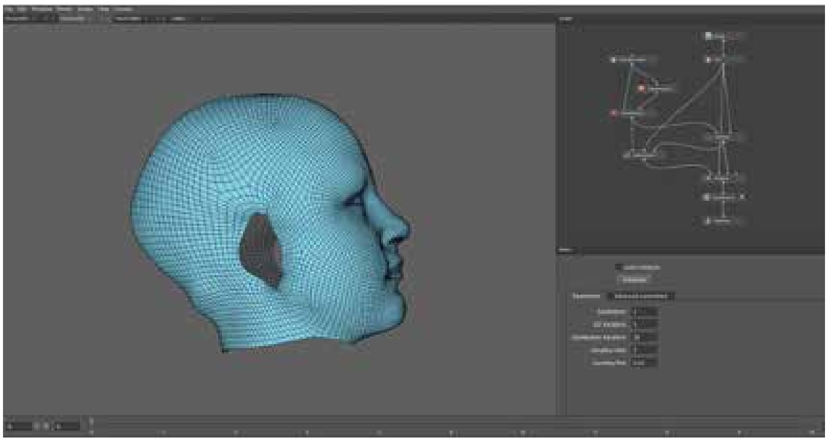
STEP 11

Compute Wrapping



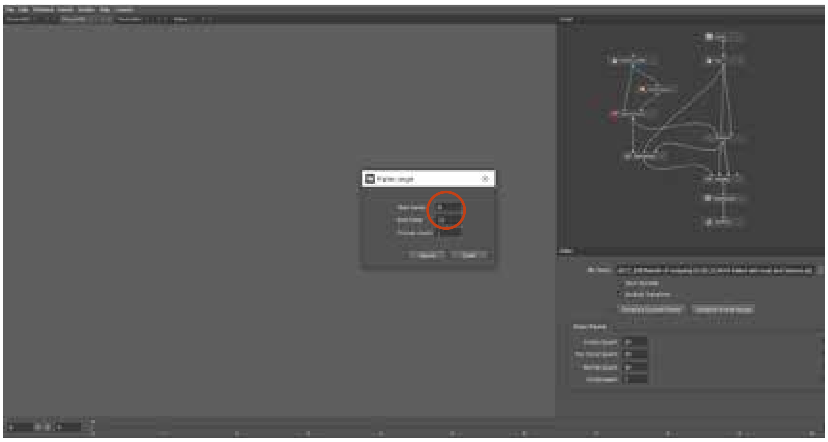
RESULTS OF STEP 11

Result of wrapping process



STEP 12

Subdivide geometry into a denser mesh.



STEP 13

Save and export geometry in batch mode *(Compute frame range)*. Set frames based on timeline.

APPENDIX P_ MATERIAL SELECTION

The purpose of the research is to analyze the area behind the ear through various methods.

Several non-contact methods have been used in previous studies to produce dimensionally accurate imaging techniques like computerized tomography (CT), magnetic resonance imaging(MRI), and laser scanning (LS), and 3D stereophotogrammetry (3D SPG).
Most of these techniques, although accurate, require the subjects to be perfectly still for a period that might vary from a couple of minutes up to 60 for Cranial MRI.

For this reason, a contact method such as the conventional impression technique(CIT) has been taken into account for comparison.
The techniques have been compared and evaluated in **Table 1.**

Each technique has been evaluated based on the defined requirements:

- **Suitability** for use on the research target group, in terms of interference between retrieval of data and uncontrollable subject movement;
- **Accuracy** in capturing the curvature of the surface;
- **Technique sensitivity** is intended as the knowledge and skills needed to acquire data with a low margin of error;
- **Feasibility** is intended as ease in the retrieval of materials and tools necessary for the technique.
- **Duration** of the data retrieval. It does not include the time necessary for the setup of the material required for the technique.

TYPE	TECHNIQUE	SUITABILITY	ACCURACY	TECHNIQUE SENSITIVITY	FEASIBILITY	DURATION
No Contact	CT	X*	High	High	Low	10 minutes
	MRI	X*	High	High	Low	60 minutes
	LS	X	High	Moderate	Moderate	Depends on technology
	3D SPG	X	High	Moderate	Moderate	5 minutes
Contact	CIT	v	Not specified***	Low	High	Depends on curing time

TABLE 1 Comparison of Methods used to analyze cranial curvature.

Positive Neutral Negative

*CT AND MRI are imaging techniques that require the subject to be too still. It is not possible in patients that have a severe mental illness. Therefore, for these methods to be applicable, it would require sedation, which has been considered a drastic procedure. For this reason, CT and MRI imaging techniques have been excluded from the study.

**The CIT is generally suited for the selected target group, except a subject that presents severe mental illness that might remove the molding material after application and therefore compromise the data collection and research.

***There have been studies comparing the different impression techniques such as CIT (Conventional Impression technique) and TLIT (Triple layer impression technique). Not enough data has been retrieved regarding the qualitative and quantitative comparison between materials that have been used in these techniques and how these materials may have different accuracy levels.

It is possible to say that CT and MRI techniques can be excluded both due to issues regarding suitability with the target group, excessive technique sensitivity, low feasibility, and extreme duration.

The technique evaluation shows that the most suited methods to conduct the topological cranial research are LS, 3DSPG, and CIT.
LS and 3DSPG have the potential behind accurate techniques that require the subject to be extremely still during the process and therefore are not suited to the research target group. The CIT technique is more likely suited for the subjects that move, but its accuracy is yet to be determined.

In conclusion, the selected techniques need to be explored for various applications in independent researches. To combine them to sample accurate data from the target group (Method A: CIT) and analyze it (Method B: LS)

Goal: ***Evaluate the CIT technique's accuracy and define the most suitable material and process to do so.***

RESEARCH

INTRODUCTION

The purpose of this research is to evaluate if the CIT technique is accurate enough to correctly reproduce the curvature of the back of the ear(specified previously in the “Area of interest” paragraph).
There is a knowledge gap regarding the technique’s accuracy and its influence on the material and method applied. Therefore different materials and procedures have been explored in the research.

MATERIAL CHOICE

The materials that have been analyzed are:

- Silicone
- Alginate
- Porcelain powder

Different types of Silicone are already used in the OPTOMETRIC industry to make accurate molds of the ear canal. It is not generally used for the rear auricular area.
Alginate powder is used in the orthodontic industry to create extremely detailed molds.
Porcelain powder is a material often used in combination with alginate to create accurate casts of body parts. It has been chosen for its capability to turn into a solid matte white cast, properties that make it an ideal candidate for 3D scanning.

RESEARCH QUESTION

What
Exploring material consistency (before and after curing), and testing the sampling process.

Key function
Be able to acquire the curvature of a given surface accurately and accurately maintain that given shape to be further analyzed.

Key Requirements of materials

- Be able to morph from a soft liquid state to a rigid form.
- Straight forward Preparation phase:
  - It does not require external heat or input other than the components themselves;
  - The various components to activate material are easily mixed;
  - The various components that need to be mix together are easily measured;

- Straight forward sampling process:
    - The curing time of the material allows enough time for application on the subject;
    - It does not require for the subject to lay down;
    - It does not require the subject to stay entirely still;
    - Once cured, the material retains the curvature of the surface to which it has been applied.
- Compatible with 3D scanning:
    - not black;
    - not lucid or reflective
- Biocompatible:
    - compatible with use on skin;
    - not harmful if ingested.

Material consistency

Each material has been evaluated based on the defined requirements to answer the "ease of preparation" aspect mentioned in the research question.

An additional **"viscosity test"** has been conducted with the alginate since the instructions reported different mixing ratios, and the relative material consistency variations were unknown.

Research questions

- *Which material is the best candidate to mold and accurately retain the area's shape behind the ear?*

- *Which material has the optimal compromise regarding "ease of preparation" and ease of sampling process?*

METHOD

In the case of silicone and porcelain powder both RQ1 and RQ2 have been explored simultaneously since the instructions of use of the material reported specific ratios. In the case of the alginate powder an additional Viscosity test has been conducted separately to explore different ratio options and verify the optimal material consistency.

TEST 1: VISCOSITY TEST OF ALGINATE RUBBER

The viscosity test has been conducted initially in containers and afterwards on skin, since that is the location of the actual test.

The research question was:

How do the different ratios affect the behavior of the alginate rubber and which one is the best option to implement in the field study?

1.A VISCOSITY TEST IN CUP

In order to obtain alginate rubber it is necessary activating the alginate white powder by adding water at a defined ratio. The instructions associated with the material suggested different ratio options: 1:2, 1:3, 1:4. In order to verify the material's behavior, each option has been tested in addition to 1:1 ratio.

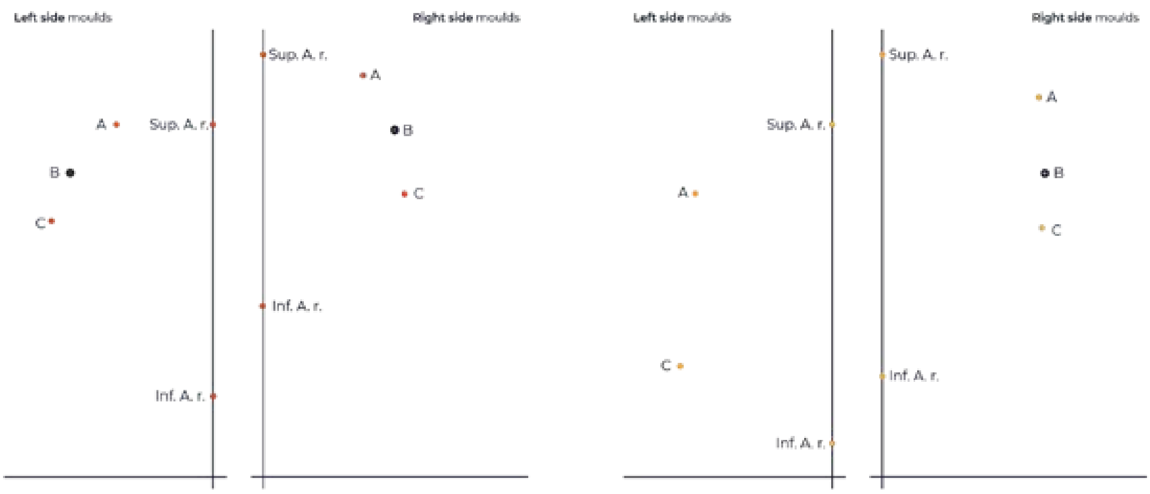
Once the activator has been added, the mixture starts changing color to a bright pink. The results in a guy mixture that cures in a couple of minutes. (the curing time is affected by the volume of mixture). The viscosity is highly influenced by the mixing ratio applied and a higher the quantity of water determines a lower the viscosity.

