CHALMERS
UNIVERSITY OF TECHNOLOGY


# Redesign of the TA-Scope

## A balancing instrument for hydronic systems

Master thesis in Industrial Design Engineering

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Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

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## Acknowledgements

The report you are currently holding in your hand (or perhaps reading on a screen) marks the end of our time at Chalmers University of Technology. To be more specific, this is our thesis report from the Master's Programme in Industrial Design Engineering. The project was carried out in the spring of 2018, in collaboration with IMI Hydronic Engineering in Ljung, Sweden.

The thesis deals with how to improve their industrial balancing tool for hydronic systems, the TA-Scope, using the skills we have acquired at the university. It's a fitting ending that reflects the years we've spent at Chalmers; educational, fun, sometimes quite hard, but always worth the effort. Even though our names are the ones on the report, we have people to thank. People who played an important part in making this project what it became.

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Staffan Enegren & Henrik Johansson

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## Abstract

Ensuring a comfortable indoor climate throughout any building, at maximum energy efficiency, requires a well-balanced hydronic system. In order for a hydronic system to be well balanced, the valves controlling the flow of hot fluids need to be adjusted against each other. When this state of balance is acquired, the pump that distributes fluids to all radiators in the system can be set to a minimum, thereby saving energy.

The TA-Scope, is a handheld, digital balancing tool, made specifically for establishing this balance. The purpose of this project was to redesign and improve the balancing instrument TA-Scope for the users, through a human-centered design process. Improving, in this case means creating a product that is adapted to the environment in which it is being used. Furthermore, the product will reflect the values of the brand to meet the needs of the buyers and increase the perceived value for the end user.

The project was carried out by first attaining an understanding of how the current product works through technical research and testing. In order to gain an understanding of how the product is perceived and used in the field, phone interviews were conducted with professional users dispersed all over Sweden. The authors also went into the field to observe a professional user performing a balancing job at Volvo Penta in Gothenburg, Sweden. From this, a comprehensive depiction of the problems was produced, as well as a list of requirements for the new product.

From here, the project went on to find solutions that could move the TA-Scope to a more modern territory. The goal throughout was to keep the context within which the product is used, and the user, in mind. Four different concepts were evaluated in collaboration with IMI Hydronic Engineering and a morph of two concepts was finalized.

The final concept is adapted to the environment in which the product will be used, and is designed to ensure simpler and safer use, minimising the risk of fall damage and reducing the bulkiness of its predecessor. The adaptation to the environment is reached through optimization of materials, utilization of anthropometric data to reach an ergonomic design and through build quality that can handle harsh conditions. To ensure simpler and safer use the product is furthermore designed to be used on the wrist as opposed to its handheld predecessor, minimizing the risk of drops and improving usability through changes to the context of use. A touch screen feature is also introduced to allow for a new generation of user interfaces with the ability to increase usability even further.

During the course of the project, there were difficulties with finding suitable opportunities for observation as well as coming in contact with a satisfactory number of users, especially outside of Sweden. Additionally, since there is no digital interface for testing yet, more work is needed in the future to evaluate if more work is needed for the concept to work as planned.

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# 1 INTRODUCTION

This introduction is meant to give the reader information as to who the involved parties in this project are, why there is a need for the project to be carried out, as well as what the specific outcome is. It concludes with the framing of questions, i.e. the questions that this thesis will answer.

## 1.1 Background

IMI Hydronic Engineering is a company that is focused on providing Heating, Ventilation and Air Conditioning (HVAC) solutions, such as valves for heating systems, in buildings. These valves control the flow of hot fluid (oftentimes plain water) through pipes, so that a comfortable indoor climate can be achieved in all parts of a building. The pipes are what make up a hydronic system. When an even distribution of heat is achieved in a building, the pump that builds the pressure in the system can be set as low as possible, while still maintaining the necessary flow. If the pump is set higher, an unnecessary amount of energy is being consumed. IMI Hydronic Engineering claim that their focus is on innovative and dependable solutions that give their customers efficiency from- and control over their hydronic systems.

