

Report

Title

- Smart Companion Pillow



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Glossary

Abbreviation	Description
2D	Two-dimensional

Abbreviation	Description
3D	Three-dimensional
app	application
AAP	American Academy of Pediatrics
AAL	Ambient Assisted Living
ABS	Acrylonitrile Butadiene Styrene
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
B2C	Business to Consumer
Brexit	Shorthand way of saying the UK leaving the EU - merging the words B ritain and ex it to get Brexit
BT	Bluetooth
bpm	beats per minute
Cd	Cadmium
CIA	Central Intelligence Agency
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
CPU	Central Processing Unit
CS ₂	Carbon Disulfide
dB	Decibel
DC	District of Columbia
DfD	Design for Disassembly
DEE	Departamento de Engenharia Electrotécnica
DFI	Departamento de Física
eCO ₂	equivalent Carbon Dioxide
EPS	European Project Semester
EU	European Union
FAAP	Fellow of the American Academy of Pediatrics
FDA	Food and Drug Administration

Abbreviation	Description
FTDI	Future Technology Devices International
GDP	Gross Domestic Product
HD	High Definition
HSO ₄	Hydrogen Sulfate
ICT	Information, Communication and Technology
IFTTT	If This Then That
IoT	Internet of Things
ISEP	Instituto Superior de Engenharia do Porto
LSA	Laboratório de Sistemas Autónomos
MD	Medical Doctor
MDR	Medical Device Regulation
MP3	MPEG-1 Audio Layer 3
MPEG	Moving Picture Experts Group
NaOH	Sodium Hydroxide
NHS	National Health System
NICHD	National Institute of Child Health and Human Development
NIOSH	National Institute for Occupation Safety and Health
NSP	National Sleep Foundation
NSPE	National Society of Professional Engineers
P	Procedure
Pb	Lead
PBI	Product Backlog Item
PDCA	Plan, Do, Check, Act
PESTEL	Political, Economic, Socio-Cultural, Technological, Environmental and Legal
ppm	parts per million
PPS	Purchasing Power Standards

Abbreviation	Description
REM	Rapid Eye Movement
RH	Relative Humidity
ROHS	Restriction of Hazardous Substances
SMART	Specific Measurable Achievable Relevant and Time-related
SMARTER	Specific Measurable Achievable Relevant and Time-related Evaluated Reviewed
SMEI	Sales & Marketing Executives International
SIDS	Sudden Infant Death Syndrome
SpO ₂	Peripheral Oxygen Saturation
SRAM	Static Random Access Memory
SWOT	Strengths Weaknesses Opportunities Threats
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
UK	United Kingdom
USA	United States of America
USB	Universal Serial Bus
USP	Unique Selling Point
VOC	Volatile Organic Compound
VOCs	Volatile Organic Compounds
WBS	Work Breakdown Structure

1 Introduction

In the European Project Semester (EPS) students from different countries and courses of studies are working together to develop a new product. In this chapter, the team members are introduced and a first overview of the project is given.

1.1 Presentation

This team is part of the European Project Semester (EPS) at Instituto Superior de Engenharia do Porto (ISEP). One of the big challenges in the EPS is the diversity of the team. The team members are coming from five different countries and five different scientific fields. Therefore, it is important to find a team spirit. Moreover, it is a great experience to learn from each other and get an insight into the work behaviour of each nation. **Table 1** sums up the background of each team member, and **Figure 1** portrays them.

Table 1: Team

Name	Alexandre Reis	Marcel Pasternak	Tobias Schneider	Elien Gielen	Ko Wopereis	Vaido Sooäär
Nationality	Portuguese	German	German	Belgian	Dutch	Estonian
Course of study	Mechanical Engineering	Mechanical Engineering	Biomedical Engineering	Product Development	Industrial Product Engineering	Electrical Engineering

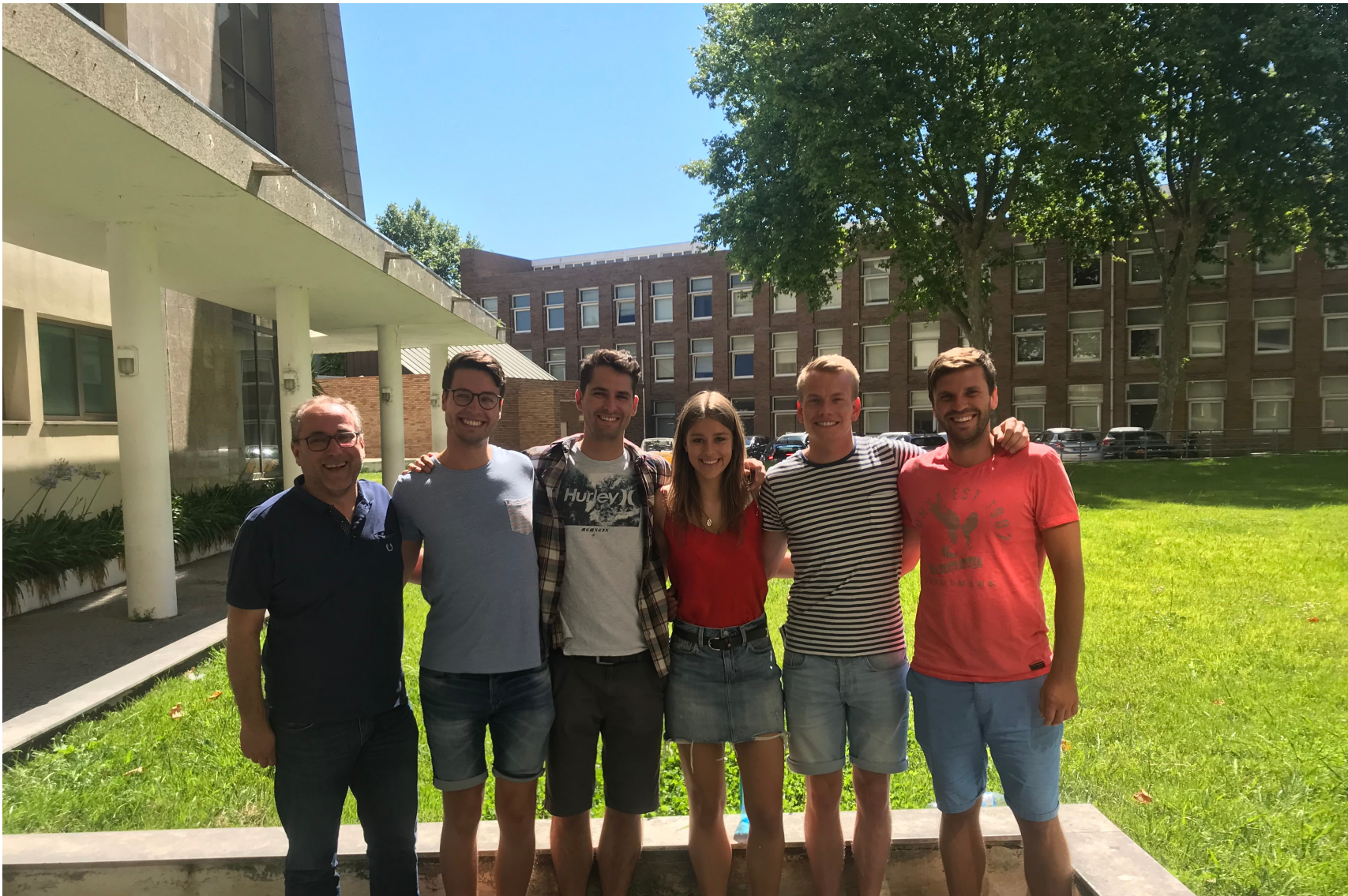




Figure 1: The Team

1.2 Motivation

In the 2019's EPS edition at ISEP, the team develops a Smart Companion PilloW for babys. For all the team members it is a new experience to work in a big group of people with different cultural and knowledge background. So the motivation of taking part in the EPS is to learn from each other and find the team spirit which is needed to create a Smart Companion Pillow. Moreover, each team member wants to improve English skills in a scientific way. The motivation for the project is to create an object that supports people to be healthy. Therefore, the team is motivated to develop a pillow that helps people in a part of their lives. With the rise of using sensors as a part of the IoT [1], it is very interesting to see how to manage the amount of data and how it can be useful for both the health of the baby and the parents.

1.3 Problem

Parents are always worried about the health of their children. According to the American Academy of Pediatrics (AAP) the Sudden Infant Death Syndrome (SIDS) is still an unsolved problem in our world [2]. Therefore the team create a product that either has the benefit of stress relief for the parents or it lowers the risk of SIDS giving the baby the best possible environment to grow up in. In the smart world, parents should be able to make sure the baby is alright by measuring vital parameters and taking care of them with an application (app).

1.4 Objectives

The main goal of the product is the stress relief of the parents during the first 24 months of having a baby. Therefore, the smart pillow monitors the baby's health and the environment. Furthermore, the gadget prevents the infant from lying on its tummy and reacts to its voice/noise with reassuring sounds. For all the objectives the team keeps attention to sustainable and ethical practices.

1.5 Requirements

There are several requirements the team has to take care of. In this section, the main requirements of the project are listed. Functional requirements - The prototype of the pillow has to collect and monitor the sensor data.

Usability requirements - The data has to be presented in a clear way (mobile application/ browser).

Environmental requirements - The manufacturing and the materials have to be addressed in environmental ethics and sustainability accordingly. Moreover, there is a 3D printer and the soldering equipment which are provided from the university to create a prototype.

Limitations - Use a maximum budget of 100.00 € to built a prototype, low-cost hardware solutions and open source software.

Technical requirements - Comply with the following European Union (EU) Directives:

- Machine Directive (2006/42/EC 2006-05-17) [3];
- Low Voltage Directive (2014/35/EU 2016-04-20) [4];
- Radio Equipment Directive (2014/53/EU 2014-04-16) [5];

- Restriction of Hazardous Substances (ROHS) in Electrical and Electronic Equipment Directive (2002/95/EC 2003-01-27) [6];
- Electromagnetic Compatibility Directive (2004/108/EC 2004 12 15) [7].

1.6 Functional Tests

In order to examine the final function of the prototype, the team has to test the software and the hardware aspects which are connected with our objectives as follows. The planned Functional Tests concern the physical product itself, the software and the hardware. **Table 2** lists the planned functional tests highlighting their purpose and the validation.

Item	Purpose	Verification
Software		
Sensors	Test the related software of the sensors	Upload a code example with the Arduino IDE software
IoT Cloud	Create graphs with an open source IoT cloud on a website	Send the measured values to the IoT cloud via Wi-Fi
Interaction	React to the crying of the baby with sounds	Write a code to notice the noise of the baby with the microphone sensor and play sounds through the speakers with the MP3 player
Hardware		
Sensors/Jumper Wires/Micro-controllers	Be sure that the delivered components are working	Upload a code example with the Arduino IDE software
Bluetooth/Wi-Fi	Proove that the Bluetooth and Wi-Fi are working	Upload a code example with the Arduino IDE software
Battery	Proove that the battery is working	Connect the battery to the micro-controller
Speaker	Proove that the speaker is working	Upload a code example with the Arduino IDE software
MP3 player	Proove that the MP3 player plays the music through the speaker	Upload a code example with the Arduino IDE software

1.7 Project Planning

The project is planned in an agile way. Therefore, the team is using the Scrum method. **Figure 2** shows the general process implied in Scrum. First of all the team creates the Product Backlog, which is also known as Project Backlog. This includes all features of the product described from the end user's point of view and the tasks the team is working on during the project. After that, the team decides the priority of each feature and divides it into tasks.

A Sprint is a constant limited time, during which the team is working on different tasks. Throughout the project, the period of the sprint is a week. The organization of the teams' Sprint happens during Sprint Planning. All the team members are assigned to the different tasks they want to do in the following Sprint and write it down in the Sprint Backlog. During the Sprint there are Daily Scrums (Daily Stand Up Meetings). They are organized by the Scrum Master. The team members are telling others, what they have done the last day and what they will do in the next 24 hours. The duration of the Daily Stand Up Meeting is very short. It is about 15 minutes.

At the end of every Sprint, there is the Sprint Review and the Sprint Retrospective. During the Sprint Review, the team discusses which tasks were done and which tasks need to be continued in the next Sprint. In the Sprint Retrospective, the team discusses what went well and what could be improved in the next sprints. Finally, the next Sprint is starting again with all the included tasks. This progress will be continued until the project ends.

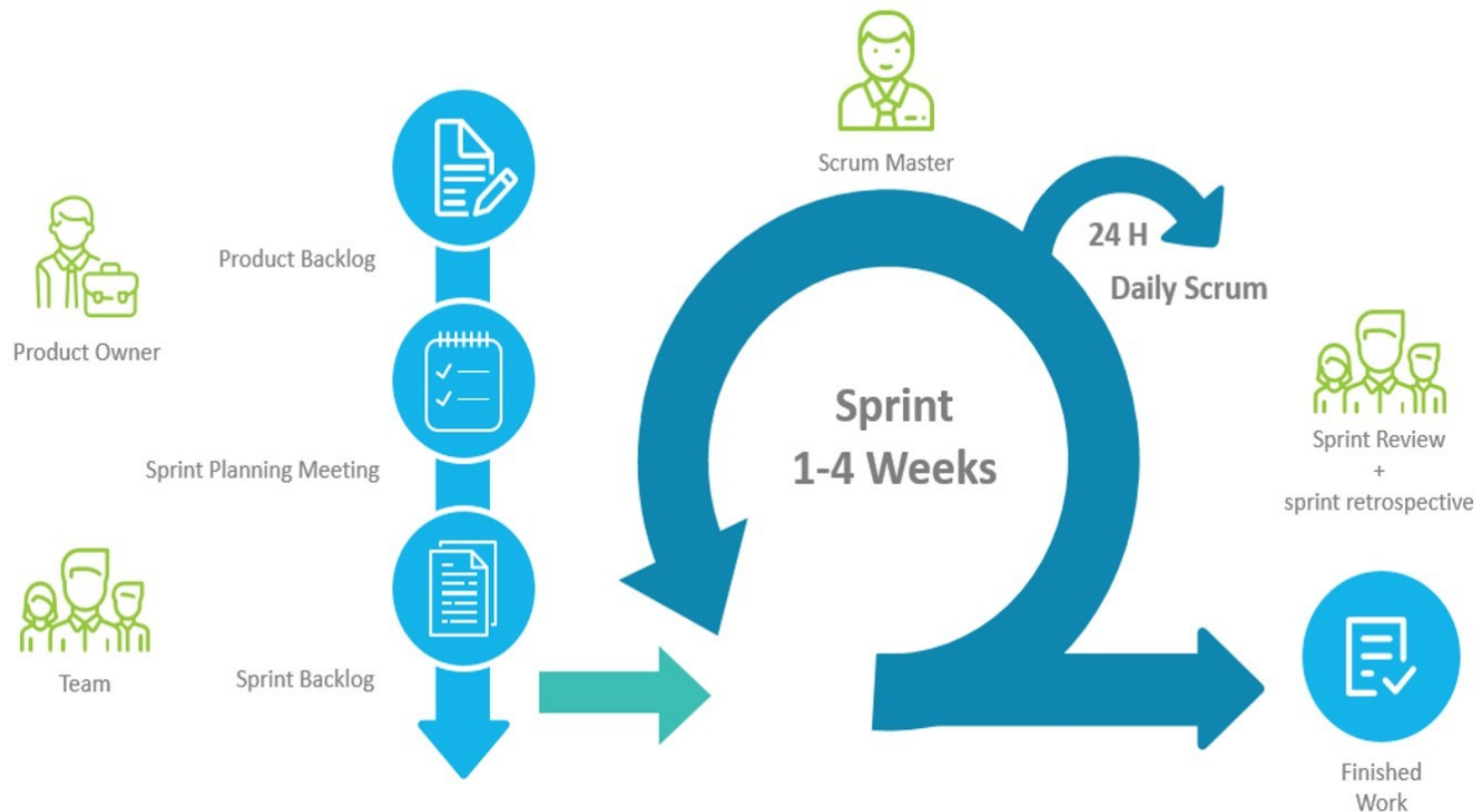


Figure 2: The process of Scrum [8]

1.8 Report Structure

This report is structured in eight chapters, detailed in **Table 3**.

Table 3: Chapters

Chapter	Title	Description
1	Introduction	Introduce the team, the motivation and the objectives of the project
2	State of the Art	Research of different products on the market and scientific studies
3	Project Management	Documentation of the progress in the agile management method SCRUM
4	Marketing Plan	The main objectives are the marketing strategy, target and advertising
5	Eco-efficiency Measures for Sustainability	All the necessary tasks to make the project sustainable
6	Ethical and Deontological Concerns	Analysis of the ethical challenges and their solutions
7	Project Development	The architecture, components and the functional tests of the prototype
8	Conclusion	Discussion of the results and the view in the future

The background studies, which included a scientific research and a survey on existing solutions, are framed in the next chapter.

2 State of the Art

2.1 Introduction

A Smart Companion Pillow helps people with monitoring and also providing interaction. But it is not clear, for which target group the pillow can offer the best support. For this reason, it is essential to research on this matter and create an overview in the form of a State of the Art analysis.

Firstly, to get a vision of possible benefits and target groups, a scientific research of different studies and statistics was made. According to a study from Kinney HC and Thach BT in 2009, the frequency of child death due to SIDS is 1 out of 1000-10000 [9]. Referred to the same study and to the National Institute of Child Health and Human Development (NICHD) of the United States of America (USA) from 2013, the biggest risk factors of SIDS are sleeping on the stomach or side, overheating, exposure to tobacco smoke and bed sharing. It also states that the likelihood of sudden child death is greatest in the first year of life [10].

Sleeping on the back has been found to reduce the risk of SIDS as Mitchell EA published in 2009 [11]. It is thus recommended by AAP. According to studies from Mitchell EA of 2009 as well as Moon RY and Fu L in 2012, sleeping on the back does not appear to increase the risk of choking even in those with gastroesophageal reflux disease while infants in this position may sleep more lightly this is not harmful [12]. Lying on the tummy is healthy and important for babies to strengthen the baby's musculature but should only be done with parental observation and is not recommended for sleeping.

Another study from Moon RY and Fu L. approves and recommends room sharing but no bed sharing for the first year of the infant [13].

Rachel Y. Moon [14], expounded in her study published in the AAP News and Journals Gateway that air quality and the abstinence of tobacco smoke and other volatile gases like formaldehyde are important for ideal child growth. Nicotine and derivatives cause significant alterations in fetal and newborn neurodevelopment as a study of Lavezzi AM, Corna MF, Matturri L [15] in 2010 substantiated. The NICHD approved that in their studies as well [16], [17], [18]. Other publications, like the one of the NICHD, verify that sleeping on the tummy and environmental stressors are the biggest risk factors for SIDS [19].

Bumper pads may increase the risk of SIDS due to the risk of suffocation. They are not recommended for children under one year of age as this risk of suffocation greatly outweighs the risk of head bumping or limbs getting stuck in the bars of the crib [20].

In the last decades either the birthrate or the age of having a baby in industrialized countries increased. A study from Central Intelligence Agency (CIA) World Factbook, United Nations Children's Fund (UNICEF), China Sixth Nationwide Census being summarized and evaluated in a huge chart at chart mix [21] state. The trend is to be older than 30 years old when people first become parents. Due to that, we can assume that due to the older age the ability to buy such a product is bigger than it would be when people are having babies at a younger age.

According to the German Institute of Statistics, the number of smartphone users in Europe increased the last years so that a need for smartphone-integration in the smart companion pillow can be assumed [22].

Secondly, the study of existing solutions on the market is framed. At the end of the chapter, a sum up of the main conclusions derived from the State of the Art analysis is included.

2.2 Existing Solutions

2.2.1 Smart Pillows



There are different devices on the market, all capable of monitoring different features associated with sleep. In the beginning, a look at the already existing smart pillows is given. **Table 4** presents the already existing smart pillows selected and analysed by the team.





Most of these pillows are also equipped with a built-in alarm thought to wake up the user when a specific stage of sleep is reached, the Rapid Eye Movement (REM), also known as light sleep. The Centa Star Relax Smart Pillow [23], iX21 [24] and Sunrise Smart Pillow [25] all contain one of these so-called smart alarms.

The more advanced pillows, like the iSense Sleep Smart Pillow [26] also contain sensors that can monitor pulse and respiratory rate.

These pillows can often be considered as gadgets because they include built-in speakers for streaming music or playing audio books. The ZeeQ Smart Pillow [27] and Sunrise Smart Pillow [28] are both good examples of this.

Table 4: Smart Pillows

Name	Features	Price [€]	Picture
ZeeQ smart pillow [29]	<ul style="list-style-type: none"> * wireless music streaming * sleep tracking and analysis * snore detection and prevention * partner-friendly alarm clock * smart-home integration - Alexa, If This Then That (IFTTT) * 2-week battery life 	132.00	
Sunrise Smart Pillow [30]	<ul style="list-style-type: none"> * sleep tracker * smart alarm/sunrise alarm * wireless music and audio books * blue light technology * cooling technology * premium memory foam 	175.00	

Name	Features	Price [€]	
iX21 [31]	<ul style="list-style-type: none"> * intelligent alarm clock * tracks and monitors the sleep cycles, movements and ambient noises * app * analyses the sleep * personalized coaching: advice on how to improve the quality of the sleep 	149.00	
iSense Sleep Smart Pillow [32]	<ul style="list-style-type: none"> * heart rate * respiratory rate * sleep cycles * time it takes to fall asleep * restlessness * total sleep score 	150.00	
Centa-Star Relax Smartpillow [33]	<ul style="list-style-type: none"> * digital sleep monitor and coach * analyses the sleep * built-in alarm to wake you gently 	199.00	






2.2.2 Sleep Trackers

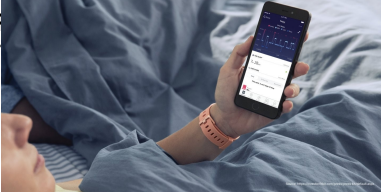

Sleep trackers are devices that are focused on giving detailed information about sleeping patterns. Smart pillows are often pillows equipped with a sleep tracker. These devices come in different forms. Some of them are wearable accessories like the OURA [34] ring or the Fitbit Versa [35]. Others have to be placed in the bed, for example, the Withings Sleep [36] and the Beddit Sleep Monitor [37]. The S+ By ResMed Sleep Tracker [38] is a contactless monitor that just needs to be placed next to the bed. The Sleep Cycle Alarm Clock [39] is an app that also doesn't require contact and can be placed outside of the bed.

All these devices measure more or less the same aspects. They focus on the different sleep stages, the duration of the sleep and the overall sleep quality. The researched products also measure the pulse of the user, only The Sleep Cycle Alarm Clock [40] doesn't have this function.

Table 5 sums up the comparison of all analysed Sleep Trackers.

Table 5: Sleep Trackers

Name	Features	Price [€]	Picture
Beddit Sleep Monitor [41]	<ul style="list-style-type: none"> * sleep time * bedtime * time to fall asleep * time awake * time away from bed * wake-up time * sleep efficiency 	134.00	 <p>The image shows the Beddit 3 Sleep Monitor, a white, thin, rectangular device placed under a white sheet. A smartphone is shown next to it displaying a sleep tracking app interface with a large '96' score.</p>
Sleep Cycle Alarm Clock [42]	<ul style="list-style-type: none"> * tracks the sleep patterns using sound or vibration analyses * detects light sleep to wake up 	22.00	 <p>The image shows a woman sleeping peacefully. Next to her is a smartphone displaying a sleep cycle graph with peaks for 'Awake', 'Sleep', and 'Deep asleep' over a 5-hour period.</p>
Withings Sleep [43]	<ul style="list-style-type: none"> * sleep cycles analysis (deep, light and REM) * heart rate tracking * snore detection * IFTTT integration: <ul style="list-style-type: none"> -dimming lights -turning up your thermostat 	88.00	 <p>The image shows a smartphone displaying a sleep tracking app interface with a bar chart, placed on top of a grey fabric sleep tracking device.</p>
S+ By ResMed Sleep Tracker [44]	<ul style="list-style-type: none"> * non-contact sleep monitor * monitors breathing, heart rate, movement and overall sleep quality * monitors environment: noise, light and temperature levels + feedback & tips * sleep score 	48.00	 <p>The image shows the S+ By ResMed Sleep Tracker, a white, rectangular, non-contact monitor. It is shown next to a smartphone displaying a sleep tracking app interface with a large '88' score and a smartwatch.</p>
Fitbit Versa [45]	<ul style="list-style-type: none"> * gyroscope and optical heart rate sensor 	175.00	 <p>The image shows a person's hand holding a smartphone displaying a sleep tracking app interface, with a blue blanket visible in the background.</p>

Name	Features	Price [€]	Picture
	<ul style="list-style-type: none"> * duration of your sleep * different sleep stages from light and REM to deep 		
OURA ring [46]	<ul style="list-style-type: none"> * very small * sleep score * statistics concerning: <ul style="list-style-type: none"> - quality of your rest; - resting heart rate; - how much you moved. 	314.00	

2.2.3 Environment Monitors


Environment Monitors are devices that measure indoor conditions like, for instance, temperature, relative humidity (RH) and some gases. There are a lot of environment monitors available on the market. The team took a look at four types of monitors that measure different things. The only thing all of them have in common is that they are contactless.




The Sense Sleep System [47] and Withings Aura Smart Sleep System [48] can also be considered as sleep trackers since they also keep track of the sleeping pattern. In addition, they also monitor the conditions in the room and give advice on how to improve them.

The Nest Protect Smoke and Carbon Monoxide (CO) Alarm [49] is, as the name clarifies, a CO and smoke detector that warns when the CO levels in the room are too high.

Last, The First Alert Onelink GLOCO Wi-Fi Environment Monitor [50] is meant for monitoring temperature, RH, and CO levels of the infant's room. It consists of a home station which indicates when something is wrong and also an app with additional information.

Table 6 points out the main features and prices of the four products.

Name	Features	Price [€]	Picture
Sense Sleep System - Cotton [51]	<ul style="list-style-type: none"> * analysis of sleep patterns * sleep score: based on the conditions of the room and the sleep * smart alarm: wakes up the user in the lightest part of your sleep cycle * sleep insights: personalised suggestions to improve the sleep quality 	113.00	

Name	Features	Price [€]	Picture
The First Alert Onelink GLOCO Wi-Fi Environment Monitor [52]	<ul style="list-style-type: none"> * monitoring temperature, relative humidity, and carbon monoxide levels * color-changing glow ring indicates a problem * monitor sends information to the smartphone or tablet 	61.00	
Withings Aura Smart Sleep System [53]	<ul style="list-style-type: none"> * wake up & go to sleep programs * music (Spotify and radio) * heart rate * light sleep * deep sleep * REM * room temperature * luminosity (light levels) 	107.00	
Nest Protect smoke and CO alarm [54]	<ul style="list-style-type: none"> * detects fast and slow burning fires * detects CO * alerts on the phone * lets hush a false alarm with the phone 	129.00	

2.2.4 Baby Monitors



Another different type of products are monitors specially developed for babies. These sort of monitors focus on the baby well-being, certifying the baby is doing fine (**Table 7**).





Some only monitor the environment. The Lollipop Smart Baby Camera and Sensor [55], VM344 Pan & Tilt Baby Monitor [56] both have cameras that give live images of the infant. Furthermore, the Lollipop Smart Baby Camera and Sensor [57] also has special features such as cry and cross detection. The Sproutling Wearable Baby Monitor [58] measures the environment but also alerts when the baby rolls over while sleeping.



On the other hand, the baby monitors that monitor things like temperature, movement and respiration are also available. The MonBaby Smart Breathing Monitor [59], Mimobaby Monitor [60] and Owlet Baby Monitor [61] are good examples of these sort of devices.

The Nanit Plus Camera [62] contains both. It is a camera that not only displays live images of the infants but also monitors the room environment (temperature and relative humidity).

Table 7 includes the compared devices with a picture, the features and the prices.

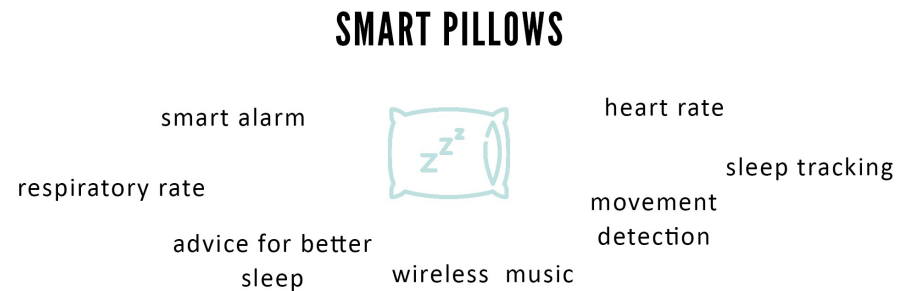
Name	Features	Price [€]	Picture
Owlet Baby Monitor [63]	<ul style="list-style-type: none"> * tracks the child's heart rate * tracks oxygen levels * notifies the parents if those levels fall outside the preset zones 	313.00	
VM344 Pan & Tilt Baby Monitor [64]	<ul style="list-style-type: none"> * pan, Tilt And Zoom The Camera From The Parent Unit * automatic Infrared Night Vision * multiple Viewing Options * temperature Sensor 	211.00	

Name	Features	Price [€]	Picture
Lollipop Smart Baby Camera and Sensor [65]	<ul style="list-style-type: none"> * live View: live feed on the tablet or smartphone * cry Detection * cross Detection: Set a border inside the camera view to track movements in the baby's crib * data History * Event List: The Lollipop saves a 30-second video of significant events 	178.00	
Nanit Plus Camera [66]	<ul style="list-style-type: none"> * 24/7 High Definition (HD) live streaming * background audio lets the parents hear baby, even when the parents' phone's screen is off * soft glow nightlight * smart sensors: temperature and humidity sensors 	263.00	
Mimobaby Monitor [67]	<ul style="list-style-type: none"> * temperature data * movement data * respiration data 	175.00	
MonBaby Smart Breathing Monitor [68]	<ul style="list-style-type: none"> * sleep position alarm * proximity alarm * real-time stats and sleep cycles * breathing movement alarm * fall detection 	70.00	

Name	Features	Price [€]	
			
Sproutling Wearable Baby Monitor [69]	<ul style="list-style-type: none"> * identify the optimal sleeping conditions; room temperature, relative humidity, sound and light * predict when the baby is most likely to wake up * alert sent to your phone if the infant rolls over while sleeping 	220.00	

2.2.5 Overview

Figure 3 sum up the already existing features of products related to the field of baby monitors on the market.



SLEEP TRACKERS

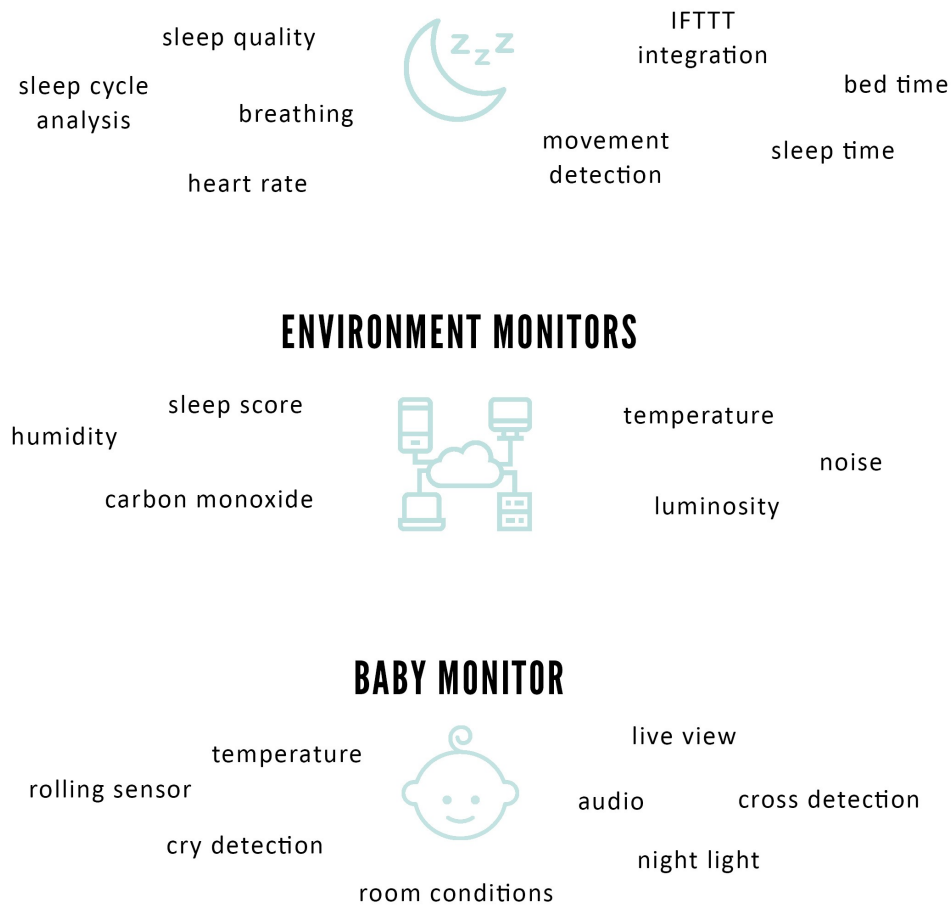


Figure 3: Overview of the already existing features of products

2.3 Conclusion

The results of the developed research show that there are already devices to monitor the health of elderly people but not, simultaneously, with the measurement of indoor air quality, RH and room temperature.

Furthermore, the market of pillows already offers gadgets to reduce the risk of babies rolling from back to the tummy, one of the potential risks of SIDS. There are also devices to monitor the health of babies and the risk of rolling from back to tummy – additionally, some devices measure room temperature and RH. Other ones interact with the baby through sounds.

In addition, it is recommended in scientific studies that infants sleep in the parents' room. Sleeping close to the parents' bed, but on a separate surface, is ideally for the first

year of life [70]. Consequently, a monitoring device for indoor air quality will also benefit the parents.

Furthermore, the age of first-time parents is getting higher which means the financial income should be high enough to buy a pillow for their baby. Moreover, they are very interested to keep on using their smartphones.

According to this research, the market lacks devices that, simultaneously, reduce the risk of rolling from back to tummy (shape of the pillow), allow interaction (microphone and speaker integrated in the pillow), monitor the health of the baby (pulse sensor sock), measure the room air quality (temperature, RH and CO₂ sensors incorporated in a base station) and provide access to all this information through a mobile application.

Taking into account these findings, the team embraced the concept of a 4 in 1 product for babies: (i) pillow with a special shape; (ii) microphone and speaker integrated in the pillow; (iii) pulse sensor in a sock; and (iv) room sensors in a home station. To contribute to relief the stress of parents, the team chose to create a mobile application to display the collected data and allow remote interaction.

For this project, the company name will be **SleepSense** and the product name **bGuard**.

As a project is a temporary effort in order to create a product, it is absolutely necessary to define its beginning and end, as also the scope and resources involved. Therefore, the next chapter is related to Project Management.

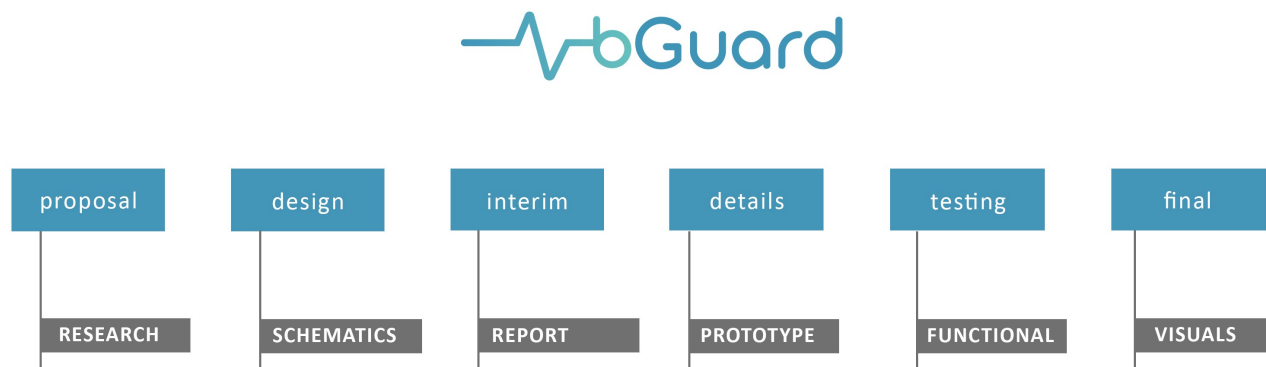
3 Project Management

3.1 Introduction

After pointing out the main goals of the project in the State of the Art chapter it is important to have an overview over the time, the costs and the risks. Thus the following chapter a Project Management strategy is made.