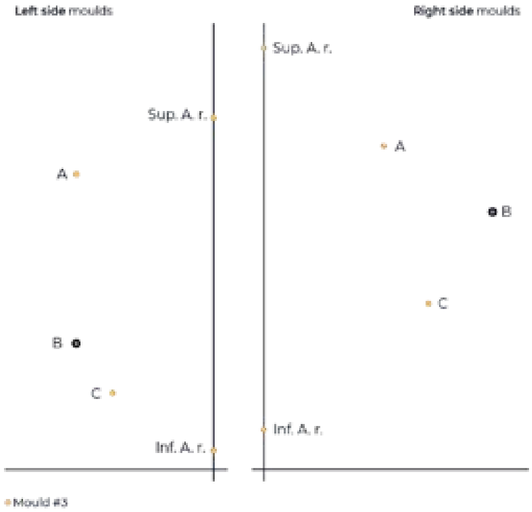
PROPERTY	SILICONE	ALGINATE	PORCELAIN POWDER
Activator	Component B	Water	Water
Mixing Ratio	1:1	1:3*	1:1
Ease of mix	Easy to measure with scoop and mix with bare hands	More complicated to measure when mixing it often created lumps	More complicated to measure when mixing it often created lumps
Consistency of mixture **before** curing	Similar to play dough	Varies based on ratio**	Thick Liquid
Consistency of mixture **after** curing	Solidified but still flexible if bent	Solid chalky, fragile if it is a thin layer, very light	Solid chalky, quite heavy
Pot life*	1-2 min	3 min	7 min

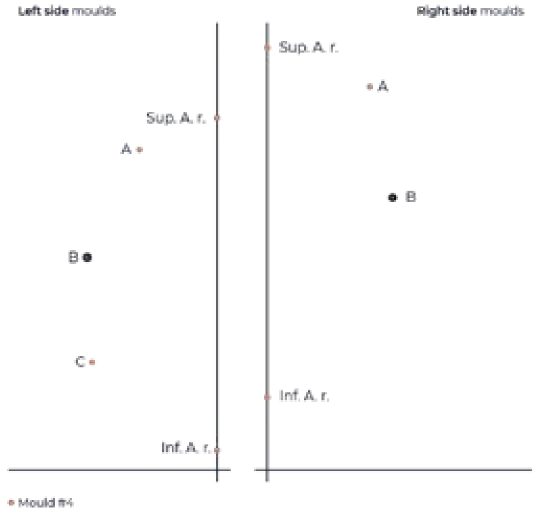
APPENDIX Q_ SILICONE MOLD APPLICATION

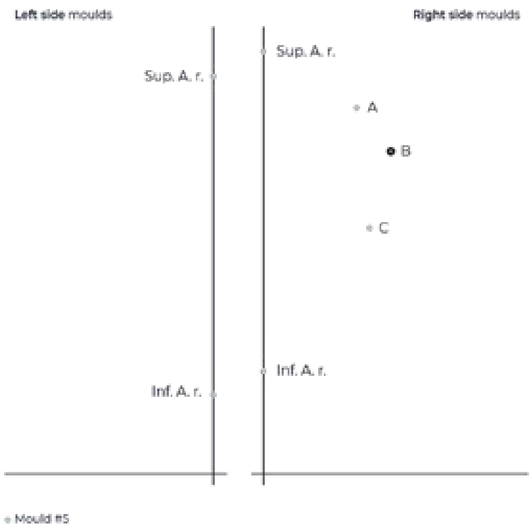
1. Take one soop of components A and B
2. Knee together until a uniform color is obtained
3. Apply on posterior auricular area while still soft
4. Make sure that the silicone reaches both point s and i and creates a sort of c shape around the ear.
5. Apply slight pressure to fill the cavity in between the pinna and the skull
6. Wait for the silicone to cure (2-minutes ca. Deepening on the thickness)
7. Gently remove silicone from area

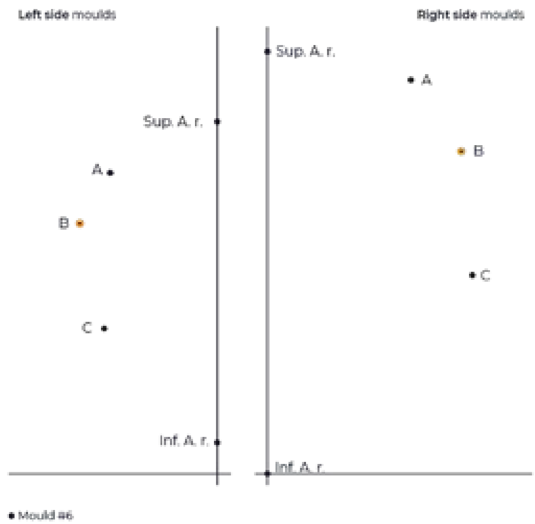
APPENDIX R_ POINT IDENTIFICATION ON SILICONE MOLDS



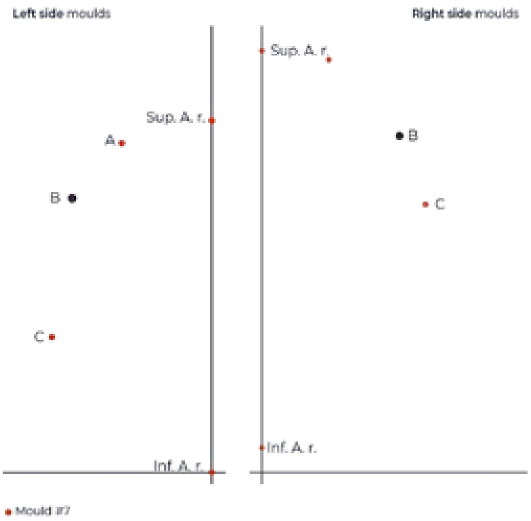


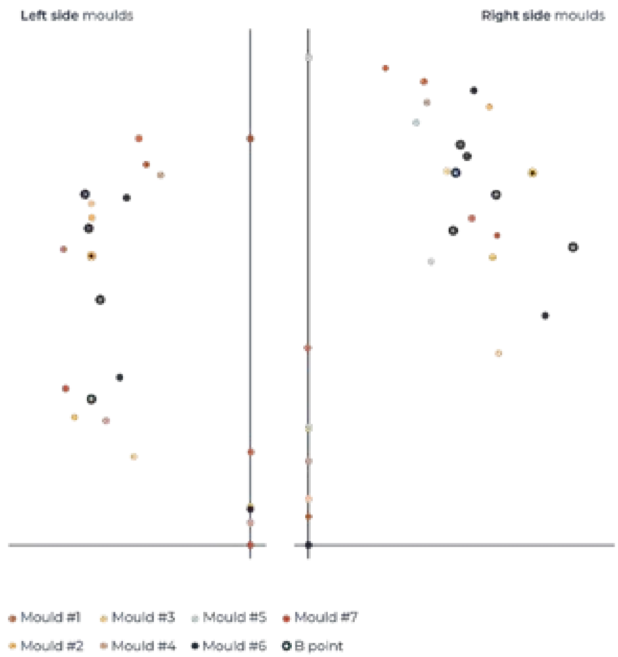






OVERVIEW OF POINT IDENTIFICATION ON SILICONE MOLDS





NORMALIZED								
	Left		**Right**		**Height Sup ar-A**		**Angle**	
A	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
A1	1.262463343	3.871698113	1.262463343	4.373584906	1.528301887	2.026415094		
A2	2.069208211	3.975471698	2.364809384	5.316037736	1.424528302	1.083962264		
A3	2.112316716	4.924528302	1.810557185	5.362264151	0.4754716981	1.037735849		
A4	1.46568915	4.9	1.675073314	5.8	0.5	0.6		
A5	-	-	1.408211144	4.71509434	-	1.68490566		
A6	1.609384164	5.554716981	2.212903226	7.245283019	-0.1547169811	-0.8452830189		
A7	1.551906158	5.773584906	1.108504399	7.132075472	-0.3735849057	-0.7320754717		
AVERAGE	1.7	4.8	1.7	5.7	0.6	0.7	111,6° (-68,4°)	69,8°
			average width of A			22.4		
	Left		**Right**		**Height A-B**		**Angle**	
B	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
B1	1.851612903	3.369811321	1.683284457	3.728301887	2.030188679	2.671698113		
B2	-	-	2.463343109	4.252830189	-	2.147169811		
B3	2.112316716	2.188679245	3.520527859	4.267924528	3.211320755	2.132075472		
B4	2.093841642	2.8	1.98914956	4.1	2.6	2.3		
B5	-	-	1.911143695	4.530188679	-	1.569811321		
B6	2.112316716	4.709433962	3.017595308	5.916981132	0.6905660377	0.4830188679		
B7	2.383284457	4.754716981	2.327859238	5.773584906	0.6452830189	0.6264150943		
AVERAGE	2.1	3.6	2.4	4.7	1.3	1.7	124,3° (-55,7°)	56,5°
			average width of B			30.8		
	Left		**Right**		**Height B-C**		**Angle**	
C	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
C1	2.104105572	2.796226415	1.76744868	3.083018868	2.603773585	3.316981132		
C2	2.26627566	1.571698113	2.463343109	3.513207547	3.828301887	2.886792453		
C3	1.508797654	1.313207547	2.514662757	2.735849057	4.086792453	3.664150943		
C4	1.98914956	1.7	-	-	3.7	-		
C5	-	-	1.709970674	3.420754717	-	2.979245283		
C6	1.709970674	2.656603774	3.118181818	3.622641509	2.743396226	2.777358491		
C7	2.660410557	2.377358491	2.771260997	4.641509434	3.022641509	1.758490566		
	2.0	2.1	2.4	3.5	3.3	2.9	141,2° (-38,8°)	46,2°
			average width of C			-13.0		
	Left		**Right**		**Height C-Inf. Au. r**		**Angle**	
Inf. Au r.	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
Inf. Au r 1	0	0.9320754717	0	1.864150943	4.467924528	4.535849057		
Inf. Au r 2	0	0.5547169811	0	1.386792453	4.845283019	5.013207547		
Inf. Au r 3	0	0.5471698113	0	0.6566037736	4.852830189	5.743396226		
Inf. Au r 4	0	0.3	0	1.1	5.1	5.3		
Inf. Au r 5	0	0.4622641509	0	1.386792453	4.937735849	5.013207547		
Inf. Au r 6	0	0.6037735849	0	0	4.796226415	0		
Inf. Au r 7	0	0	0	0.4528301887	5.4	5.947169811		
	0	0.5	0.0	1.0	4.9	5.4	0	0
						10.3		