The tool that is used for creating an even distribution of heat in a hydronic system is called a balancing instrument. This is a device used to accurately measure differential pressure, flow, temperature and power in the system. To give an idea of what a balancing instrument is, and how it is used, think of your home: If one room is uncomfortably cold, but another is not, what do you do? Most likely, you turn up the radiator in the cold room, allowing for more hot fluid to run through, giving a warmer climate. If you now imagine a large office building, you might have an entire section of the building where the temperature is too low or high, independent of what the radiator is set to. This means that the problem is that a valve, which controls how much fluid reaches the radiators, is unbalanced compared to other valves in the building. Unfortunately, simply adjusting that one valve until your section is comfortable will have repercussions in other parts of the system. All valves must be in balance with each other. In order for this to be achieved, an HVAC-worker has to attain an understanding of how the specific system is structured and walk around to each of the valves in the building, performing calculations and measurements and finally turning the valves to a setting that leads to balance.

Before electronic balancing instruments, these calculations would be made using pen and paper in order to find balance, but handheld electronic devices can perform the needed measurements and calculations quicker, more accurately and without error.

At IMI Hydronic Engineering, their balancing instrument, TA-Scope, is called a “flagship product”. It is something that the company is proud of for its functionality, accuracy and degree of innovation.

Since its introduction, it has been exposed to competition, and currently a popular approach for other companies is to take the same concept of a balancing instrument but in the form of an app for mobile phones. This option has the benefit of almost always being available for workers that need a balancing instrument, thereby removing the need for a separate device. In addition, this solution has the benefit of being cheaper for companies, as mobile phones are bought and used regardless. The working conditions during use are, however, not always optimal for the use of a mobile phone, especially if it is privately owned and not a company phone. Dirt, high degrees of moisture, direct contact with water and rough handling are prevalent. Furthermore, the process of balancing a hydronic system can include walking, crawling and climbing ladders during use. Users also expect the device to withstand being dropped on many occasions without taking damage.

Because of the emerging competition and the tough working environment, IMI Hydronic Engineering believe that an evaluation of the TA-Scope, in collaboration with designers, is necessary in order to ensure that their flagship product stays profitable. Furthermore, the TA-Scope was not developed with designers from the beginning, which means there might be an opening to improve the usability of the product, leading to more satisfied customers through a more user-friendly and modern tool.

## 1.2 Purpose

The purpose of this project is to redesign and improve the balancing instrument TA-Scope for the users, through a human-centered design process. Improving, in this case means creating a product that is adapted to the environment in which it is being used. It should be designed for the end user to allow for a high usability in practice. Furthermore, the product should reflect the values of the brand, IMI Hydronic Engineering, to meet the needs of the buyers and increase the perceived value for the end user.

## 1.4 Research questions

How should the optimal balancing instrument be designed for the end users, the buyers and the brand IMI Hydronic Engineering?

- What problems related to the environment that the users work in are there?
- What problems of use are there with current balancing instruments on the market?
- What limitations and problems of use are there with the TA-Scope and related products from IMI Hydronic Engineering?
- How can a balancing instrument be designed to meet the desired level of ergonomics of a professional tool in the HVAC business?

## 1.4 Demarcations

Due to geographical constraints and the level of advancement regarding technology, the thesis will be limited to the Swedish market to allow for qualitative interviews with the users.

Due to demands set by IMI Hydronic Engineering, the thesis will be focused on producing a conceptual proposal for the redesign of the physical product, the TA-Scope. IMI Hydronic Engineering are planning to make a follow up study during 2018 with this thesis as a base.