3.2 Scope

The Scope gives an overview of the main actions of the project. Consequently, the scope is developed. It supports to determine tasks and distribute all resources. Furthermore, it prevents the main goal of the project is not realized. **Figure 4** shows the Work Breakdown Structure (WBS). Step by step, the WBS offers all the main subjects which are part of the project.



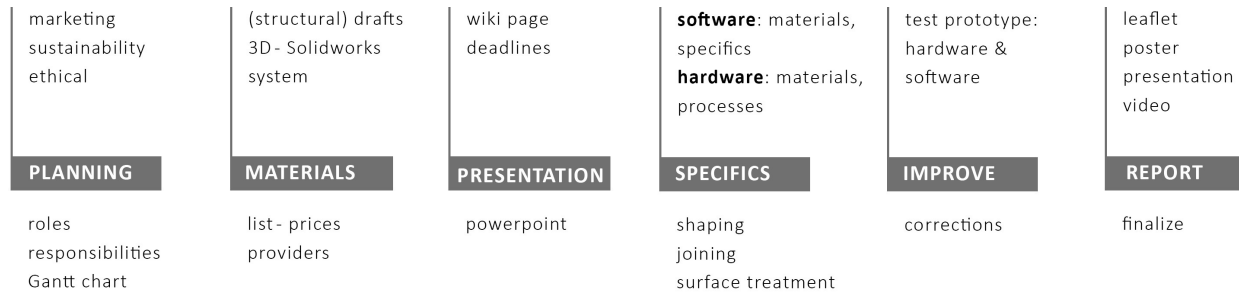
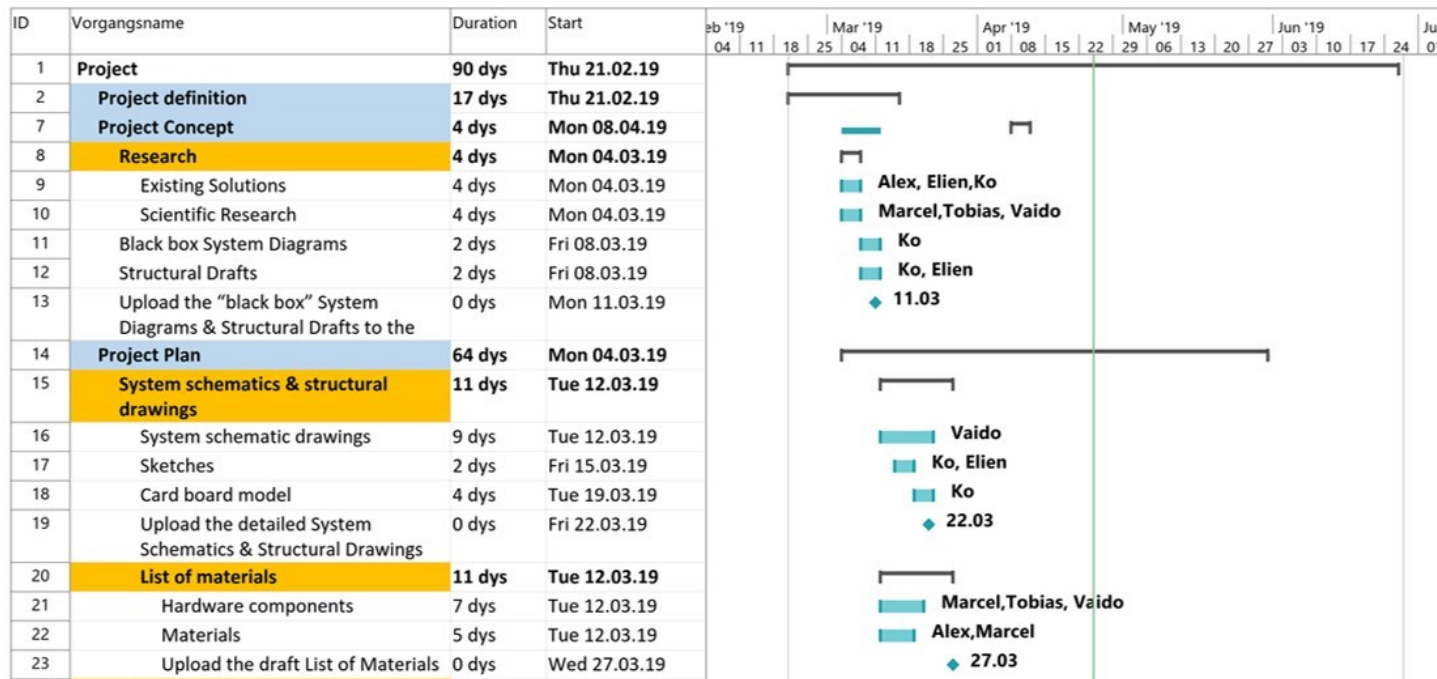


Figure 4: WBS

3.3 Time

3.3.1 Gantt Chart

Based on the scope a Gantt Chart is made. Actually, the team is planning for each Sprint and divide the tasks for each team member. This is an agile way of planning the project. But there are several deadlines the team has to care about. Therefore, the Gantt Chart has the benefit of giving an overview of the project. Moreover, it supports time management. **Figure 5** shows the construction of the Gantt Chart. It is divided into six phases: Project Definition, Project Concept, Project Plan, Prototyping, Testing, Final Reporting. Each phase has one or more deadlines.



24	Interim Report	25 dys	Mon 04.03.19
25	Introduction	5 dys	Mon 11.03.19
26	Project Management	16 dys	Mon 04.03.19
27	State of the Art	21 dys	Mon 04.03.19
28	Marketing Plan	13 dys	Thu 21.03.19
29	Eco-efficiency Measures for Sustainability	13 dys	Thu 21.03.19
30	Ethical and Deontological Concerns	13 dys	Thu 21.03.19
31	Project development	12 dys	Thu 21.03.19
35	Upload the Interim Report and Presentation to the wiki	0 dys	Sat 06.04.19
36	Prepare the Interim Presentation	4 dys	Mon 08.04.19
37	Interim Presentation	0 dys	Thu 11.04.19
38	Edit the List of Materials and finish it	8 dys	Fri 12.04.19
39	Complete List of Materials	0 dys	Tue 23.04.19
40	Work on the Refined Interim Report (based on the Feedback of the interim Report/Presentation)	36 dys	Thu 11.04.19
41	Prototyping	26 dys	Mon 29.04.19
42	Building prototype	3 dys	Mon 29.04.19
43	Programming	16 dys	Mon 13.05.19
44	Documentation	6 dys	Mon 27.05.19
45	Testing	26 dys	Mon 29.04.19
46	Sensors	16 dys	Mon 13.05.19
47	Bluetooth connection	10 dys	Mon 13.05.19
48	Wi-Fi connection	10 dys	Mon 13.05.19
49	Monitoring sensor data on a IoT cloud server	6 dys	Mon 27.05.19
50	Reaction to the crying of the baby with sounds	16 dys	Mon 13.05.19
51	Prevention of lying on the baby's tummy	5 dys	Mon 20.05.19
52	Documentation of the results	26 dys	Mon 29.04.19
53	Upload refined Interim Report	0 dys	Thu 30.05.19
54	Upload functional test to the wiki	0 dys	Mon 03.06.19
55	Final reporting	75 dys	Thu 14.03.19
56	Presentation	9 dys	Tue 04.06.19
57	Video	15 dys	Mon 27.05.19
58	Paper	15 dys	Mon 27.05.19
59	Poster	15 dys	Mon 27.05.19
60	Leaflet	5 dys	Thu 14.03.19
61	User Manual	10 dys	Mon 03.06.19
62	Arduino Code	16 dys	Mon 13.05.19
63	Upload the Final Report, Presentation, Video, Paper, Poster and Manual	0 dys	Fri 14.06.19
64	Project completion	9 dys	Fri 14.06.19
65	Preparation of the final presentation	4 dys	Fri 14.06.19
66	Holding the final presentation	0 dys	Wed 19.06.19
67	Document collection	6 dys	Wed 19.06.19
68	Update wiki with all correction suggestions	5 dys	Wed 19.06.19
69	Hand CD with corrected	1 dys	Tue 25.06.19

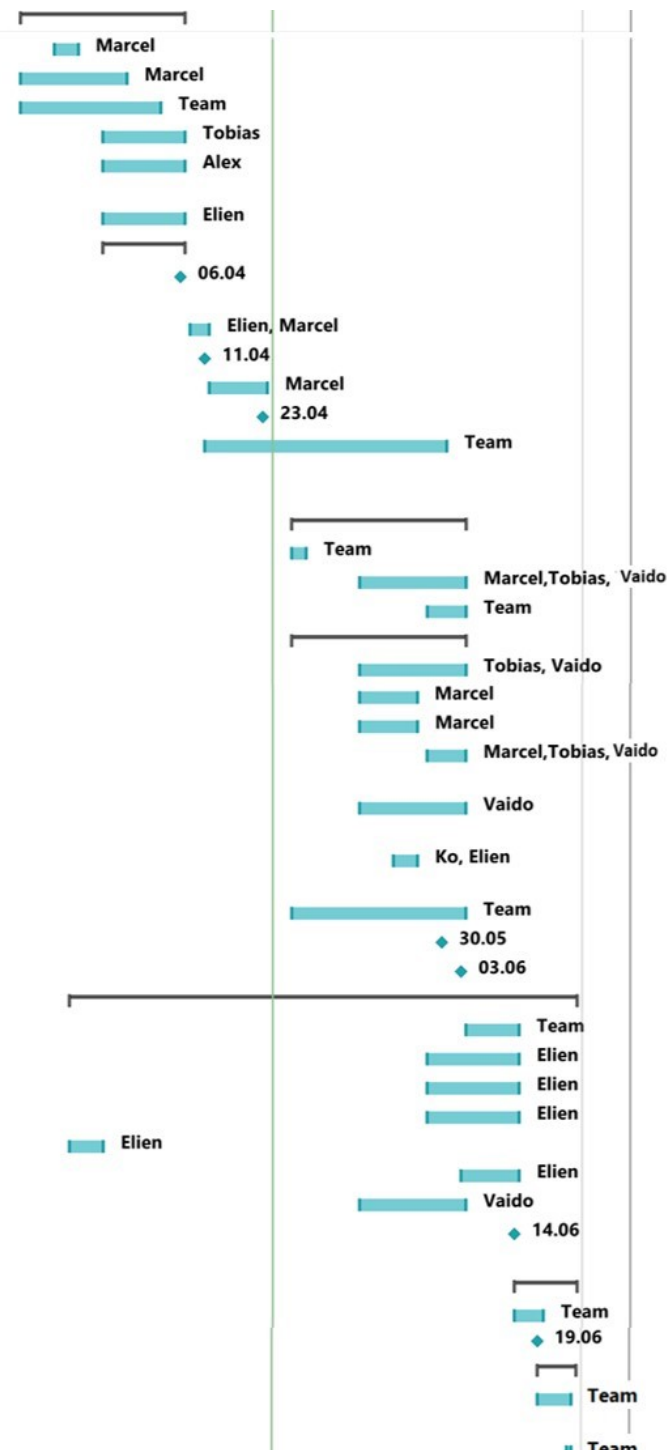




Figure 5: Gantt Chart

3.3.2 Deliverables & Deadlines

In Table 8 the deliverables from the Gantt Chart with the deadlines are summarized.

Table 8: Deliverables & Deadlines

Deliverables	Deadlines
Define the Project Backlog	2019-03-06
Black Box (System Diagrams & Structural Drawings)	2019-03-11
Detailed Schematics, Structural Drawings and Cardboard Model	2019-03-22
List of Materials (What & Quantity)	2019-03-27
Upload Interim Report and Presentation	2019-04-06
Interim Presentation	2019-04-11
Complete the List of Materials	2019-04-23
Upload refined Interim Report	2019-05-30
Upload results of the Functional Tests	2019-06-03
Upload the Final Report, Presentation, Video, Paper, Poster and Manual	2019-06-14
Final Presentation, Individual Discussion and Assessment	2019-06-19
Update the wiki with all correction suggestions	2019-06-25
Hand in the prototype and user manual	2019-06-27

3.4 Cost

Cost management is necessary for every project. It has an influence on the decision. Therefore the working costs and the material cost are analyzed in this subsection.

Work Resources

Normally the costs for the work resources are one of the largest proportions in developing a product. In the EPS it is different because students are working for no salary on the project. Nevertheless, it is interesting to see how the cost for the development of the smart pillow would be if the team members are working as engineers in a company. For this reason **Table 9** shows these costs. The calculation of the costs is based on the research of the engineers' salary for each country from which the members of the team come [71]. From all the values, an average salary per hour was calculated. It is multiplied with the effective working hours of each team member.

Table 9: Working Cost 2019-02-25 to 2019-04-12

Name	Cost [€]	%
Elien	2329.00	17
Alex	2192.00	16
Ko	2329.00	17
Tobi	2329.00	17
Vaido	2192.00	16
Marcel	2329.00	17

Material Resource

The material resources are based on the price for each component and the respective quantity. **Table 10** shows the list of hardware components. The list is ordered by the sponsors who are supporting the team in this project. Furthermore, the total costs and the costs which are from the budget of the prototype are listed. In this way, the team has an overview of the complete hardware costs.

Table 10: List of hardware components for the prototype

Nr	Item	Parts	Provider	Quantity	Unit price [€]	Item Costs [€]	Item Costs Prototype [€]
Departamento de Engenharia Electrotécnica (DEE), ISEP (100.00 € Budget)							
1	Espressif ESP32 DevKitC [72]	Home Station, Pillow	pt.mouser	2	8.73	17.76	17.76
2	Micro SD card 8GB [73]	Pillow	pt.mouser	1	6.50	6.50	6.50
3	Transportation costs [74]	-	pt.mouser	1	20.00	20.00	20.00
Departamento de Física (DFI), ISEP							
4	Heart rate sensor module [75]	Sock	DFI, ISEP	1	22.09	22.09	0.00
5	DHT22 Temperature & Humidity Sensor [76]	Home Station	DFI, ISEP	1	11.60	11.60	0.00

Nr	Item	Parts	Provider	Quantity	Unit price [€]	Item Costs [€]	Item Costs Prototype [€]
Departamento de Engenharia Electrotécnica (DEE), ISEP (100.00 € Budget)							
6	BreadBoard [77]	Home Station, Pillow	DFI, ISEP	2	6.00	12.00	0.00
7	Jumper Wires - Female/Female [78]	Home Station, Pillow	DFI, ISEP	20	0.07	1.40	0.00
8	Jumper Wires - Male/Female [79]	Home Station, Pillow	DFI, ISEP	20	0.11	2.20	0.00
9	PCB - board [80]	Home Station, Pillow	DFI, ISEP	2	1.35	2.70	0.00
10	1kΩ Resistor [81]	Home Station	DFI, ISEP	1	0.11	0.11	0.00
SOLIUS							
11	SGP30 -eCO2 and VOC [82]	Home Station	botnroll	1	22.95	22.95	0.00
12	MAX4466 - Microphone sensor [83]	Pillow	pt.mouser	1	6.07	6.07	0.00
13	DFPlayer - MP3 mini player [84]	Pillow	electrofun	1	5.45	5.45	0.00
14	Mini Speaker [85]	Pillow	botnroll	1	1.00	1.00	0.00
15	5V Battery [86]	Pillow	electrofun	1	5.50	5.50	0.00
16	5V, 2A Power Supply [87]	Home Station	electrofun	1	6.80	6.80	0.00
					Total costs	164.83	44.26

3.5 Quality

The Smart Pillow is a product with many features. To keep the trust of the customers it is necessary to have high quality. Therefore it is important to know what the team has to check during the tests.

Product quality

The designing and testing phases are very important to get a high quality of the product. In the designing phase, it is important to don't make the product too complicated and use the knowledge of experts. During the testing phase, it is important to calibrate the sensors and evaluate the values in a scientific way. The tests will be furthermore explained in Tests and Results. After the designing and testing phase, it is important to know if the supplier is reliable, so all the components will be tested by the delivery.

Material quality

The quality of the materials is also important. After the delivery, the team members make a visual check if the parts are damaged. Furthermore, the materials have to conform to all the EU Directives of health and low voltage.

Service quality

Bguard has an integrated application for smartphones with several features like a warning system and the monitoring of the baby and room status. Therefore it is important that the application has no false warnings. Furthermore, the monitoring has to be right too.

To verify good product quality, requirements management including the **requirement analysis documentation** is very important. In the **requirements specification document**, the customer requirements towards to product are stated. In the **technical specification document**, the service provider presents in a concrete form how he would and could implement the project for the client. While the Scope Statement sets how to do it the Product requirements document states in an easily understandable way what the customer wants. - it can be seen in Chapter 4.2.1 Problem Statement.

In the Technical Specification Document or the Functional Specifications, the customer requirements are transferred into technical solutions. The objectives should include measurable success criteria for the project. It can be seen in 7.6.2 Functional Specification.

3.6 People

A Responsibility Matrix (**Table 11**) is used to define who in the team is responsible for individual work elements and deliverables. By forming a matrix with the WBS, responsibilities can be assigned to lower level tasks. In the table there are some initials used, meanings are: P= Participant; A= Accountable; R= Responsible; I= Inform; S= Sign; C= Consultant.

Table 11: Responsibility Matrix

Task/People	Alex	Elieen	Ko	Marcel	Tobias	Vaido	Supervisors
Scrum Planning (Scrum Master)	R	P	P	P	P	P	A,C
Gantt chart	P	P	P	R	P	P	A,C
Blackbox diagram	P	P	R	P	P	P	A,C
Technical research	I				R	P	A,C
Market research, existing products	P	R	P	I	I	I	A,C
Initial budget planning	R			P		P	A,C
Specific plan	P	P	R	P	P	P	A,C
Business plan	P	P	P	P	R	P	A,C
Final schemes, diagrams	I	R	R	P	P	R	A,C
List of materials	P	P	P	R	I	P	A,C
Interim presentation	P	R	P	P	P	P	A,C

Task/People	Alex	Elien	Ko	Marcel	Tobias	Vaido	Supervisors
Interim report	R	P	P	P	P	P	A,C
Prototype construction hardware	P	P	P	P	P	R	A,C
Prototype construction software	P	P	P	P	P	R	A,C
Prototype assembly	P	P	R	P	P	P	A,C
Prototype functional tests	P	P	P	P	R	P	A,C
Final report	P	P	P	R	P	P	A,C
Video		R					A,C
Poster		R					A,C
Manual				R			A,C

3.7 Communications

An important part of a project is communication. Inefficient communication can result in tension in the team. To prevent inefficient communication a communication matrix is made (**Table 12**). This communication matrix shows how communication is organized in the team. When the team is not together Google Drive and a WhatsApp group is used. Besides that, the team has several meetings by doing Scrum planning. Furthermore, the team has a weekly meeting with the supervisors.

Table 12: Communication matrix

What	Who	Why	When	How
Deliverables	Responsible person	Development of the project	On the deadline	Uploading to Wiki
Meetings with supervisors	The team	To update the supervisors about the progress of the project	Weekly on Thursday	Face-to-face with a presentation
Agenda	The team	To inform the supervisors about the subject to discuss	24 hours before the weekly meeting with the supervisors	Uploading to Wiki
Interim presentation	The team	To get feedback from the supervisors and other students on our project	2019-04-11	Oral presentation
Daily Scrum	The team	Short communication what	Daily	Face-to-face

What	Who	Why	When	How
		each team member had done the last day and what he is planning to do the next 24 hours		
Sprint planning	The team	Add tasks to the Project Backlog, divide the tasks to the team members, assess the time for each task	Weekly	Face-to-face
Sprint Review	The team	The team discusses which tasks were done and which tasks need to be continued in the next Sprint	Weekly	Face-to-face
Sprint Retrospective	The team	The team discusses what went well and what could be improved in the next sprints	Weekly	Face-to-face

3.8 Risk

During the project, problems can appear. Every problem can have an impact on the progress of the project. Therefore, it is important to have an overview of possible risks. If risks appear, the team has to handle with them.

Table 14 shows the risk analysis of the project. In the first step, the risk is identified. After that, the risks are categorized into three risk categories: Organizational, Project Management and Technical. The second step is the Risk Exposure. Therefore, each risk is valued. The main target is to get a Score between the probability and the impact.

Table 13 shows the Impact-Probability Matrix which is used to determine the score. For this purpose, the impact rating and the risk probability is multiplied **[88]**.

		Probability			
		1 = high (80% ≤ x ≤ 100%)	2 = medium high (60% ≤ x < 80%)	3 = medium low (30% ≤ x < 60%)	4 = low (0% < x < 30%)
Impact	A=high (Rating 100)	(Exposure – Very High) (Score 100)	(Exposure – Very High) (Score 80)	(Exposure – High) (Score 60)	(Exposure – Moderate) (Score 30)
	B=medium (Rating 50)	(Exposure – High) (Score 50)	(Exposure – Moderate) (Score 40)	(Exposure – Moderate) (Score 30)	(Exposure – Low) (Score 15)
	C=low (Rating 10)	(Exposure – Low) (Score 10)	(Exposure – Low) (Score 8)	(Exposure – Low) (Score 6)	(Exposure – Low) (Score 3)

Table 13: Impact-Probability Matrix [89]

In the final step is the Risk Response. It is divided into the following types:

- Avoid - Eliminate the cause of the risk;
- Mitigate - Reduce the impact of a risk;
- Exploit - Add work to make sure the opportunity occurs.

The Strategy gives an explanation of the Risk response. It shows possible solutions to manage the problem.

Table 14: Risk analysis

Risk Identification	Probability	Impact	Score	Response	Strategy
Organizational					
Insurance of a team member	1	B	50	Mitigate	The risk can not be eliminated, the team tries to split the work of the team member
The wiki does not work for a period	2	B	40	Mitigate	The team keeps on the work in OneDrive until it is fixed
Files are not available anymore/ Have to be done a second time	4	B	15	Mitigate	Make a private secure of the files
Suppliers do not deliver components in the planned time	2	A	80	Avoid	Only choose suppliers who are able to deliver in the right time
Conflict with stakeholders over proposed changes	4	C	3	Avoid	Proof the changes with scientific research
Project Management					
Requirements are incomplete	4	A	60	Exploit	The team makes more research to solve the problem
Wrong time management- the team misses' deadlines	2	A	80	Exploit	Try to do another task faster

Risk Identification	Probability	Impact	Score	Response	Strategy
Organizational					
Project team misunderstand requirements	3	A	60	Avoid	Ask a lot of questions in the meetings with the supervisors
Under communication	4	B	15	Avoid	Talk to each other if something is not clear
The documentation is not complete	4	B	80	Avoid	Try to do another task faster
Wrong time management- the team misses' deadlines	2	A	80	Exploit	Before uploading the final report, the team checks every chapter of completeness
Technical					
Programmed code does not work	2	A	80	Mitigate	Ask one of the teachers for help/ Search on the Internet
The hardware does not work	4	A	30	Mitigate	Contact the supplier for replacement
Parts are wrong designed/ produced in a wrong way	4	B	15	Avoid	Four-eyes principle - Two team members check the drafts
The quality of the materials is bad	4	B	15	Exploit	Make the prototype of it, but search for other suppliers and materials of the next steps
Not enough Know-How	3	C	6	Mitigate	Ask the teacher for help/ Research on the internet
The product does not follow EU requirements	4	A	30	Avoid	Research of all EU- requirements

Summary of the Risk Analysis

After the risk analysis, the team knows about the impact of several tasks and how to handle them with care. Many risks can be avoided with detailed research. Moreover, the communication in the team and with the stakeholders is important. The risks with the highest score in **Table 14** have all an impact on time management. In consequence, the team has to take care of that challenge over the whole time of the project. Nevertheless, a risk can appear. In this situation, the team has to manage the problem with the Response Strategy.

3.9 Procurement

Time management highly impacts on the team's success. One important process to manage time is Procurement. Everything required from outside of the team has to be in place when it is needed. So the team has to analyze what items will be purchased from the outside. It is important to make sure that the Team received products at the best possible price but also high quality compared with other external suppliers.

The following analysis takes focus on two types which have to be purchased from outside:

Hardware components and materials

In order to sell a sustainable product, the team has to take care of cost, quality and time. To save those objectives it is important that the team has to evaluate the delivery of components and materials. Hence, the team compares only suppliers only from Portugal. They keep the delivery costs low and the time to deliver short. Another requirement is

the availability of the products. All of them has to be in stock to keep the factor of time. Therefore, the team does the research and comparison of the hardware components with the following providers:

- botnroll.com [http://botnroll.com];
- electrofun.pt [http://electrofun.pt];
- pt.mouser.com [http://pt.mouser.com].

For the same reasons, the materials for the pillow are also to be chosen from local suppliers. When a component or material is cheaper or better in another country, the team cannot use it. This challenge leads the team to think harder about the materials that are considered in the design solution.

Services

The services that are necessary to build the prototype are free to use for the team. On the one hand, ISEP provides tools and machines. The most important machine for realizing casings for the prototype is the 3D Printer. Only the filament has to be bought by the team. Furthermore, an electric soldering iron is needed for soldering the hardware components.

On the other side, there are software services, which are free to use. Open-source programs and open-source IoT platforms are offered on the internet. So the team can save this money for the prototype and has not to buy licenses.

3.10 Stakeholders Management

Stakeholders are persons, groups or organizations that have interests or concerns in an organization. Moreover, a stakeholder can affect or be affected by the organization's actions, objectives and policies [90]. **Table 15** shows the power and influence of the stakeholders which have an impact on the project.

First of all the team is listed. With all decisions during the whole process, it has the most affect the success of the project. Other stakeholders are sponsors and supporters. Sponsors and supporters give the team the components, materials, tools, labour and counselling for working in the project. On the third place, there are the supervisors. With the weekly meetings, they can give the team feedback and advice. The suppliers only provide the materials but have no how influence on the project. After that, the competitors are listed. They, with prices and features, have an influence on the segmentation of the product. Finally, there are the consumers. They have low power and a medium influence. The team takes care to sell benefits that the consumers need and offer the price for the product they are willed to buy.

Table 15: Stakeholders analysis

Who	Role	Power	Influence
Team	Developers	High	High
Supervisors	Controllers	High	Medium
Sponsors and Supporters	Providing components, materials, tools, labour and counselling	High	Low
Competitors	Competition	Low	Medium
Consumers	Buying products	Low	Medium
Suppliers	Providing materials	Low	Low

Figure 6 shows the stakeholders' matrix. The matrix gives an overview of the power and the impact of all stakeholders.

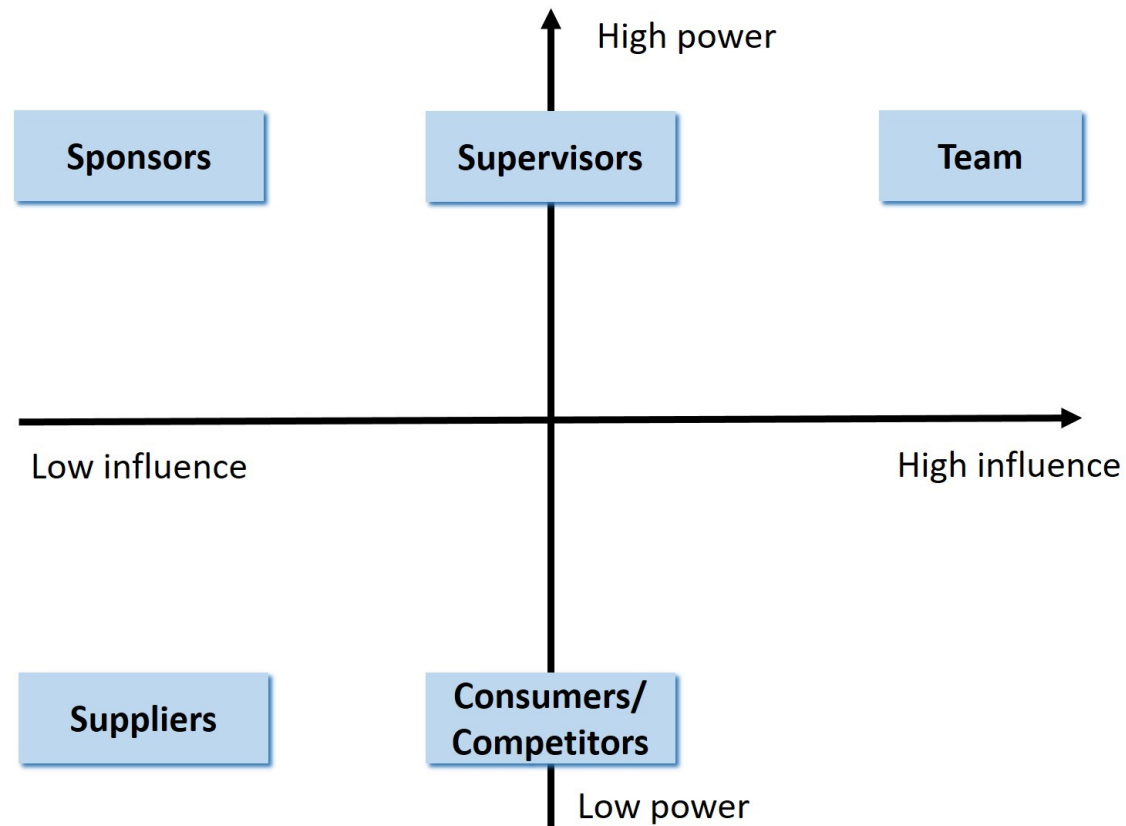


Figure 6: Stakeholders matrix

3.11 Sprint Outcomes

Table 16 to Table 28 show the summary of the Sprint Reviews the team has done during the project. It includes the number of the Product Backlog Item (PBI). In the same column are Procedures (P). They are tasks which have to be done every week. After that, there is the description of the Tasks which are ordered to the Sprint out of the Project Backlog. Moreover, there is the assignee, the planned effort, the needed time and the status. The team started with Sprint Planning after the third week of the project. For the organization, the Microsoft Planner is used.

Table 16: Sprint 1, 2019-03-14 to 2019-03-20 - Sprint Review						
PBI/P	Task	Assignee	Planed effort [days]	Needed time [days]	Status	Reasons why tasks were not completed

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
1	Design product logo	Elien	1	1	Completed	/
P	After meeting with supervisors of 2019-03-14	Alex	0.1	0.1	Completed	/
4	Prepare the presentation of the logo	Elien	0.2	0.2	Completed	/
13	Design company logo	Ko	1	1	Completed	/
11	Prepare the presentation for the ethical scandal	Ko, Tobi	1	1.5	Completed	/
2	Prepare the leaflet	Elien	1	2	Completed	/
3	Sustainability - Introduction	Alex	1	1	Completed	/
6	Research of environmental sensors	Vaido	/	/	Not Completed	Doubts on the accuracy of the sensors
7	Research of baby sensors (wireless, analog)	Tobi	/	/	Not Completed	Doubts on the type of sensors to research
9	Research of Microcontrollers/ Bluetooth module/ Microcomputers	Marcel	/	/	Not Completed	Doubts on the way communications will be done
8	Research of Microphone/Speakers	Marcel	/	/	Not Completed	Doubts on the type of microphone needed for the project
10	System Schematics	Vaido	/	/	Not Completed	Waiting for which components will be needed
P	Prepare the meeting with supervisors of 2019-03-21	Elien	0.1	0.1	Completed	/
20	Design of the pillow and the baby sensor	Elien, Ko	/	/	Not Completed	Difficulties on the decision of the dimensions
43	Ethic Scandal Presentation	Elien	1	1	Completed	/
44	Design product logo	Tobi, Ko	0.1	0.1	Completed	/
29	Solidworks – Structural Drawings (Home Station)	Ko	0.5	1	Completed	/

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
		Sprint Velocity	7.0	9.0		

Table 17: Sprint 2, 2019-03-21 to 2019-03-27 - Sprint Review

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
P	Prepare the meeting with supervisors of 2019-03-28	Ko	1	1	Completed	/
6	Research of environmental sensors	Vaido	1	1	Completed	/
7	Research of baby sensors (wireless, analog)	Tobi	0.5	0.5	Completed	/
9	Research of Microcontrollers/ Bluetooth module/ Microcomputers	Marcel	0.5	1	Completed	/
8	Research of Microphone/Speakers	Marcel	0.5	0.5	Completed	/
55	Write conclusion of the choice of sensors and micro-controllers	Marcel	0.1	0.5	Not Completed	The research was finish but now its is necessary to compare the available options and decide
56	Adding the comparison of all sensors and micro-controllers as tables into the wiki	Marcel	1	1	Not Completed	Still on going the task of preparing the information for the tables
P	Sustainability - Introduction	Alex	0.5	0.5	Completed	/
P	Week Report (wiki Logbook) on 2019-03-25	Marcel	0.1	0.1	Completed	/
45	Project Management - Scope	Elien	1	1	Completed	/
30	List of Sensors – to hand in, requirements and sensor range	Vaido	0.5	0.5	Completed	/
5	Build the cardboard model	Elien, Ko	1.5	1.5	Completed	/

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
P	After meeting with supervisors of 2019-03-21	Marcel, Vaido	0.1	0.1	Completed	/
P	Sprint 1 analysis	Alex	0.1	0.1	Completed	/
18	Research to confirm ranges of RH, temperature, CO ₂ in baby's room	Alex	0.1	0.1	Completed	/
P	5 th Week Report	Marcel	0.1	0.1	Completed	/
14	Sustainability – UNESCO Sustainable Development Goals	Alex	/	/	Not Completed	Still to decide what goals the project matches with
25	Ethical and Deontological Concerns - Introduction	Elien	0.1	0.1	Completed	/
24	Marketing Plan – Strategy Positioning	Elien	1	1	Completed	/
		Sprint Velocity	9.7	10.6		

Table 18: Sprint 3, 2019-03-28 to 2019-04-03 - Sprint Review

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
41	Project Management - Costs	Marcel	2	2.5	Completed	/
P	Week Report (wiki Logbook) on 2019-04-01	Alex	0.1	0.1	Completed	/
16	Sustainability - Life Cycle Analysis	Alex, Ko	/	/	Not Completed	Decisions to still be taken concerning some parts of the product
28	Marketing Plan - Market analysis	Tobias	2	3	Completed	/
27	Marketing Plan - SWOT Analysis	Tobias	/	/	Not Completed	Difficulties on some decisions to be included or not

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
12	Presentation for the Communication class	Elien	1	1	Completed	/
10	System Schematics	Vaido	2	2	Completed	/
P	Week Report (wiki Logbook) on 2019-04-01	Alex	0.1	0.1	Completed	/
52	Table for the voltage of power supply and decide	Vaido	/	/	Not Completed	Decision is taken but still need to make the table
36	Project Management - Stakeholders management	Marcel	1	1	Completed	/
		Sprint Velocity	8.1	9.7		

Table 19: Sprint 4, 2019-04-04 to 2019-04-10 - Sprint Review

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
35	Project Management - Procurement	Marcel	/	/	Not Completed	Parts and suppliers still to be decided
22	Marketing Plan - Strategic Objectives	Elien	/	/	Not Completed	Some strategies still to be decided
50	Ethics - Conclusion	Elien	0.2	0.2	Completed	/
49	Ethics - Liability	Elien	0.3	0.5	Completed	/
48	Ethics - Environmental Ethics	Elien	0.3	0.5	Completed	/
47	Sales and Marketing Ethics	Elien	0.3	0.3	Completed	/
17	Sustainability - Conclusion	Alex	0.2	0.2	Completed	/
19	Sustainability - Environment	Alex , Ko	0.3	0.3	Completed	/
15	Sustainability - Economic	Alex	0.3	0.3	Completed	/