				Left (depth values in mm)			**Right (depth values)**		
Mould #	**Age**	**Gender**	**Syndrom**	**A**	**B**	**C**	**A**	**B**	**C**
1	50	female	Down	5.9	11.2	10.9	3.1	6.4	4.6
2	18	female	Down	2.2	not identified	4.5	3.4	4.2	Not visible
3	10	Male	Down	2.1	5.8	2.1	2.9	6.5	3.5 ca
4	4	Male	Down	1.6	5.7	4.6	1.6	3.7	not identified
5	9	female	Down	-	-	-	4.2	4.8	1.6
6	18	female	Down	0.8	1.9	0.7	1.2	2.7	1.5
7	56	female	Down	4.5	9.5	5.1	4.2	9.1	6.6
			AVERAGE	2.85	6.82	4.65	2.94	5.34	2.86

C	Left		Right	
mould	X	Y	X	Y
1	10.9	1	4.6	1
2	4.5	1.2	Not visible	-
3	2.1	0.5	3.5	1.4
4	4.6	1.3	not identified	-
5	-	-	1.6	2.3
6	0.7	0.7	1.5	1.9
7	5.1	0.8	6.6	3.6
AVERAGE	4.65	0.92	3.56	2.04

NORMALIZED RESULTS

C	Left		Right	
mould	X	Y	X	Y
1	9.173900293	0.7169811321	3.298113208	0.7169811321
2	4.434017595	1.109433962	-	-
3	2.112316716	0.5471698113	3.830188679	1.532075472
4	4.815835777	1.3	-	-
5	-	-	1.479245283	2.126415094
6	0.7041055718	0.8452830189	-	-
7	5.653372434	0.9056603774	7.471698113	4.075471698
AVERAGE	4.48	0.90	4.02	2.11

B	Left		Right	
mould	X	Y	X	Y
1	11.2	1.8	6.4	2
2	not identified	-	4.2	2.6
3	5.8	1.5	6.5	2.7
4	5.7	2.9	3.7	3
5	-	-	4.8	3.3
6	1.9	2	2.7	3.2
7	9.5	2.7	9.1	4.7
AVERAGE	6.82	2.18	5.34	3.07

B	Left		Right	
mould	X	Y	X	Y
1	9.426392962	1.290566038	5.386510264	1.433962264
2	-	-	4.138416422	2.403773585
3	5.834017595	1.641509434	6.538123167	2.954716981
4	5.96744868	2.9	3.873607038	3
5	-	-	-	3.050943396
6	1.911143695	-	2.715835777	-
7	10.53079179	3.056603774	10.08739003	5.320754717
AVERAGE	6.73	2.22	5.46	3.03

A	Left		Right	
mould	X	Y	X	Y
1	5.9	2.8	3.1	2.9
2	2.2	3.8	3.4	3.7
3	2.1	3.7	2.9	3.8
4	1.6	4.6	1.6	4.7
5	-	-	4.2	4
6	0.8	3.1	1.2	4
7	4.5	3.7	4.2	6.2
AVERAGE	2.85	3.6	2.94	4.2

A	Left		Right	
mould	X	Y	X	Y
1	4.96568915	2.00754717	2.609090909	2.079245283
2	2.167741935	3.513207547	3.350146628	3.420754717
3	2.112316716	4.049056604	2.917008798	4.158490566
4	1.675073314	4.6	1.675073314	4.7
5	-	-	-	3.698113208
6	0.8046920821	-	1.207038123	-
7	4.988269795	4.188679245	4.655718475	7.018867925
AVERAGE	2.79	3.67	2.74	4.18

Sup a r	Left		Right	
mould	X	Y	X	Y
1	3.1	0	3.1	3.7
2	4.9	0	3.4	5
3	5.2	0	2.9	6
4	5.1	0	1.6	5.3
5	-	0	4.2	4.8
6	4.2	0	1.2	5.1
7	4.3	0	4.2	7
AVERAGE	4.47	0	2.94	5.3

Sup a r	Left		Right	
mould	X	Y	X	Y
1	2.609090909	0	2.222641509	0
2	4.828152493	0	3.143396226	0
3	5.230498534	0	3.173584906	0
4	5.339296188	0	1.6	0
5	-	0	3.883018868	0
6	4.224633431	0	-	0
7	4.766568915	0	4.754716981	0
AVERAGE	4.50	0	3.13	0.0

The values of width have been defined by using higlighted values below (yellow and orange)

	Height Moulds		Width Moulds		measured directly Height Moulds	
	L	R	L	R	L	R
mould #1	4.1	3.8	2.5	2.1	38	34
mould #2	4.8	4.9	2.3	2.5	46	44
mould #3	4.9	5.8	2.1	3.5	42	49
mould #4	5.1	5.3	2	1.9	44	42
mould #5	4.9	4.9	-	1.9	40	40
mould #6	4.9	6.4	2.1	3.1	44	46
mould #7	5.4	6	2.1	2.5	43	52
AVERAGE	4.9	5.3	2.2	2.5		
			Values of C			

X values to determin max width (higligted in yellow)

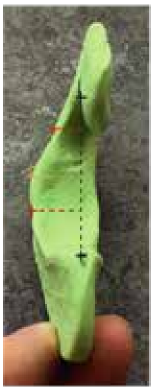
	Left				Right			
	A	B	C	Inf Ar	A	B	C	Inf Ar
mould #1	1.5	2.2	2.5	0	1.5	2	2.1	0
mould #2	2.1	-	2.3	0	2.4	2.5	2.5	0
mould #3	2.1	2.1	1.5	0	1.8	3.5	2.5	0
mould #4	1.4	2	1.9	0	1.6	1.9	-	0
mould #5	-	-	-	0	1.4	1.9	1.7	0
mould #6	1.6	2.1	1.7	0	2.2	3	3.1	0
mould #7	1.4	2.15	2.4	0	1	2.1	2.5	0
	1.7	**2.1**	2.05	0	1.7	**2.4**	**2.4**	0

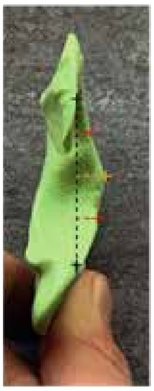
		LEFT		RIGHT					
alignmnt point		Superior auricular root in:		Superior auricular root in:			Height refers to Y		
		X	Y	X	Y		Width refers to X		
		0	5.4	0	6.4		Angle measured directly on illustrator		
		Left		**Right**		**Height Sup ar-A**		**Angle**	
	A	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
	A1	1.5	5.4	1.5	6.1	0	0.3		
	A2	2.1	4.3	2.4	5.75	1.1	0.65		
	A3	2.1	4.5	1.8	4.9	0.9	1.5		
	A4	1.4	4.9	1.6	5.8	0.5	0.6		
	A5	-	-	1.4	5.1	-	1.3		
	A6	1.6	4.6	2.2	6	0.8	0.4		
	A7	1.4	5.1	1	6.3	0.3	0.1		
	AVERAGE	1.7	4.8	1.7	5.7	0.6	0.7	111,6° (-68,4°)	68,5°
				average width of A			15.5		
		Left		**Right**		**Height A-B**		**Angle**	
	B	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
	B1	2.2	4.7	2	5.2	0.7	0.9		
	B2	-	-	2.5	4.6	-	1.15		
	B3	2.1	2	3.5	3.9	2.5	1		
	B4	2	2.8	1.9	4.1	2.1	1.7		
	B5	-	-	1.9	4.9	-	0.2		
	B6	2.1	3.9	3	4.9	0.7	1.1		
	B7	2.15	4.2	2.1	5.1	0.9	1.2		
	AVERAGE	2.1	3.5	2.4	4.7	1.3	1	124,9° (-55,1°)	56,4°
				average width of B			-19.1		
		Left		**Right**		**Height B-C**		**Angle**	
	C	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
	C1	2.5	3.9	2.1	4.3	0.8	0.9		
	C2	2.3	1.7	2.5	3.8	-	0.8		
	C3	1.5	1.2	2.5	2.5	0.8	1.4		
	C4	1.9	1.7	-	-	1.1	-		
	C5	-	-	1.7	3.7	-	1.2		
	C6	1.7	2.2	3.1	3	1.7	1.9		
	C7	2.4	2.1	2.5	4.1	2.1	1		
		2.05	2.1	2.4	3.6	1.4	1.1	142,2° (-37,8°)	46,2°
				average width of C			-20.3		
		Left		**Right**		**Height C-Inf. Au. r**		**Angle**	
	Inf. Au r.	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
	Inf. Au r 1	0	1.3	0	2.6	2.6	1.7		
	Inf. Au r 2	0	0.6	0	1.5	1.1	2.3		
	Inf. Au r 3	0	0.5	0	0.6	0.7	1.9		
	Inf. Au r 4	0	0.3	0	1.1	1.4	-		
	Inf. Au r 5	0	0.5	0	1.5	-	2.2		
	Inf. Au r 6	0	0.5	0	0	1.7	3		
	Inf. Au r 7	0	0	0	0.4	2.1	3.7		
		0	0.5	0	1.1	1.6	2.5	0	0
				average width of inf au r			53.7		