## 2. THEORETICAL FRAMEWORK

The following chapter describes key areas of research that was used throughout the project. As this project was focused on exploring the redesign of the TA-Scope, a tool for a small group of professional users, the user needs and requirements were deemed of utmost importance. Human-centered design was therefore considered the most effective and accurate approach for the project. Furthermore, ergonomics and anthropometry in the HVAC business were key elements to complement the usability of the product. As the TA-Scope is a professional tool, usability was identified as the singlehandedly most important factor to meet the user needs. Finally, as the TA-Scope is a flagship product of IMI Hydronic Engineering, the importance of branding became apparent.

### 2.1 Human-centered design

According to ISO Standard 9241-210:2010, Human-centered design is defined as follows: "Human-centered design is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, usability knowledge, and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance". It is further mentioned that human-centered design and user-centered design are often used as synonyms. However, human-centered design focuses on human users, while user-centered design contains no specification.

#### 2.1.1 Process

The human-centered design process as defined by ISO Standard 9241-210:2010 can be seen in figure 1 below. This process is based on talking with and observing actual users to understand the user context in practice. From there, requirements are derived that serves as a base for conceptual products. These concepts are finally evaluated and necessary iterative steps are taken to produce a final concept that meets the user requirements.

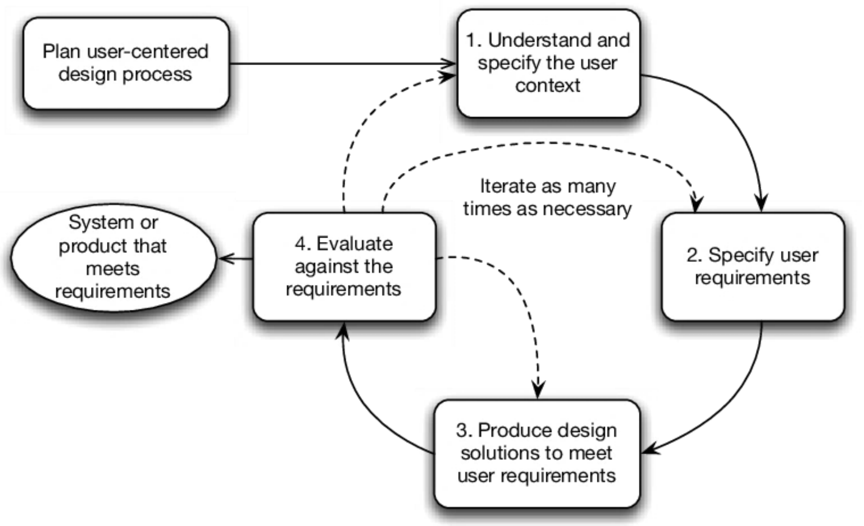


**Figure 1 The user-centered design process (Schulz, Fuglerud, Arfwedson, & Busch, 2014).**

The important thing to consider in human-centered design is that the users are the driving force of the design process. Therefore, all information regarding needs and requirements should come from the users, rather than the designer. Furthermore, as human-centered design is an iterative process, as can be seen in figure 1, the designer should maintain the users in the loop throughout the project to validate and analyze decisions. According to Preece, Rogers, & Sharp (2002), involving users in the design process leads to more effective, efficient and safe products.

In order to understand and specify the user context and specify the requirements that the users have, Preece et al. (2002) suggests background interviews and questionnaires, sequence of work interviews and questionnaires, focus groups, on-site observations and role playing, walkthroughs, and simulations as possible tools. Abras et al. (2004) complements these tools with prototyping and sketching where the users are asked to evaluate ideas and participate directly in the design process.

As can be seen in figure 1, the process continues with ideation and concept development, where the users are continuously asked for input and ideas, which are then used for reiterations until a successful product emerges.

## 2.2 Ergonomics & Anthropometry

Anthropometry refers to the systematic collection of data on human body measurements (Encyclopedia Britannica, 1998). Anthropometric data has been collected globally for many different reasons since its start, one of the reasons being to aid designers in creating solutions of the right scale, i.e. to fit the intended segment of a population. When attempting to create a design that includes as many people, and their physical differences, as possible, a good size of the product would be one that is in the overlap of acceptable intervals for people in the higher and lower percentiles (Österlin, 2011). Furthermore, Österlin (2011) points out that it is crucial that one is observant of whether or not the data matches the target group, since differences can be significant.