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
28	Marketing Plan - Market analysis	Tobias	0.3	1	Completed	/
P	Sprint 2 analysis	Alex	0.1	0.1	Completed	/
P	After meeting with supervisors of 2019-03-28	Alex	0.1	0.1	Completed	/
53	List of components - Power supply	Vaido, Marcel	0.5	0.5	Completed	/
26	Project Management - Risk	Marcel	1	1	Completed	/
31	Project Management - Time	Marcel	0.5	0.5	Completed	/
55	Write conclusion of the choice of sensors and micro-controllers	Marcel	0.1	0.5	Completed	/
56	Adding the comparison of all sensors and micro-controllers as tables into the wiki	Marcel	1	1	Completed	/
14	Sustainability – UNESCO Sustainable Development Goals	Alex	0.2	0.5	Completed	/
20	Design of the pillow and the baby sensor	Elien, Ko	2	6	Completed	/
		Sprint Velocity	7.7	13.5		

Table 20: Sprint 5, 2019-04-11, 2019-04-23 and 2019-04-24 - Sprint Review

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
102	Edit the report based on the feedback received for the moment	Team	/	/	Not Completed	Still chapters to improve based on the feedback
74	Concept first pictures of the application	Elien	0.5	0.5	Completed	/
62	Start working on the arduino code/ Testing Sensors	Vaido	3	3	Completed	/
12	Research of pillow materials	Elien, Ko	/	/	Not Completed	Some materials are not decided yet

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
P	Sprint analysis - Sprint 4, 04-04-2019 to 10-04-2019	Alex	0.6	0.6	Completed	/
P	Week Report (wiki Logbook) 8th Week Report (2019-04-08 to 2019-04-12)	Alex	0.1	0.1	Completed	/
P	Prepare the meeting with supervisors - 8th Meeting (2019-04-24)	Alex	0.1	0.1	Completed	/
16	Sustainability - Life Cycle Analysis	Alex, Ko	1.5	1.5	Completed	/
27	Marketing Plan - SWOT Analysis	Tobias	0.3	0.3	Completed	/
52	Table for the voltage of power supply and decide	Vaido	0.2	0.5	Completed	/
		Sprint Velocity	6.3	6.6		

Table 21: Sprint 6, 2019-04-24 to 2019-04-30 - Sprint Review

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
89	Refine Ethics chapter	Elien	0.8	1	Completed	/
87	Refine State of the Art chapter	Ko	0.5	0.5	Completed	/
88	Refine Sustainability chapter	Alex	/	/	Not Completed	Waiting for decision on still missing materials
90	Refine Project Development (the parts we have so far)	Marcel	1	1	Completed	/
101	New Black Box	Elien	0.1	0.1	Completed	/
P	After meeting with supervisors - 8th Meeting (2019-04-24)	Alex	0.1	0.1	Completed	/
P	Sprint analysis - Sprint 5, 11-04-2019, 23-04-2019 and 24-04-2019	Alex	0.6	0.6	Completed	/
P	Week Report (wiki Logbook) 9th Week Report (2019-04-22 to 2019-04-26)	Alex	0.1	0.1	Completed	/

PBI/P	Task	Assignee	Planed effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
85	Refine Project Management chapter	Alex, Marcel	1.5	2	Completed	/
86	Refine Marketing chapter	Tobi	4.5	4.5	Completed	/
135	Reorganize the information in wiki to show the differences between the Prototype and the Vision of the Product	Marcel	1	1	Completed	/
7	Research of baby sensors (wireless, analog)	Tobi	0.5	0.5	Completed	/
9	Research of Microcontrollers/ Bluetooth module/ Microcomputers	Marcel	0.5	1	Completed	/
22	Marketing Plan - Strategic Objectives	Elien	0.4	0.6	Completed	/
12	Research of pillow materials	Elien, Ko	1.5	4	Completed	/
		Sprint Velocity	13.1	17.0		

Table 22: Sprint 7, 2019-05-02, 2019-05-03, 2019-05-13 to 2019-05-15 - Sprint Review

PBI/P	Task	Assignee	Planed effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
P	Prepare the meeting with supervisors - 9th Meeting (2019-05-02)	Alex	0.1	0.1	Completed	/
P	Sprint analysis - Sprint 6, 26-04-2019 to 30-04-2019	Alex	0.6	0.6	Completed	/
P	After meeting with supervisors - 9th Meeting (2019-05-02)	Alex	0.1	0.1	Completed	/
P	Week Report (wiki Logbook) 10th Week Report (2019-04-29 to 2019-05-03)	Alex	0.1	0.1	Completed	/
124	Include the resistor in the list of components	Marcel	0.1	0.1	Completed	/

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
96	First step of the Final Report in Overleaf/LaTeX	Alex	3	4	Completed	/
103	Graph with the concept of the product (similar to the concept of the prototype)	Elien	0.2	0.2	Completed	/
106	Separate compartments for the sensors in the home station	Ko	0.5	1	Completed	/
114	Reposition of bGuard on a higher price level	Alex, Elien, Tobi	0.1	0.1	Completed	/
115	Redefine estimated price for bGuard	Alex, Elien, Tobi	0.1	0.1	Completed	/
128	Plant-based memory foam or normal PU foam	Alex, Elien, Ko	0.2	0.2	Completed	/
130	Decide the range of measurements to send a notification (pulse, temperature, humidity and CO ₂)	Alex, Elien	0.1	0.1	Completed	/
129	Decide the references to be used for the range of measurements	Alex, Elien	0.1	0.1	Completed	/
132	New designs for the app	Elien	0.2	0.2	Completed	/
134	Improve the Stakeholders Analysis	Marcel	0.1	0.1	Completed	/
136	Redefine the Positioning Matrix	Alex, Elien, Tobi	0.2	0.2	Completed	/
137	Global Review of wiki	Alex	/	/	Not Completed	Waiting for new information to be included in the chapters
140	Home Station Structural Drawing	Ko	2	4	Completed	/
143	Testing the sensors	Vaido	3	4	Completed	/
		Sprint Velocity	10.8	15.3		

Table 23: Sprint 8, 2019-05-16 to 2019-05-22

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
P	Prepare the meeting with supervisors - 10th Meeting (2019-05-16)	Alex	0.1	0.1	Completed	
75	Choice of open-source IoT platform	Marcel	0.4	1	Completed	
P	Sprint analysis - Sprint 7, 02-05-2019, 03-05-2019, 13-05-2019 to 15-04-2019	Alex	0.6	0.6	Completed	
P	After meeting with supervisors - 10th Meeting (2019-05-16)	Alex	0.1	0.1	Completed	
146	Initial tests – CO ₂ sensor	Tobi	/	/	Not Completed	Bad connections in the breadboard
145	Initial tests – pulse sensor	Tobi	1	3	Completed	
147	Initial tests – relative humidity sensor	Marcel	/	/	Not Completed	Measurements far from reality
148	Initial tests – temperature sensor	Marcel	2	2	Completed	
149	First version of the manual	Elien	3	4	Completed	
150	Overleaf/LaTeX workshop	Alex	0.2	0.2	Completed	
P	Week Report (wiki Logbook) 11th Week Report (2019-05-13 to 2019-05-17)	Alex	0.1	0.1	Completed	
151	Solidworks drawings for the 3D printing – home station bottom	Ko	1.5	2	Completed	
152	Solidworks drawings for the 3D printing – home station top	Ko	2	2	Completed	
		Sprint Velocity	11.0	15.1		

Table 24: Sprint 9, 2019-05-23 to 2019-05-29

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
146	Initial tests – CO ₂ sensor	Tobi	2	3	Completed	
147	Initial tests – RH sensor	Marcel	2	2	Completed	
P	Prepare the meeting with supervisors - 11th Meeting (2019-05-23)	Alex	0.1	0.1	Completed	
P	Sprint analysis - Sprint 8, 16-05-2019 to 22-05-2019	Alex	0.6	0.6	Completed	
P	After meeting with supervisors - 11th Meeting (2019-05-23)	Alex	0.1	0.1	Completed	
P	Week Report (wiki Logbook) 12th Week Report (2019-05-20 to 2019-05-24)	Alex	0.1	0.1	Completed	
107	Thermal insulation - electronic components in the pillow	Alex, Elien, Ko	0.4	0.4	Completed	
144	Check the wiki where it says humidity and replace it for HR	Alex	/	/	Not Completed	Wiki needed to be refined first
127	Water proof but not air proof for the cover of electronic components in the pillow	Alex, Elien, Ko	0.6	0.6	Completed	
153	Solidworks drawings for the 3D printing – rigid cage for the pulse sensor	Ko	/	/	Not Completed	Problems while printing
155	Solidworks drawings for the 3D printing – flexible part for the sock	Ko	2	2	Completed	
154	Solidworks drawings for the 3D printing – flexible part for the pulse sensor	Ko	2	2	Completed	
159	First tests on the IoT platform	Marcel	2	2	Completed	
160	Refine the manual	Elien	3	3	Completed	
		Sprint Velocity	14.9	15.9		

Table 25: Sprint 10, 2019-05-30 to 2019-06-05

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
/	/	/	/	/	/	
		Sprint Velocity	0.0	0.0		

Table 26: Sprint 11, 2019-06-06 to 2019-06-12

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
/	/	/	/	/	/	
		Sprint Velocity	0.0	0.0		

Table 27: Sprint 12, 2019-06-13 to 2019-06-19

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
/	/	/	/	/	/	
		Sprint Velocity	0.0	0.0		

Table 28: Sprint 13, 2019-06-21 to 2019-06-27

PBI/P	Task	Assignee	Planned effort [days]	Needed time [days]	Status	Reasons why tasks were not completed
/	/	/	/	/	/	
		Sprint Velocity	0.0	0.0		

3.12 Sprint Evaluations

After every Sprint the team comes together for a Sprint Retrospective meeting. The main goal of the meeting is to figure out the positive and negative things during the Sprint period. Therefore, the strategy is continuously improved. The consequence is that mistakes are turned off and the team can work more efficiently. **Table 29** shows the main points of each sprint.

Table 29: Sprint Retrospectives

Sprints	Positive	Negative	Start Doing	Keep Doing	Stop Doing
Sprint 1, 2019-03-14 to 2019-03-20	* Constant cooperation between team members	* Some tasks were not completed	* Better time estimation of tasks * Create "smaller" tasks, this means to be done in one week	* Productive brainstorming sessions	* Taking from the PBI to a sprint, tasks that can not be finished in one week due to lack of information
Sprint 2, 2019-03-21 to 2019-03-27	* The dividing of the tasks is better than the Sprint before * The schematics and the tables for the hardware components are better than the Sprint before	* The writing skills in the wiki have to be improved	* Everyone reads the finished chapters of the other team members, to get the first feedback * Write in the passive voice * Write "Wi-Fi" instead of "Wifi" * Write for example "1 to 10 000" instead of "1-10.000" * Write a paragraph to each figure and table * Each picture which is not done by the team should have a reference	* Working on the Wiki Chapters * Decide what the actual shapes of the products are	/
Sprint 3, 2019-03-28 to 2019-04-03	* Everybody has focused on the interim report	* Not every team member is present and/or on time at the weekly meeting with the supervisors	* Write for example "2019-04-06" instead of "06.04.2019" * Write for example "[mm]" instead of "(mm)" Write ";," in each line after ":" and then "." at the last line	* Writing every progress on the wiki	* Not being present and/or on time in the weekly meeting with supervisors
Sprint 4, 2019-04-04 to 2019-04-10	* Excellent team cooperation to prepare the interim presentation * Interim Report was	* Some tasks are not yet well divided between the team members * Some chapters in the interim presentation were too long	/	* Writing every progress on the wiki	/

Sprints	Positive	Negative	Start Doing	Keep Doing	Stop Doing
	finished and uploaded in time	just for one team member			
Sprint 5, 2019-04-11, 2019-04-23 and 2019-04-24	* Very good feedback from teachers and supervisors on the interim presentation * Some updates were already done in the report based on the feedback from supervisors and teachers	* Not every team member is present and/or on time at the weekly meeting with the supervisors	* Update more chapters of the report based on the feedback	* Writing every progress on the wiki	* Not being present and/or on time in the weekly meeting with supervisors
Sprint 6, 2019-04-24 to 2019-04-30	* More chapters were refined based on the feedback * First images of bGuard app were done	* Not every team member is present and/or on time at the weekly meeting with the supervisors	/	* Writing every progress on the wiki	* Not being present and/or on time in the weekly meeting with supervisors
Sprint 7, 2019-05-02, 2019-05-03, 2019-05-13 to 2019-05-15	* Very good feedback from the supervisors about the images of bGuard app * The first version of the paper was finished in time	/	* Thinking in the information the manual must have	* Writing every progress on the wiki	* Not being present and/or on time in the weekly meeting with supervisors
Sprint 8, 2019-05-16 to 2019-05-22	* Nice looking of the first version of the manual	Not all sensors are working properly	* Write in the passive voice	* Writing every progress on the wiki	* Not being present and/or on time in the weekly meeting with supervisors
Sprint 9, 2019-05-23 to 2019-05-29	Now all the sensors are working properly	/	/	* Writing every progress on the wiki	/
Sprint 10, 2019-05-30 to 2019-06-05	/	/	/	/	/
Sprint 11, 2019-06-06 to 2019-06-12	/	/	/	/	/
Sprint 12, 2019-06-13 to 2019-06-19	/	/	/	/	/

Sprints	Positive	Negative	Start Doing	Keep Doing	Stop Doing
Sprint 13, 2019-06-21 to 2019-06-27	/	/	/	/	/

3.13 Conclusion

This study allowed the team to define the limits of the project but also to determine an optimal management strategy. The scope and the Gantt Chart gives the team an overview of the deadlines and deliverables. By making a risk analysis the team is able to minimise the risk. The main risks are based on time management. Hence, the team has to take care of the planning and documentation of the Sprints. Furthermore, the Scrum method gives the team the opportunity to change tasks fast and improves the work of the team continuously. So the team can save time, lows the costs of developing and also keep the quality of the product high. The early analysis of the people, costs, stakeholders and communication has also an impact on the success of the project. It is the basis for the following marketing strategy.

4 Marketing Plan

4.1 Introduction

Marketing is the targeted and target group orientated lining up of a company to the needs of the market. Thus, marketing is much more than advertisement or sales which most people associate with it. In the development process of a new product, marketing has a significant role in success. Customer orientation should nowadays not only be an abstract idea in books – it should be lived in the company. Processes should always be verified to be important for the customer. The balance between demand-pull and technology-push has strongly shifted toward demand-pull in recent years [91].

“Customers don't buy products – they buy benefits.”

Therefore, the benefit for the customer should always be in the focus during the development process. It is absolutely necessary to know the customer, the market and especially the future customer. At the end of this chapter, the team wants to have a proper market and customer analysis to have the opportunity to create a solid Marketing Mix where either price, product, place or promotion are defined.

4.2 Market Analysis

The Market analysis will define the work environment, the market situation and the (future) position in it. Thus, it will give the team input for the Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. The main questions that will be answered in the market analysis are: Who are the potential customers and what are their buying and shopping habits? How many of them are there, how much will they pay and **how can the product reach them?** What may be the best pricing/promotion/place strategy? Who is the competition?

Therefore, the market analysis actually helps to reduce the risk by understanding the potential market and customer conditions. It gives the team the opportunity to develop a viable product and gives input to recheck the situation during the development process and focus the resources on the strengths or to alleviate our weaknesses.

Figure 7 shows that the market analysis is divided into 3 levels:

- The macro-environment;

- The meso-environment;
- The micro-environment.

Macro- and meso-environment are part of the external analysis. The microanalysis will be an internal analysis.

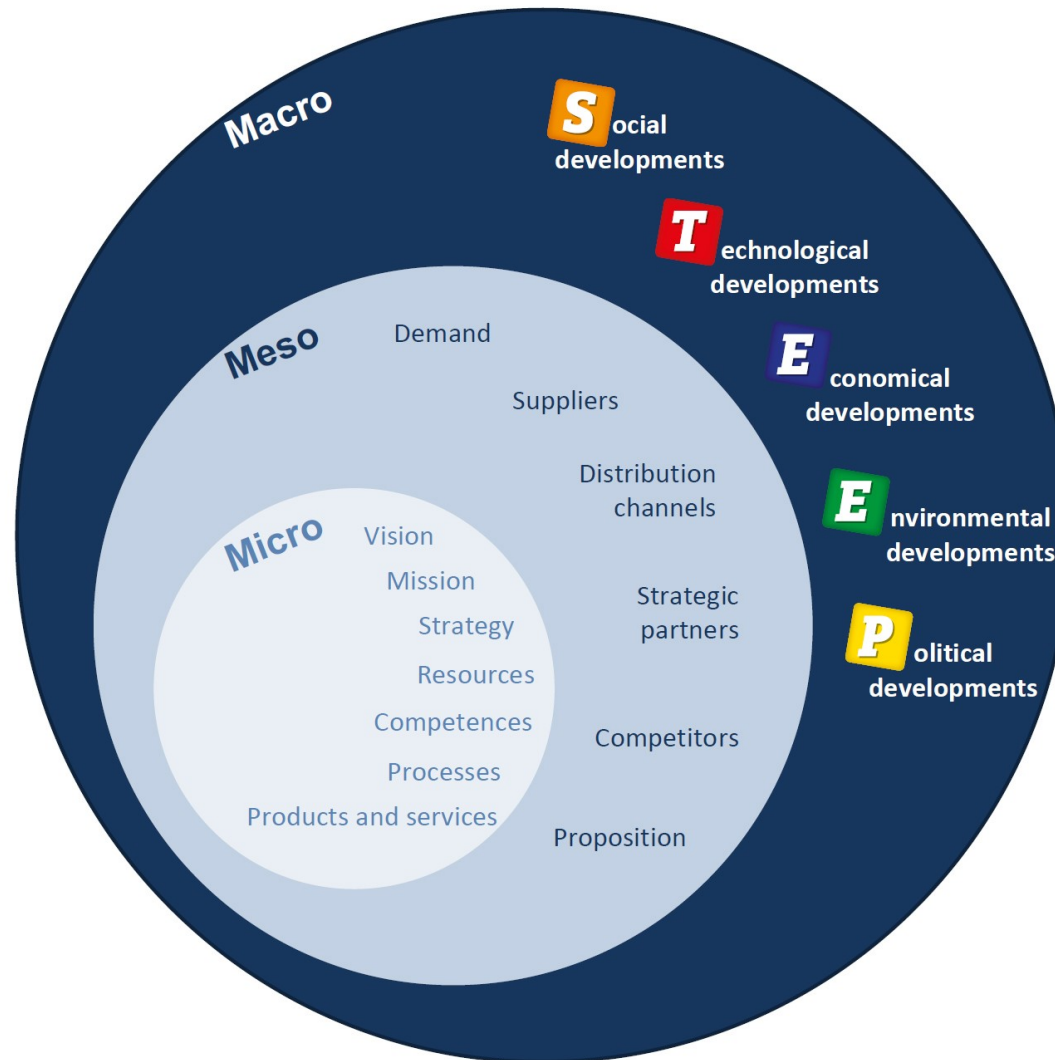


Figure 7: Market analysis and the 3 levels [92]

4.2.1 Problem Statement

The problem statement of the project focus on worried parents and SIDS. Based on the problem statement, an agile and modern way to define the requirements specifications is phrasing User Stories, so product requirements can be simply abstracted. **Table 30** includes a set of User Stories referring to bGuard.

Table 30: User Stories

ID	User Story
1	As a parent I want to have a special pillow for my baby so that he/she does not roll from back to tummy.
2	As a parent I want to have sensors to monitor my baby so that the risk of SIDS is reduced and also as prevention for diseases.
3	As a parent I want to have a microphone near my baby so that I know if he/she is crying and also that he/she can listen to his/her parents' voice or music.
4	As a parent I want to have room sensors to measure CO ₂ , relative humidity and temperature so that my baby and also the parents have a good indoor air quality.
5	As a parent I want to have all sensors connected so that I can have the information centralized.
6	As a parent I want to have the information in one platform so that I can see/hear alarms.
7	As a human being I want a sustainable product so that I don't burden the environment unnecessarily.
8	As a customer I want to have a good product quality so that I can rely on the product.
9	As a parent I want a pillow that has an adjustable ground layer so that is suitable for different sizes of babies.
10	As a parent I want to remove the cover of the pillow so that I can wash it.
11	As a parent I want that the pillow has an anti-allergic cover so that my baby does not have health problems.
12	As a parent I want to have no strong Signals right next to my Baby so that there is no health risk.
13	As a parent I want to have a user-friendly software so that it is easy to use.
14	As a parent I want to have a safe software so that I can be sure to be notified when something is wrong.
15	As a parent I want to order the product easily on the internet so that the product will be delivered easy and fast.
16	As Sleepsense I want to have a good product and produce cheap so that I have the opportunity to earn money.

4.2.2 Internal Analysis

The Internal Analysis will stick to the micro-environment and will especially result in the SWOT analysis of our team. The strengths and weaknesses of the team and the project are defined. McKinsey's 7S model is used for analysing the micro-environment.

7S Model of McKinsey for Micro-Environment

McKinsey's 7S Framework is used as a tool to make sure that all parts of an organization work in harmony to achieve development success. The basic premise of the model is the need for seven internal aspects of an organization to be aligned to reach success.

The McKinsey 7S model involves seven interdependent factors which are categorized as either "hard" or "soft" elements represented in **Figure 8**. The model shows the

interdependency of the elements and how a change of a single element affects all the others. The Shared Values element is placed in the middle surrounded by all the others. It is a central factor and the key to developing all the other critical elements[93]. “Hard S” refers to strategy, structure and systems, while the “Soft S” include skills, staff and style.

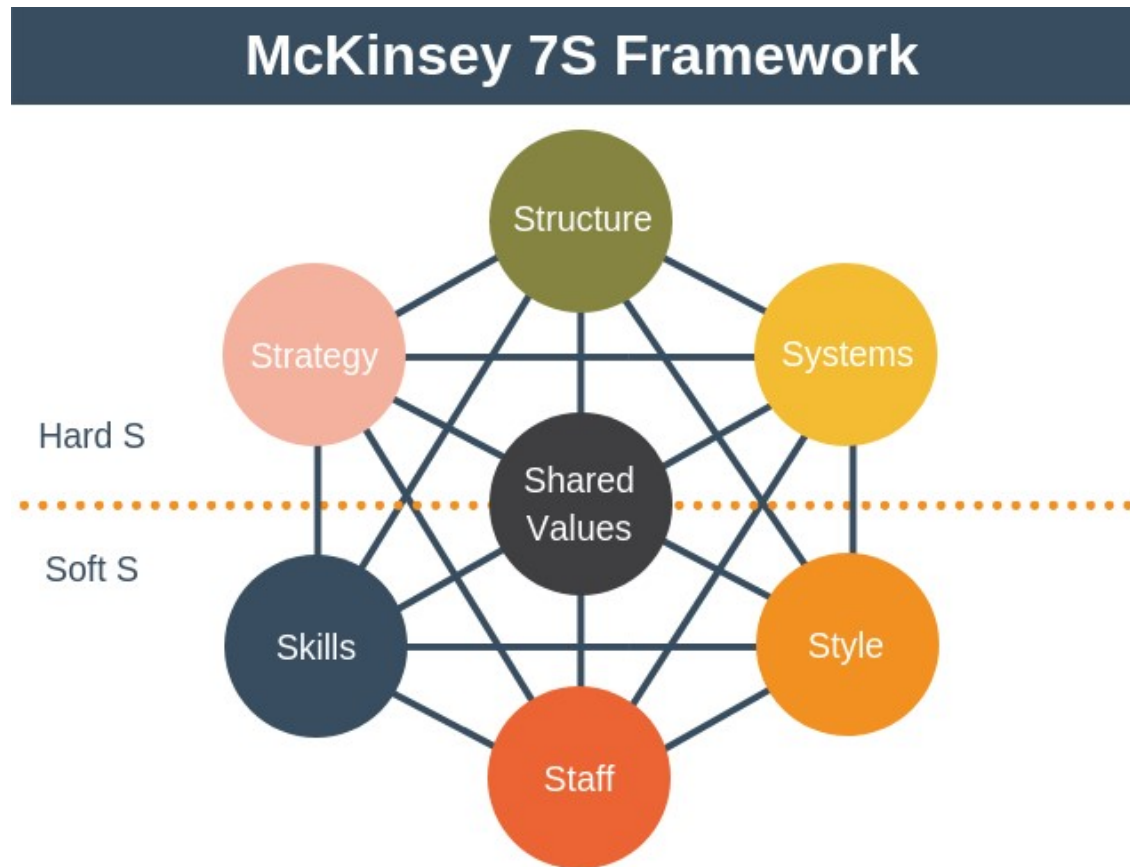


Figure 8: McKinsey 7S Framework Model [94]

The 7S model is most often used as an internal organizational analysis of micro-level to assess and monitor changes in the internal situation of an organization. It provides input for strengths and weaknesses considered in the SWOT analysis. It can help to analyse the current internal situation or a proposed future situation. So possible inconsistencies can be detected.

The model is based on the theory that, for an organization to perform well, the seven elements need to be aligned and mutually reinforced. Therefore, the model can be used to identify what needs to be realigned to improve performance [95].

In the following, it is analyzed how our team is applying and identifying teamwork with these 7S.

Hard Elements

Strategy - Purpose of the business and the way the organization seeks to enhance its competitive advantage.

The team has different experiences and capabilities. Moreover, the team members have a different educational background which gives a wide horizon of know-how. A lot of communication and coordination is our key to success. The main strategy is to use everybody's capabilities to achieve the best possible result.

Structure - Division of activities and coordination mechanisms.

Due to the different experiences, know-how and specialities, some tasks are divided. But still, everybody is included in decision processes and also somebody may have more experience with several tasks, only communication and openness are key to succeed and outgrowth. The different team members' capabilities are optimized by respecting the inherent diverse work methods.

Systems – Measurement procedures, reward and resource allocation.

In every supervisor-meeting on Thursdays, the team presents the progress and results. Doing this, the opportunity is given to get constant feedback and the operation can be adjusted. Furthermore, the team can work in an agile manner. Results are immediately written down in the wiki to be always up to date. During the working process, Google-Drive is used to make everything for everybody available and also to work on the same issue simultaneously.

Soft Elements

Shared Values - Corporate culture and work ethic.

The team is motivated, multicultural and multilingual. Every team member has a different speciality. By using those values the team is able to develop a remarkable project and create a great product.

Skills - The organization's core competencies and distinctive capabilities.

The team members are coming from different fields of study. All of them are somehow connected to engineering. Marcel Pasternak and Alexandre Reis: Mechanical Engineering, Elien Gielen: Product Development, Vaido Sooäär: Electrical Engineering, Ko Wopereis: Industrial Product Engineering and Tobias Schneider: Biomedical Engineering. Moreover, the members are coming from 5 different countries. All of them are part of the European Union and are industrialized countries. Except for Alexandre, each team member has a working environment which is different from home.

Staff - Team members and their general capabilities.

Although everybody has different main focuses on the work, the team members are integrating everyone in every work field and discuss in the group and make decisions together.

Style - Typical behaviour patterns of key groups, such as managers, and other professionals.

When working in the project, teamwork is very important. For this reason, the team has no hierarchy. This maintains an open communication atmosphere.

4.2.3 External Analysis

The External Analysis will deal with the meso- and the macro-environment. To do that, Porter's Five Forces model (**Figure 9**) and Political, Economic, Socio-Cultural, Technological, Environmental and Legal (PESTEL) analysis (**Figure 12**) are used. The External Analysis will especially result in the opportunities and threats of the market and will give input for the SWOT analysis.

4.2.3.1 Porter's Five Forces Analysis For Meso-Environment

As presented in **Figure 9** the Porter's-Five-Forces is a powerful competitive analysis tool to determine the principal competitive influence in a market. In the next paragraphs, the five forces of bGuard are analyzed considering this tool specifications. Furthermore, the strengths or weaknesses of our strategy are examined. Opportunities to strengthen the organization's position compared to the other players for reducing the competitive pressure as well as generate competitive advantage can be stated. Thus, an additional input for the SWOT analysis is given [96].

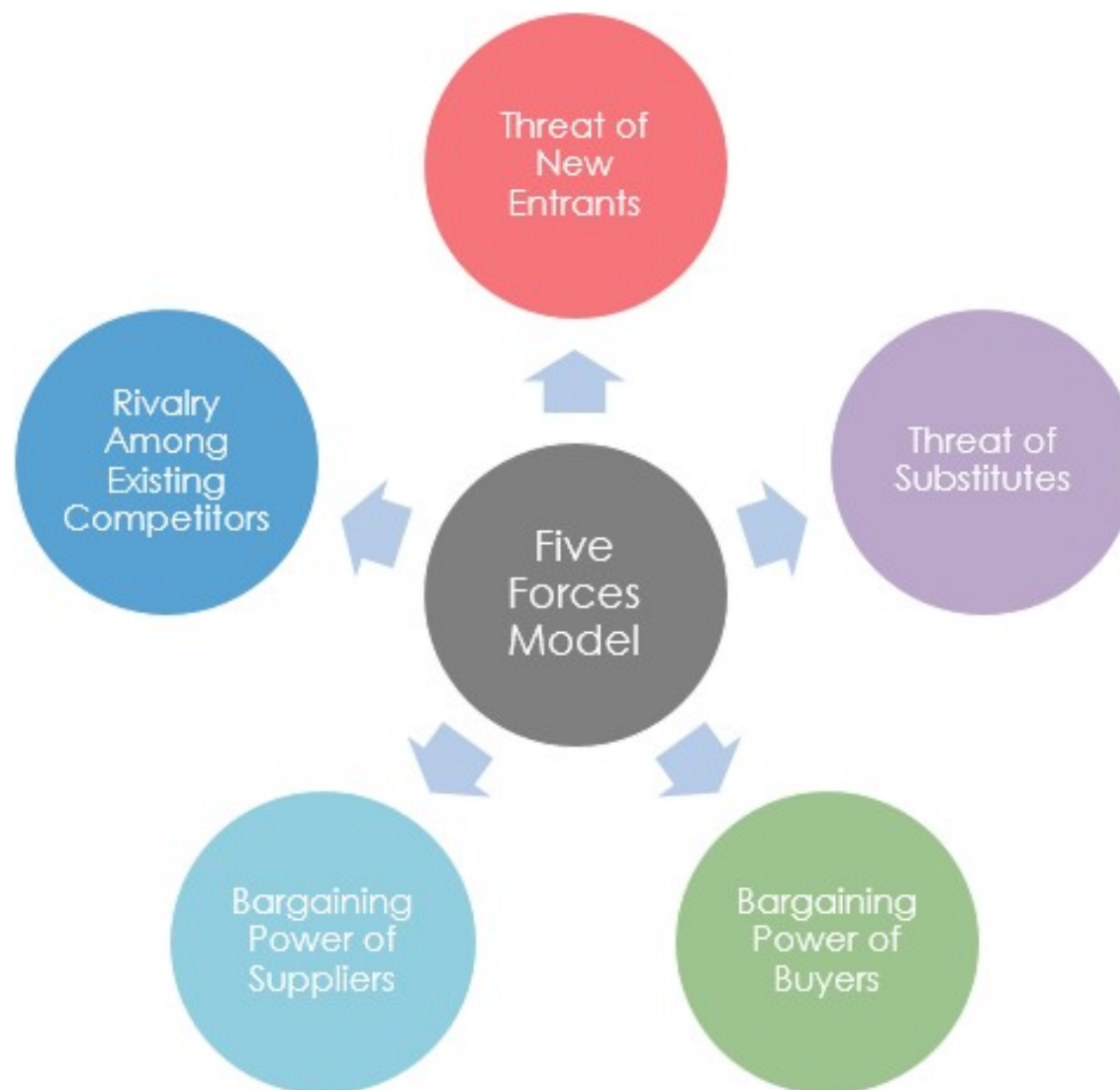


Figure 9: Porter's Five Forces Model [97]

Threat of new entrants

The Threat of new entrants is a threat for every company affecting the competitive environment. New competitors always have the ability to directly influence the profitability of a

company. Competition is one really important factor for quality, progress and pricing on a market. In the case of the team, a threat of new entrants is given. In the Moment the project team is a new company entering the market. However, the idea of smart products is really a trend and attractive to companies. Besides, the Baby market is really attractive because the willingness to buy products is usually high. If the Product is declared as a lifestyle product and not a medical product of Medical Device Regulation (MDR) the regulations and the admission are not that hard and expensive which makes entering the market cheaper and easier. As presented in the State of the Art chapter, there are a lot of different smaller companies, and not several giants, which might make entering the market more difficult. Also, the price of microcontrollers and sensors is really low so that there is not a really high investment needed to enter the market.

Bargaining power of suppliers

Supplier power is one of the factors to consider when you are analyzing the structural environment of an industry using Porter's Five Forces framework. For the bGuard especially the supply of microcontrollers and sensors are important. Due to the huge demand and production of electronics, these sensors are quite cheap and should be available at all time. The product will not have a giant demand for sensors which makes the bargaining position of the suppliers better for us. Also, in the supplier market for microelectronics, the competition is hard so that the team has the ability to choose the suppliers which betters our bargaining position. Due to the plurality of possible suppliers thee bargaining position about prices is good.

Bargaining power of buyers

The bargaining power of buyers refers to the pressure consumers can exert on companies to provide higher quality products, better service or lower prices. With huge competition on the market, the source of the pressure on the company is the consumer. The company is only successful if there are consumers buying the product. To convince them to buy our product, we need unique selling points or arguments to convince them. The Health market, especially for infants, is a really sensitive market where trust in the company is the biggest selling factor. Being a company with trusting policy like a pleasant buyer or return service we want to earn that trust. Having a specific product people buy mostly only once in a lifetime a good image is an important factor for the company's success.

Threat of substitutes

The threat of substitution is about a revolutionary invention which makes our product redundant. At the moment all modern devices are built smart and with microcomputer technology. A permanent monitoring of the baby by implanted devices can be a possible future technology. Still, there are a lot of ethical questions to be answered. Also, there can be a trend away from monitoring back to conservative methods. Anyway, creating a product dealing with the health of the baby goes hand in hand with the trust of the buyer. Therefore ethical correct, sustainable and reliable acting is even more important. At the moment the threat of substitutes is quite low but still, continuously research and development are important to always be able to deliver an up to date product.

Rivalry among existing competitors

An important part of the market economy is competition on the market. This makes companies improve continuously and invest in research and development. As pointed out, we do not have any direct competitors in our niche yet, hence we do not need to worry about the competition at the moment. But the team has to focus on the unique selling points to make sure the benefits are clear to every customer. Also, with a sustainable and ethical correct product, a base for the trust of the consumer in our product is built. Smart and Health devices are really trendy at the moment which makes it interesting for a lot of companies to enter. So, the team members have to be aware that other companies are trying to get in the market as well which makes research and pricing even more important. The profit potential may be decreased due to that point. As well the threat of other companies offering a better product with more benefits or a better price is always a fear to consider. The threat of substitution in an industry affects the competitive environment for the firms in that industry and influences those firms' ability to achieve profitability. The State of the Art research enabled us to be conscious of the companies in this market. But none of the existing products has so many benefits in a single product which gives us a unique selling point. Preventing companies to enter our "gap" we have to continuously invest in research and development to ameliorate our product.





Figure 10: Porter's Five Forces Model [98]

	Level	Impact
Threat of new entrants	High	-
Bargaining Power of suppliers	Low	+
Bargaining power of customers	Medium	o
Threat of substitutes	Low	+
Competitive rivalry within an industry	High	-

Figure 11: Impact of the five Forces to our Business

4.2.3.2 PESTEL Analysis for Macro-Environment

With the PESTEL analysis the biggest influencing factors of the macro-environment are analyzed. Specific market conditions, possible market developments can be described so that you get a sound decision-making basis for the management. The macro-environment influences greatly the strategy of the company on the market. The overall company surroundings are analysed in the PESTEL-Analysis presented in **Figure 12**. It analyses which future trends could change the demand and market behaviour [99].