NORMALIZED								
	Left		**Right**		**Height Sup ar-A**		**Angle**	
A	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
A1	1.262463343	3.871698113	1.262463343	4.373584906	1.528301887	2.026415094		
A2	2.069208211	3.975471698	2.364809384	5.316037736	1.424528302	1.083962264		
A3	2.112316716	4.924528302	1.810557185	5.362264151	0.4754716981	1.037735849		
A4	1.46568915	4.9	1.675073314	5.8	0.5	0.6		
A5	-	-	1.408211144	4.71509434	-	1.68490566		
A6	1.609384164	5.554716981	2.212903226	7.245283019	-0.1547169811	-0.8452830189		
A7	1.551906158	5.773584906	1.108504399	7.132075472	-0.3735849057	-0.7320754717		
AVERAGE	1.7	4.8	1.7	5.7	0.6	0.7	111,6° (-68,4°)	69,8°
			average width of A			22.4		
	Left		**Right**		**Height A-B**		**Angle**	
B	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
B1	1.851612903	3.369811321	1.683284457	3.728301887	2.030188679	2.671698113		
B2	-	-	2.463343109	4.252830189	-	2.147169811		
B3	2.112316716	2.188679245	3.520527859	4.267924528	3.211320755	2.132075472		
B4	2.093841642	2.8	1.98914956	4.1	2.6	2.3		
B5	-	-	1.911143695	4.530188679	-	1.569811321		
B6	2.112316716	4.709433962	3.017595308	5.916981132	0.6905660377	0.4830188679		
B7	2.383284457	4.754716981	2.327859238	5.773584906	0.6452830189	0.6264150943		
AVERAGE	2.1	3.6	2.4	4.7	1.3	1.7	124,3° (-55,7°)	56,5°
			average width of B			30.8		
	Left		**Right**		**Height B-C**		**Angle**	
C	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
C1	2.104105572	2.796226415	1.76744868	3.083018868	2.603773585	3.316981132		
C2	2.26627566	1.571698113	2.463343109	3.513207547	3.828301887	2.886792453		
C3	1.508797654	1.313207547	2.514662757	2.735849057	4.086792453	3.664150943		
C4	1.98914956	1.7	-	-	3.7	-		
C5	-	-	1.709970674	3.420754717	-	2.979245283		
C6	1.709970674	2.656603774	3.118181818	3.622641509	2.743396226	2.777358491		
C7	2.660410557	2.377358491	2.771260997	4.641509434	3.022641509	1.758490566		
	2.0	2.1	2.4	3.5	3.3	2.9	141,2° (-38,8°)	46,2°
			average width of C			-13.0		
	Left		**Right**		**Height C-Inf. Au. r**		**Angle**	
Inf. Au r.	**X**	**Y**	**X**	**Y**	**L**	**R**	**L**	**R**
Inf. Au r 1	0	0.9320754717	0	1.864150943	4.467924528	4.535849057		
Inf. Au r 2	0	0.5547169811	0	1.386792453	4.845283019	5.013207547		
Inf. Au r 3	0	0.5471698113	0	0.6566037736	4.852830189	5.743396226		
Inf. Au r 4	0	0.3	0	1.1	5.1	5.3		
Inf. Au r 5	0	0.4622641509	0	1.386792453	4.937735849	5.013207547		
Inf. Au r 6	0	0.6037735849	0	0	4.796226415	0		
Inf. Au r 7	0	0	0	0.4528301887	5.4	5.947169811		
	0	0.5	0.0	1.0	4.9	5.4	0	0
						10.3		

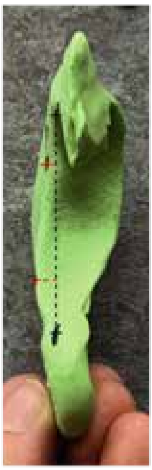
APPENDIX S_ OVERVIEW OF "FRONT VIEW" MOLD POINT MAPPING

Mold #1


Left

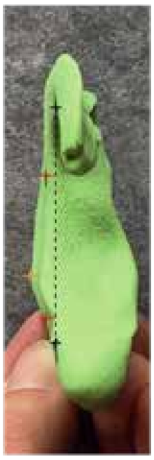

Right

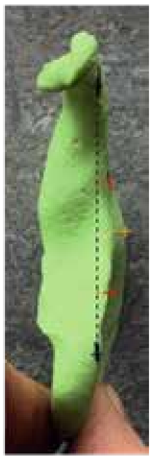
Mold #2


Left

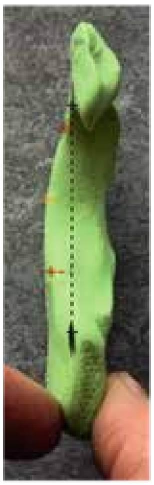

Right

Mold #3


Left

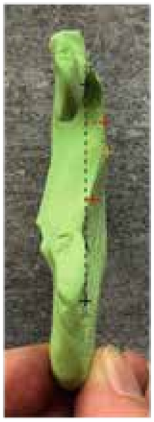

Right

Mold #4


Left


Right

Mold #5


Left

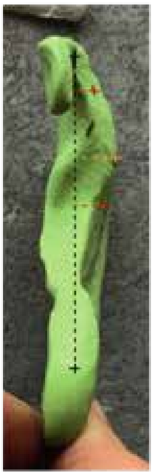

Right

Mold #6


Left


Right

Mold #7

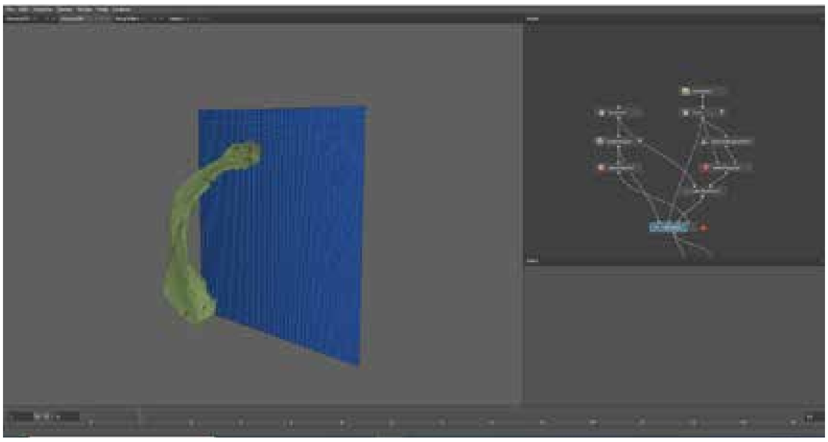

Left


Right

APPENDIX T_ STEPS IN WRAP TO UNIFORM SILICONE MOLDS

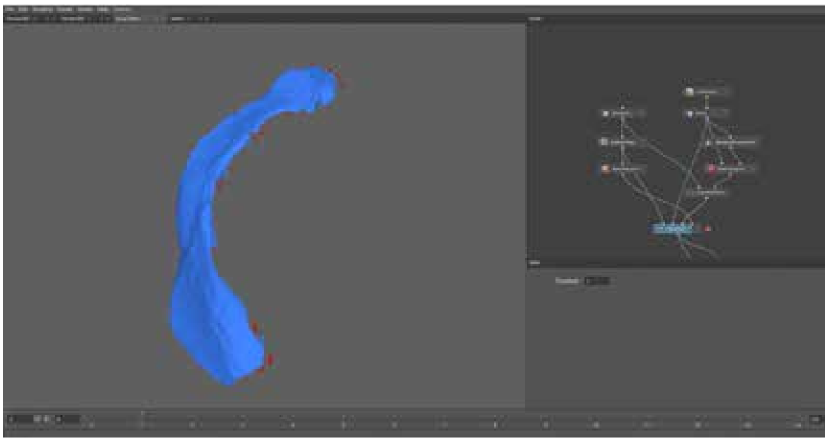
STEP 1

Node map of mould analysis;



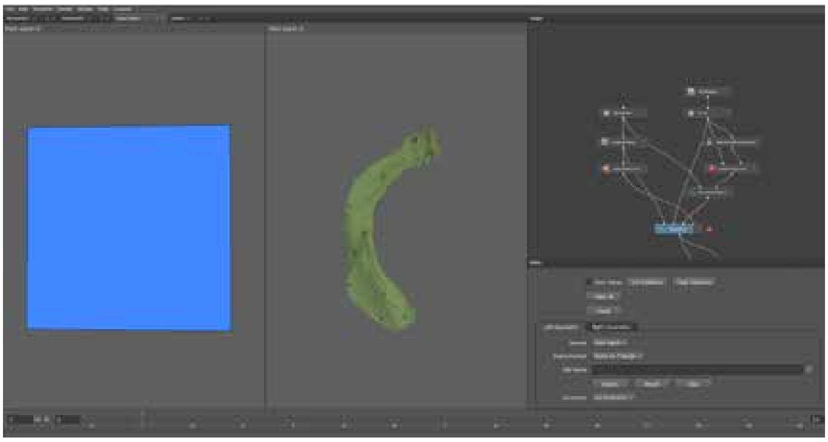
STEP 2

Import **scan with texture** and custom **basemesh** subdivided with scale of 7.



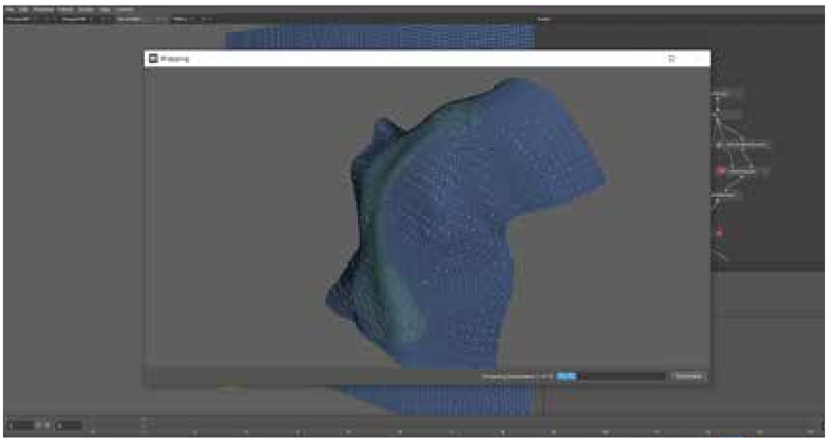
STEP 3

Small object filter;



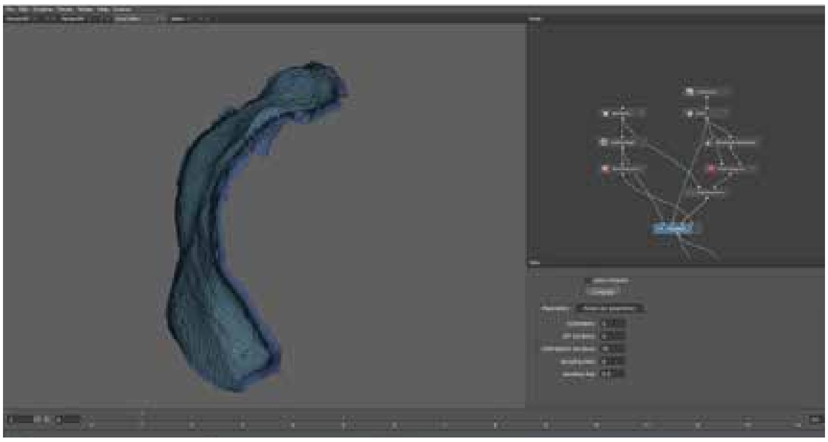
STEP 4

No **landmark** placement needed;