Since this project is centered around a handheld product, the anthropometric data that is of importance is the one that deals with hand sizes. The most readily available data concerning measurements of hands is length and width, which is why these are used in this thesis. The length measurement is from the tip of the middle finger to the distal wrist crease, and the width is the widest part of the hand, measuring above the thumb (figure 2).

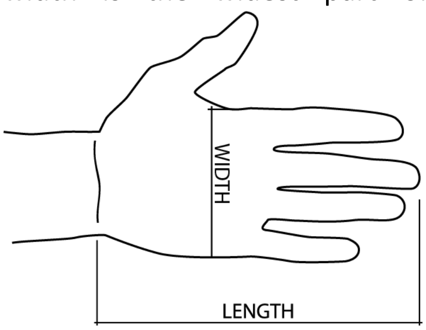


**Figure 2 Illustration of how measurements for hand length and width are acquired.**

As previously mentioned, anthropometric data is often not only global, but divided into groups, which can help a designer in specifying sizes close to what the actual users need. In one compilation of anthropometric data for Swedish people (Pheasant, 2003), adult men have the largest hands in the 95th percentile, with a length of 205 mm and a width of 95 mm. In the same compilation one can find that the smallest in the 5th percentile is those of females, with a length of 165 mm and a width of 70 mm. Pheasant's (2003) data has since been revised, refined and extended, but this excerpt is deemed suitable for this project.

During the pre-study phase of this project, a number of users were contacted for help with finding the right people to interview and to find appropriate opportunities for observations. Out all of the people that were contacted, none were female. This was not intentional, but rather something that helped shine a light on an important aspect of the users. When conducting further research, a document from Statistiska Centralbyrån (2016) revealed that 99% of Swedish HVAC-workers between 16 and 64 years of age, are in fact male.

If the final product would turn out to be a handheld device, much like the current one, this leads to a need for reflection over which percentiles of hand sizes are reasonable to design for. Designing for people between the 5th and 95th percentile of men would mean that the few women that have these jobs may have to work with equipment that does not fit their hand size, which is a poor choice. Designing for people between the 5th percentile of women and the 95th of men could be seen as ignoring the distribution of users.

However, designing for between the 5th percentile of women and the 95th percentile of men would obviously include the 5th percentile of men. This would make for the better design choice, given that it is possible to create a design that is in the overlap of acceptable sizes for both ends of the spectrum.

As for the ergonomics during use, there are quite a few tools used for evaluation. One that is designed to evaluate potential harm of the upper limbs is RULA (Rapid Upper Limb Assessment). Since the TA-Scope is a handheld device, the largest risk for damage is in the upper limbs, making the RULA a suitable tool. For the RULA, a position that involves high degrees of flexion or extension, high loads, or is frequently occurrent is chosen for the first evaluation (McAtamney, 1993), since these aspects raise the risk of damage. The load refers to the force that the product exerts on the user's body. In the case of the TA-Scope the load equals the weight, since no other operations than lifting it will occur. Since its weight does not even exceed 1 kilogram, this means that the product will perpetually fall under the least damaging category.

## 2.3 Usability

The official definition of Usability according to ISO 9241-11 is: "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." The specified goals in the case of the TA-Scope is to balance systems with precision. The effectiveness, efficiency and satisfaction in the specified context of use is where this project comes in. This is explicitly mentioned in the purpose of the project and usability is therefore one of the key factors to accomplish the set goals.

Usability in this project will be handled through the human-centered design process. The project will be focused on identifying the problems of use that the users have and solve these issues through the design of the final concept. It will also take into account the environment that the users work in, to produce a product that is optimized for surrounding factors that affects the context of use. Finally, the users will be observed to identify how the current TA-Scope is used, both regarding physical usage and through the interface, and the concept will be designed accordingly. Physical usage implies the overall interaction and handling of the TA-Scope, such as placement when not in use, ergonomic aspects and recharging habits. The interface includes the direct interaction with the TA-Scope using the screen and the buttons.