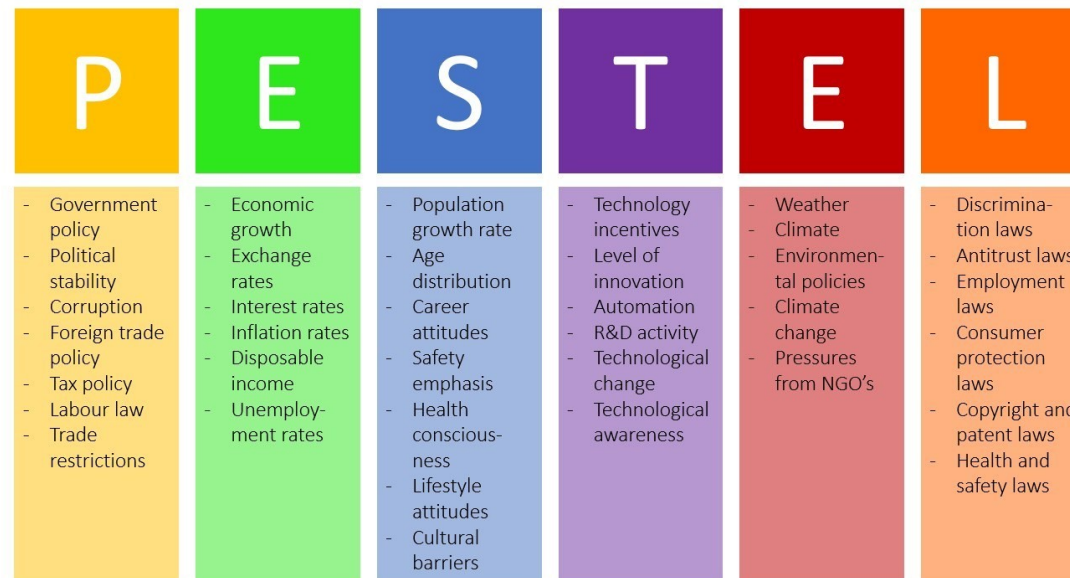


Figure 12: PESTEL [100]

POLITICAL ASPECT

The smart pillow is supposed to be sold in industrialized and democratic countries. It will be first available in Europe and to be expanded to America and Asia.

Opportunities:

- The EU holds a free trading zone;
- Using recyclable and local materials complies with the EU legislation. This gives us both a unique selling point and a sustainable product;
- Complying with national and international regulations increases the product value.

Threats:

- Brexit makes us no more selling products in the free trading zone and either we lose a market or prices increase because of taxes;
- Regulatory affairs are expensive and take a lot of time especially in the USA.

ECONOMIC ASPECT

Opportunities:

- Parents are usually ready to invest money for the well-being of their baby;
- Smart devices are popular and used a lot especially by young people. These young people and possible parents are our target group.

Threats:

- The baby market is attractive;
- Our price will be quite high so competitors can compete and maybe offer lower prices.

SOCIAL ASPECT

Opportunities:

- People are getting children later in life, which means the ability to buy may be larger because older people usually have more money;
- The opportunity to lower the risk of SIDS may make people invest in technology because it is still an unsolved problem;
- The awareness about sustainable and ethical products increases in industrialized countries;
- The awareness about health is increasing.

Threats:

- The monitoring of their kids may be threatening for some people so that there is not the expected willingness to buy the product.

TECHNOLOGICAL ASPECT

Opportunities:

- More and more people are using smart devices and the trend goes up;
- Using technology for minimizing risks of health issues is becoming more and more common;
- The technological gap between western countries is getting smaller and smaller.

Threats:

- In our prototype some features which are important for the consumer may not be feasible;
- Health issues of radiation (Bluetooth or Wi-Fi) can be discovered.

ENVIRONMENTAL ASPECTOpportunities:

- Making the pillow, the sock and the home station easily disassembled.

Threats:

- Nothing relevant.

LEGAL ASPECTOpportunities:

- Nothing relevant.

Threats:

- There may be hard regulations of EU or Food and Drug Administration (FDA) in the USA especially for babies;
- Because of producing and developing in Europe the labour law is quite strict and wage is comparatively high.

4.3 SWOT Analysis

The aim of a SWOT analysis is to specify the objectives of the project and to identify internal or external factors that are favourable or unfavourable achieving those objectives. Strengths and weakness are frequently internally-related, while opportunities and threats commonly focus on the external environment [101].

To be more specific we have considered a SWOT analysis for both the product and the team.

4.3.1 Team SWOT Analysis

In the following, the SWOT Analysis of the Team can be seen in **Figure 13**.

Team analysis

INTERNAL ANALYSIS

EXTERNAL ANALYSIS



Figure 13: Team SWOT Analysis

*internal***Strengths:**

The ambitious team has different educational backgrounds, different experiences and capabilities. This gives a wide horizon of know-how. Other strengths are communication and teamwork.

Weaknesses:

Coming from different countries English is a foreign language for all of the members. Thus, communication is sometimes more difficult than talking to each other in the mother tongue. Most of the members have no experience with the development of a project this big. Moreover most of the members are inexperienced in business.

*external***Opportunities:**

With the Project, the team members can gain experience in project development and entrepreneurship. Furthermore, new knowledge and improve language and soft skills can be acquired. With weekly supervision of professors with different specialities, the team gets continuously a lot of feedback and advice. With this advice, the team can weekly adjust the development of the product.

Threats:

Having different educational and cultural backgrounds the members of the team have different working habits. The main Threat is the time limitation for the development which may make problems. Having limited money capabilities development actions have to be adapted to it and maybe be downgraded. Due to the fixed surroundings of the project by the university, not all processes are optimized and some work is done twice which makes the time even shorter.

4.3.2 Product SWOT Analysis

Next, the SWOT Analysis of the product can be seen in **Figure 14**.

Product analysis

INTERNAL ANALYSIS



EXTERNAL ANALYSIS

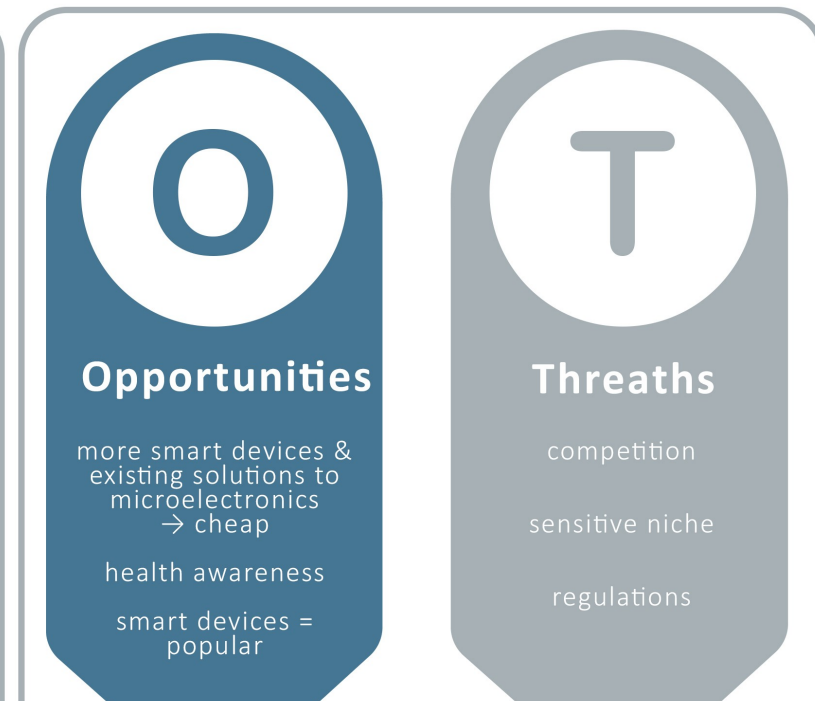




Figure 14: Product SWOT Analysis

*internal***Strengths:**

The bGuard combines a lot of benefits for the consumer which gives the company a unique selling point.

Weaknesses:

In the development process, the team has limited money and time capabilities. Working like a startup the team do not have an existing company or development infrastructure.

*external***Opportunities:**

Awareness of health is increasing. Also, smart devices to monitor health are becoming more and more popular. Though it is a sensitive market which makes it important to have a good and trustful image of both the product and the company. The awareness of sustainability and ethics increases as well. To make this to the product identity, the company has another benefit to sell and another argument why people should pay the price. Due to the fact that people are giving birth to children on an older age the ability to buy such a product increases. Also, smart devices, especially for health issues, are really trendy and people require them nowadays. Because of this trend, there are a lot of existing solutions to microelectronics what makes them always available and quite cheap due to the large produced quantities. Another opportunity is that SIDS is still a frightened, unsolved problem why people ask for solutions. bGuard is the contribution to the solution. More and more people are using smart devices and the trend increases. Especially smart devices to minimize health issues become more and more common (e.g. Apple watch). Globalization and free trading zone give a huge number of possible customers.

Threats:

Because the market is attractive, the team has to aspect a lot of competition. As it is said before the niche is a sensitive one and image and trust are important factors. So small factors which cause damage to the company image may affect our selling much more than in other markets. Also, the monitoring of children may be a threaten some people and also the awareness of radiation as a possible danger is getting bigger. Politically, Brexit can have a serious impact on our selling. Also, the regulation in the market is quite huge which may increase the costs of the developing process. Because of the attractiveness of the market, there are a lot of competitors which makes pricing really important. Approximately the product will have quite a high price so that is to emphasize our USPs and benefits.

4.4 Strategic Objectives

Strategic objectives are statements that indicate what is critical or important in our organizational strategy. To state them the SMART criteria is used. SMART stands for **S**pecific, **M**easurable, **A**chievable, **R**elevant, and **T**ime-related. The principal advantage of SMART objectives is that they are easier to understand and to know when they have been done. Sometimes the SMART criteria are added as "SMARTER" which makes them **E**valuated and **R**eviewed as well. It can be seen in **Figure 15**.



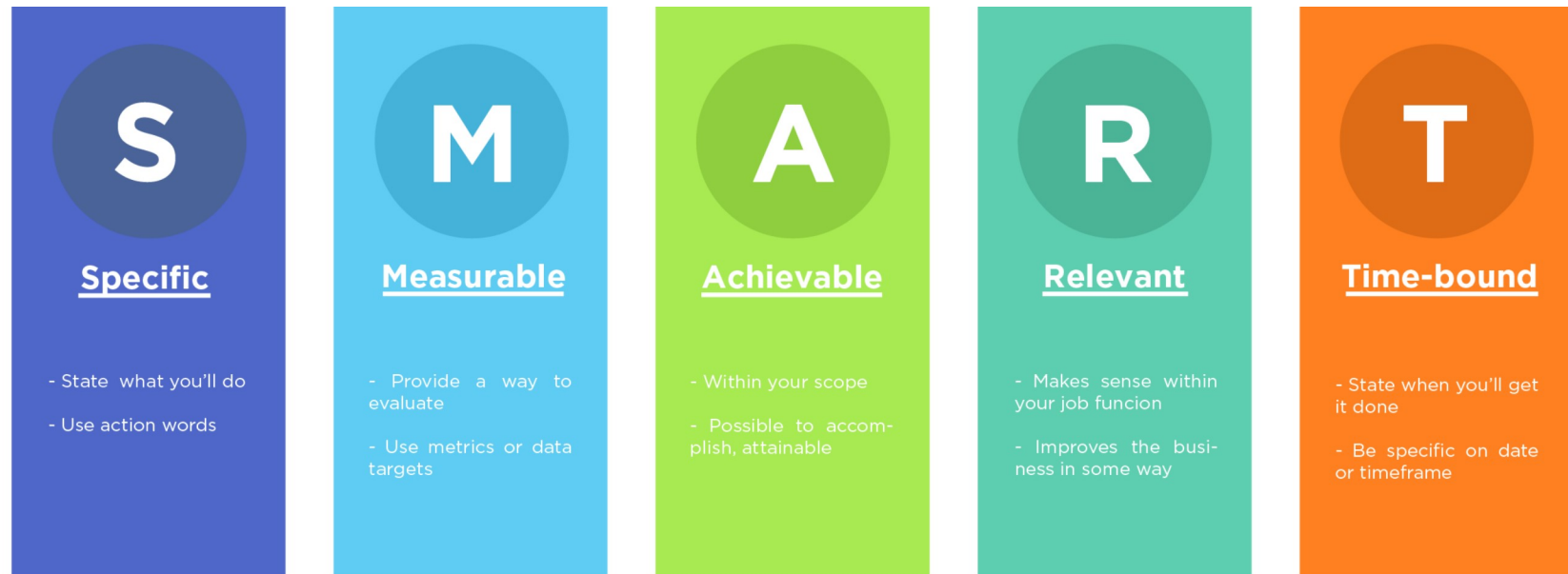


Figure 15: SMART Goals [102]

For the bGuard product the following objectives are defined:

- Build a working smart pillow prototype before 2019-06-14;
- Finish the project report before 2019-06-14;
- Find the main supplier for everything before 2019-08-14;
- Build a final product of bGuard which can go into series production before 2019-12-14;
- Make a professional website with the online shop before 2019-12-14;
- Negotiate a contract with wholesalers like Amazon before 2019-12-14;
- Generate more than 100 clicks on our website before 2019-12-31;
- Invest 5% of the sales in the advertisement to grow before 2020-06-01;
- Invest 5% of the sales in innovation before 2020-06-01;
- Increase market share to 5% in Europe before 2020-06-01.

Furthermore, an initial investment of 10 000 € is made as stated in the Budget chapter listed in **Table 31**.

4.5 Segmentation

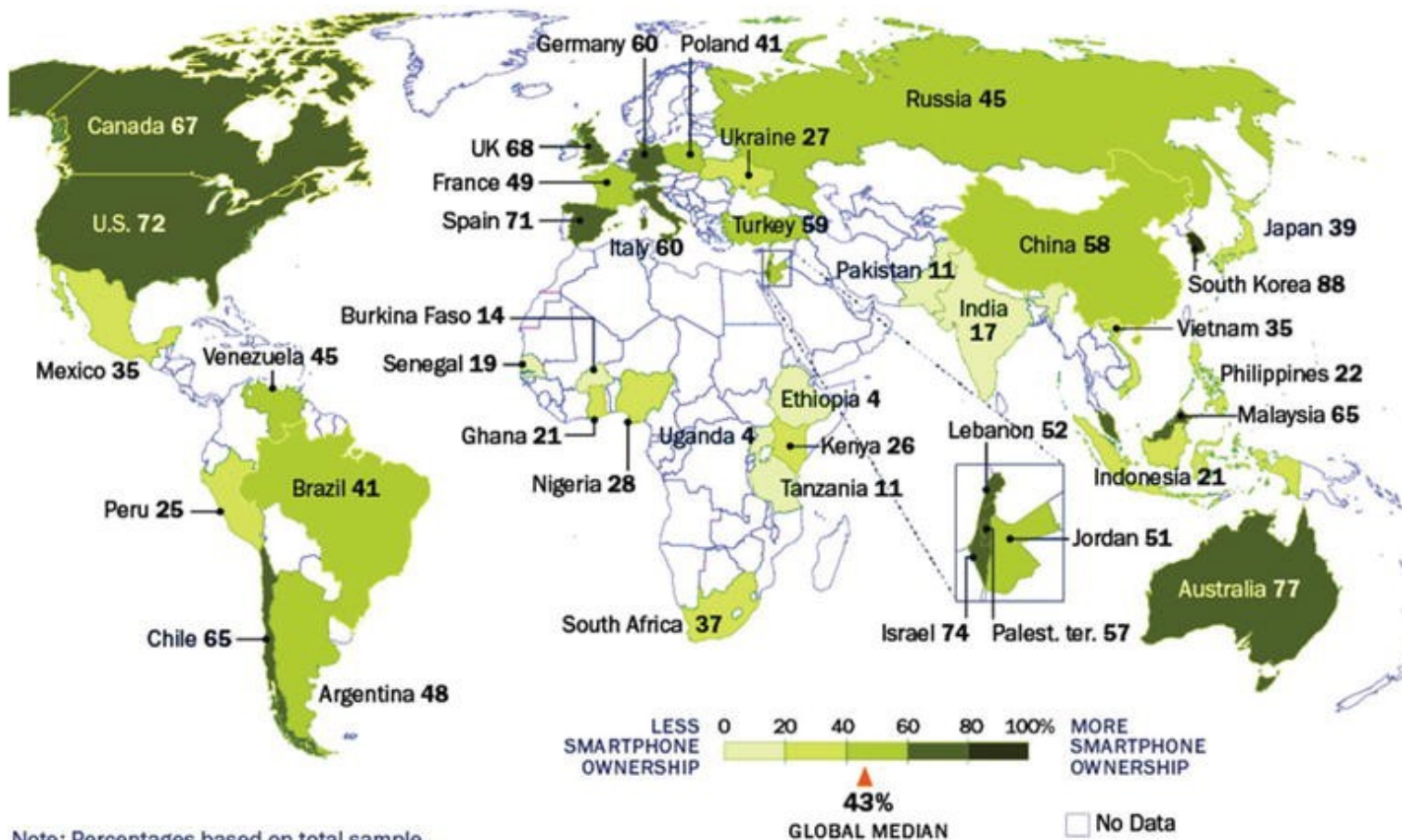
bGuard is sold to the Business to Consumer (B2C) market. Knowing that the product will be sold with a mobile application we know that not everybody will be interested in buying the product or will not have the possibility to use the product. This geographical, demographic and psychological study gives a better view of who our potential customers are.

4.5.1 Geographic

Thus the supply of the product in a country depends on the number of smartphone users there. According to Smartphone as a Portable Detector, Analytical Device, or Instrument Interface the map below in **Figure 16** shows the distribution of smartphone users by countries [103] where it can be seen that most smartphone users are situated in Europe or the United States. Because of that, the company wants to start off small and keep the ecological footprint small. Therefore, the focus is on the European market.

Smartphones are more common in Europe, U.S., less so in developing countries

Percent of adults who report owning a smartphone



Note: Percentages based on total sample.

Source: Spring 2015 Global Attitudes survey. Q71 & Q72.

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Figure 16: Smartphone Users Worldwide [104]

4.5.2 Demographic

Taking a closer look at the map of Europe, it is shown that the distribution of wealth in Europe is not equally divided (**Figure 17**). Because the product is a technological product

and will thus not be considered cheap, it is best to focus on the wealthier countries in Europe. According to Eurostat, 2015 **[105]** Western Europe can be considered as more wealthy seeing that their GDP (Gross Domestic Product) per capita in Purchasing Power Standards (PPS) is bigger than the GDP per capita in PPS when comparing with other parts of Europe.

European regions by GDP per capita in PPS

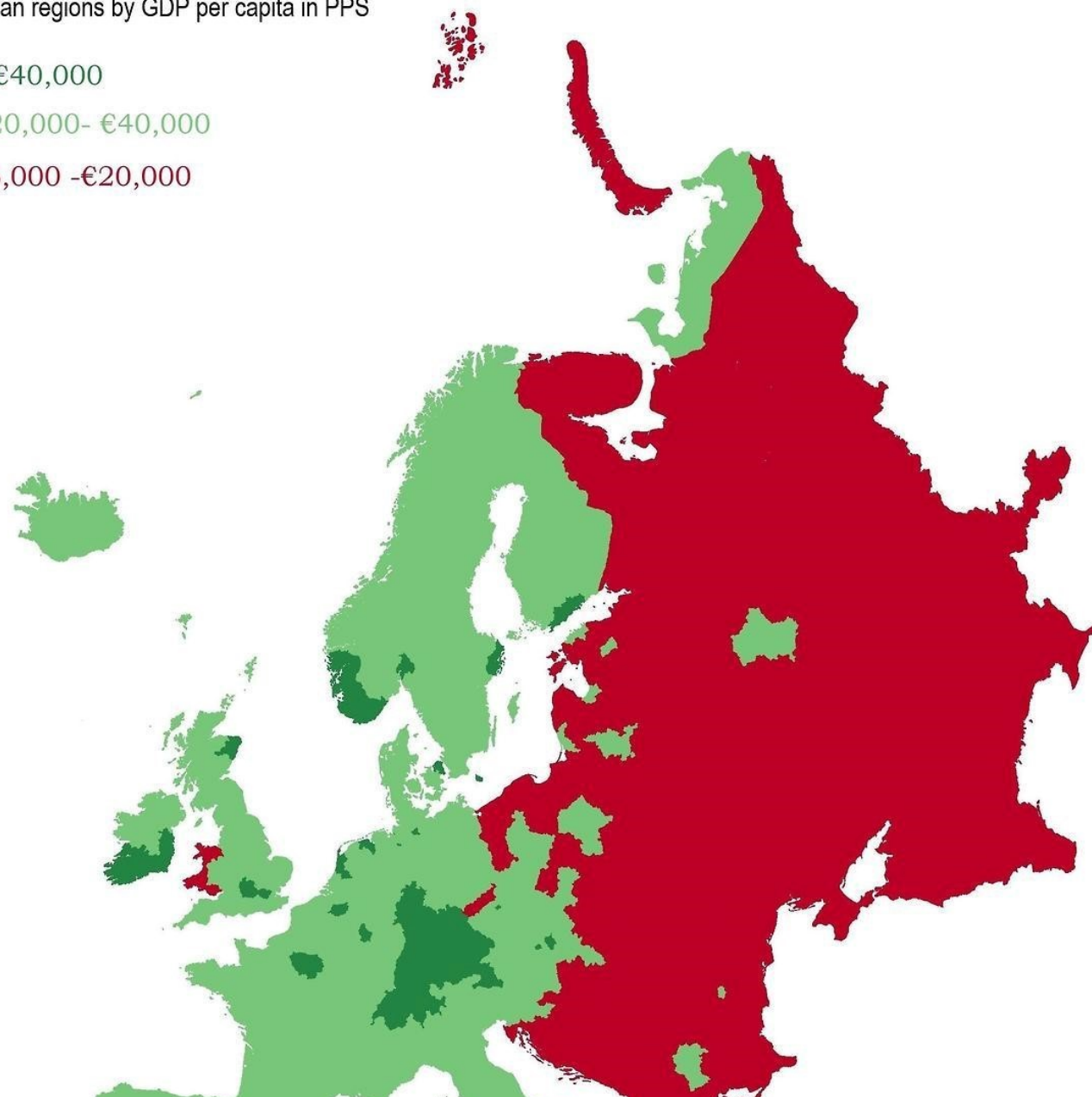
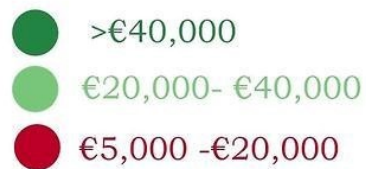


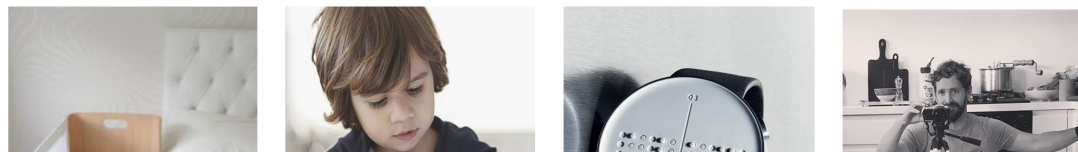


Figure 17: European Regions by GDP per capita in PPS [106]

To get a better idea of the target group, a mood board is made to create the look and feel of the type of people bGuard wants to reach. The target group is concerned parents (25 to 35 years), ranging from middle-class through upper-class, who were raised with technology and constantly rely on their smartphone (Figure 18 and Figure 19).



Figure 18: Moodboard Target Group - mom (adapted from several sources)



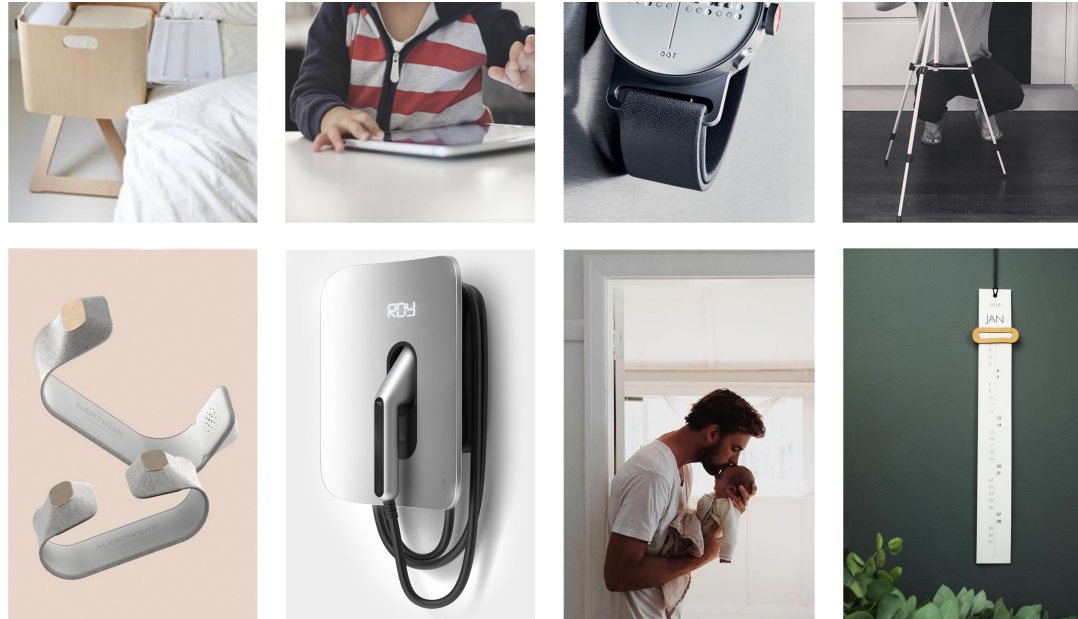


Figure 19: Moodboard Target Group - dad (adapted from several sources)

4.5.3 Psychological

Concerning the psychological segmentation, it is found that nowadays parents worry a lot. According to a study looking into the parental worries of 2 000 parents conducted by OnePoll in conjunction with Lice Clinics of America [107] the average parents worry about their children around 37 hours a week. Consequently, bGuard wants the parents to be able to have less stress and assure them that their kid is doing fine.

4.6 Strategy/Positioning

For the strategic choices, the outside-in approach has opted. This approach helps to identify the holes in the market and assists you in taking advantage of these opportunities. A positioning matrix (Figure 20) is created to get a clear image of what the competitors have already brought on the market. This way can illustrate where the holes in the market are found. The figure shows that there is still a gap in the sector of low to medium priced monitors that have a lot of functions. This gap is filled by bGuard.

With the help of the **Porter model** [108] bGuard is positioned. Porter describes three different strategies a company can use from an outside-in point of view: cost leadership, differentiation and focus strategy. The differentiation strategy is chosen by the team. This strategy focuses on differentiating the product compared to its competitors. By creating a unique product combination, bGuard stands out from the crowd. Because bGuard is offering a unique product with an unseen combination of parameters, the potential customers are willing to pay more.



high price

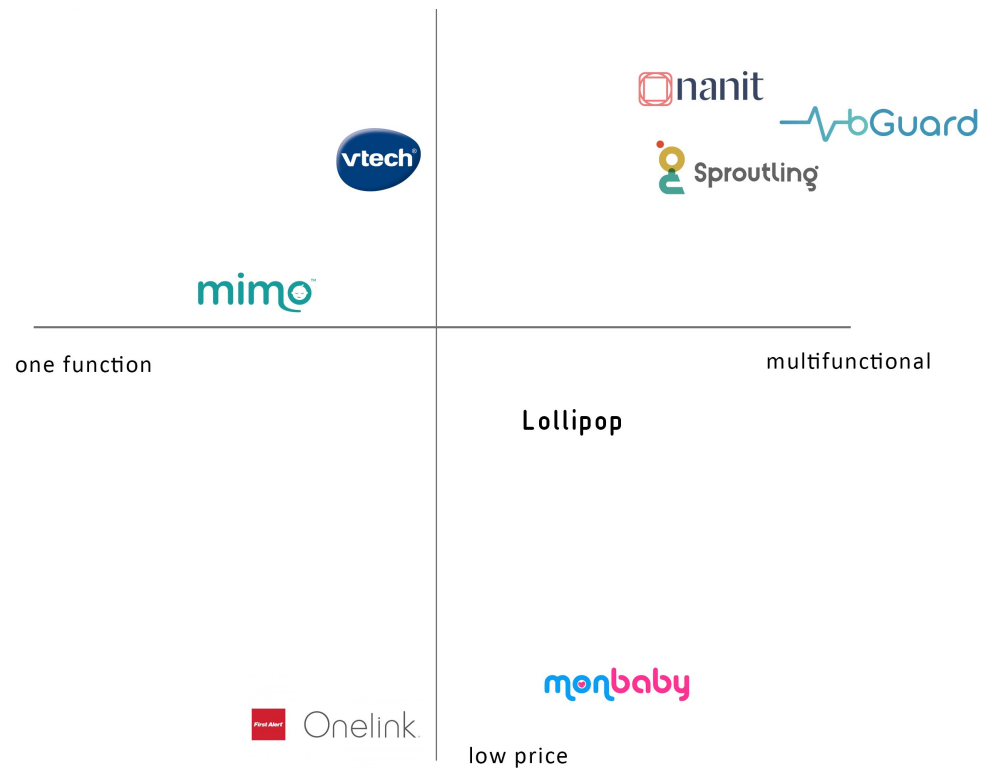
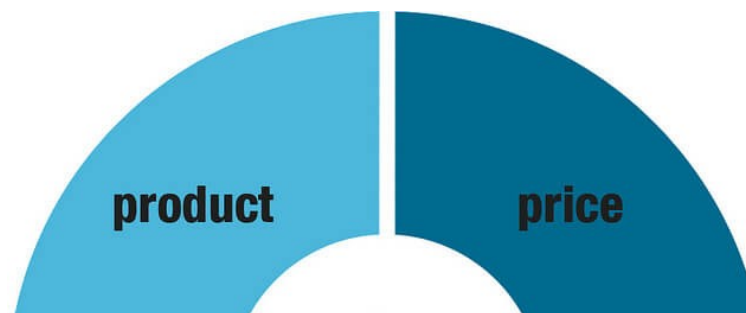


Figure 20: Positioning Matrix

A detailed analysis of the competitors and the existing solutions can be seen in Chapter 2.2 *Existing Solutions* listed in **Table 4** and below.

4.7 Adapted Marketing-Mix

The 4 P's Marketing Mix is a tool to translate the marketing strategies based on the analysis of the chapters before into concrete actions. It focuses on the product, price, place and promotion as you can see in **Figure 21**.



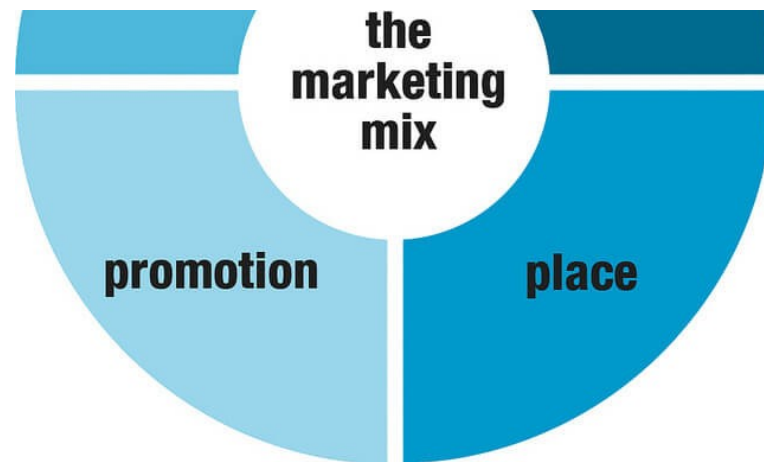


Figure 21: 4 P's of Marketing Mix [109]

Product

The bGuard combines multiple benefits for the customer. Therefore bGuard contains a home station measuring environmental parameters and being the Wi-Fi source for App connection. The pillow has a tummy-roll-prevention shape and contains speakers for interaction with the child and connects via Bluetooth to the home station. Moreover, the product is a sock which measures and monitors the heart activity of the baby. Especially the combination of all that is unique on the market. To keep a hygienic standard the pillow has a washable surface and is adjustable.

Price

In the State-of-the-Art chapter, the competitors are also compared concerning the prices. Most of the comparable products vary between 113.00 € and 313.00 €. **Figure 20** shows that the bGuard wants to position multifunctional and in the middle-upper price segment. The estimated price should be around 249.00 €.

Place

Having a smart product, the target group is familiar with online shopping. Due to that bGuard should only be sold on the internet on our own website which makes us safe money negotiating with big warehouses or resellers. This saved money is to be invested in advertisement and promotion. Because our website is our main promotion it has to work properly and the logistics have to work as well so that the customer is satisfied at the end.

Promotion

Our target group are parents of a newborn with a high income. This target group is familiar with internet and social media like Facebook and Instagram. Therefore, social media will also be considered for promotion. Additionally, parents of first-born children are usually really careful and want the best for their kids. Being present at baby exhibitions would directly touch our target group as well.

Our Promotional Claim is **“Sleepcurity for your Baby”**. This Slogan intends to increase awareness and to give the customer an idea of what his benefits are when he buys the product.

4.8 Budget

Table 31 shows the division of the marketing budget being calculated with 10 000.00€. Regarding our target group, the main promotion will be digital. It can be assumed that people who buy this smart product are familiar with online shopping and will be reached by online advertisement best. The Facebook, Instagram and Google advertisements are paid by clicks. This means when the budget is achieved the advertisement is not visible anymore. That's why after having spent the first amount of 10 000.00€ the promotion budget will be 5% of our sales as it can be seen in *4.4 Strategic Objectives*. To provide the customers with the best possible service the team will spend 3000 € to create a good website and customer service. Because we are selling our product online, consumers need the best possible comfort buying the product online and the website has to work properly instead this feels unprofessional and might have an impact on our reliability and image. Our product is to be sold in industrialized European countries. The digital promotion has to be precise for a specific country. Because of the high average income and the willingness to buy in Germany and the United Kingdom, the Google, Instagram and Facebook promotion is focused on these countries. With the investment of 10 000€, we want to increase the awareness of our product by 40% according to our target group. More than four-fifths of businesses (81%) spend at least \$50,000 on digital marketing each year[110]. Therefore 10 000€ as an initial investment is a good amount. Also, 10 000€ is still a realistic amount in our particular case.

Table 31: Marketing budget

Action	Price [€]
Facebook advertisement	1 000.00
Instagram advertisement	2 000.00
Google advertisement	2 000.00
Website	3 000.00
Exhibitions for baby materials	2 000.00
Total	10 000.00

4.9 Strategy Control

In an agile world acting agile in a development process is really important. Plan, Do, Check, Act (PDCA) is an iterative, four-stage approach for continually improving processes, products or services, and for resolving problems. It also includes always to recheck if the actions are beneficial for the project success. It is a continuous way to systematically test solutions, assessing results and implementing solutions which are considered good.

The four phases are:

Plan. Identify improvement potentials and establish objectives and processes required to deliver the desired results.

Do. The plan is enacted, and the potential solution is tested ideally on a small scale first. Results are measured.

Check. Study results and compare the effectiveness and decide whether the hypothesis is supported or not.

Act. If the solution was successful then implement it instead adapt it and go through the circuit again.

Figure 22 represents those four phases.



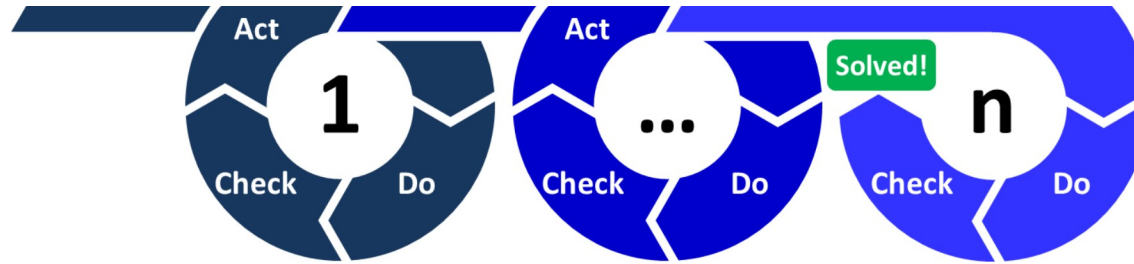


Figure 22: PDCA Deming cycle [111]

To always recheck the focus on the company goal the requirements of the customer and the market must continuously be rechecked and the actions must be adapted to them. Besides that, it is important to check if the targeting group is reached and if our promotion actions work. If not market researches can help to find out how to better reach our targeting group.