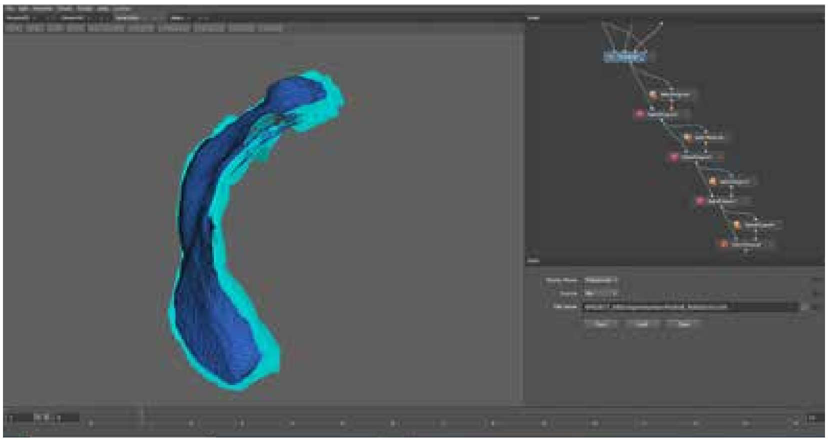
STEP 5

Wrapping process;



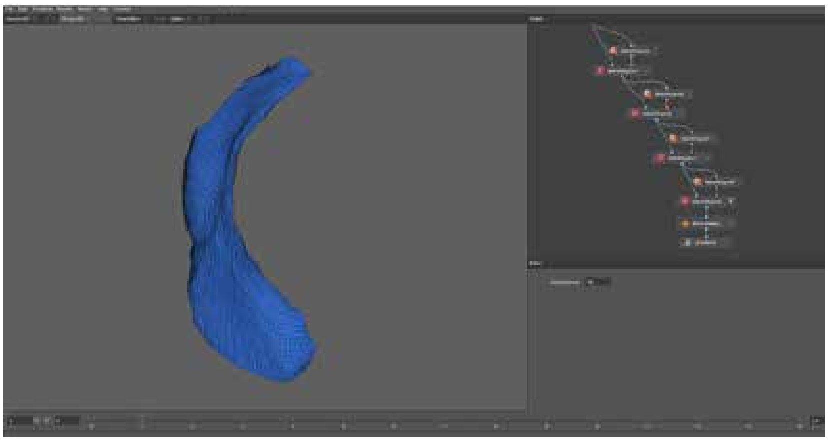
STEP 6

Result of wrapping;



STEP 7

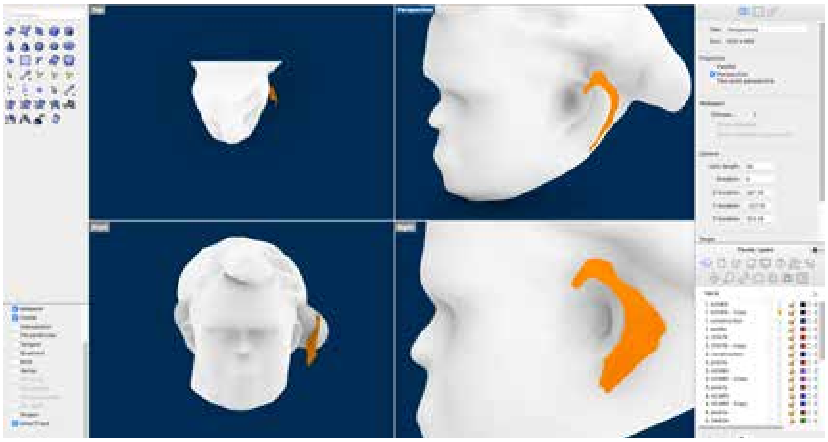
Select **edge polygons** corresponding to wrinkled wrapping;



STEP 8

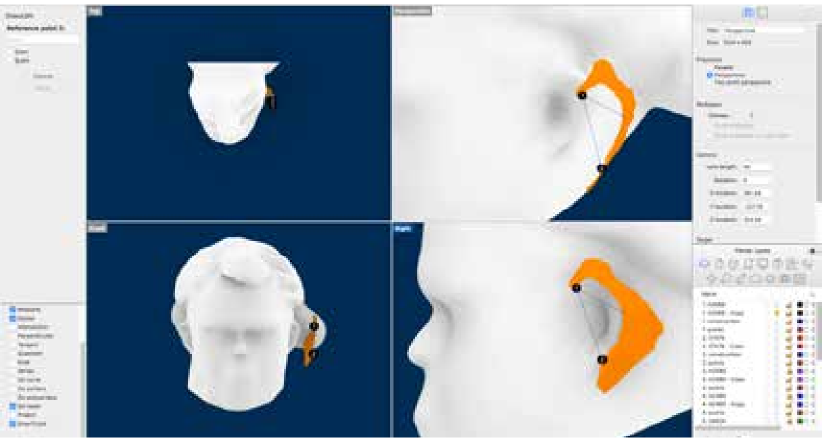
Remove spikes from geometry and **save** result.

APPENDIX U_ ALIGNMENT STEPS OF MOLD TO HEAD SCAN IN RHINO



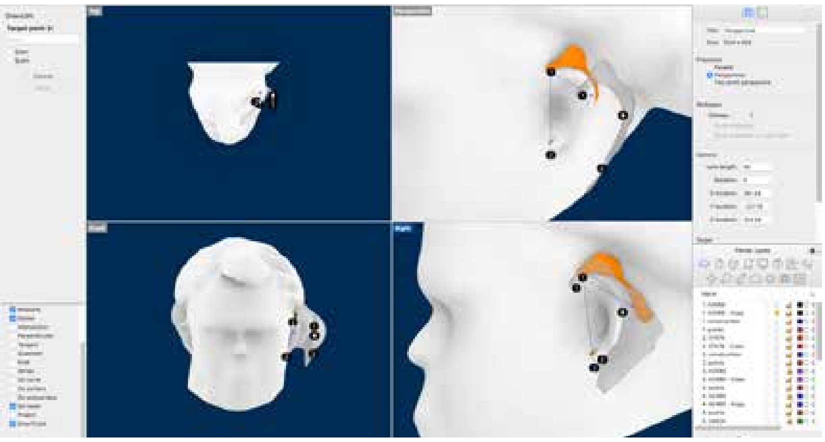
STEP 1

Import wrapped mould onto scan in Rhino and roughly orient;



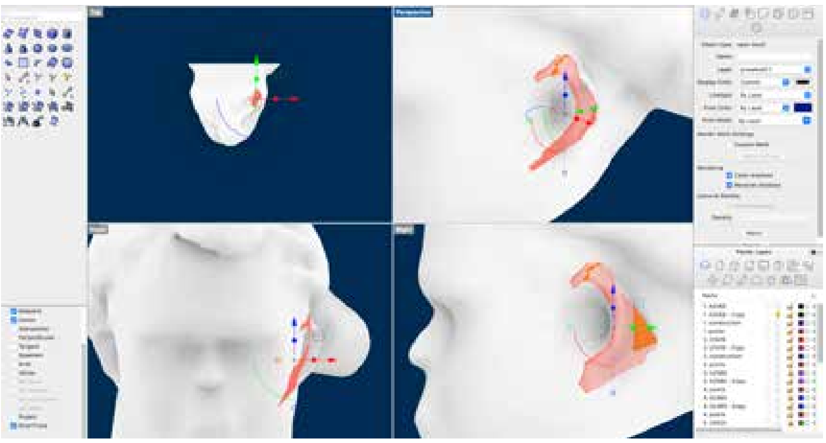
STEP 2

Select **Orient3pt** command and select scans as reference object. Select **3 points** on mould corresponding to **obs**, **obp**, and **obi** landmarks;



STEP 3

Select **3 landmarks points** corresponding to head scan;



STEP 4

Results of alignment of mould onto head scan;

PREMISE

Duration: 2 weeks

I've decided to do a sprint to "escape" the loop in which I was stuck of not being able to elaborate the ergonomic data efficiently.

I believed that observing the project again from a distance and looking at the bigger picture would help refocus and obtaining effective results by the end of the sprint.

1. BRAINSTORM PHASE

GOAL

- Set a long term goal
- Pick a target on the map

METHODOLOGY

The methods applied for the initial phase are an iteration of the "Monday Sprint session" methodology developed by Jake Knapp at Google venture (Knapp et al., 2016). The adjustments were needed since the original methodology contemplates team participation while in this case there was only one participant.

STEPS

1. Brainstorm on the "Long Term Goal" by answering questions such as:
   - "Why are we doing this project?"
   - "What are our Principles and Aspirations?"
   - "Where do we want to be in 2 months?" (Approximate end of the project)

2. List sprint questions by getting pessimistic and turning fears into questions.
3. Make a map of the “actions” needed to reach the goal.
4. Ask yourself “How might we...”(HMW)
5. Cluster the “HMW” in groups.
6. Vote on the HMW
7. Pick a target
8. The HMW questions turned out to be very effective consideration to keep in mind as potential design requirements.