## 2.4 Branding & Visual brand identity

Since this project is so tightly tied to IMI Hydronic Engineering, it is important to talk about the implicit and explicit values that are associated with the brand in order to be able to achieve the correct segmentation. Warell (2006) mentions the importance of design as a way of creating both product identity and brand recognition and that it is therefore important to make conscious decisions in the design that is in line with the overall strategy of the company. However, as IMI Hydronic Engineering supplied a design manual for the project, the most important part of the branding in this case was the implicit cues.

One way of exploring a brands personality is through the use of archetypes (Roberts & Marshall, 2014). The archetypes that are further suggested by Roberts & Marshall are:

| | |
|---|---|
| Caregiver | caring, compassionate, generous, protective, devoted, sacrificing, nurturing, friendly |
| Creator | innovative, artistic, inventive, non-social, a dreamer looking for beauty and novelty, emphasizes quality over quantity, highly internally driven |
| Everyman | working class common person, underdog, neighbor, persevering, wholesome, candid, cynical, realistic |
| Explorer | independent, free-willed adventurer, seeking discovery and fulfillment, solitary, spirited, indomitable, observant of self and environment, a wanderer |
| Hero | courageous, impetuous, warrior, noble rescuer, crusader, undertakes an arduous task to prove worth, inspiring, the dragonslayer |
| Innocent | pure, faithful, naïve, childlike, humble, tranquil, longing for happiness and simplicity, a traditionalist |
| Jester | living for fun and amusement, playful, mischievous comedian, ironic, mirthful, irresponsible, prankster, enjoys a good time |
| Lover | intimate, romantic, passionate, seeks to find and give love, tempestuous, capricious, playful, erotic |
| Magician | physicist, visionary, alchemist, seeks the principles of development, interested in how things work, teacher, performer, scientist |
| Outlaw | rebellious iconoclast, survivor, misfit, vengeful, disruptive, rule-breaker, wild, destructive |
| Ruler | strong sense of power, control, the leader, the judge, highly influential, stubborn, tyrannical. high level of dominance |
| Sage | values truth and knowledge, the expert, the counselor, wise, pretentious, philosophical, intelligent, mystical |
| Shadow | violent, haunted, primitive, tragic, rejected, awkward, darker aspects of humanity, lacking morality |

**Table 1 List of brand archetypes (Roberts & Marshall, 2014)**

These archetypes and some more from other models have been summarized into five categories by Leidenkrantz (2017) and simplified to a visual model than be seen in figure 3 below. The categories are Dominance, Freedom, Belonging, Cautiousness and Expertise and all symbolize how the company presents themselves and builds an image towards the customer. As mentioned before, the products are just a small part of this, but are a vital component to achieve a coherent brand image by reflecting the same values as the brand through using visual cues.