4.10 Conclusion

Based on this market/economic analysis, the team concluded to develop a **pillow** with a special shape - two side bumpers - to reduce the risk of rolling from back to tummy. In one of the bumpers, there will be a speaker to sooth the baby when crying. There will also be a **sock** to measure the baby's pulse and finally, a **home station** to monitor the room air quality. We considered the Promotional Claim "**Sleepcurity for Your Baby**" which increases awareness and focuses on the main benefit for the customer. Also, we focus on the unsolved problem of SIDS and deliver solving approaches.

On the whole, bGuard will be promoted on the internet and social media, sold on our own website and due to its unique combination of features, young parents from the middle class to upwards will be willing to pay 249.00€ for its benefits.

Eco-efficiency Measures for Sustainability are framed in the next chapter.

5 Eco-efficiency Measures for Sustainability

5.1 Introduction

The project started by being based on the **3 Pillars of Sustainability [112]**. Additionally, the **12 Principles of Green Engineering [113]** were considered as well as the **United Nations Educational, Scientific and Cultural Organization (UNESCO) 17 Sustainable Development Goals [114]**. Finally, the **Life Cycle Analysis [115]** of bGuard was devised. In this chapter, these four sets of principles are presented in relation to our proposal.

5.2 Pillars of Sustainability

The 3 Pillars of Sustainability are shown in **Figure 23**.



Figure 23: The 3 Pillars of Sustainability [116]

Social Sustainability (Figure 24) is about the protection of people's health and wellness through strong legislation and maintaining access to basic resources. bGuard, is following not only **legislation** – maximum CO₂ of 1250 parts per million (ppm) according to Portaria n.º 353-A/2013 [117] - but also **recommendations** from: the National Institute for Occupation Safety and Health (NIOSH) - the level of CO₂ should never rise above 1 000 ppm [118],[119]; the National Sleep Foundation (NSF) - the humidity level should always be kept between 30 % to 60 % [120]; the United Kingdom (UK) National Health System (NHS) concerning room temperature – from 16 °C to 20 °C [121]; as also from John Mersch - the average pulse for a sleeping baby fluctuates between 80 beats per minute (bpm) to 160 bpm [122]. Concerning the cover of the pillow and the sock, they are made in Lyocell (Tencel) that is a very breathable material and is also less prone to the growth of bacteria, which means it is very hygienic [123], [124].



Figure 24: Social Sustainability [125]

Re-using, reducing and recycling are the main purposes of **Environmental Sustainability (Figure 25)**. Furthermore, it is also about integrity, natural resources and how ecosystems and air quality can be protected. Therefore, the components of bGuard were thought to be easily disassembled for recycling according to the Design for Disassembly (DFD) [126] principles. The home station can be dismantled due to its manual screw threading system. When dismantled the electronic components can be taken out for recycling. The cover textiles of the pillow and the sock are made in Lyocell (Tencel) fabrics that are naturally biodegradable and additionally during the manufacturing non-toxic solvents are used, making its production eco-friendly. On top of that, it also recycles 99% of the water used in its production [127], [128].



Figure 25: Environmental Sustainability [129]

Economical Sustainability (Figure 26) depends on the political ideology so it is really the most problematic issue as it is hard to decide what is economically sound and the implications on businesses, jobs and employability. The bGuard concept was thought to contribute to good health and quality of life both for the baby and parents. Electronic components were chosen based not only on the price but also on accuracy and local availability. The foam [130], the cover of the pillow and the sock [131], the thermal insulation board [132] to insert in the pillow to avoid overheating and the textile [133] to protect the electronic components to the spillage of liquids, will also be bought to local manufacturers.



Figure 26: Economical Sustainability [134]

5.3 Principles of Green Engineering

Principle **#1 Inherent Rather Than Circumstantial** means that all materials as also energy inputs and outputs must be inherently nonhazardous as possible. This principle has led us to look for solutions with the lowest adverse impact possible like the textiles for the pillow and the main raw material for the home station - Acrylonitrile Butadiene Styrene (ABS) that can be recycled up to 99% [135].

Principle **#2 Prevention Instead of Treatment** and **#3 Design for Separation** were considered as well as **#4 Maximize Efficiency**, **#6 Conserve Complexity**, **#10 Integrate Local Material and Energy Flows**, **#11 Design for Commercial “Afterlife”** and **#12 Renewable Rather Than Depleting**. These seven principles were extremely important in the design of bGuard. For instance, the easy way parts can be disassembled on the home station, the pillow and the sock, allow to take the electronic components out in a really simple way. This means that all materials can easily be sent for recycling.

Through principles **#5 Output-Pulled Versus Input-Pushed**, **#7 Durability Rather Than Immortality**, **#8 Meet Need, Minimize Excess**, it was clear that some features that were at the beginning of the project were not so needed. In the research that was made looking for news about similar products, it was found an article written by Linda Carrol [136] stating that there are parameters rather complex to measure like SpO_2 for instance. Based on this information the focus was really to meet the need of parents - stress relief and not giving them lots and lots of information - this means that concerning the baby we will only monitor the pulse.

Finally, it was not so easy to have so fewer components as principle **#9 Minimize Material Diversity** says. Nevertheless, there was, as explained before, a big focus on design for easy disassembly.

5.4 UNESCO Sustainable Development Goals

According to goal 3, **Good Health and Well-Being (Figure 27)**, good health is about the protection from sickness and well-being concerns a state of health, happiness and prosperity. bGuard will contribute to stress relief of the parents concerning the “**good health**” of their baby by reducing the risk from rolling from back to tummy due to the special shape of the pillow which means a lower risk of SIDS. Furthermore, a special sock will monitor the baby's pulse and additionally, the home station will inform the parents about the air quality of the room, so a double benefit for the “**well-being**” of the baby and the parents, which means “**a feeling of satisfaction with life**”. This information is to be completed once all the components have been decided.



Figure 27: Good Health and Well-Being [137]

One of the aims of goal 9 **Industry, Innovation and Infrastructure (Figure 28)** is to have innovative products or services. bGuard, as an **innovative product** on the market, it will not only be a pillow to reduce the risk of rolling from back to tummy - reduces the risk of SIDS - but also will allow to sooth the baby when crying with audio files from its mother for instance.



Figure 28: Industry, Innovation and Infrastructure [138]

Goal 12 “**Responsible Consumption and Production**” (Figure 29) is about the use of products which brings a better quality of life manufactured with non-toxic raw materials, with the less possible production of waste as also that are safe and healthy while economically viable. bGuard is aimed to bring a **better quality of life** to the family **with the minimum waste** over its lifecycle in order not to jeopardise the needs of future generations. As an example, the foam of the pillow is certified with OEKO-TEX STANDARD 100 [139], class I, which corresponds to the strictest requirements, suitable for babies. The STANDARD 100 by OEKO-TEX contributes to high and effective product safety.

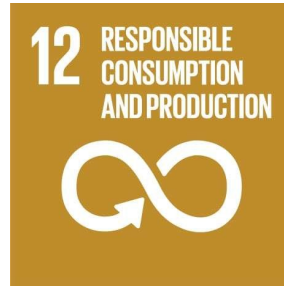


Figure 29: Responsible Consumption and Production [140]

5.5 Life Cycle Analysis

The **Life Cycle Analysis** of our solution was based in five steps [141] as shown in **Figure 30**.

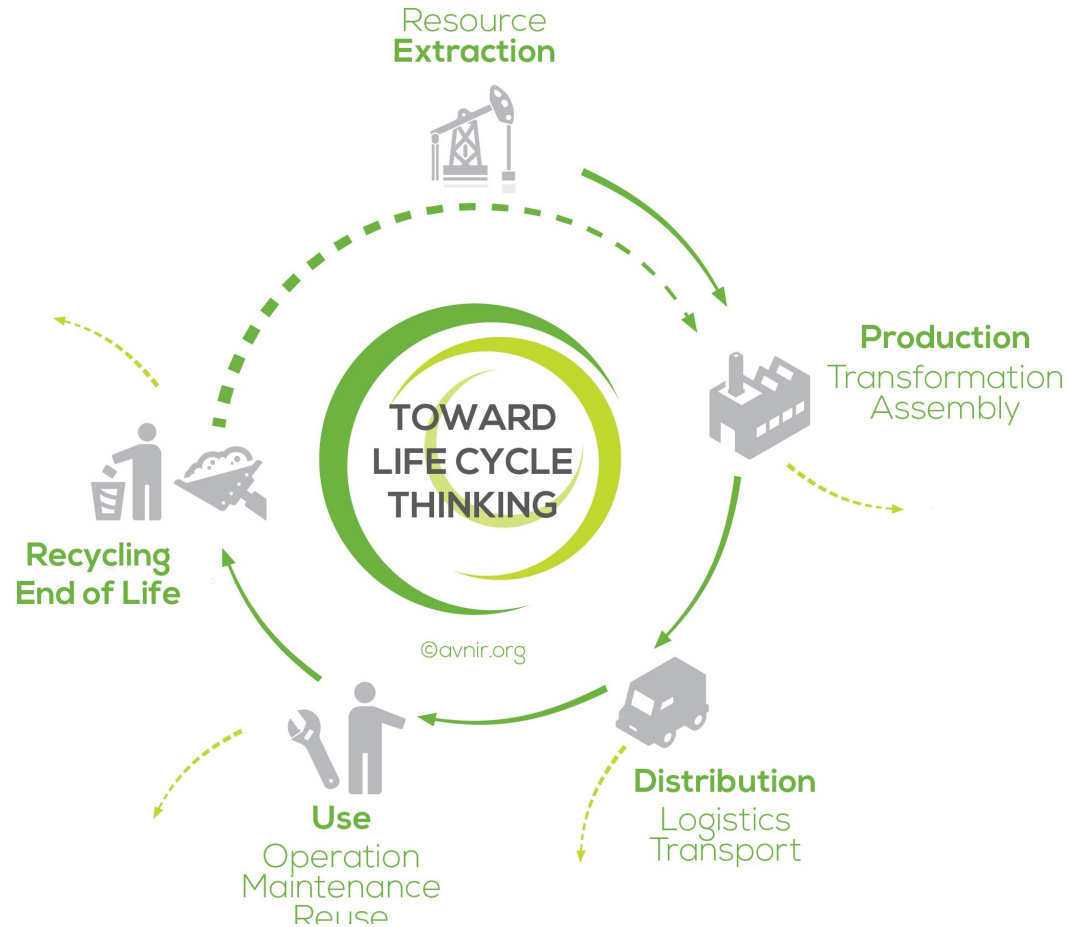


Figure 30: Life Cycle Analysis in Five Steps [142]

Step #1 **Resource/Extraction** ⇒ Components to be bought locally.

Step #2 **Production/Transformation|Assembly** ⇒ To be done locally.

Step #3 **Distribution/Logistics|Transport** ⇒ Outsourcing to logistics companies.

Step #4 **Use/Operation|Maintenance|Reuse** ⇒ Use of bGuard for the baby until 24 months. The home station can be used afterwards to monitor the room air quality.

Step #5 **Recycling|End of Life** ⇒ Easy disassembly of the home station due to its screw threading system so internal components can also be easily taken out for recycling.

Pillow and sock also thought to allow to take out components without difficulty.

5.6 Conclusion

Based on this sustainability analysis, the team chose to develop a multifunctional product. bGuard is a **pillow** with a special shape to reduce the risk of rolling from back to tummy, with a speaker to sooth the baby when crying, a **sock** to measure the baby's pulse and a **home station** to monitor the room air quality. This innovative multifunctional product protects baby's as also parent's health (industry, innovation and infrastructure [143], social sustainability [144], good health and well-being [145]). Additionally, its components are recyclable (environmental sustainability [146], 12 principles of green engineering [147], responsible consumption and production [148], life cycle analysis [149]) and last but not least it is made with low-cost components bought locally (economical sustainability [150], 12 principles of green engineering [151]).

Thus, bGuard will contribute to relieve the **stress of the parents** and improve the **quality of life of the family** with **minimum waste** over its lifecycle, **without jeopardising the needs of future generations**.

In the next chapter, the Ethical and Deontological analysis is scaffolded.

6 Ethical and Deontological Concerns

6.1 Introduction

When launching a product nowadays it is very important to take ethical concerns into account. Ethics helps to think about doing the right thing. Ethical arguments regard the rights, interests, and wishes of all of the people who are involved. The way the team is planning to address these problems as a company will help create an image for our company, so it's important that we pay enough attention to this subject. Ethical issues are often difficult to solve because there is no black or white. The answer is often found in a grey zone, found by arguing and compromising.

It is also important to keep ethics in mind while doing our teamwork. This means that every team member is equal and has the same rights. Therefore it is important to have respect for each other and each other's opinion. The main ethical vision is based on 6 ethical principles, displayed on the diagram in **Figure 31**.



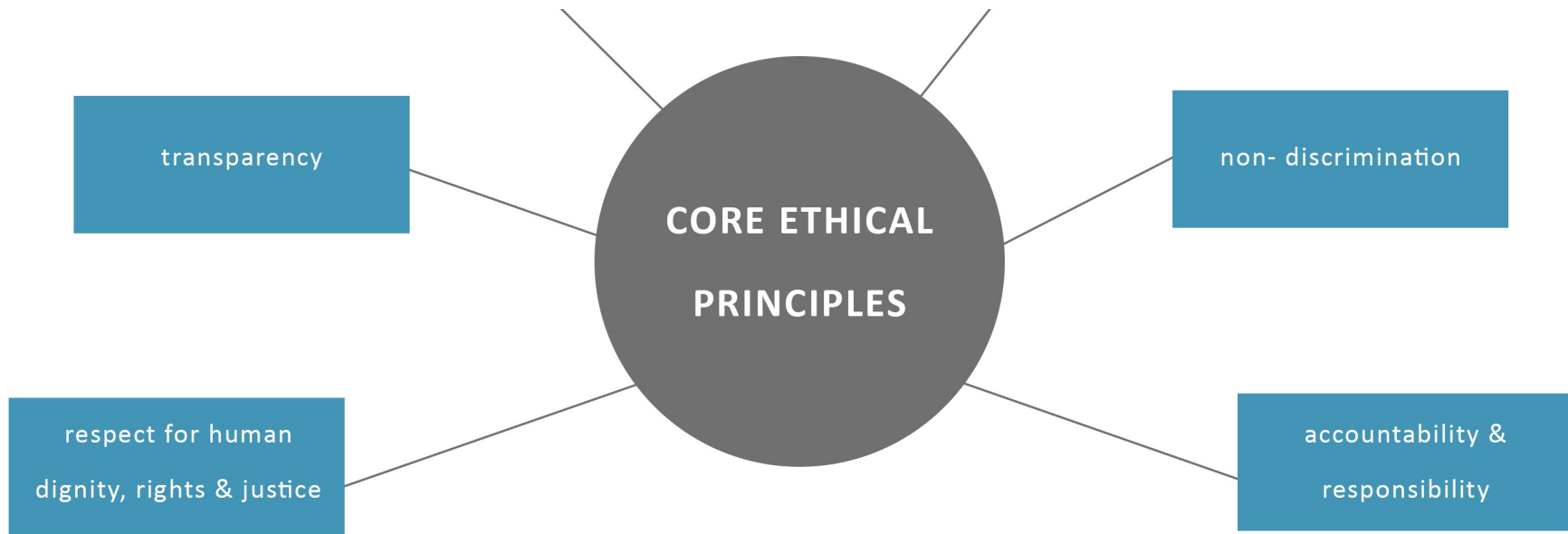


Figure 31: Core Ethical Principles

6.2 Engineering Ethics

Engineers have an important function in this world. They are constantly coming up with new ideas to make the world a better place and improve the overall quality of life. This means that every engineer has an ethical duty that he/she can't ignore when developing a new product. With every choice we make, it is important that we think of the consequences our decisions will have on the society, humans and the environment.

Seeing that our team mainly consists of engineers, engineering ethics is a topic we must prioritize. The National Society of Professional Engineers (NSPE), is an organization that will help us with this. The NSPE has a set of rules which every engineer should apply to his/her moral code. The NSPE Code of Ethics for Engineers is divided into three sections. The first section addresses the Fundamental Canons. This section contains six points an engineer, in the fulfilment of his/her professional duty, should always keep in account. The second part is about the Rules of Practice. It contains rules concerning the safety, health, and welfare of the public and also mentions the fact that an engineer should only serve in the areas of his/her competence. The final section is about the engineer's Professional Obligations **[152]**.

6.3 Sales and Marketing Ethics

Ethical marketing is shown up when the chosen marketing strategy seeks to promote honesty, fairness, and responsibility in all advertising. As said in the introduction ethics is a sensitive subject because there is no real right or wrong. This results in a set of guidelines that can be followed when a company wants to develop a marketing strategy. Sales & Marketing Executives International (SMEI) is a global sales and marketing professional association that brought out a document with eleven guidelines to Ethical Marketing **[153]**. The SleepSense company will keep these guidelines into account while developing and marketing our product.

It is important for a company to take these ethical guidelines into account. This way a company can develop a long and trustworthy relationship with its clients. It is a good thing when a product lives up to the expectations/claims made in the advertisement. When a company does not live up to its claims, it reflects poorly on the entire company.

bGuard wants to make sure that accurate information concerning the product is provided. Furthermore, the company wants to make sure that the customer's wishes and expectations are fulfilled. As a company, SleepSense also wants to have a fair price for our product. This means that the price should cover all the costs we made and also provide a profit for the company. But it also means that the customers can see where the price is coming from and that they agree that they get value for their money. Although the aim is to keep the price as low as possible, bGuard still has to keep in account that the employees are working in good conditions and leaving an as small as possible ecological footprint. These things will increase the selling price but create added value to the product.

6.4 Environmental Ethics

It is undeniable that technology, industry, economic expansion and population growth during the past few years has had a huge impact on the environment. All of these factors have contributed to pollution and depletion of natural resources. Also, climate change intinction of lots of animal and plant sorts is happening because of the increasing amount of people. Environmental ethics is all about including the rights of fauna and flora in our ethical and moral values. Even if the human race is considered the primary concern of society, animals and plants are in no way less important.

The company is obligated to keep our environmental footprint as small as possible. It is very important to keep the economic and ecological benefits in balance. Even more than individual people, companies have a big impact and an important role in keeping the planet a clean place. Thanks to environmental ethics the company can ensure that the environment is kept safe and protected.

On the other hand, creating a brand that has a sustainable character and is environmentally friendly can come in handy during marketing. Nowadays sustainability is a hot topic, so promoting the company as a sustainable one can definitely be seen as a strength.

During the design process, the environment is kept in mind. Moreover, the product is designed according to the design for disassembly principles. This means that when the product is at the end of its life the product can easily be disassembled and the parts can be recycled. Even when building the prototype the team wants to work with materials and sensor provided by local companies **[154]**, **[155]**.

6.5 Liability

It is necessary to deliver a safe and user-friendly product to the customers. To assure this the team conduct a liability analysis. This analysis consists of two areas: civil and professional liability. The first regards that a company being held liable for delivering a defective product to the consumer. The SleepSense company must take full responsibility for a product defect that causes injury. It is very important that the product meets the expectations of the consumer. When an unexpected danger occurs it means that the product does not live up to the ordinary expectations of the consumer.

First of all, the team want to try and prevent any unpleasant/dangerous situations. Furthermore, bGuard is provided with a manual which carefully explains step by step how the product works. In this way, possible confusion in using the product is avoided.

The professional is is the second part of the liability analysis. In this area, it is important that the team follows the European Union's directives according to the machines, machinery and electronics. The requirements are the following:

- Machine Directive (2006/42/EC 2006-05-17) **[156]**;
- Low Voltage Directive (2014/35/EU 2016-04-20) **[157]**;
- Radio Equipment Directive (2014/53/EU 2014-04-16) **[158]**;
- Electromagnetic Compatibility Directive (2004/108/EC 2004-12-15) **[159]**;

- Restriction of Hazardous Substances (ROHS) in Electrical and Electronic Equipment Directive (2002/95/EC 2003-01-27) [160].

The first directive does not apply to our product because it regards machines. This means the product should have joined components with a least one component that is able to move. Likewise, the second directive is not applicable to our product because our voltage is lower than 50 V.

bGuard does not emit or receive any kind of radio waves so this means that the third directive does also not apply to the product.

The last two directives are applicable to the product and it is important that the team keeps these in mind during the design process. The directives should not be working restrictive, on the contrary, they should help and guide the team with developing our product. The electromagnetic compatibility directive makes sure that electrical equipment does not generate electromagnetic disturbance. Thus, the product complies to this directive. The last directive regards a restriction of the use of certain hazardous substances in electrical and electronic equipment. These are substances like Lead (Pb) or Cadmium (Cd).

6.6 Conclusion

In summary, this chapter discovered that ethical issues are inevitable when developing a product. Ethics help to think about the role in the world as a company to make the world a better place. They help to deliver a safe and environmentally friendly product that is good for the users and the world.

Concrete this means that the team wants to keep the product limited to the European market to keep the footprint small, work with local providers and design according to the Design for Disassembly (DfD) [161] principles.

Furthermore, bGuard wants to deliver a safe and user-friendly product. The aim is to ensure that users are not exposed to danger, such as causing injuries and minimise liabilities. To help the user, bGuard is to be shipped with a manual detailing operation and maintenance instructions.

Last but not least, the team envisages launching marketing campaigns to build a realistic image and promote this solution.

Above all, bGuard wants to live up to **customer expectations**.

The next chapter concerns the development of our project.

7 Project Development

7.1 Introduction

This chapter includes the Black Box Diagram and the Structural Drafts. We also took a look at the product architecture, as well as the list of Components, Materials and the Functionalities of bGuard. Tests and Results as also Conclusion will come in a later stage.

7.2 Black Box Diagram and Structural Drafts

Black Box Diagram is shown in **Figure 32**.

BLACK BOX

INPUT

OUTPUT

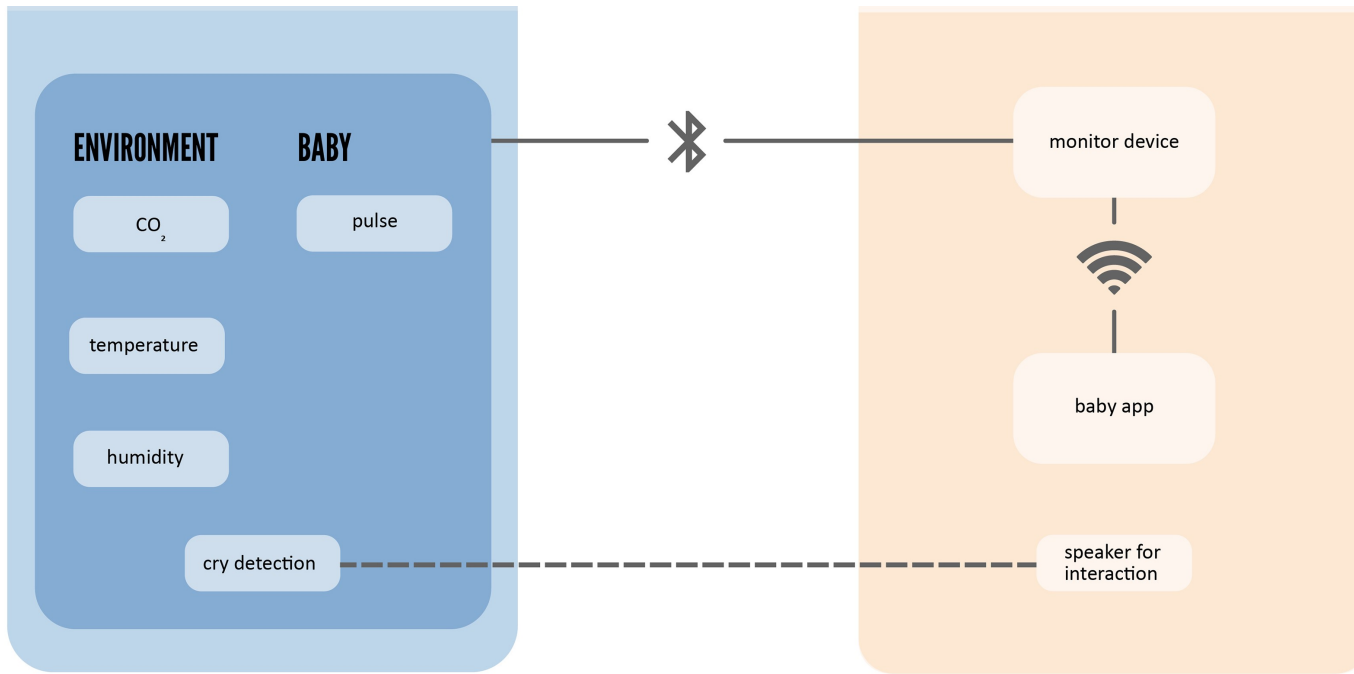


Figure 32: Black Box Diagram

bGuard Structural Draft is shown in **Figure 33**.

BABY MONITOR

INITIAL IDEA

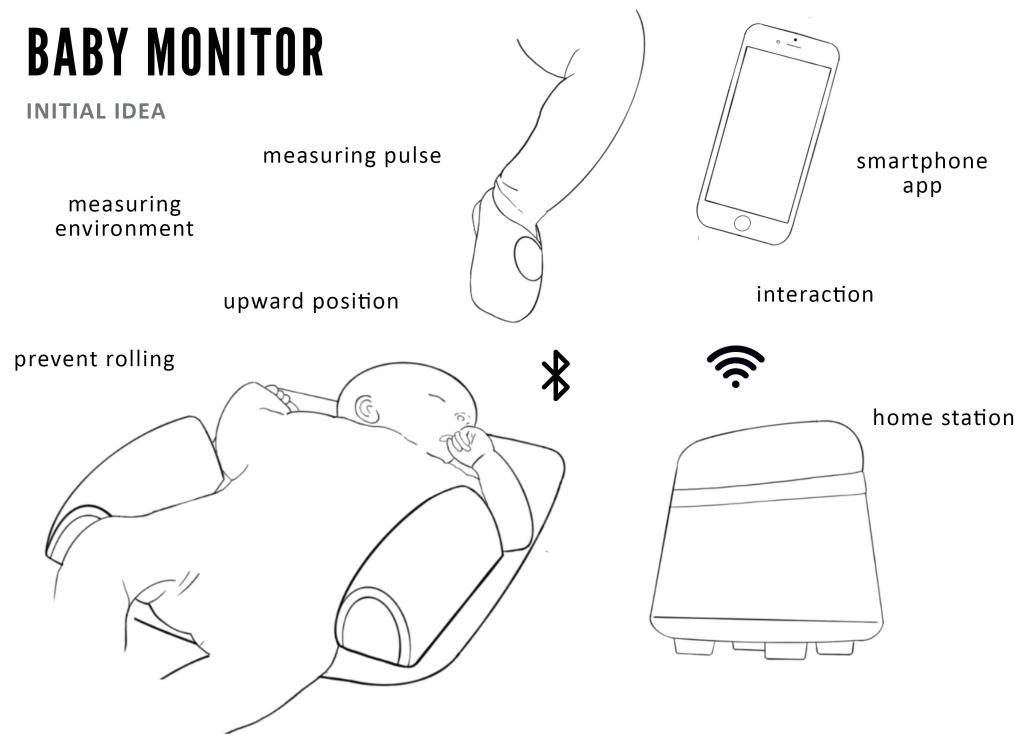


Figure 33: bGuard Structural Draft

Pillow 2D Structural Draft is shown in **Figure 34**.



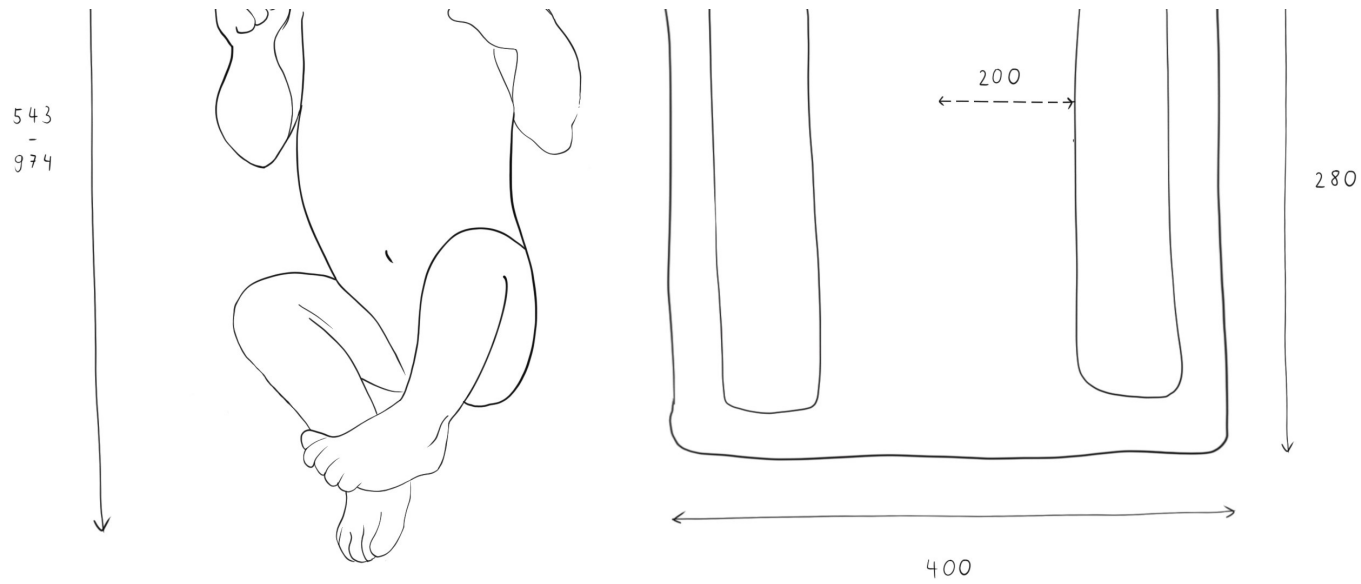
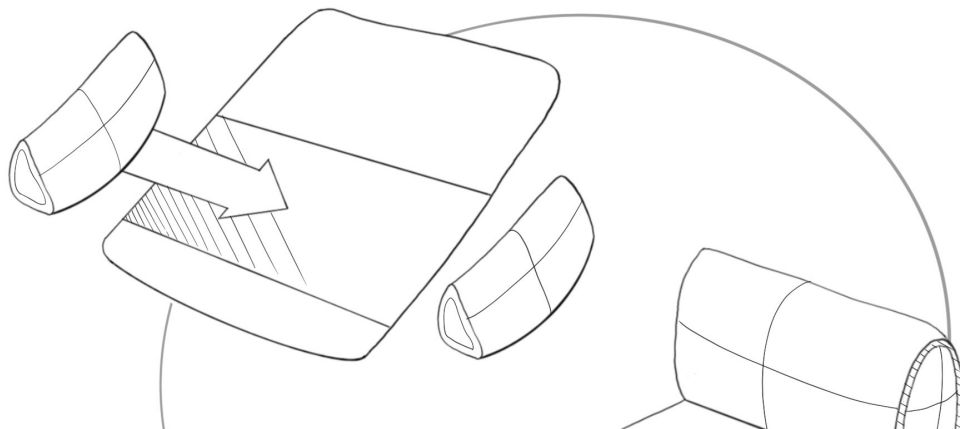


Figure 34: Pillow 2D Structural Draft

Pillow 3D Structural Draft is shown in **Figure 35**.



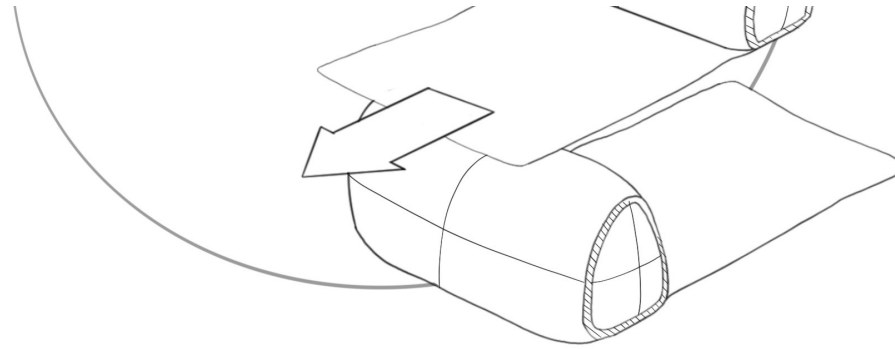


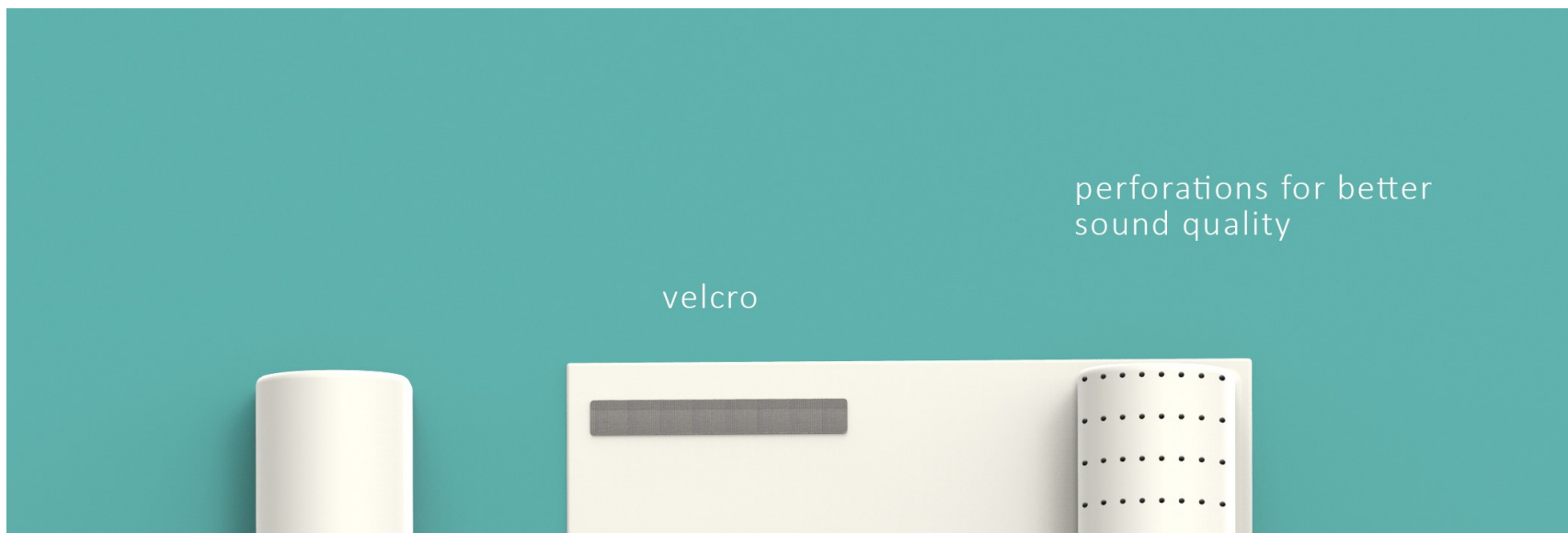
Figure 35: Pillow 3D Structural Draft

According to DINED (anthropometric database [162]), the average length of a newborn baby is 543 mm. When the baby reaches the age of 3, he/she has grown up to a size of 974 mm. This is important data that the team need to keep in mind when designing the pillow.

The team wants a pillow to be used as long as possible. In order to do this, the pillow has to grow with the baby. Therefore the width of the pillow is adjustable according to the width of the baby. The width of the baby expands up to around 200 mm. This means the design has to make sure that the width of the pillow can be adjusted up to around this distance. On the ground layer of the pillow, two strips of velcro have placed that stick to the velcro on the bottom of the adjustable side bumper. A big benefit of making it adjustable is that it makes the product more sustainable because there is no need to buy a new pillow when the baby starts growing.