RESULTS

Each step of the session has been carried out on canvas, and the results are visible in *images X-XXX.*

IMAGE X Results of Brainstorm Sprint session: STEP 1

IMAGE X Results of Brainstorm Sprint session: STEP 2

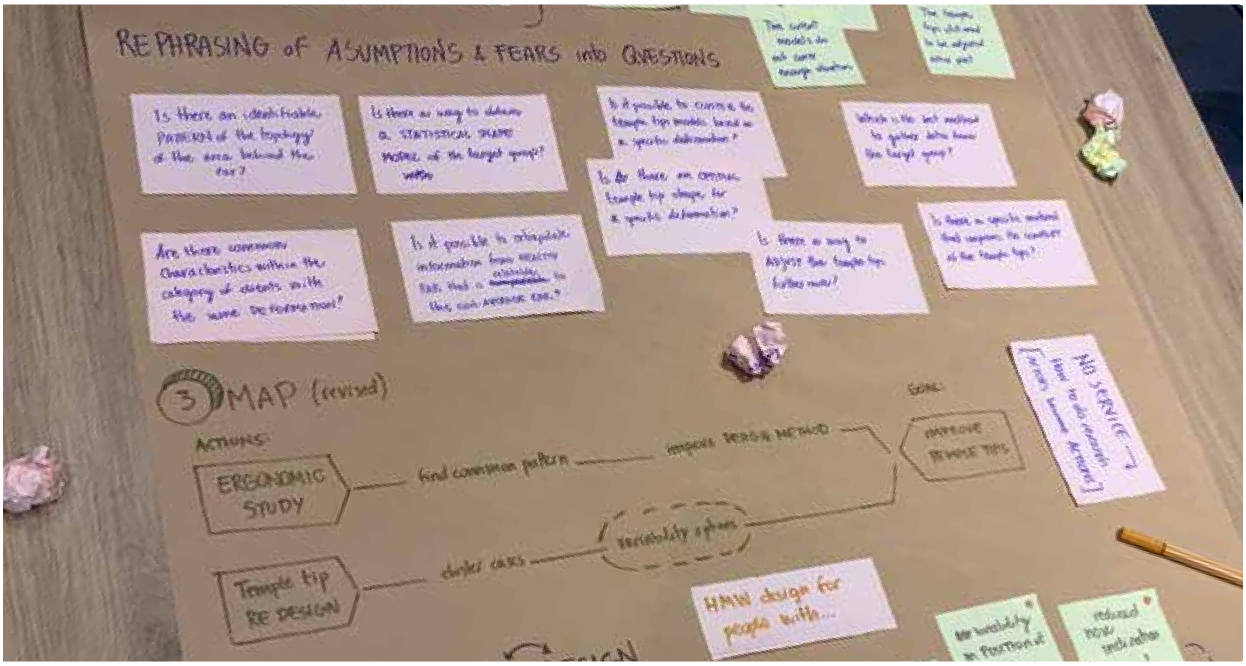


IMAGE X Results of Brainstorm Sprint session: STEP 3 and 7

IMAGE X Results of Brainstorm Sprint session: STEP

Long term goal for the session:

Redesign temple tips to investigate the necessity of knowing the curvature of the area behind the ear.

REFLECTION

The method would have been more effective if the session had occurred with a team. Nevertheless refocusing and retracing what has been researched until now proved to be beneficial for the refocusing of the goal.

What appeared to be the obvious (in my mind) original goal has been rephrased into something more concrete.

2. IDEATION PHASE

GOAL

Generate a variety of possible solutions/ideas.

METHODOLOGY

The methodology is inspired by the concept of “lighting Demos” introduced by XXX in the “Tuesday Sprint session” (Knapp et al., 2016).
This method consists of evaluating great solutions that are from a range of companies, including the client’s and quickly capture good insights on a drawing.
In addition to the sketching methodology, I felt the need to thinker with actual eyeglasses components to feel more inspired.

STEPS

1. Research and Collect valid examples from competitors;
2. “Lightning demos” of external companies;
3. “Lightning demos” focused on the client material;
4. Tinkering with prototyping material.

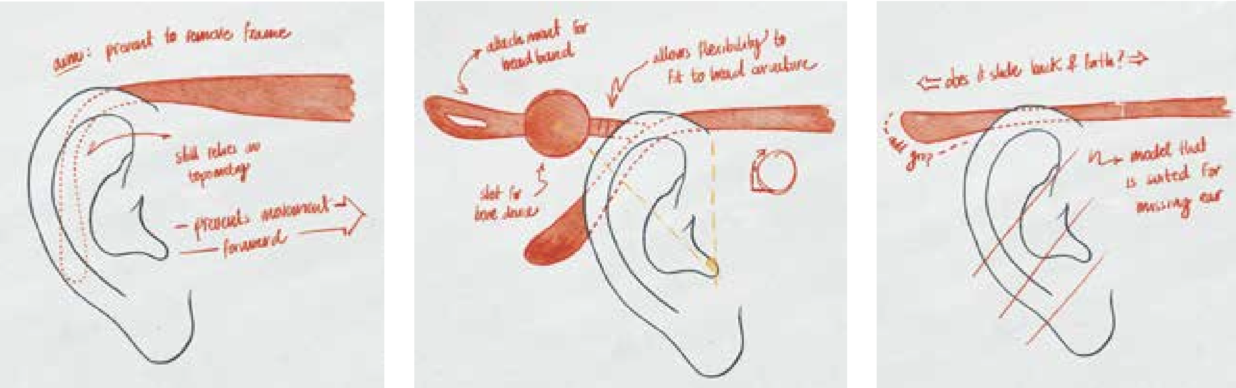
IMAGE X Competitor Analysis

RESULTS

In image X "competitors Analysis" I have summarized the notes taken on the post-it notes during the "Lightning demos" referring to external companies existing products.

The "Lightning demos" referring to Maatbril's temple tips models consisted in sketching and evaluating the existing products.

Tinkering with the material for inspiration did not lead towards new temple tips concepts but more towards insights and potential directions. Such as:



IMAGES X Notes on Maatbril temple tips

- Experimenting with the connection between the temple and an elastic band.
- Adding an additional material to the temple to generate friction
- Giving a texture to such material might increment or reduce the friction on the skin

IMAGE X Tinkering results

REFLECTION

For the "Lightning demos" phase I had to restrict the variety of competitors to companies that focus on designing glasses for the special needs target group since the entire eye-wear market was too vast. This decision might have influenced my ideation phase by restricting it but at the same time, it was a time-efficient decision. Reflecting on the existing Maatbril portfolio was not as effective as it would have been by having direct feedback from either the experts or clients. The notes were

based on assumptions made on the product.
Tinkering with the spare eye-wear parts helped getting unstuck from the 2D sketching phase but while doing so I realized the need of having a physical model representing a human head. This decision affected the development of the rest of the sprint.

3. HEAD MODELS AND 3D PRINTS PHASE

GOAL

Recreate possible client scenarios in which the glasses need to function.

METHODOLOGY

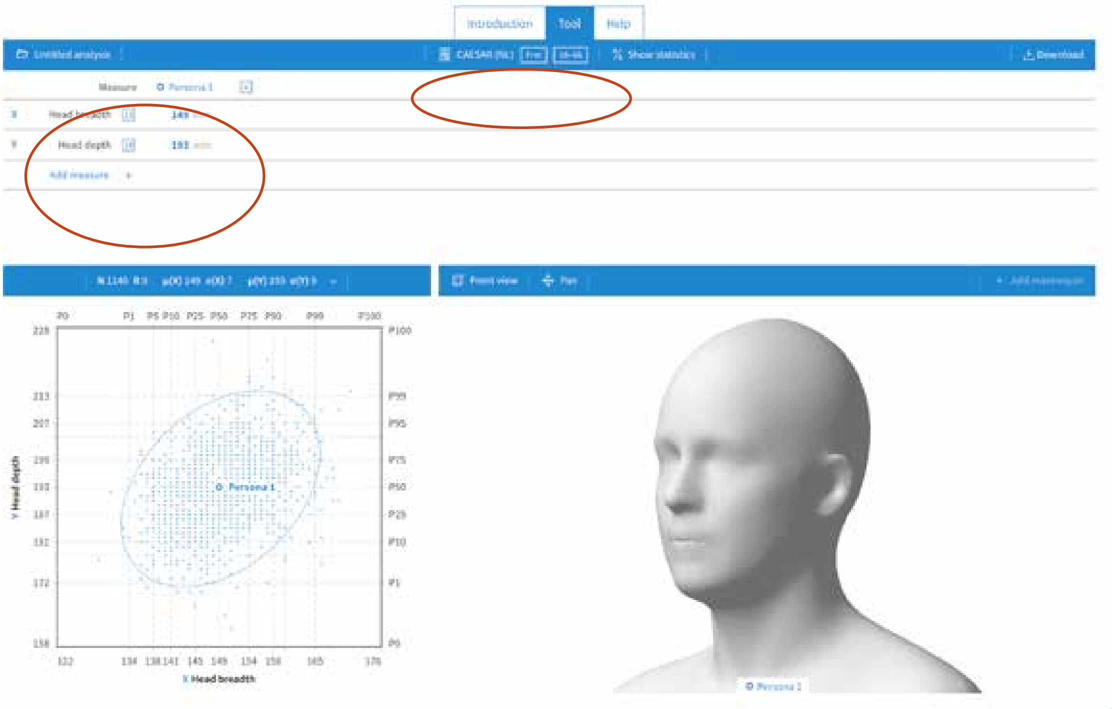


IMAGE X DINED P50 Head

The idea was to 3D print heads that depict different situation occurring in the clients. An initial Head has been downloaded from the DINED database (CITE) with the following characteristics:

STEPS

1. Download a P50 head representing the target group age and gender
2. Modify the STL file in Rhino (*See image X_ Cage edit modification*) based on different situations occurring within the client group:
   - Presence of only one ear
   - Absence of both ears
   - Deformation based on common Down syndrome parameters: Flatter and lower nose bridge, flatter neck, lower ears, prominent forehead.