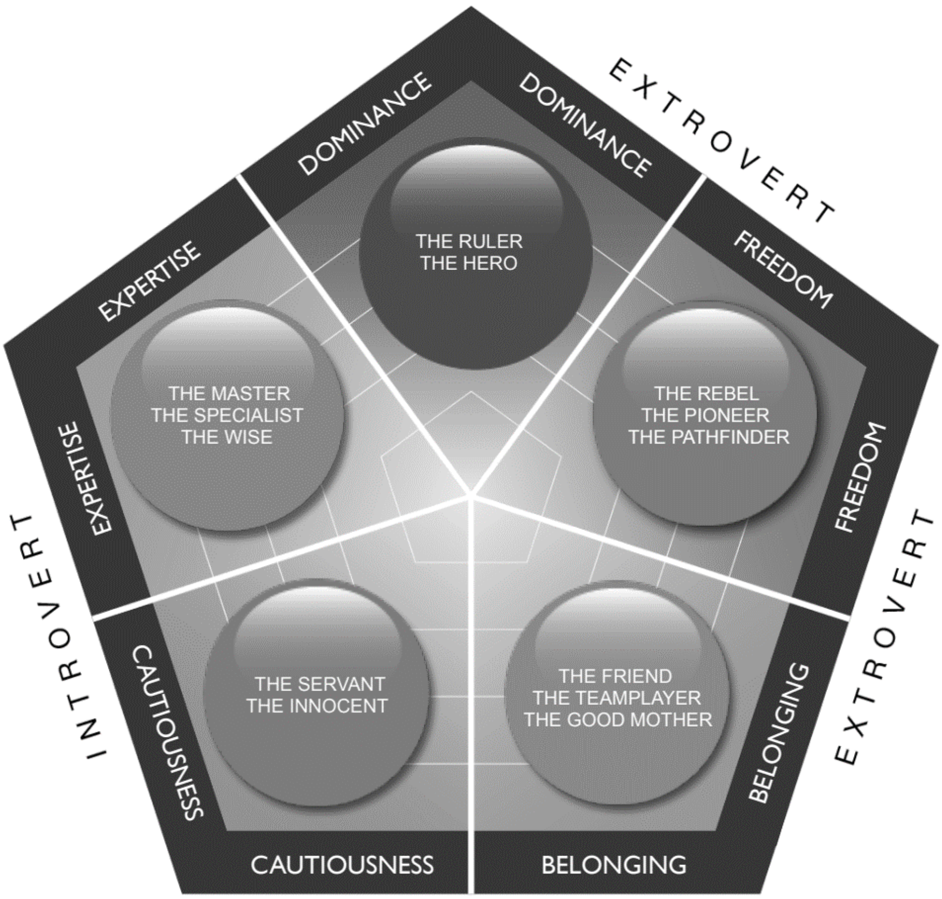


**Figure 3 The five brand categories (Leidenkratz, 2017).**

## 2.5 Conclusion

The human-centered design process will be the underlying model for the project as it allows for an approach that focuses on the problems that the users have found themselves. Through this process, ergonomics and usability of the product can be optimized for the end users. Ergonomics will be analysed through a Rapid Upper Limb Assessment (RULA) according to the anthropometric data of the users. Usability meanwhile will be a theoretical focus, but as this project is limited to presenting a conceptual solution, more evaluation of finished prototypes will be needed after the project. Finally, branding will play a key role in decisions, as IMI Hydronic Engineering sells the TA-Scope as a flagship product and the end user is rarely the buyer.

## 3. THE TA-SCOPE


**Figure 4 The TA-Scope**

The TA-Scope is a handheld balancing instrument for hydronic systems and is designed and manufactured by IMI Hydronic Engineering and can be seen in Figure 4 above. It allows for the balancing of hydronic systems through a connection with a differential pressure sensor unit, called DpS-Visio. The DpS-Visio is manually connected to a valve with two tubes, and connected via Bluetooth with the TA-Scope, to communicate the measurements. The TA-Scope is then used to perform precise calculations to determine the optimal settings for the valves in the hydronic system.

The TA-Scope as a product is focused towards precision and durability and is marketed towards experts who value quality products with a minimum margin of error. As the settings of one valve impacts all other valves in a hydronic system, it is vital to have a complete overview of the entire system to reach optimal efficiency. Because of this, IMI Hydronic Engineering have developed a unique set of methods for the TA-Scope, to allow maximum precision in the settings. The methods in the TA-Scope enable all of the valves in a system to be precisely balanced against each other internally. Thereafter, the pump and the partner valve (a valve placed in proximity to the pump, thereby controlling flow through the entire system) can be used to fine-tune the system to a point where all valves get the optimal flow. This, in turn, means an even, comfortable climate throughout the building and a minimum waste of energy.