The pillow consists of a thin ground layer with two side bumpers. One of the bumpers is stationary the other one is adjustable. The stationary side bumper is the one with the cry detection sensors and speaker inside. To make sure that the sound quality is good we made perforations in this bumper to make the sound come out better. On the bottom of this bumper, there is a small groove where the sensors and speaker are placed in. This way they can easily be replaced or fixed when broken.

The pillow with velcro, side bumpers and speakers is shown in **Figure 36**.



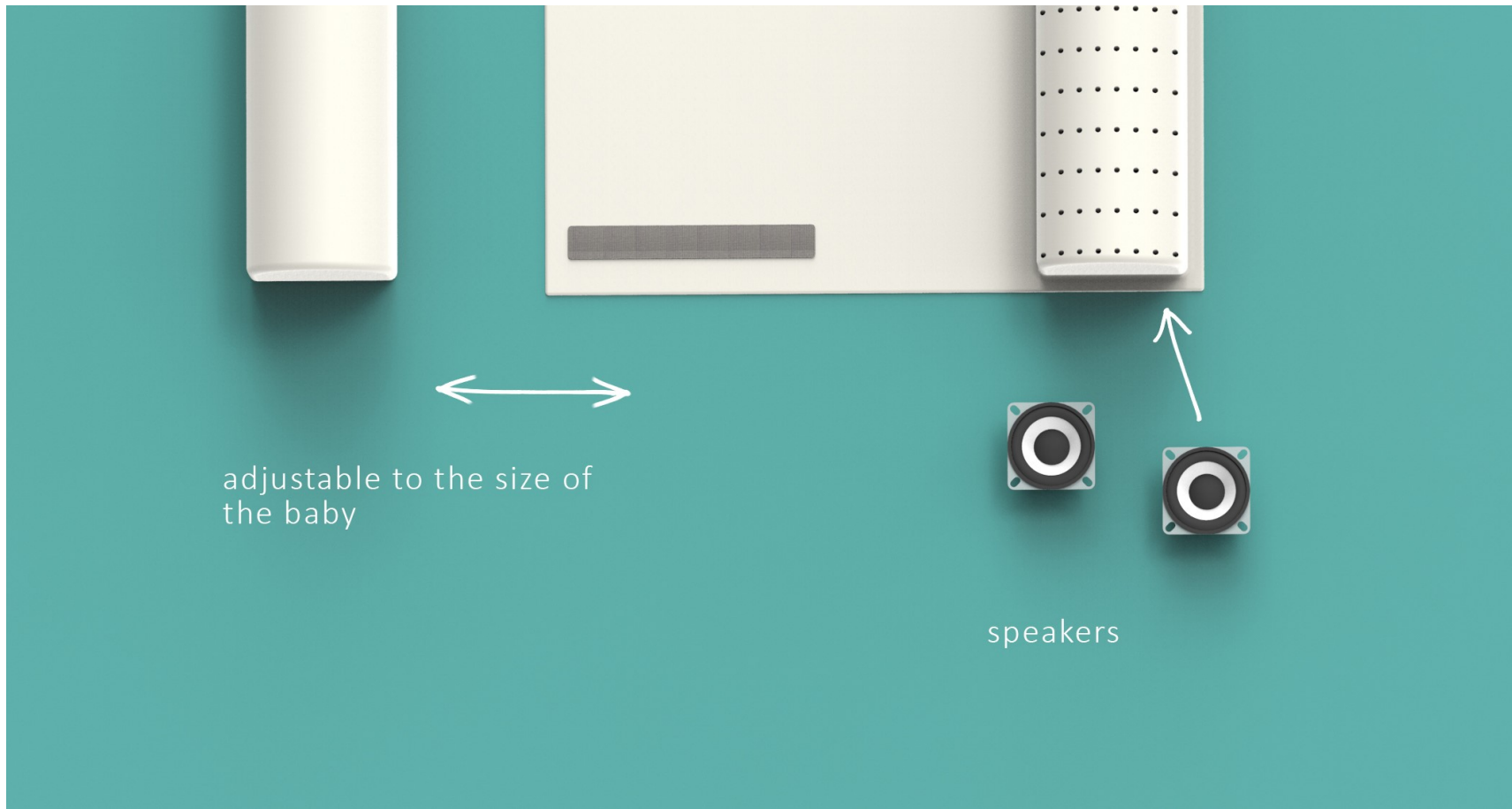
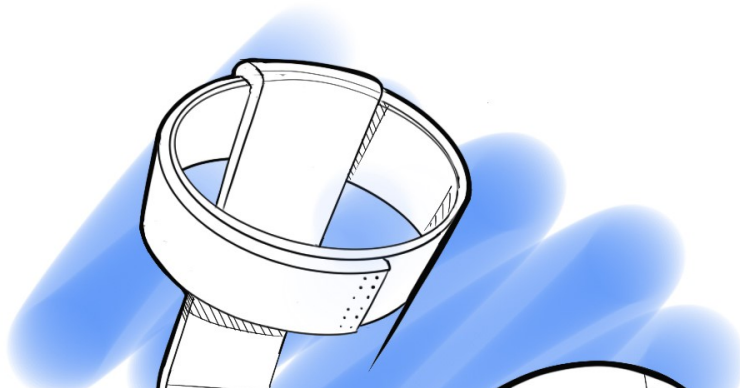


Figure 36: Pillow with velcro, side bumpers and speakers

Sock 3D Structural Draft is shown is shown in **Figure 37**.



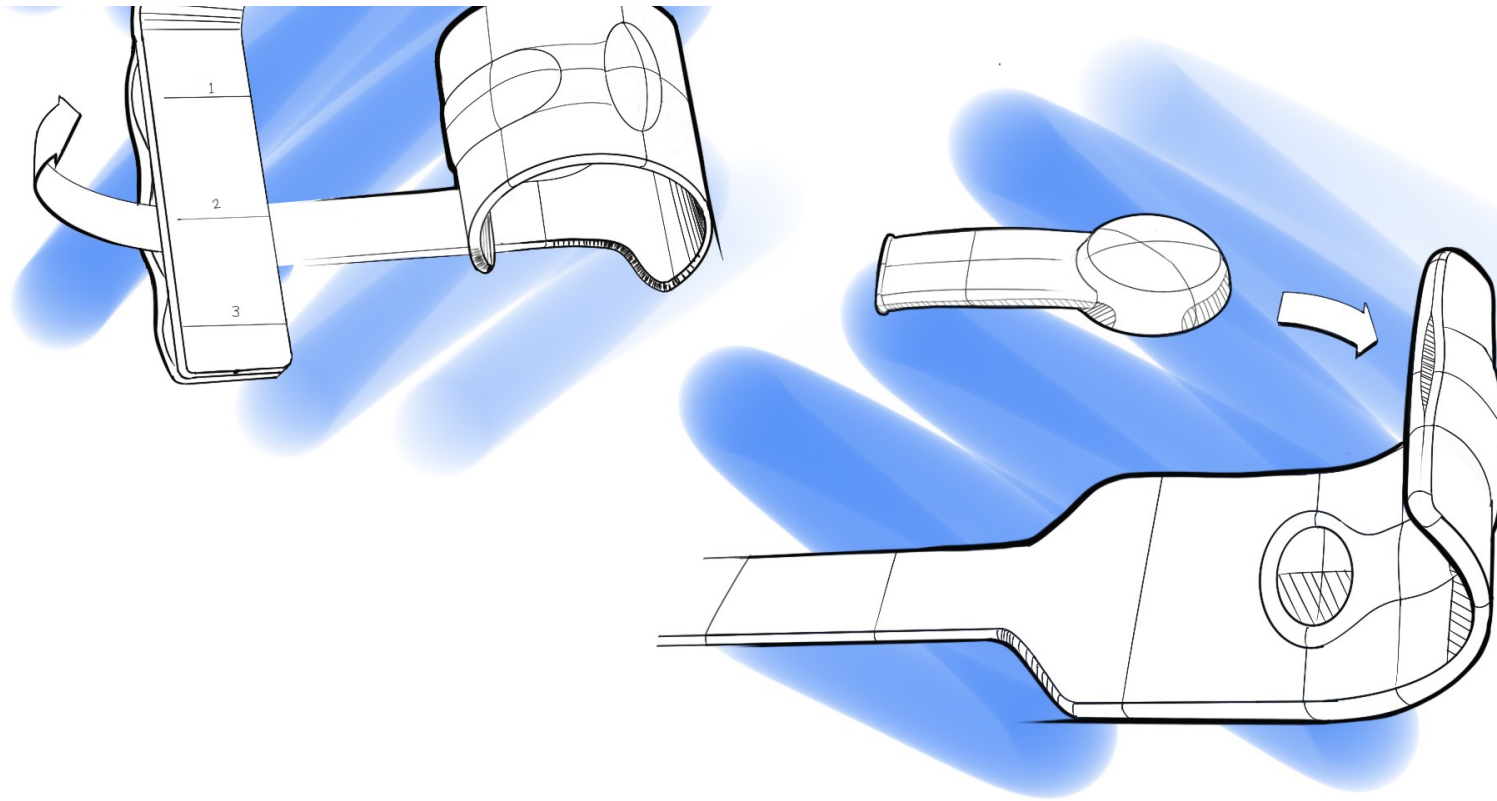
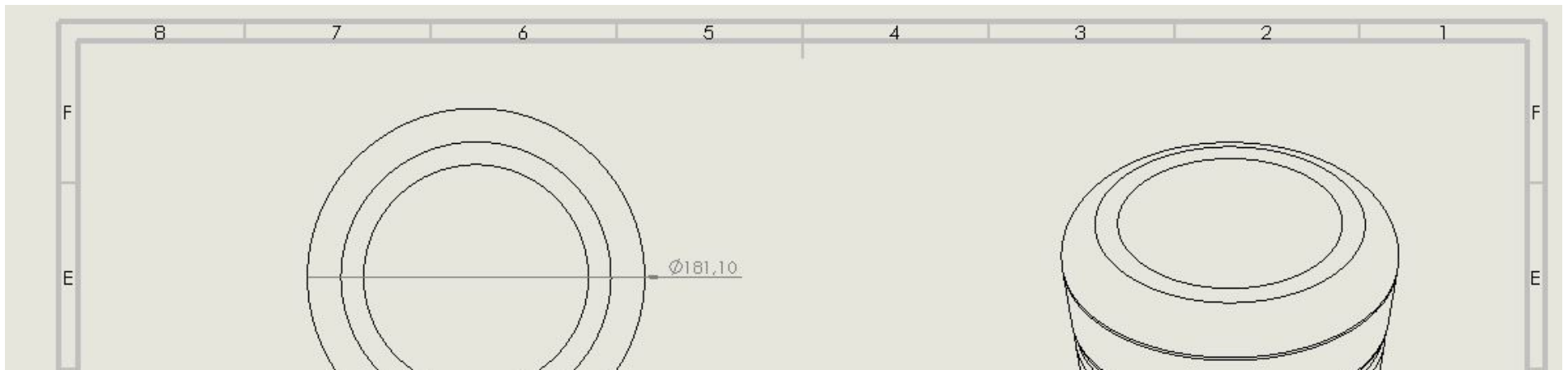


Figure 37: Sock Sketch

Home Station 2D Structural Draft is shown in **Figure 38**.



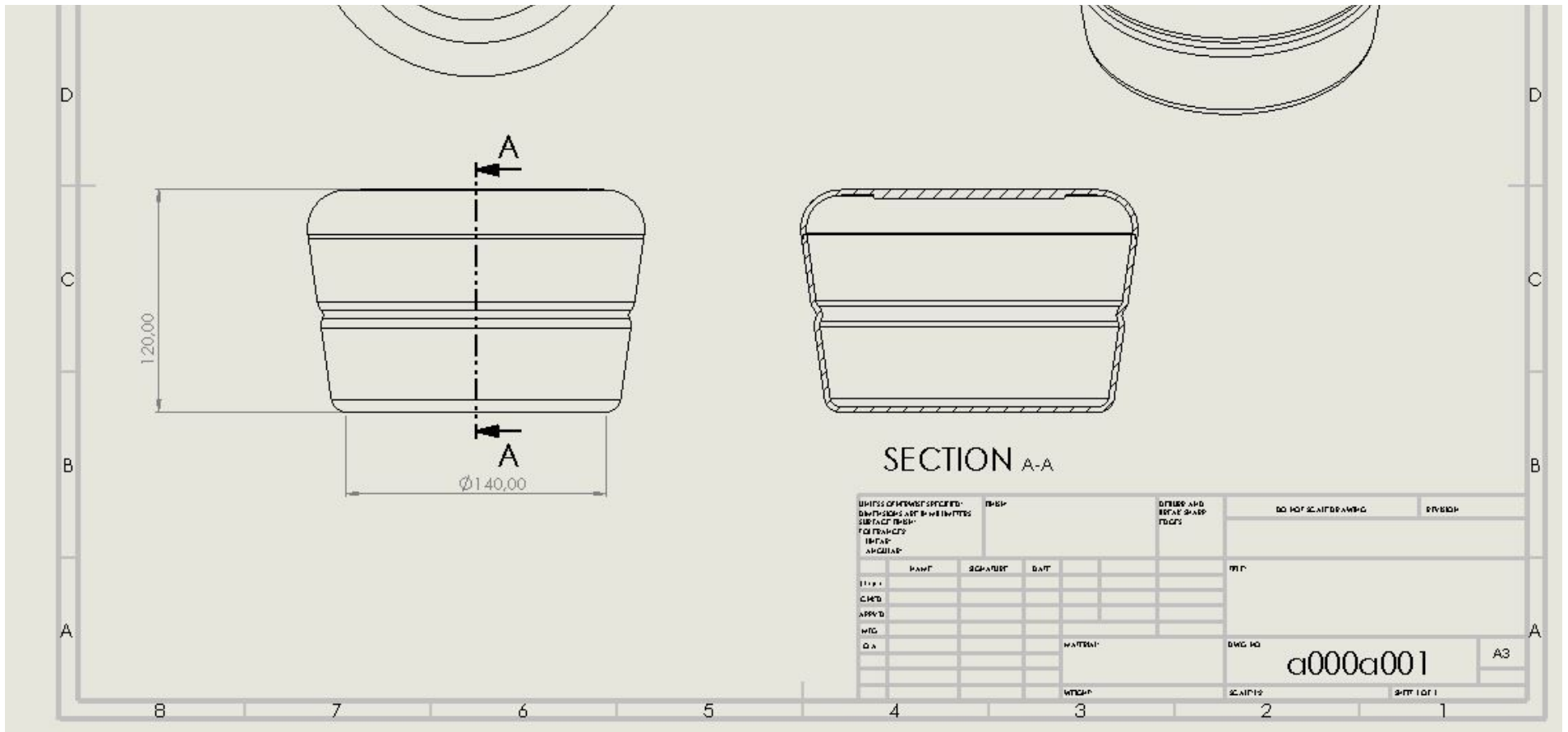
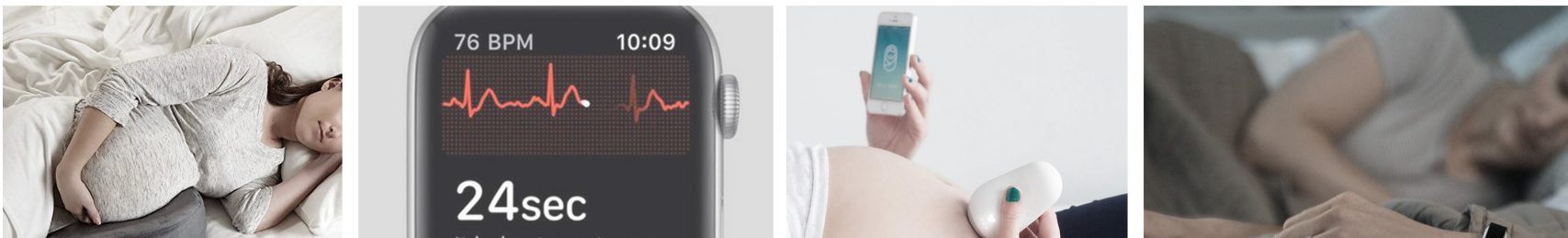


Figure 38: Home Station 2D Structural Draft

7.3 Architecture

7.3.1 Look and Feel

A mood board of similar products is created to give an idea of how the final product to look like. This mood board Look & Feel is shown in **Figure 39**.



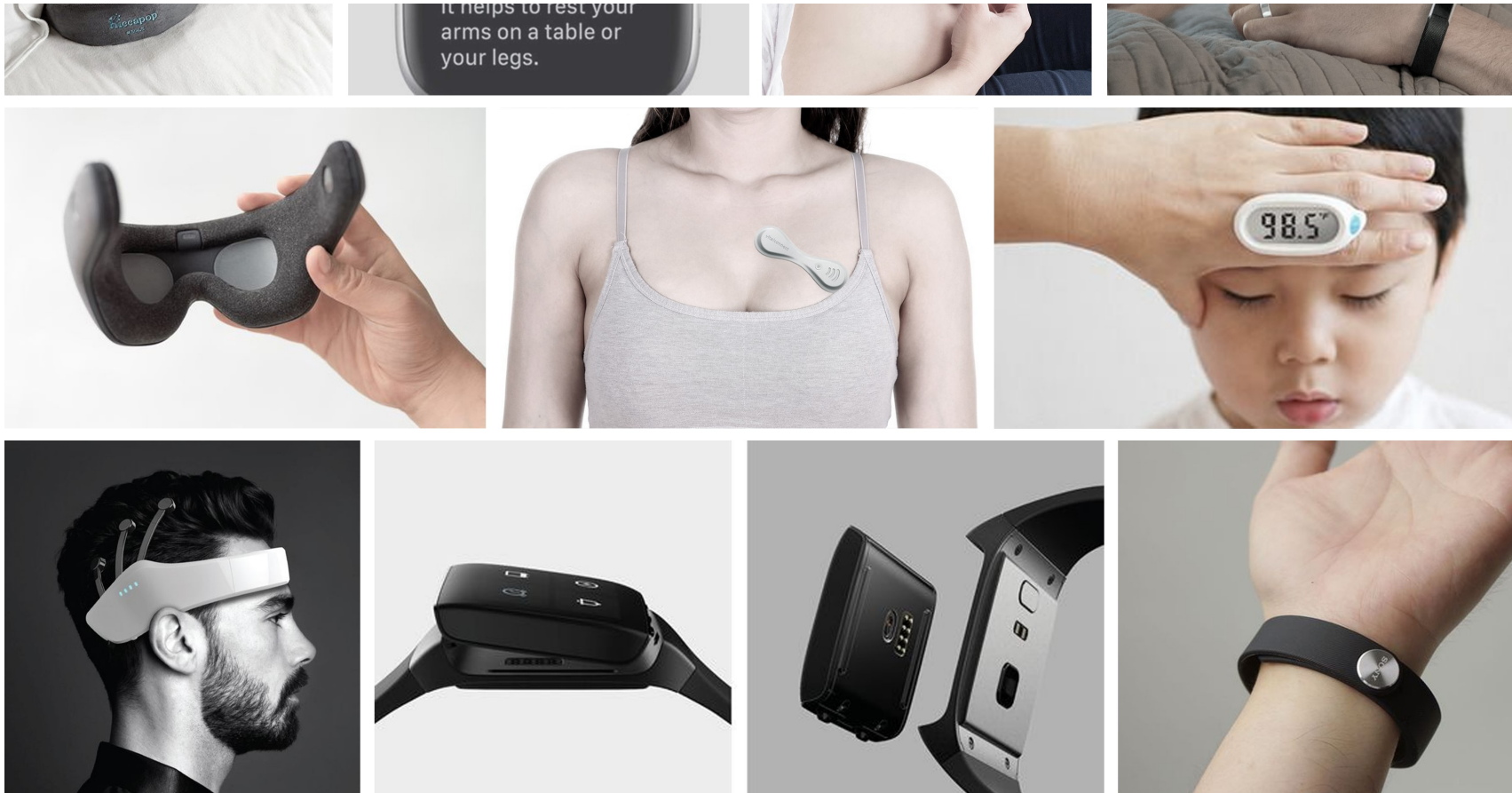


Figure 39: Moodboard Look & Feel (adapted from several sources)

7.3.2 Cardboard Model

A cardboard model of the home station and the pillow is created. Thus, the team gets an idea about the size of the pillow and the home station. **Figure 12** and **Figure 41** shows the cardboard models of the product in the parents' bedroom.

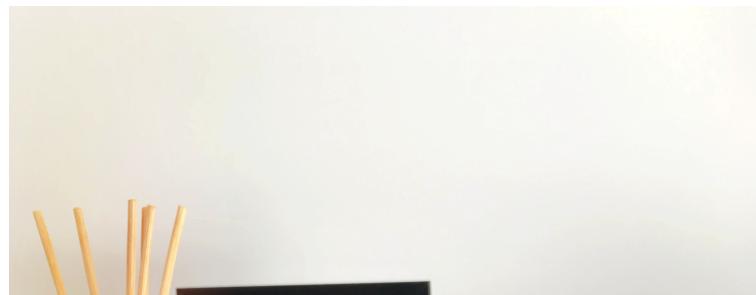




Figure 40: Cardboard Model - Home Station








Figure 41: Cardboard Model - Pillow

7.4 Components

7.4.1 Microcontrollers

Table 32 lists the microcontrollers. These are divided into Arduino-boards and ESP-boards.

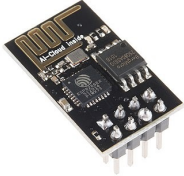

Table 32: List of possible microcontrollers

Microcontroller	Price [€]	Size [mm ²]	Input Voltage [V]	CPU/Speed [MHz]	Analog In/Out	Digital In/Out	SRAM [kB]	Flash [kB]	USB	Wi-Fi	BT
Arduino Uno [163] 	22.90	52.3 × 68.8	7 to 12	16	6	14	2	32	USB Cable A to B	No	No
Arduino Nano V3.0 [164] 	12.90	18 × 43	7 to 12	16	8	14	2	32	Mini	No	No
Arduino Micro [165] 	23.00	17 × 48	7 to 12	16	6	16	2.5	32	Micro	No	No

Microcontroller	Price [€]	Size [mm ²]	Input Voltage [V]	CPU/Speed [MHz]	Analog In/Out	Digital In/Out	SRAM [kB]	Flash [kB]	USB	Wi-Fi	BT
Arduino Pro Mini [166] 	13.78	18 × 33	5 to 12	16	6	16	2	32	FTDI cable needed	No	No
Arduino Lilypad [167] 	18.94	∅ 50 mm	2.7 to 5.5	8	6	8	1	16	FTDI cable needed	No	No
Bluno beetle [168] 	13.01	28.8 × 33.1	5	16	4	4	2	32	Micro	No	Yes
Espressif ESP32 DevKitC [169] 	8.73	27.4 × 54.4	3.3 to 5	160	/	10	520	16 Mbit	Micro	Yes	Yes
Node MCU ESP8266 [170] 	9.90	24.5 × 49	3.3 to 5	80	/	17	/	/	Micro	Yes	No

It could be possible that the team decides for a microcontroller with no included Wi-Fi or Bluetooth. Therefore, there is a list of the possible modules in **Table 33** to compare the amount of the prices.

Table 33: List of possible Bluetooth and Wi-Fi modules

Module	Price [€]	Input Voltage [V]	Current [mA]
Wifi ESP8266 [171] 	4.25	3.3 to 3.6	40
HC-05 Bluetooth module [172] 	6.80	3.6 to 6	170


As a result of the research, the team comes to the conclusion that the “Espressif ESP32 DevKitC” is the best choice for the pillow and the Home Station. The microcontroller has a small size and is faster than the other microcontrollers. So it is not needed to buy one of the modules in **Table 33**. The most reason for the ESP32 is the low cost and the capability to Arduino sensors.

For the sock, the team decides, that the “Bluno beetle” is the best choice. With its small size, the micro-controller is perfect for textiles. In comparison with the “Arduino Lilypad” the microcontroller has an included Bluetooth module. This benefit saves more space in the sock and money for the Bluetooth module.

7.4.2 Baby Condition Sensors

The product monitors the condition of the baby by measuring the pulse. For that objective, there is a building kit and a solo pulse sensor for Arduino. They are shown in **Table 34**

Table 34: List of pulse sensors

Module	Price [€]	Size [mm]	Input Voltage [V]	Current [mA]
Heart rate sensor kit [173] 	22.09	16	3 to 5.5	3 to 4




Module	Price [€]	Size [mm]	Input Voltage [V]	Current [mA]
 Heart rate sensor module [174] 	7.95	16	3 to 5.5	3 to 4


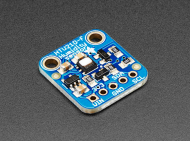
The “Heart rate sensor kit” is sponsored by DFI from ISEP. Thus, the team can use it for the prototype. For the vision of the final product the team decides for the “Heart rate sensor module”. It is available in Portugal and it is cheaper.

7.4.3 Environmental Sensors

According to the Black Box Diagram in **Figure 32** the team is planning to put environmental sensors into the Home Station, which is also in the bedroom. Consequently, the team divides the results of the research in Humidity and Temperature Sensors (**Table 35**) and Gas Sensors (**Table 36**).

Table 35: Comparison of Humidity and Temperature Sensors




Module	Price [€]	Size [mm ²]	Input Voltage [V]	Current [mA]	Temperature range [°C]	Temperature accuracy [°C]	Humidity [%]	Humidity accuracy [%]
 DHT22 [175]	11.60	30.1 x 10.5	3.3 to 6	1 to 1.5	-40 to 80	± 0.5	0 to 100	± 2
 DHT11 [176]	5.95	23.5 x 12	3.3 to 5	3 to 4	0 to 50	± 2.0	20 to 90	± 4
 DHT22 Onboard [177]	12.50	39.92 x 15.40	3.3 to 5	2.5	-40 to 80	± 0.5	0 to 100	± 2

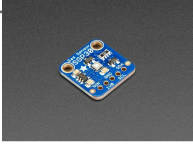



Module	Price [€]	Size [mm ²]	Input Voltage [V]	Current [mA]	Temperature range [°C]	Temperature accuracy [°C]	Humidity [%]	Humidity accuracy [%]
								
HTU21D-F Temperature & Humidity Sensor [178] 	13.93	18 x 16	3 to 5	± 0.5	-30 to 90	± 1	5 to 95	± 2

In comparison with the DHT11 and the DHT22, the HTU21D-F is more accurate. For the vision of the end product, the “HTU21D-F” is the best choice because it saves the highest quality for the customer.

For the prototype, the team uses the DHT22. The sponsor DFI from ISEP can provide the module for the development of the prototype. Thus the team can save money from the budget. Furthermore, the use of DHT22 ensures the proof of the concept as well.

Table 36: Comparison of Gas Sensors

Module	Price [€]	Size [mm ²]	Types of gases	Input Voltage [V]	Current [mA]	Accuracy [ppm]
MQ9 [179] 	2.96	32 x 20	Methane, propane and carbon monoxide	5	150	100 to 10 000
MQ7[180] 	2.31	35 x 22	Carbon monoxide	5	180	10 to 1 000
SGP30[181] 	22.95	17.9 x 17.9	eCO ₂ , VOC	3.3 to 5	50	0 to 60 000

Module	Price [€]	Size [mm ²]	Types of gases	Input Voltage [V]	Current [mA]	Accuracy [ppm]
						
MG-811[182] 	69.90	32 x 42	CO ₂	6	200	350 to 10 000
ADA3566 - CCS811[183] 	33.83	21 x 18	eCO ₂	3.3 to 5	30	400 to 8 192
Sparkfun CCS811[184] 	31.00	/	eCO ₂	1.8 to 3.3	30	400 to 8 192

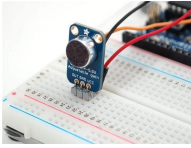

The Accuracy of the methane and carbon monoxide modules is not starting with 0 ppm. Because of that, they are only for the outside area and not for the bedroom [185]. Because of that, the team decides to renounce these sensor types.

For the CO₂ sensors the team decides for the “SGP30” module. It has the highest accuracy than the other sensors and it is the cheapest module.

7.4.4 Cry Detection and Speaker Reaction

One of the features of the end product will be the reaction to the crying of the baby. For that benefit, the team needs a sensor to measure the noise of the baby in dB. According to a study of the Eastern Kentucky University, the sound level of a crying infant can be between 80 and 120 dB of noise level [186]. Thus the sensor of the smart pillow has to measure in that range as well. **Table 37** shows the summary of possible microphone sensors.


Table 37: Comparison of microphone sensors

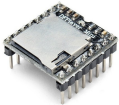
Module	Price [€]	Size [mm ²]	Maximum ratio [dB]	Input Voltage [V]	Current [mA]
MAX4466 module [187] 	6.07	9.7×4.5	125	2.4 to 5	/
BOB-12758 module [188] 	6.80	9.7×4.5	110	3.3 to 5	0.5

The “MAX4466 module” has a maximum ratio of 125 dB. So it follows the requirement of the measuring range. Furthermore, it is cheaper than the “BOB-12758 module”. In conclusion, the team decides for the “MAX4466 module”.

Moreover, the end product needs speakers and if possible an MP3 player, which plays the sounds and music of the parents. For this reason **Table 38** shows an overview over these features. There is only one MP3 player for Arduino and esp micro-controllers on the market. For this MP3 player, there is the requirement that the speaker has to have a maximum power of 3 W [189]. On this aspect, the research pays attention to.

Table 38: Overview over possible speakers and a possible MP3 player

Module	Price [€]	Size [mm ²]	Input Voltage [V]	Current [mA]
Mini Speaker [190] 	1.00	40 (diameter)	2.4 to 5	/
3W Stereo Speaker [191] 	4.95	70×30	3.3 to 5	0.5

Module	Price [€]	Size [mm ²]	Input Voltage [V]	Current [mA]
 MP3 Mini Player DFPlayer [192]	5.45	21 x 21	3.2 to 5	20 to 150

The “DFPlayer” module is the only MP3 player for the Arduino on the market. Therefore, the team makes the decision for this module. On one side the “3W Stereo Speaker” is more powerful than the “Mini Speaker”. On the other side, it is more expensive. Consequently, the team takes the “Mini Speaker” for the prototype test. For the end product, the team would choose the “3W Stereo Speaker”, because it has a better sound quality.

7.4.5 Power Supply Calculation

As already mentioned in Microcontrollers and Environmental Sensors there are two differences between the vision of the end product and the prototype because of the budget of the project and the limited time of the semester. In the prototype, the microcontroller “Bluno beetle” for the sock is not included. The pulse sensor will be connected with the microcontroller of the pillow through wires. Moreover, the DHT22 is used for the temperature and humidity measurement for the prototype instead of the HTU21D-F.

Table 39 to **table 43** are for the choice of the power supply. They are divided into prototype and vision of the final product.

7.4.5.1 Choice of the Power Supply - Prototype

Table 39: Calculation of the Battery Supply - Prototype (Pillow and Sock)

Module	Voltage [V]	Current [mA]	Power [mW]
Heart rate sensor module	3.3	4	13.2
MAX4466 module	3.3	1	3.3
Mini Speaker	3.3	1	3.3
MP3 Mini Player DFPlayer	3.3	150	495.0
Total			514.8

Table 40: Calculation of the Power Supply - Prototype (Home Station)

Module	Voltage [V]	Current [mA]	Power [mW]
DHT22	3.3	1.5	4.95

Module	Voltage [V]	Current [mA]	Power [mW]
SGP30	3.3	50	165.00
Total			169.95

Every module needs a voltage of 3.3 V. The board can handle up to 5 V. Furthermore the total value of the current is under 1 A. In conclusion, a maximum 5 V power supply with 1 A or 2 A will give enough power for each part of the prototype.

7.4.5.2 Choice of the Power Supply - Vision of the Product

Table 41: Calculation of the Battery Supply - Vision of the Product (Pillow)

Module	Voltage [V]	Current [mA]	Power [mW]
MAX4466 module	3.3	1	3.3
Mini Speaker	3.3	1	3.3
MP3 Mini Player DFPlayer	3.3	150	495.0
Total			514.8

Table 42: Calculation of the Battery Supply - Vision of the Product (Sock)

Module	Voltage [V]	Current [mA]	Power [mW]
Heart rate sensor module	3.3	4	13.2
Total			13.2

Table 43: Calculation of the Power Supply - Vision of the Product (Home Station)

Module	Voltage [V]	Current [mA]	Power [mW]
HTU21D-F Temperature & Humidity Sensor	3.3	0.5	1.65
SGP30	3.3	50	165.00
Total			166.65

The calculation of the power supply for the final product is similar to the calculation of the prototype. Therefore a maximum 5 V power supply with 1 A or 2 A will give enough power for each part of the end product.

7.4.6 List of Hardware Components

The list of hardware components is divided into the prototype and the final vision of the product. As already mentioned in Cost the team has several sponsors. In that way, the purchase of some components for the prototype is not needed. **Table 44** shows the list of Components for the Prototype. The components that are provided by the sponsors are not considered in the total costs for the prototype. Moreover, **Table 45** shows the list of components for the vision of the final product. It sums up all the prices and local providers to give an overview of the possible maximum costs. The transportation costs are not mentioned in the tables because otherwise, a comparison of the total costs is not possible.

Table 44: List of Hardware Components - Prototype

Nr	Name	Parts	Provider	Quantity	Price per part [€]	Partital Costs [€]	Partial Costs Prototype [€]
DEE, ISEP (100.00 € Budget)							
1	Espressif ESP32 DevKitC [193]	Home Station, Pillow	pt.mouser	2	8.73	17.76	17.76
2	Micro SD card 8GB [194]	Pillow	pt.mouser	1	6.50	6.50	6.50
DFI, ISEP							
3	Heart rate sensor module [195]	Sock	ISEP	1	22.09	22.09	0.00
4	DHT22 Temperature & Humidity Sensor [196]	Home Station	botnroll	1	11.60	11.60	0.00
5	BreadBoard [197]	Home Station, Pillow	ISEP	2	6.00	12.00	0.00
6	Jumper Wires - Female/Female [198]	Home Station, Pillow	ISEP	20	0.07	1.40	0.00
7	Jumper Wires - Male/Female [199]	Home Station, Pillow	ISEP	20	0.11	2.20	0.00
8	PCB - board [200]	Home Station, Pillow	ISEP	2	1.35	2.70	0.00
9	1kΩ Resistor [201]	Home Station	ISEP	1	0.11	0.11	0.00
Sponsor SOLIUS							
10	SGP30 -eCO2 and VOC [202]	Home Station	botnroll	1	22.95	22.95	0.00
11	MAX4466 - Microphone sensor [203]	Pillow	pt.mouser	1	6.07	6.07	0.00

Nr	Name	Parts	Provider	Quantity	Price per part [€]	Partial Costs [€]	Partial Costs Prototype [€]
DEE, ISEP (100.00 € Budget)							
12	DFPlayer - MP3 mini player [204]	Pillow	electrofun	1	5.45	5.45	0.00
13	Mini Speaker [205]	Pillow	botnroll	1	1.00	1.00	0.00
14	5V Battery [206]	Pillow	Electrofun	1	5.50	5.50	0.00
15	5V, 2A Power Supply [207]	Home Station	Electrofun	1	6.80	6.80	0.00
Total costs						144.83	24.26

Table 45: List of Hardware Components - Vision of the Product

Nr	Item	Parts	Provider	Quantity	Unit price [€]	Item Costs [€]
1	Espressif ESP32 DevKitC [208]	Home Station, Pillow	pt.mouser	2	8.73	17.76
2	Bluno beetle [209]	Sock	botnroll	1	13.01	13.01
3	Micro SD card 8GB [210]	Pillow	pt.mouser	1	6.50	6.50
4	Heart rate sensor module [211]	Sock	pt.mouser	1	7.95	7.95
5	HTU21D-F Temperature & Humidity Sensor [212]	Home Station	pt.mouser	1	13.93	13.93
6	BreadBoard [213]	Home Station, Pillow	electrofun	2	6.00	12.00
7	Jumper Wires - Female/Female [214]	Home Station, Pillow, Sock	pt.mouser	20	0.07	1.40
8	Jumper Wires - Male/Female [215]	Home Station, Pillow, Sock	pt.mouser	20	0.11	2.20
9	PCB - board [216]	Home Station, Pillow	electrofun	2	1.35	2.70
10	1kΩ Resistor [217]	Home Station	pt.mouser	1	0.11	0.11
11	SGP30 -eCO2 and VOC [218]	Home Station	botnroll	1	22.95	22.95
12	MAX4466 - Microphone sensor [219]	Pillow	pt.mouser	1	6.07	6.07
13	DFPlayer - MP3 mini player [220]	Pillow	electrofun	1	5.45	5.45

Nr	Item	Parts	Provider	Quantity	Unit price [€]	Item Costs [€]
14	Mini Speaker [221]	Pillow	botnroll	1	1.00	1.00
15	3.7 V Battery [222]	Pillow, Sock	electrofun	2	4.15	8.30
16	5V, 2A Power Supply [223]	Home Station	electrofun	1	6.80	6.80
					Total costs	128.13

7.4.7 Schematic Drawings

After choosing the components schematic drawings of the prototype are made. **Figure 42** shows the Schematic drawings for the components inserted in the Home Station.