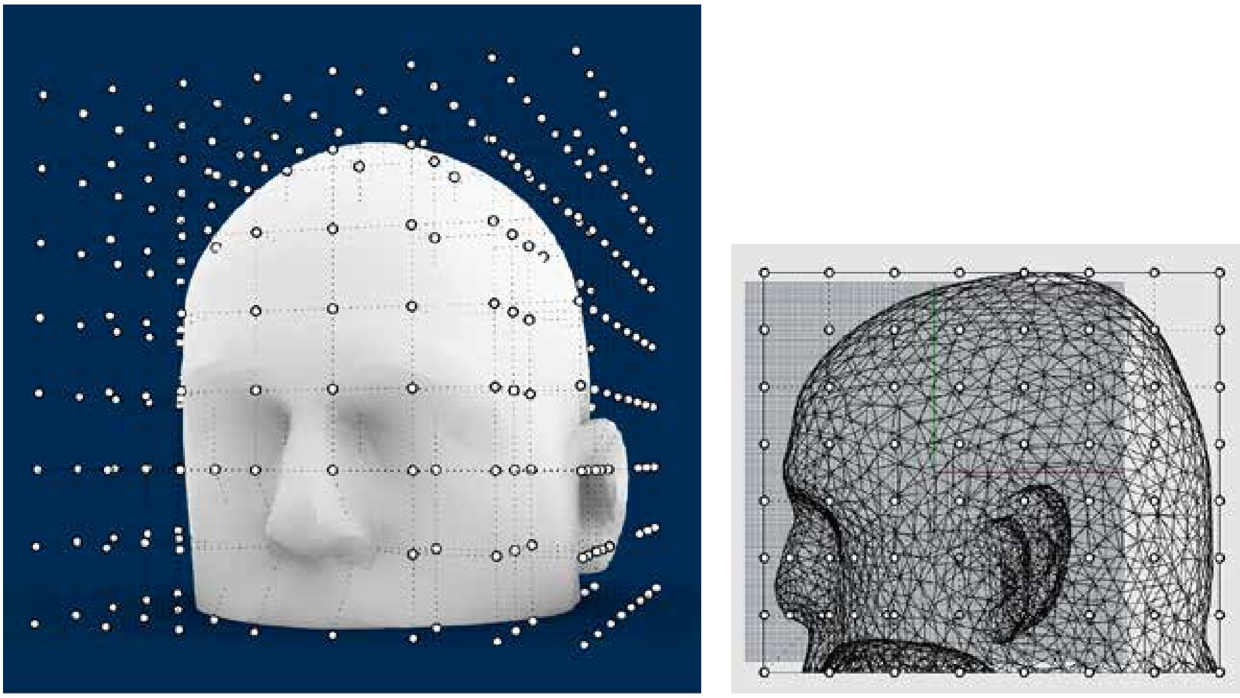


IMAGE X Cage edit modification

The ears have been misalignment on both axis: frontal and top view (*see image X_ Misalignment of ears*)

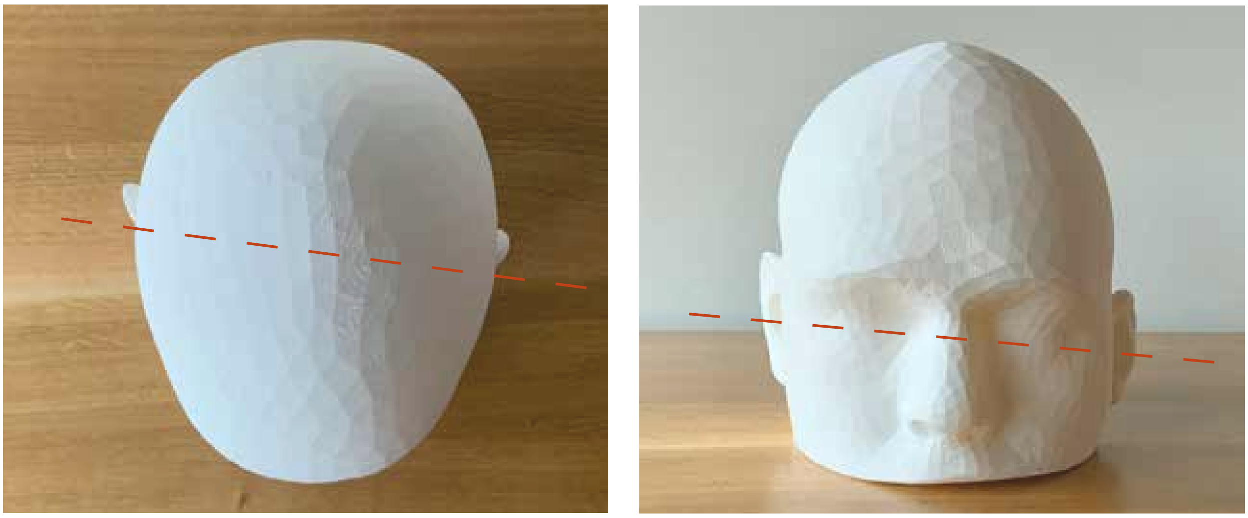


IMAGE X Misalignment of ears

IMAGE X 3D printed sample heads

RESULTS

From left to right (*see image X_ 3D printed sample heads*:

1. Model with deformation regarding flattening of nose, prominent forehead, flatter neck and misalignment of ears in both frontal and top view axis. (Scale 90%)
2. Model with deformation regarding flattening of nose, prominent forehead, flatter neck and misalignment of ears only frontally. (scale 77%_ vase mode)
3. Model with absent ears (Scale 77%)
4. Model with only one absent ear (Scale 90%)
5. P50 average head (Scale 90%_ vase mode)

REFLECTION

To obtain multiple print variations in a shorter amount of time, it was necessary to print in vase mode. This process drastically reduced the printing time from about 40 hours to around 3h. Unfortunately, the head models with thinner walls did not whitstand the use during the prototyping phase and therefore needed to be reprinted with a low infill percentage (between 5-10%). The thicker ones have been filled with paper and foam.

An additional modification necessary was reducing the scale of the original file for it to fill the build plate. The file of a P50 head has been scaled to a maximum of 90% to allow proper fit on the build plate while still maintaining a brim of 5 mm. The minimum scale printed of the same file is 77% to create an additional variation between the samples by representing the head size of a child.

4. PROTOTYPE PHASE

GOAL

Create quick and rough prototypes that could be evaluated and tested.

METHODOLOGY

Roughly recreate an example of an existing product and iterate on it as a starting point.

STEPS

1. Recreate a prototype of the observed existing products by including key characteristics
2. Iterate on the prototype creating different variations by improving the observed flaws
3. Generate different concept for different possible scenarios

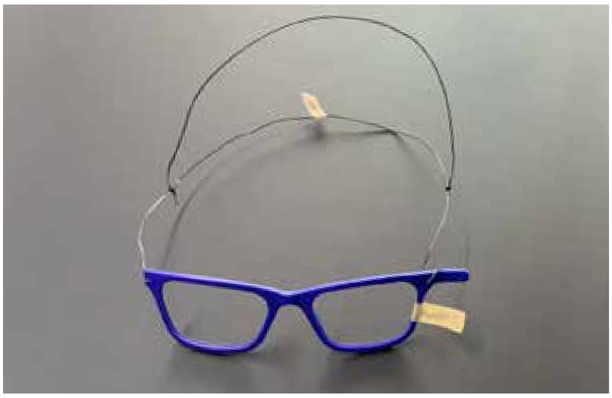


IMAGE X Prototype 1

IMAGE X Prototypes 1.1

IMAGE X Prototype 2

IMAGE X Prototype 4

IMAGE X Prototypes 3-3.1-3.2

IMAGE X Prototype 5

IMAGE X Prototype 6

5. TEST & EVALUATE PHASE

GOAL

The test focuses on evaluating the FUNCTION and not the comfort of use of each concept.

METHODOLOGY

The method is based on observing and differentiating between different issues and aspects that have been highlighted following a coloring code system:

- *Issues with FUNCTION*
- *Issue with PROTOTYPE FIDELITY*
- *Points that are used for ADAPTABILITY*
- *Aspect to improve for the NEXT PROTOTYPE ITERATION*
- *Explanation of particular FUNCTION*
- *Facial elements that influence ERGONOMY of the glasses*

(*) link between two or more aspects

The evaluation also took into account the stability of the prototype when subject to movement that has been simulated by slightly shaking the head in both longitudinal and sagittal direction.

STEPS

1. Each prototype has been placed on the corresponding head model;
2. Mark with green tape the adjustment points needed to place and fix the frame correctly;
3. Mark with tape on the prototypes the problematic points and note down insights. For each prototype answer these questions:
   - What works and what does not in terms of FIT and not use
   - What are the parts that need iteration?
   - What facial elements influence the ergonomic of the prototype?

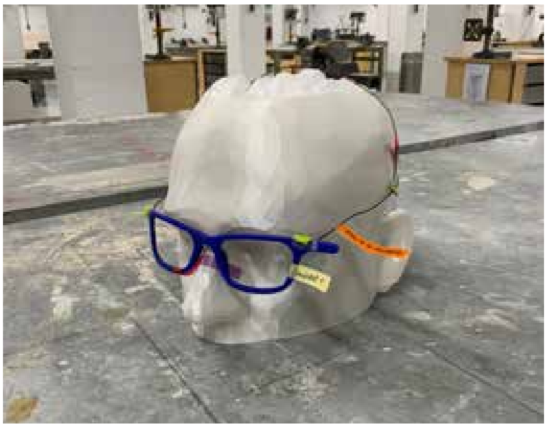
4. Mark the head models with purple tape corresponding to the areas that are relevant in terms of ergonomics

RESULTS

Model 1

Quick prototype version of the product from “Suhhermsen”. In this case the hole is in the upper corner of the frame, and this causes the lower part of the frame to lift up.

The use of wire is intentional since it simulates nylon mono-filament. There are multiple points that require adjustment for a proper fit.



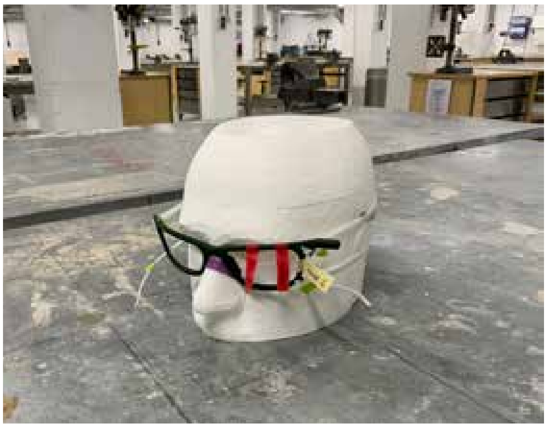
Model 1.1

Iteration of prototype 1 with a second wire to prevent the frame from lifting upwards.

The product appeared to be stable even without the top wire. The adaptability still requires to be fitted individually.

Model 2

Evolution of Model 1.1 with elastic bands instead of wire to solve the precise adaptability issue. The elastic band applies excessive pressure to the frame, which causes it to bend and move upward on the nose bridge.



Model 3

The temples have been reintroduced to alleviate the rubber band pressure on the frame. They appear to be excessively short and interfere with the temples.

The stability of the glasses could be improved with the addition of a second rubber band.

Model 3.1

In this prototype the temples have been extended.