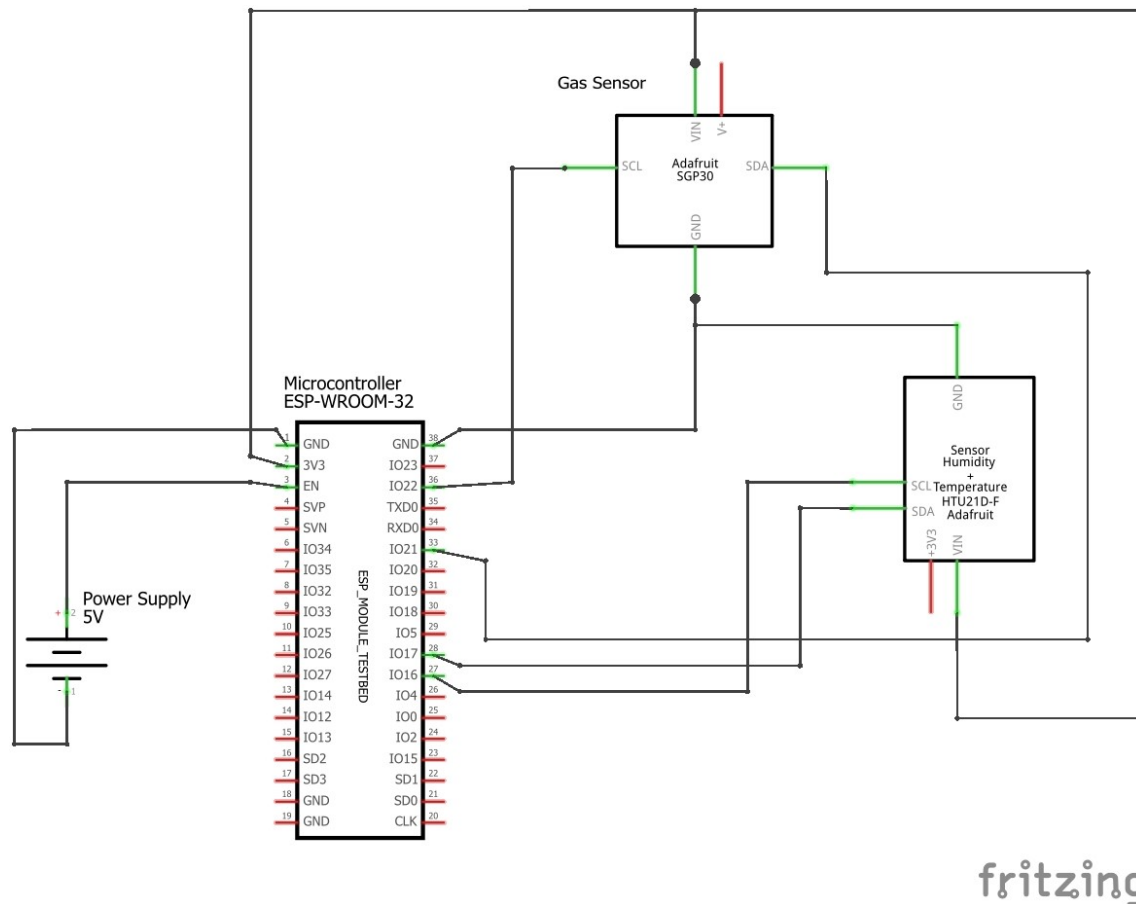


Figure 42: Home Station Schematic Drawing

Figure 43 shows the schematic drawing of the components that are inserted in the pillow & sock.

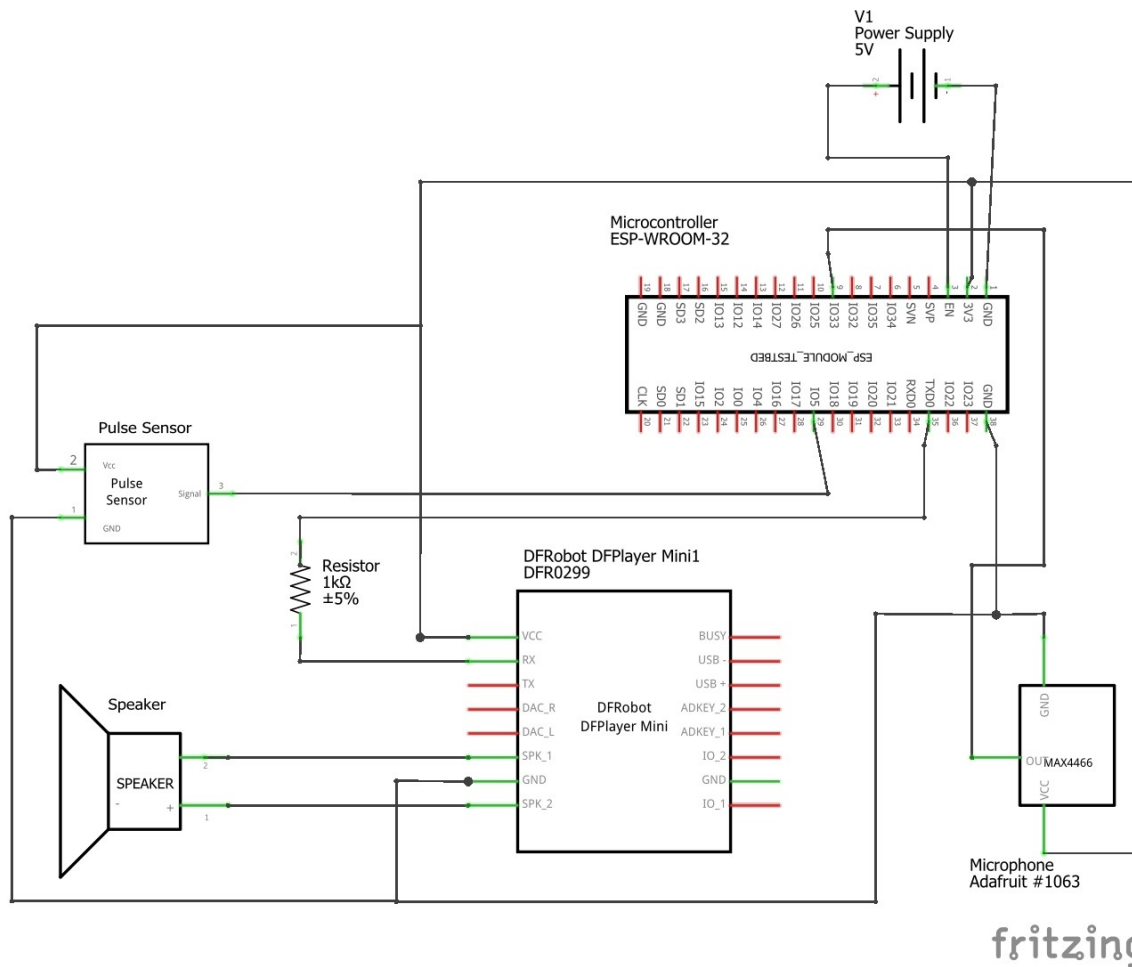


Figure 43: Pillow & Sock Schematic Drawing

7.5 Materials

7.5.1 Pillow

7.5.1.1 Foam

Pillows nowadays are often made of memory foam. Memory foam is great for use when working with babies because the material is hypoallergenic. This means the material tends to repel dust mites and on top of that also limits other allergens like mould from coming inside the pillow. Memory foam is also known for its good durability. This means the quality stays high and the pillow can thus be used for multiple children if wanted. [224]

Besides normal memory foam, that is made out of polyurethane, there are also plant-based memory foams. As a company we strive to make the bGuard as “green” as possible. Therefore, we took a look at different solutions.

In plant-based memory foam, all synthetic materials will be replaced by plant-derived materials. Soy based foam is made out of, as the name suggest, soybeans. The mattresses and pillows made out of this kind of foam claim to be more eco-friendly. But the truth is that these type of foams often only contain 5% to 40% of soy. **[225]**

The remaining percentage is still polyurethane. In other words, the soy creates a fake green image, misleading the customers and letting them believe that the product they are buying is eco-friendly. As we discussed in our ethical chapter, bGuard stands for transparency and openness towards there customers and don't support these kind of products.

Because there will be electrical components inside of our pillow it is important that it won't heat up. An important quality of memory foams is that they have an open cell structure. This means that the material tends to be more breathable. Nevertheless, we will still be adding perforations to encourage airflow and prevent overheating. The perforations will also improve the sound quality **[226]**.

7.5.1.2 Cover

As we discussed earlier, the pillow will consist of memory foam. We want the memory foam to be provided of a cover, to protect the material and the sensors inside the memory foam. We looked at different materials for the cover and found three materials that would be suitable for making a cover.

Viscose is the first material that we will be discussing. Viscose is a material that is made from regenerated cellulose fibre. This cellulose fibre comes from plants or wood pulp. During the manufacturing process, the cellulose is chemically transformed into a viscose solution. Next, they extract the threads from these solutions and produce the fabric with these strings. Even though the process might sound harmless, it is definitely not the most environmentally friendly solution. The plants are broken down through a chemical and mechanical process - involving Sodium Hydroxide (NaOH) and Carbon Disulfide (CS₂) - into a liquid, followed by a process which spins the threads using Hydrogen Sulfate (HSO₄) **[227]**.

Our second option is a bamboo-based material. There are two different types of bamboo fibres. First of all, we have mechanically crushed bamboo. The manufacturing of this material doesn't involve any chemicals, which makes it the most eco-friendly option of the two. Nevertheless, this option is not so popular because it is a more expensive option. The second type of fibre is more common. Here the bamboo fibre is chemically extracted from the bamboo stem. The chemicals and water used during this process are often not re-used, resulting in a non-eco-friendly end product **[228]**.

Last, we opted for the material Lyocell (Tencel). This material is made from cellulose that comes from wood pulp. The pulp gets chemically broken down into a fluid and reformed into more easily woven fibres. This is why Lyocell (Tencel) is often called a regenerated fibre. Lyocell (Tencel) fabrics are naturally biodegradable and additionally during the manufacturing non-toxic solvents are used, making its production eco-friendly. On top of that, it also recycles 99% of the water used in its production. Another benefit of this material is that Lyocell (Tencel) is a very breathable material and is also less prone to the growth of bacteria, which means it is very hygienic **[229]**, **[230]**. All these characteristics make Lyocell the perfect material for our pillow cover.





VISCOSE

made from regenerated
cellulose fiber

harmful chemicals
used during manufacturing



BAMBOO

two different types:

1. mechanically crushed

→ environmentally
friendly
→ expensive

2. chemically extracted

→ non-eco-friendly



LYOCELL

made from cellulose
from wood pulp

chemically broken down

naturally biodegradable

non-toxic solvents are
used during
manufacturing

Figure 44: Materials Pillow Cover

7.5.2 Sock

The research for the sock material is also ongoing together with the materials for the pillow.

7.5.3 Home Station

Also on going.

7.5.4 List of Materials

Also on going.

7.6 Functionalities

7.6.1 Product Requirements Document

In the requirements specification document, the customer requirements towards to product are stated. While the Scope Statement sets how to do it the Product requirements document states in an easily understandable way what the customer wants. - it can be seen in **Chapter 4.2.1** Problem Statement.

7.6.2 Functional Specification

In the Technical Specification Document, The Customer requirements are transferred into technical solutions. The objectives should include measurable success criteria for the project.

Table 46: functional specifications, requirements and acceptance criteria

ID	User story	technical requirement	link to chapter	acceptance criteria	status	deviation report
ID01	As a parent I want to have a special pillow for my baby so that he/she does not roll from back to tummy.	<ul style="list-style-type: none"> * The Pillow has to have two bumpers * The Pillow has to have a ground layer * The bumpers and the ground layer have to be connected 		<ul style="list-style-type: none"> * size of.. with an accuracy of ± 1 cm measured by * the size of 400x280 with an accuracy of ± 1 cm measured by * The bumpers and the ground layer are connected by the velcro 	6	14
ID02	As a parent I want to have sensors to monitor my baby so that the risk of SIDS is reduced and also as prevention for diseases.	<ul style="list-style-type: none"> * Measuring heart rate with the Heart Rate Sensor * The Heart Rate Sensor has to be connected to ESP32 * The program what is written in the Arduino environment has to show a pulse curve in the serial monitor * The program has to send data to the IoT platform Thingsboard where heart rate is presented as a bpm 	SIDS	<ul style="list-style-type: none"> * Test with the calibrated the Heart Rate Sensor * ESP32 Pin ? has to be connected with the Heart Rate Sensor * Connect the heart rate sensor and open the serial monitor for the pulse curve * Open the Thingsboard and see if the bpm is shown 	6	14
ID03	As a parent I want to have a microphone near my baby so that I know if he/she is crying and also that he/she can listen to his/her parents' voice or music.	<ul style="list-style-type: none"> * Measuring sound with the Microphone MAX4466 * Microphone MAX4466 have to be connected to the ESP32 * The program what is written in the Arduino environment has to show noise level in the serial monitor * The design of the Thingsboard 	Microphone Interaction	<ul style="list-style-type: none"> * Test the Microphone with the Sonometer * ESP32 Pin ? has to be connected with the Microphone * When testing with the Sonometer open the serial monitor to see the noise level 	6	14

ID	User story	technical requirement	link to chapter	acceptance criteria	status	deviation report
		<p>Dashboard has to show if there is a noise</p> <ul style="list-style-type: none"> * A microphone detects noise level and if it is over 80dB it detects a cry 		<ul style="list-style-type: none"> * Open thingsboard and see if the noise level is shown * Measures noise level with an accuracy of ± 5 % 		
ID04	As a parent I want to have room sensors to measure CO ₂ , relative humidity and temperature so that my baby and also the parents have a good indoor air quality.	<ul style="list-style-type: none"> * Measuring Temperature with the temperature and humidity sensor DHT22 * The DHT22 has to be connected to the ESP32 * The program what is written in the Arduino environment has to show temperature values in the serial monitor * The program has to send the temperature values to the IoT platform Thingsboard * Measuring Humidity with the temperature and humidity sensor DHT22 * The program what is written in the Arduino environment has to show humidity values in the serial monitor * The program has to send humidity values to the IoT platform Thingsboard * Measuring CO₂ with the gas sensor SGP30 * The SGP30 has to be connected to the ESP32 * The program what is written in the Arduino environment has to show CO₂ values in the serial monitor * The program has to CO₂ values to the IoT platform Thingsboard * The design of the Thingsboard Dashboard has to show all the data in one view 	<p>Temperature Humidity CO₂</p>	<ul style="list-style-type: none"> * Compare the temperature sensor with the calibrated device in a range of 16 °C-20 °C * ESP32 Pin ? has to be connected with the DHT22 * Measure the temperature and see the values in the serial monitor * See if the values are shown on IoT platform * Compare DHT22 with the calibrated humidity measuring device in a range of 30 %-60 % * Measure the humidity and see the values in the serial monitor * See if the values are shown in IoT platform * Compare with medical device with an accuracy and calibrate softwarewise (1000 ppm) * ESP32 Pin ? has to be connected with the SGP30 * Measure the CO₂ and see the values in the serial monitor * See the Thingsboard interface if the all measured things are shown there 	6	14
ID05	As a parent I want to have all sensors connected so that I can have the information centralized.	<ul style="list-style-type: none"> * The DHT22 has to be connected to the ESP32 * The SGP30 has to be connected to the 		<ul style="list-style-type: none"> * ESP32 Pin ? * ESP32 Pin ? * ESP32 Pin ? 	6	14

ID	User story	technical requirement	link to chapter	acceptance criteria	status	deviation report
		ESP32 * The Heart Rate Sensor has to be connected with the ESP32 * The Microphone MAX4466 has to be connected with the ESP32 * The DFPlayer has to be connected with the ESP32 * The MiniSpeaker has to be connected with the DFPlayer * The Pillow ESP32 has to be connected via Bluetooth to the Home Station ESP32 * Home Station ESP32 has to be connected with IoT via Wi-Fi		* ESP32 Pin ? * ESP32 Pin ? * DFPlayer is connected to the speaker * Open serial monitor to see if the connection with two ESP32 microcontrollers is established by Bluetooth * Open serial monitor and see if the Wi-Fi connection is established		
ID06	As a parent I want to have the information in one platform so that I can see/hear alarms.	* ESP32 has to be connected with the sensors * ESP32 has to be connected with Wi-Fi * The program what is written in the Arduino environment has to send data to the IoT platform Thingsboard * On Thingsboard interface when the temperature is too low it has to send push notification * On Thingsboard interface when the temperature is too high it has to send push notification * On Thingsboard interface when the humidity is too low it has to send push notification * On Thingsboard interface when the humidity is too high it has to send push notification * On Thingsboard interface when the babies heart rate is too low it has to send push notification * On Thingsboard interface when the CO ₂ is too low it has to send push notification * On Thingsboard interface when the CO ₂ is too high it has to send push notification * On Thingsboard interface when the	...	* * Open serial monitor and see if the Wi-Fi connection is established * See on Thingsboard if the data is sent there * If the temperature is under 16 then the push notification is shown on Thingsboard interface * If the temperature is over 20 then the push notification is shown on Thingsboard interface * If the humidity is under 30 % then the push notification is shown on Thingsboard interface * If the humidity is over 60 % then the push notification is shown on Thingsboard interface * if the heart rate is under 80 bpm then the push notification is shown on Thingsboard	6	14

ID	User story	technical requirement	link to chapter	acceptance criteria	status	deviation report
		babies heart rate is too high it has to send push notification * On Thingsboard interface when the noise information is received from the ESP32 it has to send a push notification * On Thingsboard interface if no data is received it has to show a notification * On Thingsboard interface there have to have a 24 hour history of all the data * All the functionalities have to be available in an application for Android and iOS		interface * if the heart rate is over 160 bpm then the push notification is shown on Thingsboard interface * if the CO ₂ level is over 1000 ppm then the push notification is shown on Thingsboard interface * if the noise level is over 80 db then the push notification is shown on Thingsboard interface *		
ID07	As a human being I want a sustainable product so that I don't burden the environment unnecessarily.	* The product should comply with the UNESCO Sustainable Development Goals * Have to use Local materials * Have to Produce locally	...	16	6	14
ID08	As a customer I want to have a good product quality so that I can rely on the product.	* The Home Station has to resist the fall * The electronics inside the Home Station has to resist the fall * The material of the pillow has to resist the pulling force * The material of the pillow has to be water resistance * The foam what is used for the bumpers has to resist the pulling force	...	16	6	14
ID09	As a parent I want a pillow that has an adjustable ground layer so that is suitable for different sizes of babies.	* The Bumpers for the pillow has to be adjustable	...	16	6	14
ID10	As a parent I want to remove the cover of the pillow so that I can wash it.	* The pillow cover material has to have a zipper * The pillow cover material has to be washable * The cover of the bumpers has to have a zipper * The cover of the bumpers has to be	...	16	6	14

ID	User story	technical requirement	link to chapter	acceptance criteria	status	deviation report
		washable				
ID11	As a parent I want that the pillow has an anti-allergic cover so that my baby does not have health problems.	<ul style="list-style-type: none"> * The material of the pillow has to be anti-allergic * The material of the pillow has to be waterproof * The bumpers have to be made from a foam 	...	16	6	14
ID12	As a parent I want to have no strong Signals right next to my Baby so that there is no health risk.	<ul style="list-style-type: none"> * The ESP32 in the pillow has to use low power Bluetooth * The ESP32 in the pillow has to use Bluetooth to send data 	...	16	6	14
ID13	As a parent I want to have a user-friendly software so that it is easy to use.	<ul style="list-style-type: none"> * Looking on the Dashboard of Thingsboard or the application the customer has to see all the important data simultaneously * When the customer clicks on the symbols the history and more precise information show up 	...	16	6	14
ID14	As a parent I want to have a safe software so that I can be sure to be notified when something is wrong.	<ul style="list-style-type: none"> * The software has to orientate on the ISO 13485 * Developers have to document everything * Developers have to regularly update the software 	...	16	6	14
ID15	As a parent I want to order the product easily on the internet so that the product will be delivered easy and fast.	<ul style="list-style-type: none"> * The Webpage has to be on the first page of Google when you search for "Babytrackers", "Sleeptrackers", "bGuard", "Sleepsense" or "Sleepcurity" * After the order the product should be delivered max. 3 days later 	...	16	6	14
ID16	As Sleepsense I want to have a good product and produce cheap so that I have the opportunity to earn money.	needs..	...	16	6	14

7.6.3 Concept of the Product

Figure 45 shows the graph of the concept of the vision of the final product. On the left-hand side are the sock and the pillow. Like said in Designs, the pillow has two side bumpers. They low the risk of rolling from back to tummy. Furthermore in the pillow is a microphone and a speaker included. In combination with the MP3 player, the pillow can play music or voices, when the infant is crying. Moreover, there is a pulse sensor included in the sock. To save money for the prototype, the sock is connected with wires to the micro-controller of the pillow. In the vision of the end product, the sock has a smaller textile micro-controller with a small battery included realizing a wireless connection.

The sensor data of the sock and the pillow is delivered by Low Power Bluetooth to the Home Station, which is in the center of **figure 45**. In this part of the product the values are received and temperature, humidity and CO₂ are measured.

After this step, all the sensor data of the pillow, the sock and the home station are saved on IoT platform, which is shown on the right side of **figure 45**. The measurements are sent by Wi-Fi from the Home Station. Finally, the data can be monitored online and seen on a smartphone application. In the case of a risk of the baby or the environment, a notification can be sent through the application. Because of the limited time and budget, the application will be not realized for the prototype. Nevertheless, the measurements are monitored on an open source IoT platform to prove the concept. The diagrams are available on an online dashboard. Furthermore, a concept of the application is designed.

bGuard doesn't want to emit high radiation to the infant in the first months after its' birth. Therefore the team decides to send the measurements by Low Power Bluetooth to the Home Station. The Home Station is positioned in the sleeping room of the baby. SleepSense recommends putting the Home Station as far away from the sleeping area as possible. In addition, the interval of the sending and receiving processes will be 30 seconds. In this way, there is no long-term radiation.

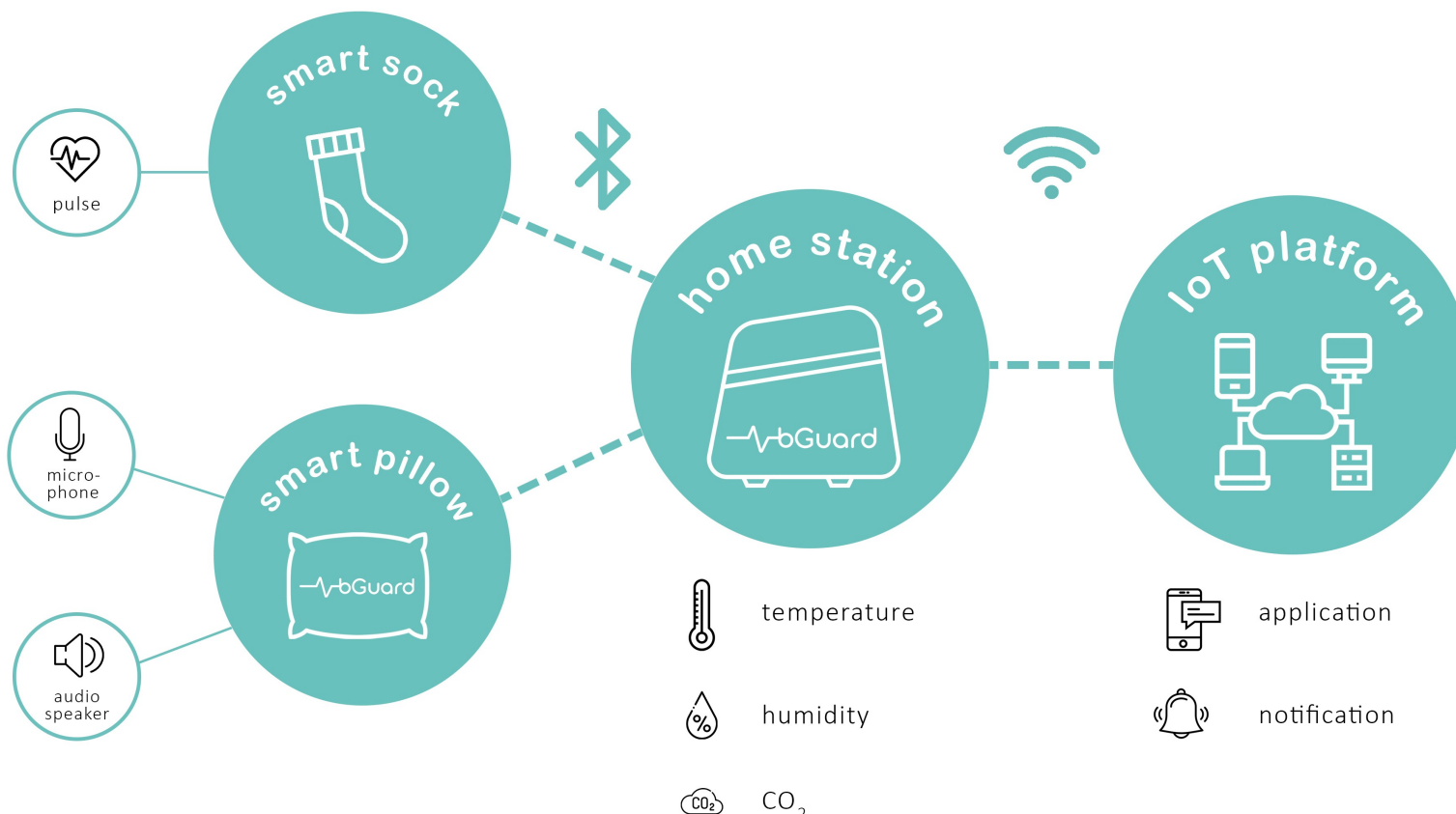


Figure 45: Graph of the concept of the product





Figure 46: Home Station function

bGuard Smart Pillow

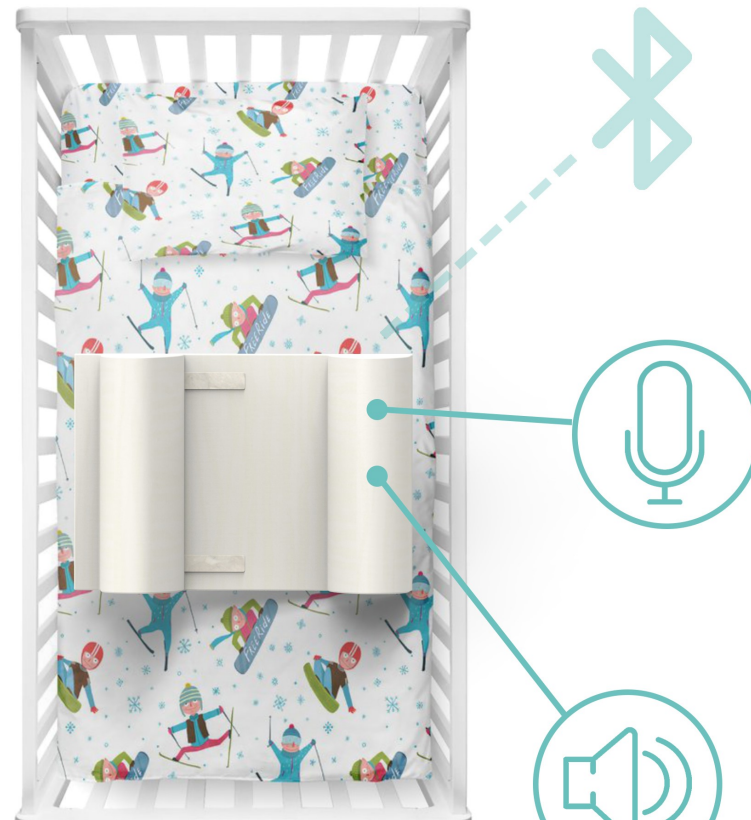




Figure 47: Smart Pillow function



Figure 48: Smart Sock function

7.6.4 Mobile Application

bGuard is supported by a mobile phone application. Here are the measurements by the smart sock and home station gathered. The app provides an easy and visual overview for the parents to see how their baby is doing. It shows if the measured values are inside of the safe range.

The average pulse for a sleeping baby fluctuates between 80 beats per minute (bpm) to 160 bpm. Our app will give a notification if the baby's pulse does not fall inside this range [231].

Table 47: Baby Pulse

Age	Awake Rate	Sleeping Rate
< 28 days	100 bpm to 165 bpm	90 bpm to 160 bpm
1 month to 12 months	100 bpm to 150 bpm	90 bpm to 160 bpm
> 12 months to 24 months	70 bpm to 110 bpm	80 bpm to 120 bpm

The temperature of the baby's bedroom is also an important factor. The United Kingdom (UK) National Health System (**NHS**) advises that the room temperature should be from 16 °C to 20 °C [232]

Concerning the humidity, the humidity level should always be kept between 30 % to 60 % [233], [234]. A percentage higher than 60 would mean that the risk of mould growth increases. Mould growth can lead to respiratory complaints like asthma.

The home station will also be monitoring the level of CO₂. High CO₂ levels in a bedroom are associated with dry mouth and skin, low air freshness and may even lead to an unstable mental state. On top of that, rising CO₂ levels mean that the level of volatile organic compounds (VOCs), odours and micro-organisms in the bedroom also rise. The National Institute for Occupation Safety and Health (NIOSH) states that the level should never rise above 1 000 ppm [235], [236].

The application will also allow the parents to interact with their baby. The pillow will be equipped with a cry detection sensor. This sensor measures the sound level in decibel (dB) the baby produces. When the threshold of 80 dB is exceeded the sensor application will send a notification to the parents. An average baby produces 110 dB whilst crying [237].