The connection slots have been adjusted in order to allow two rubber bands to fit. The rubber bands overlap with the temples since the connection between the two elements is near the frame.

Model 3.2

The connection between rubber band and temple has been pushed towards the end of the temple, reducing the pressure.

Model 4

The temple on the side of the missing ear has been modified by adding a strip of hot glue, i to simulate the friction of a silicone strip. The placement is on the inner side of the temple, in correspondence to the touch point of the superior auricular root.

Model 5

The prototype introduces a different approach to the temple tip by reshaping it in order to minimize the contact on the posterior ear and therefore avoiding the issue of not knowing the curvature of this area. (see image X).

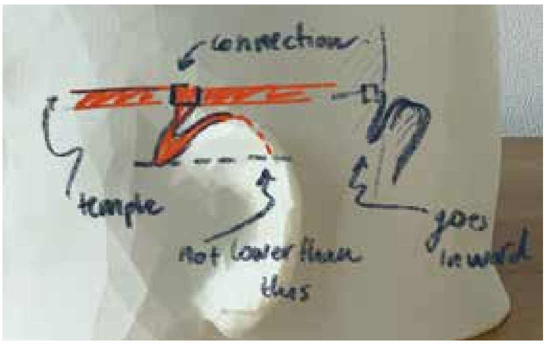


IMAGE X Detail of Model 5

Model 6

The prototype simulates a solution that is being implemented by maatbril at the moment (see image X_ temple tip model 7). An arched temple tip is added to the existing one in order to create an additional grip functioning as a sort of headband.

REFLECTION

There are some limitations to the test:

- No proper correspondence between head sizes and frames;
- Not enough detail on the head model of the area behind the ear, to understand the proper interaction with the temple tip;
- The friction between the PLA and the elastic band is greater than what would occur between skin and the fabric elastic band;
- No lenses present on the frames, therefore there is an impact on the weight distribution

In order to conduct a future biomechanical study it will be necessary utilising the proper materials to simulate a realistic environment in terms of materials and weight.

6. SELECTION PHASE

GOAL

Identify and narrow down the key takeaways from the prototypes.

METHODOLOGY

Evaluation of the final iteration of each model and identify the best performing results based on the previous evaluation

RESULTS AND REFLECTION

Of the developed prototypes the most promising were:

- Model 3.2 for the interesting potential direction of the shortened temple tip but it requires iteration concerning:
  - The proper connection between temple tip and elastic band;
  - The curvature of the temple, that has to follow the cranial curvature;
- Model 5 has potential in terms of the idea behind the "grip" addition to silicone.

FEEDBACK FROM DISCUSSION WITH CLIENT

I have shown him the most promising directions and He was not enthusiastic about the idea of having temple tips since this would not be in line with the idea behind the company.

We have discussed the idea of a shorter temple tip, and it emerged that the head's curvature would cause the glasses to fall off (*see image X_ Glasses slide off*). To prevent this from happening the reliance on the rubber-band would be quite high, most likely resulting in an uncomfortable frame.

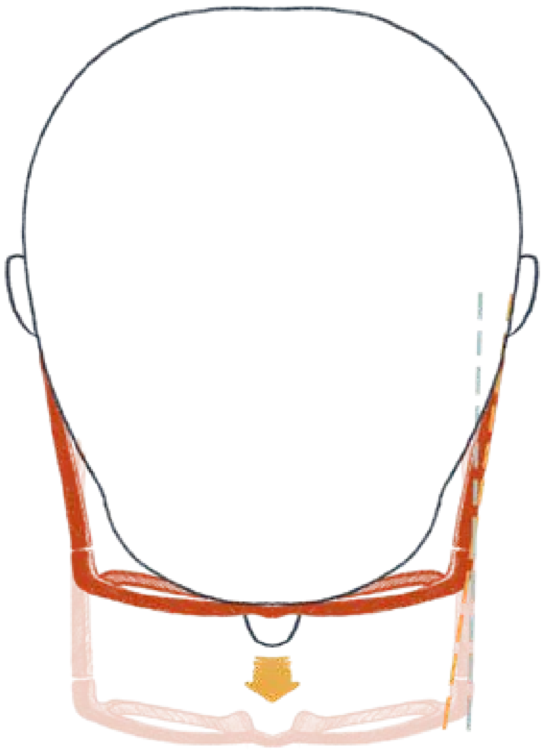


IMAGE X Glasses slide off

It was also noticed that the curvature of the nose of "model head 5" should be modified with the aim of flattening the nose curvature and lowering the nose bridge even further (*see image X_ Head 5 variations suggestions).*

IMAGE X Head 5 variation suggestions

APPENDIX W_ CONCEPT EVALUATION TABLES

TABLE 5.3_ HARRIS PROFILE CONCEPT 1_ ARCH WITH WIRE

	REQUIREMENTS	-- (BAD)	- (MODERATE)	+ (GOOD)	++(EXCELLENT)
PROCESS	User friendly*				
	Ease of application/ removal				
	Comfort for user				
	Potential accuracy of collected data**				
	Risk of compromising data				
PROTOTYPE	Feasibility of prototype				
	Compactness				
	TRL				
	TOT.	23			

TABLE X.1_ HARRIS PROFILE CONCEPT 2_ INFLATABLE CUSHION

	REQUIREMENTS	-- (BAD)	- (MODERATE)	+ (GOOD)	++(EXCELLENT)
PROCESS	User friendly*				
	Ease of application/ removal				
	Comfort for user				
	Potential accuracy of collected data**				
	Risk of compromising data				
PROTOTYPE	Feasibility of prototype				
	Compactness				
	TRL				
	TOT.	19			

* Quantity of steps required to obtain data

** Based on an estimation since this requirement can't be verified until prototyped and tested

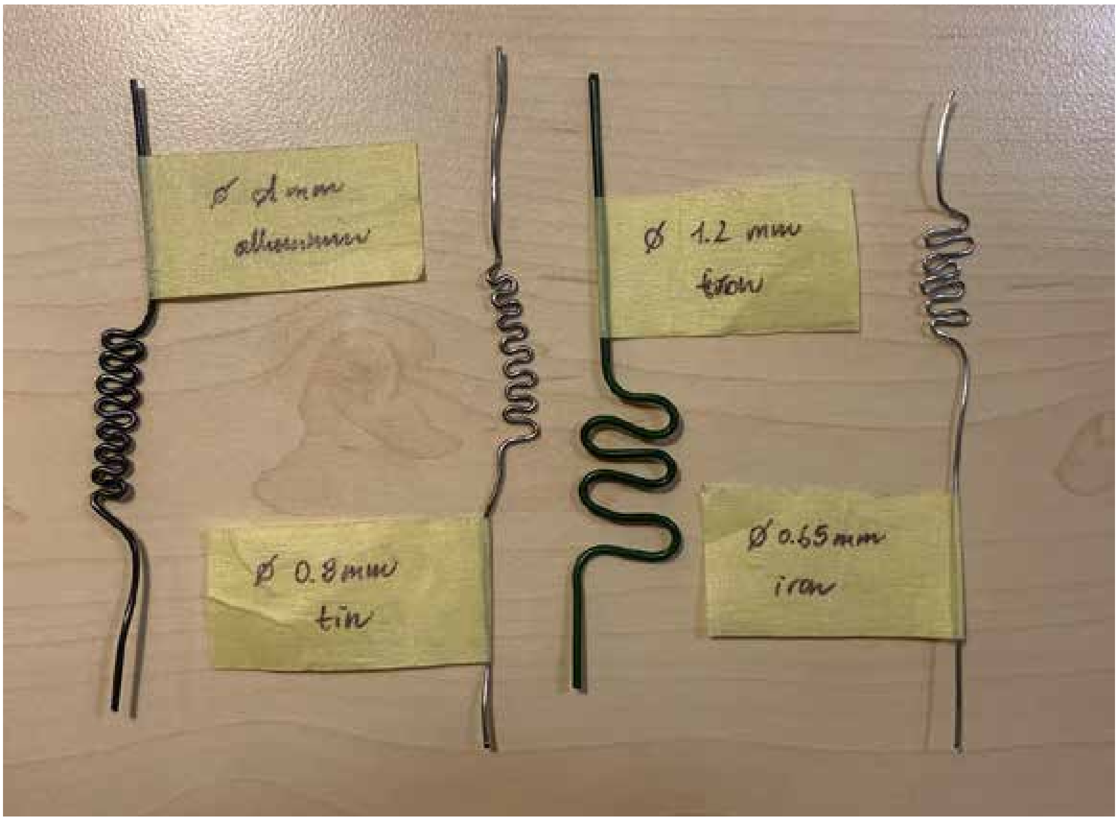
TABLE X.2_ HARRIS PROFILE CONCEPT 3_ VACUUM CUSHION

	REQUIREMENTS	-- (BAD)	- (MODERATE)	+ (GOOD)	++(EXCELLENT)
PROCESS	User friendly*				
	Ease of application/ removal				
	Comfort for user				
	Potential accuracy of collected data**				
	Risk of compromising data				
PROTOTYPE	Feasibility of prototype				
	Compactness				
	TRL				
	TOT.	17			

TABLE X.3_ HARRIS PROFILE CONCEPT 4_ INTEGRATED MEASURING TOOL

	REQUIREMENTS	-- (BAD)	- (MODERATE)	+ (GOOD)	++(EXCELLENT)
PROCESS	User friendly*				
	Ease of application/ removal				
	Comfort for user				
	Potential accuracy of collected data**				
	Risk of compromising data				
PROTOTYPE	Feasibility of prototype				
	Compactness				
	TRL				
	TOT.	26			

APPENDIX Y_ METAL COMPARISON



APPENDIX X_ COST BREAKDOWN

PART OF FRAME	MATERIAL	WEIGHT	MATERIAL COST	COST OF COMPONENT
Front	PA 11	2g	50€/kg	0,10 €
Socket of joint	TPU	0,5g	24 €/ kg	0,012 €
Ball joint stud	PA 11	0,7g	50€/kg	0,035 €
Sliding Temple	PA 11	4g	50€/kg	0,2 €
Aluminum wire	Aluminum	0,8 g	200€/kg	0,16 €
Silicone temple tip	Silicone shore 30	2g	50€/kg	0,1 €
Mold for silicone	PA 11	3g	30€/kg	0,09 €
Metal mold	PA 11	0,2g	50€/kg	0,01 €
TOT.				**0,707 € = 70 cent.**

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