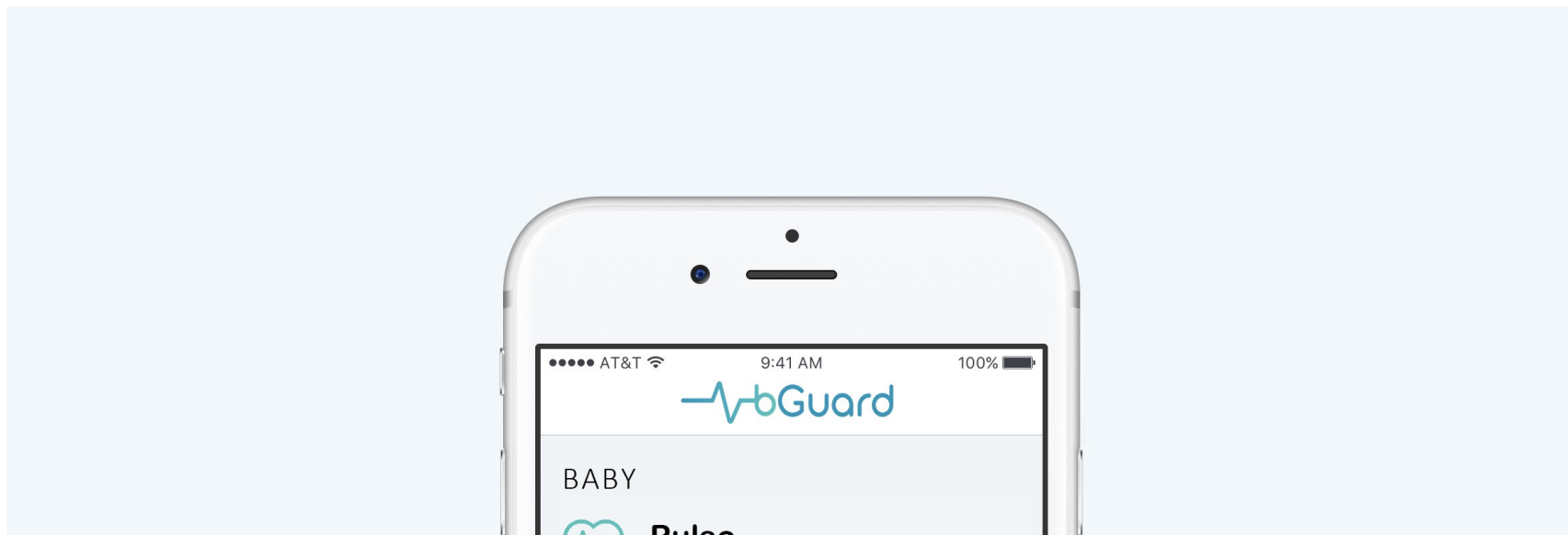




Figure 49: Mobile Application - data

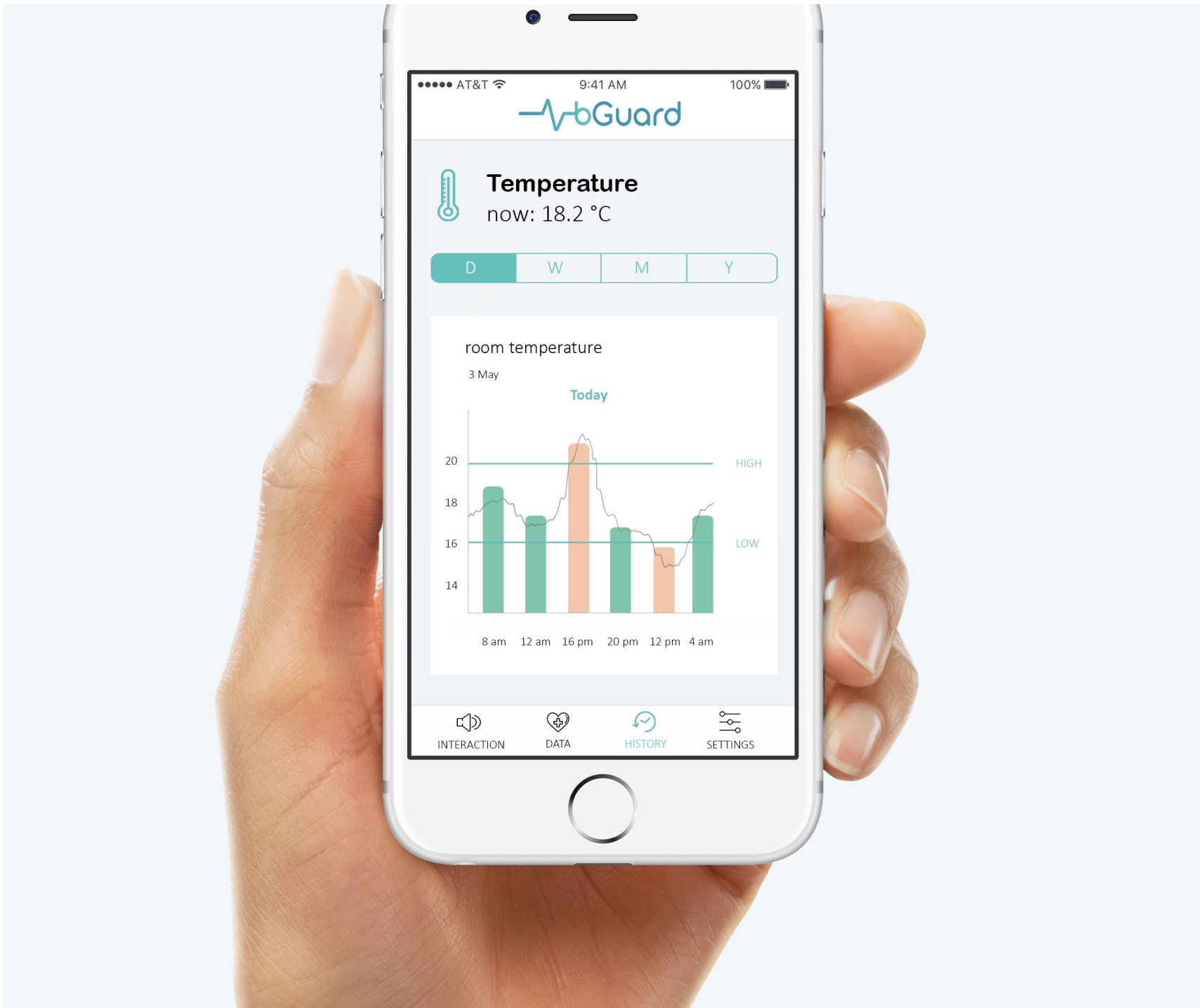


Figure 50: Mobile Application - history

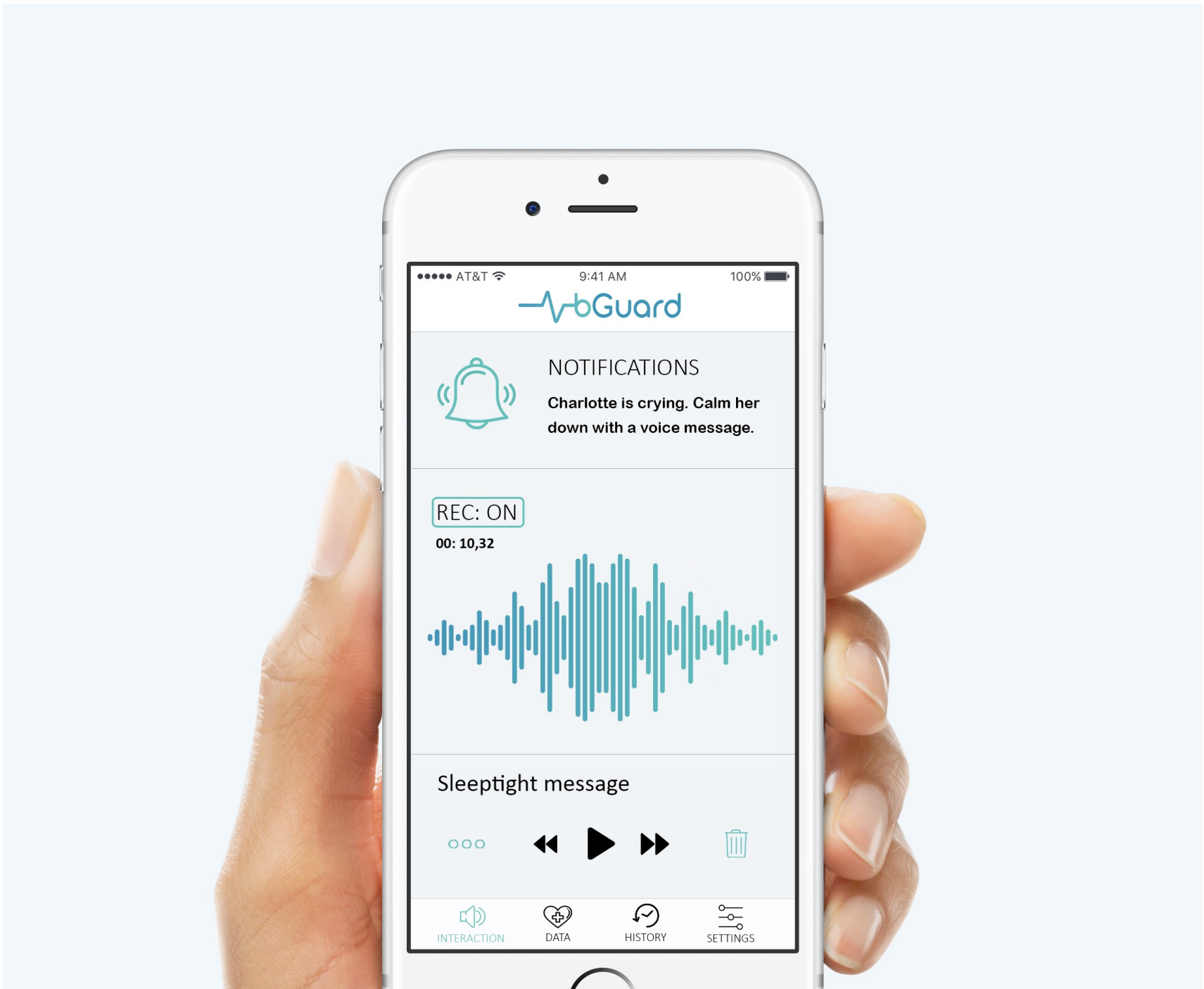




Figure 51: Mobile Application - interaction

7.7 Software Requirements and Regulations

Software development is a “special process” which makes it hard to verify the correctness of the process result in an economical way. Therefore, especially documentation of the software is a really important point because not only hardware defects can put a risk on the customer also software bugs. Especially if your business treats a sensible niche, like our product does, you have to make sure that the customer takes the lowest possible risk according to both hardware and software. To make sure that, standards and regulations do an important job for customers’ security. For example the IEC 62304 specifies life cycle requirements for the development of medical software and software within medical devices. It is a European harmonized standard for medical device software that says how to accomplish a well-thought-out software development process. Unlike most other standards, the requirements of IEC 62304 are adapted to the safety relevance of the software to be developed. Security relevance is determined by a risk-based approach. The more sensitive the software is, the more effort must be made during development and documentation. For this adaptation, IEC 62304 defines three safety classes where our product would be declared in the lowest risk declaration called “A” due to the non-invasive and low voltage purpose.

Also, we use Software of unknown provenance (short: SOUP) in our product. Libraries are included which are not written on our own and may not fulfill the requirements of e.g. IEC 62304 and is not documented enough and might be a security risk.**[238]**

According to risk management in medical devices, ISO 14971 establishes the requirements for risk management to determine the safety of a medical device by the manufacturer during the product life cycle.

Talking about the hardware the IEC 60601 is a technical standards regulation for the safety and essential performance of medical electrical equipment.

Although our product is not a medical product, we can get input from regulations and good development standard due to the fact that medical devices have high requirements according to software and hardware security and as well as quality management requirements (ISO 13485). One basic idea of this standard is the Deming circle to continuously Plan-Do-Check-Act as you can see for instance in Strategy Control. To ensure the best possible quality, documentation is very important.

Also, to verify a good product, requirements management including the requirement analysis documentation is very important. In the requirements specification document, the customer requirements towards to product are stated. In the technical specification document, the service provider presents in a concrete form of how he would and could implement the project for the client. In the specification, the exclusion principle is used, that is, concrete cases are either included or excluded to form the basis for further action. It is described in Quality.

According to that verification and validation, it is important to check if the product (including the software) meets requirements specifications and fulfills the intended purpose. Verification means to check if the product complies with regulations and requirements and is an internal process. Validation is to check if the product meets the needs of the customer and is an external process.

Our product is not a medical product and does not fulfill the requirements of these standards but due to the sensibility of our customers, we see those as a guideline to orientate

ourselves on them [239].

in progress..

7.8 Tests and Results

7.8.1 Electrocardiography

The Electrocardiography is a graph with voltage over time measuring the electrical activity of the heart. The cardiac muscle re- and depolarization during a cardiac cycle is detected. As you can see in **figure 52** the heartbeat is divided into specific phases. During each heartbeat, a healthy heart has an orderly progression of depolarization that starts with pacemaker cells in the sinoatrial node, spreads throughout the atrium, passes through the atrioventricular node down into the bundle of His and into the Purkinje fibers, spreading down and to the left throughout the ventricles. [240]

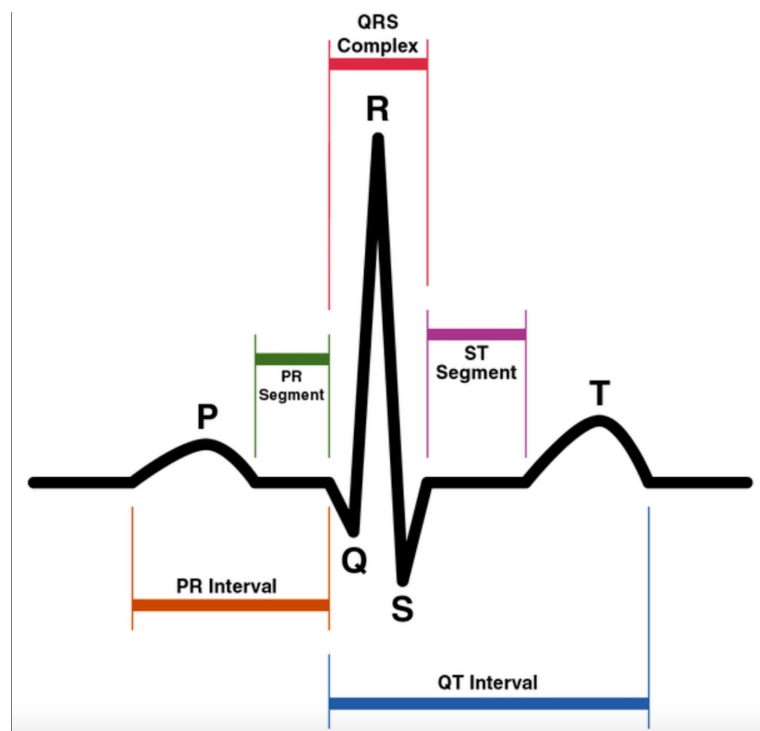


Figure 52: Schematic representation of a normal ECG [241]

- The P wave represents atrial depolarization.
- The QRS complex represents ventricular depolarization.
- The T wave represents ventricular repolarization.
- The U wave represents papillary muscle repolarization.

7.8.2 Pulse Sensor

The Pulse Sensor works using photoplethysmography. The analogue heart pulse signal in green comes in Voltage over time and reacts on light intensity changes of the LED. [242] The Pulse Sensor is directly connected to the Microcontroller working on 3.3 Volt. The Analog data of the sensor are processed by the software and finally plotted as you can see in **figure 53**. The software works with 20Hz so 20 values per second are analyzed using an interrupt service routine (ISR). We are using an 8bit onboard timer to measure the time between each beat sampling with 500Hz. Doing that the amplitude of the heartbeat has to go over 512 at first, which is the middle of the analogue range and changes during the run to 50% of the average last ten wave amplitudes. When the waveform rises past the thresh value, and 3/5 of the last Interbeatintervall (IBI) has passed, a pulse had occurred. In an array, the last ten Interbeatintervall (IBI) Values are saved. The BPM is derived every beat from an average of the previous 10 IBI times. If the Signal is over a threshold, the Q-S Bool (Quantified Self) is set to true to count a Heartbeat and so that the rest of the program knows a beat is found. Timer filters are included to avoid high-frequency noise. For example to avoid dichroic noise by waiting for 3/5 of last IBI. The time between each Heartbeat is measured by the IBI and processed with the red line. Beats per Minute (BPM) are calculated in the software and are plotted with the blue line. The green line images the pulse Signal itself.

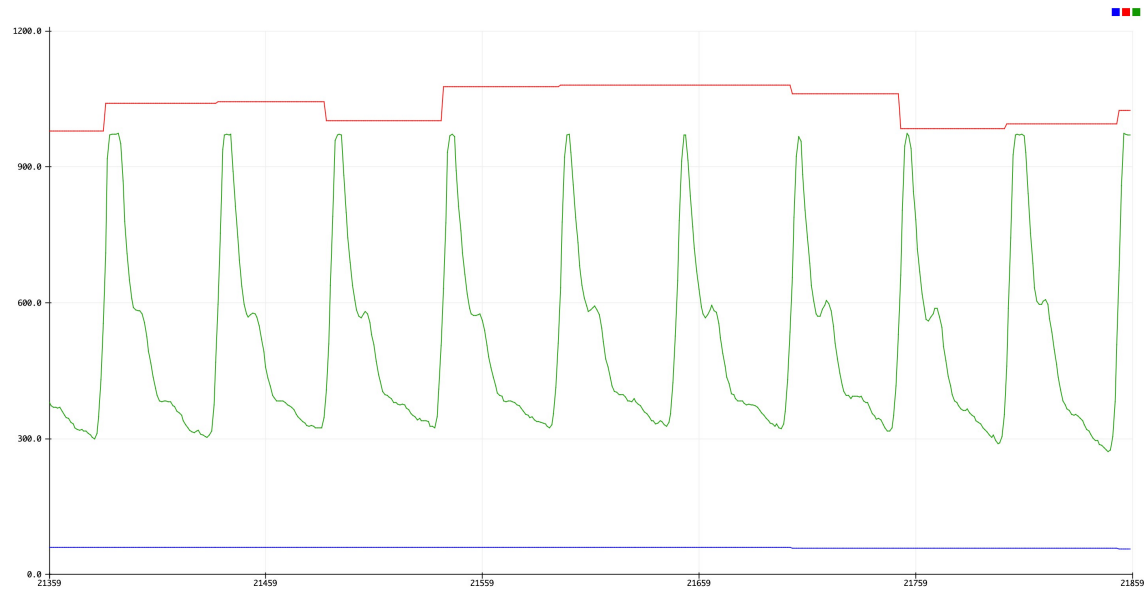


Figure 53: Pulse, IBI and BPM plot

The difference is that **figure 52** shows the voltage signal of the heart. What we measure is the response to this. We are measuring the arterial pulse waveform using photorelectance containing a photocell sensor as our pulse sensor. The wave you can see in **figure 53** is a shockwave which means it travels much faster than the actual blood. It represents the impulse of ventricular contraction. The wave can be separated into an anacrotic upstroke limb and a dicrotic downstroke limb [243]. **Figure 54** shows the dependance.

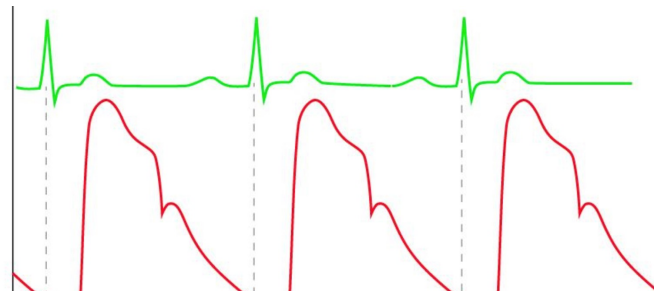




Figure 54: Timing of arterial pulse and the ECG [244]

The systolic upstroke does not occur immediately following the contraction of the heart. On the ECG, the electrophysiological phenomenon which signals the beginning of systole is the R wave. Usually, the arterial pulse wave does not appear on the monitors until a 160-180 millisecond delay. The main reason next to measurement uncertainties is that after the R wave, (the depolarization wave) has to spread through the left ventricle, some isovolumetric contraction needs to take place, then the aortic valve has to open, and then the aortic pressure wave needs to travel up the aorta and down the arm (at 6-10 m/s). The systolic upstroke is the ventricular ejection being generated by the fast-moving 10m/sec wave and corresponds to the peak aortic blood flow acceleration at the opening of the aortic valve[245].

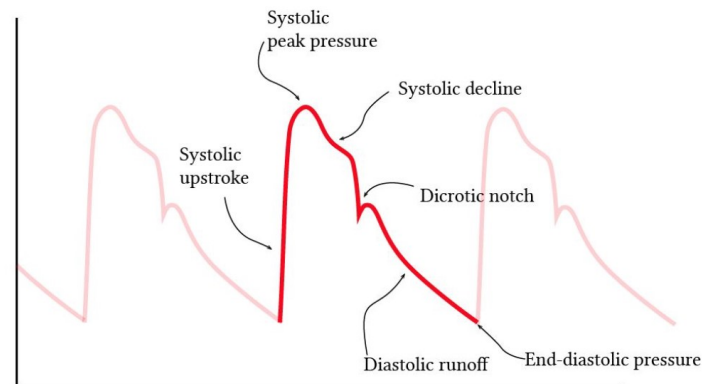


Figure 55: Phases of Pulse Signal [246]

Therefore, the pulse wave which is measured is, apart from the heartbeat also influenced by the pressure, the contractility, aortic valve flow, arterial peripheral resistance, diastolic pressure, the pattern of the electrical activation.

The dicrotic notch as you can see in **figure 55** happens because there is a sudden increase in pressure as the valve closes. It is a secondary upstroke in the descending part of a pulse tracing corresponding to the transient increase in aortic pressure upon closure of the aortic valve[247].

Following the Pulse Signal is exactly as it is to be expected for a young person. The BPM values of pulse and heart rate are the same due to the characteristic that they measure the peaks.

7.8.3 Temperature and Humidity Sensor

To measure the temperature and the humidity we used the DHT22 Sensor. This sensor consists of humidity sensing component, an NTC thermistor and an IC (Integrated Circuit) on the back side of the sensor. For measuring humidity they use the humidity sensing component which has two electrodes with moisture holding substrate between them. So as the humidity changes, the conductivity of the substrate changes or the resistance between these electrodes changes. This change in resistance is measured and processed by the IC which makes it ready to be read by a microcontroller. [248]

Measuring the temperature works using an NTC thermistor. A thermistor is a variable resistor that changes its resistance with the change of the temperature. These sensors are made by sintering of semiconductive materials such as ceramics or polymers in order to provide larger changes in the resistance with just small changes in temperature. The

term “NTC” means “Negative Temperature Coefficient”, which means that the resistance decreases with the increase of the temperature.

In the Arduino code first the libraries of the Sensor had to be included

When we take a look at the sensor performance we can say that typical advertised specifications for DHT22 are:

Table 48: DHT22 specifications

Absolute accuracy	Repeatability	Long term stability
±2%	±1%	±0.5% per year

It is important to know that the typical accuracy is ±2%, but the accuracy can degrade to ±5% at the two extreme limits, <10% and >90%. In the following tables we take a closer look to the accuracy of sensor:

Table 49: DHT22 Relative Humidity performance table

Parameter	Condition	min	typ	max	Unit
Resolution			0.1		%RH
Range		0		99.9	%RH
Accuracy	25°C		±2		%RH
Repeatability			±0.3		%RH
Exchange		Completely interchangeable			
Response	1/e(63%)		<5		S
Sluggish			<0.3		%RH
Drift	Typical		<0.5		%RH/yr

Table 50: DHT22 Relative Temperature performance table

Parameter	Condition	min	typ	max	Unit
Resolution			0.1		°C
Resolution			16		bit
Accuracy			±0.5	±1	°C
Range		-40		80	%RH

Parameter	Condition	min	typ	max	Unit
Repeat			±0.2		°C
Exchange		Completely interchangeable			
Response	1/e(63%)		<10		S
Drift			±0.3		°C/yr

The following two graphs represent the error of relative humidity (at 25°C) and the maximum temperature error.

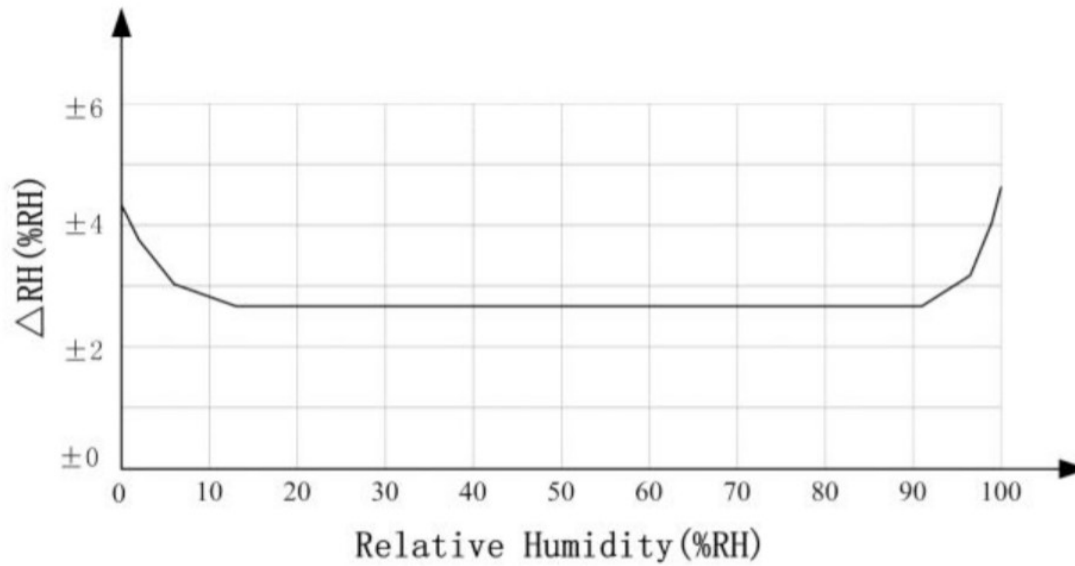
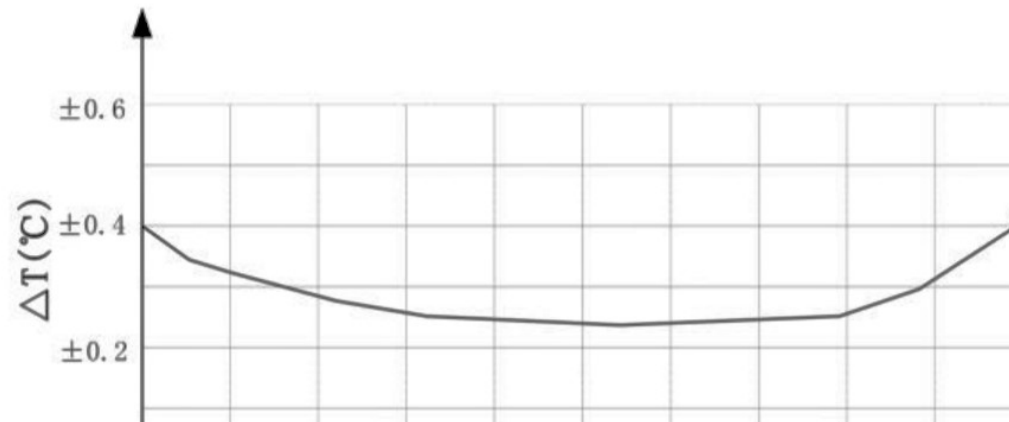


Figure 56: At 25°C The error of relative humidity



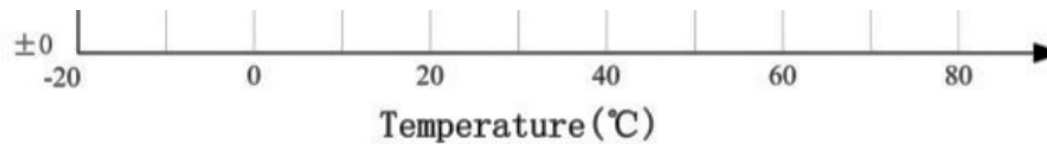


Figure 57: The maximum temperature error

Although the manufacturer claims in the datasheet that the DHT22 is “temperature compensated” during the factory calibration procedure, this procedure is often not that precise. This is why we test the temperature sensitivity of the sensor.

For calibrating the sensor the method of critical relative humidity above a saturated aqueous solution can be used. This method is an often used method of controlling humidity, used in many fields. It relies on an air-tight sealed hygrometer in a vessel with a sample of a saturated solution. The concentration of the solution allows us to control the humidity of the air above that solution. Typically sodium hydroxide, sulphuric acid or lithium chloride have been used. The sensor’s measurements are compared to the humidity known from published lab tests to be generated by that particular solution and help make a conclusion. A possible source of error can be temperature and temperature stability. The relative humidity is a strong function of air temperature. For a given absolute humidity the measured relative humidity varies with temperature. As mentioned earlier this method relies on a sealed, air-tight test vessel. This means that this particular source of error correlates to the rate of change of temperature or temperature gradients within the test cell. We are working with the natural equilibrium which the solution, vapour and air are constantly trying to achieve. The material of the vessel also has an influence on when the equilibrium is achieved. A lot of plastics, like nylon, ABS, polycarbonate and PET, have the tendency to be hygroscopic. This means that there is another source of humidity besides the saturated solution which results in an extended equilibration time.

With high temperature, the air is able to support more vapour. This vapour will be provided by the solution that is evaporating. All of this leads to a lower measured humidity than expected. On the other side, when the temperature is falling, the vapour will condense back to the solution. This results in a higher measured relative humidity than the calibration value we are trying to achieve. The only way the equilibrium can be established is if the temperature remains stable for a period of time. Active thermal control and good air circulation is thus from big importance. Additionally, the temperature gradients in the equipment can also cause humidity variations. The thermostatic control is based on the temperature at the sensor. If there is a temperature gradient inside the cell then that can cause exactly the same error as if the temperature varied temporally.

When conducting the test it is important to pay attention to a few things. The ideal vessel has a small volume but a big surface area of the saturated solution. This way the equilibrium is likely to be achieved quicker. In some situations, dampened solids are recommended instead of a liquid solution although for particular salts this will not work. A golden mean is when both methods are combined by using a shallow pool of saturated solution with a small amount of dampened solid piled up in the middle. This way all of the liquid, solid and gaseous material phases are in contact and allow the equilibrium to be established.

Three different types of tests are conducted. First of all, a test to look at the response of the sensor to different reference humidities, all measured at a single fixed temperature. Next, the humidity is kept fixed and the temperature will be varied between 10 and 40°C. Lastly, if the sensor will be used to measure the humidity under a range of varying temperatures a full bivariate calibration is needed. Over a narrow temperature range (for example $20 < ^\circ\text{C} < 30$) the thermal effects are not large. However, if the sensors are to be used over a wider range (e.g. $5 < ^\circ\text{C} < 40$), then the bivariate calibration would be necessary.

To sum up, it is important to take into account that this experiment does not contain an external reference against which to calibrate the temperature output. This experiment relies on plotting and comparing one sensor’s offset from the mean of all the other sensors. In other words, there is only a comparison between the different sensors, but it can be said that the absolute calibration seems to be good to $\sim 0.5^\circ\text{C}$ with a relative drift of $< 0.1^\circ\text{C}$ over a 30°C range. Repeatability for most of the sensors is $\pm 0.01^\circ\text{C}$.

7.8.4 Carbon Dioxide Sensor

For the CO_2 Sensor the SGP30 Sensor is used. It is a fully integrated MOX gas sensor. It has I2C interfacing and comes with fully calibrated output signals with a typical accuracy of 15% within measured values. The SGP combines multiple metal-oxide sensing elements on one chip to provide more detailed air quality signals.

The SGP30 has a standard hot-plate MOX sensor, as well as a small microcontroller that controls power to the plate, reads the analog voltage, tracks the baseline calibration, calculates TVOC (total volatile organic compounds) and eCO₂ (equivalent calculated carbon-dioxide) values, and provides an I2C interface to read from. In bGuard only eCO₂ is measured.

This part will measure eCO₂ concentration within a range of 400 to 60,000 parts per million (ppm). Like all VOC/gas sensors, the SGP30 has variability and to get precise measurements you will want to calibrate it against known sources! For general environmental sensors, it will give a good idea of trends and comparison. The SGP30 does have built in calibration capabilities, note that eCO₂ is calculated based on H₂ concentration, it is not a 'true' CO₂ sensor for laboratory use or a medical device.

Another nice element to this sensor is the ability to set humidity compensation for better accuracy. An external humidity sensor is required and then the RH% is written over I2C to the sensor, so it can better calculate the TVOC/eCO₂ values.

The first 10-20 readings will always be TVOC 0 ppb eCO₂ 400 ppm . That's because the sensor is warming up, so it will have 'null' readings. All the calculations for the TVOC and eCO₂ of the SGP30 are done within the sensor itself, no other data is exposed beyond the baseline values. All VOC/gas sensors use the same underlying technology: a tin oxide element that, when exposed to organic compounds, changes resistance. The 'problem' with these sensors is that the baseline changes, often with humidity, temperature, and other non-gas-related-events. To keep the values coming out reasonable, the sensor needs to be calibrated. **[249]**

7.8.5 Interaction

For the interaction, we used the Microphone MAX4466. With the Microphone, we are getting a voltage over time signal. The Serial monitor works with a Baud rate of 115200. The signal is read and mathematically logarithmically transferred into a dB signal. To calibrate we use a function generator and a speaker in a closed area, and we measure the constant sound level with a Sonometer. Simultaneously we measure the same signal with our Microphone. Now we get one parameter called "const int x" in dB which is the actual sound level of the Sonometer and a "const int y" which represents the value of the ESP32 in Volt. To get the output sound level in dB we transfer it mathematically using:

$$outputdb = x + 10 * \log_{10}\left(\frac{mic3v3Val}{y}\right) \tag{1}$$

If the sound level is over the level of 80dB the cry detection goes on. Now a timer counts 2 seconds and if the sound level is still over 80dB a cry is detected. Doing this we avoid false alarms caused by small peaks.

The Output of the Microphone is filtered as you can see in **figure 58**.

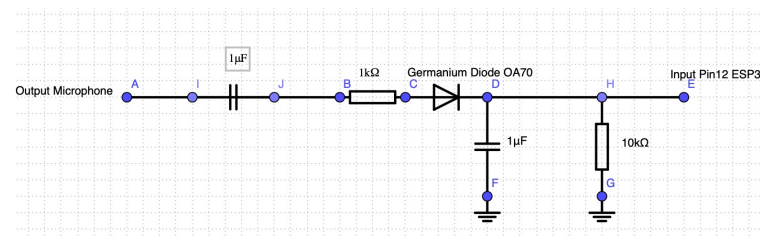


Figure 58: Microphonesignal filter for cry detection

Having an AC Sinus Signal the Diode cuts the sub wave due to its one-way permeability. The positive wave loads the capacitor and makes the signal fade much slower as you can see in **figure 59**.

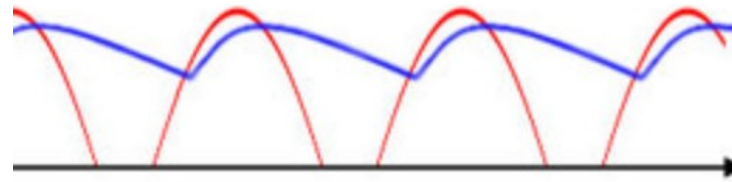


Figure 59: signal after filter

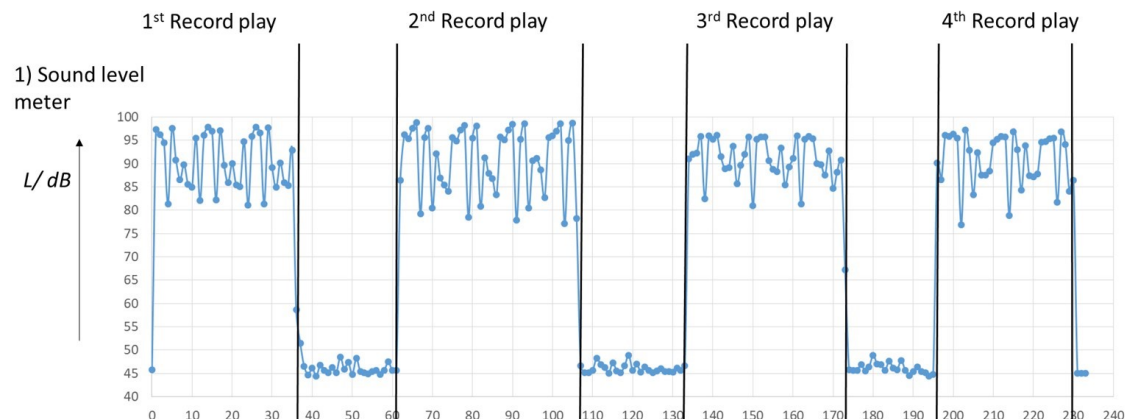
After a Cry is detected the Microcontroller plays 3 songs of the MP3 player stopping after 3 minutes. If a cry is detected the playMusic bool is set on one to start playing music. Meanwhile, the parents are notified by a Push notification.

After the installation of the microphone two tests are followed: The calibration of the sensor and reaction to the baby crying. For both tests, the same experimental setup is used which is shown in figure XXXX. The sound level meter "SC-30" sold by "CESVA", the Microphone MAX4466 and a speaker are positioned under a transparent plastic box. The sound level meter is connected with the computer. On the computer, the manufacturer software is installed which can measure the sound level in decibel and export the values in an Excel-file. Furthermore, the speaker is connected with a frequency station which creates constant noises for with different frequencies. The microphone is connected with the Arduino IDE, where all measurements are shown over the time in the Serial Monitor and the Serial Plotter. During the measurements, the plastic box saves noise measurement from background noises.

PICTURE EXPERIMENTAL SETUP

Calibration + Phrase from Tobi for different frequencies

After the calibration, the reaction to the baby crying is tested. The main target of the test is to figure out how fast the microphone can react to the infants' noise and in which range of the noise level it measures in comparison with the sound level meter. Thus, a baby crying is simulated by a recording from YouTube [250]. The recording is played by a mobile phone which is added to the experimental setup. Moreover, the volume of the mobile phone is set up to the average range of a baby cry [251]. The microphone and the sound level meter have the same distance to the speaker of the mobile phone. During the measurement, the record is played four times and stopped between the passages. **Figure 60** shows the comparison of the sound level meter and the microphone with the sound level L in decibel dB over the time t in seconds s . It stays clear that the sensibility of the sound level meter is much higher the sensibility of the microphone. As an example, the first measurement can be used. For the sound level meter has a range between the maximum and the minimum is 16.5 dB. In comparison with the microphone of the pillow, the range is 3 dB. Nevertheless, the average of the noise level of all four measurements is close. For the noise meter, the average of the baby crying is 90.82 dB and the average of the microphone is 92.0 dB. Also, the reaction of when the recording starts and stops is for both measurements similarly. As seen in **figure 60** a significant difference is not shown.



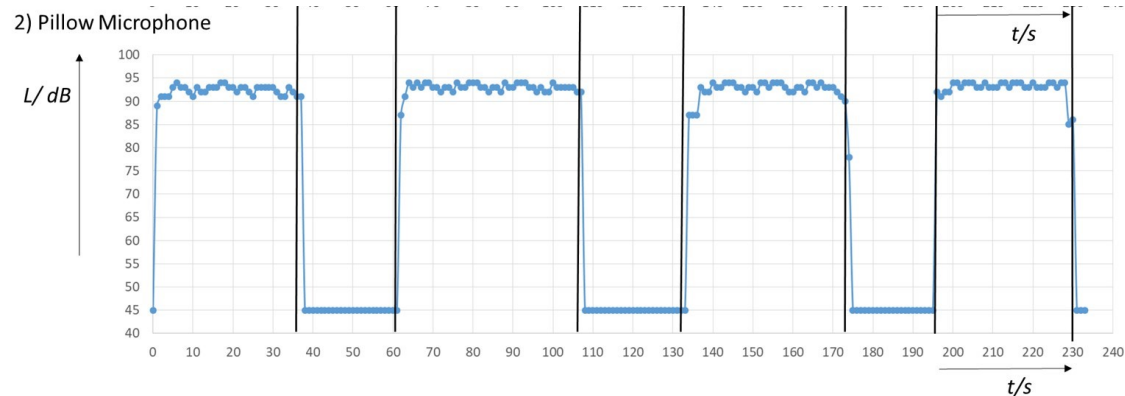


Figure 60: Diagrams of the baby crying record with the sound level L over the time t with 1) Sound level meter and 2) Pillow Microphone

Consequently, it is demonstrated that the reaction to the crying of the baby and the measurement of the noise level is precisely enough to react to the crying of the baby. Even when the sensibility of the low-cost microphone is not high, the average of the crying is close to the value of the calibrated sound level meter. Furthermore, the reaction when the crying starts and ends has no important difference between the two devices.

7.8.6 IoT Platform Thingsboard

7.9 Conclusion

Provide here the conclusions of this chapter and introduce the next chapter.

8 Conclusions

8.1 Discussion

Provide here what was achieved (related with the initial objectives) and what is missing (related with the initial objectives) of the project.

8.2 Future Development

Provide here your recommendations for future work.

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