The TA-Scope is furthermore used in damp and dirty industrial environments and the users frequently work on ladders and construction elevators. Because of this, IP Classification and build quality are key features for the product to be worth its premium price tag of around 1500 euros. IP Classification is used to measure an electrical products resistance against dust particles and water (IEC 60529).

## 3.1 Technical information

The TA-Scope contains four main modules that enable its features. A sandwich construction is used for the first module where the keyboard and the screen are encased with a plastic layer on the inside, which keeps the printed circuit board (PCB) for the keyboard in place. A brushed metal layer that acts as an aesthetic design feature for the rugged look is then fitted on the outside of the sandwich. Module 1 can be seen in Figure 5 below.


**Figure 5 Module 1 - Sandwich construction**

The second module, that can be seen in Figure 6 below, is the main PCB that houses the processor and the connectors for charging and transferring data. The PCB can be seen in figure 6 below.

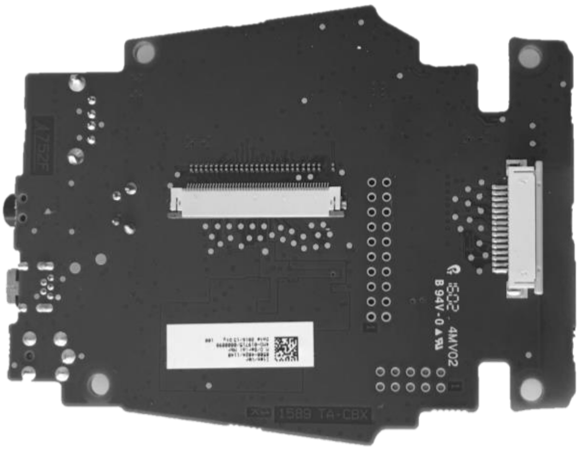

**Figure 6 Module 2 - PCB**

The third module is the screen, which is connected to the main PCB and positioned directly on top of it. As can be seen in figure 7 below.

**Figure 7 Module 3 – Screen**

The fourth module is a 3.7 Volt, 4.4 mAh certified battery pack that uses two Li-ion 18650 batteries. The battery is the limiting factor regarding the thickness of the product and is mounted in the bottom of the outer casing. The mounted battery and the casing can be seen in figure 8 below.

**Figure 8 Module 4 - Battery, mounted in housing**

As can be seen in the previous picture, the technical components are encased in a relatively thick, rugged polymer housing that partly acts as a seal for water and dust through stretch-fitting over module one. As also seen in the previous picture, a tight fit is ensured through bolt fittings that are attached through module one into the housing. The assembly of all the parts can be seen in figure 9 below.


**Figure 9 Assembly of the TA-Scope**

## 3.2 Balancing methods

The following flowcharts (Figures 10-13) were created in order to give an overview of how the different balancing methods are performed out in the field. The methods that are described are programmed in the TA-Scope and are designed by IMI Hydronic Engineering.

Text above or besides an arrow indicates what the TA-Scope informs the user to click. As there are no buttons marked “Enter” or “No”, for example, the button that corresponds to “Enter” or “No” are somehow indicated on the screen.

As a result from the flowcharts, it was possible to see that the methods can be quite complicated to perform. This is not necessarily bad, since the users have been trained in dealing with valves and balancing. However, the process should be possible to streamline and make more intuitive for the user.

The primary thing that can be observed is that the user enters a loop when starting over part of the process for a new valve. This aspect can unfortunately not be solved, since valves sometimes need to be far away from each other to cover a big grid of pipes. Inserting the DpS-Visio into the valve needs to be done as well, as the valves themselves are not equipped with a power source or sensor. Adding this would add a huge cost per valve. This leaves two possibilities; working with the interface to make sure that what the TA-Scope tells the user to press is matched with an obvious option and making sure that establishing a connection between the TA-Scope and the DpS-Visio is a simple task. There are, of course, other aspects that need to be dealt with, that cannot be seen from the flowcharts.

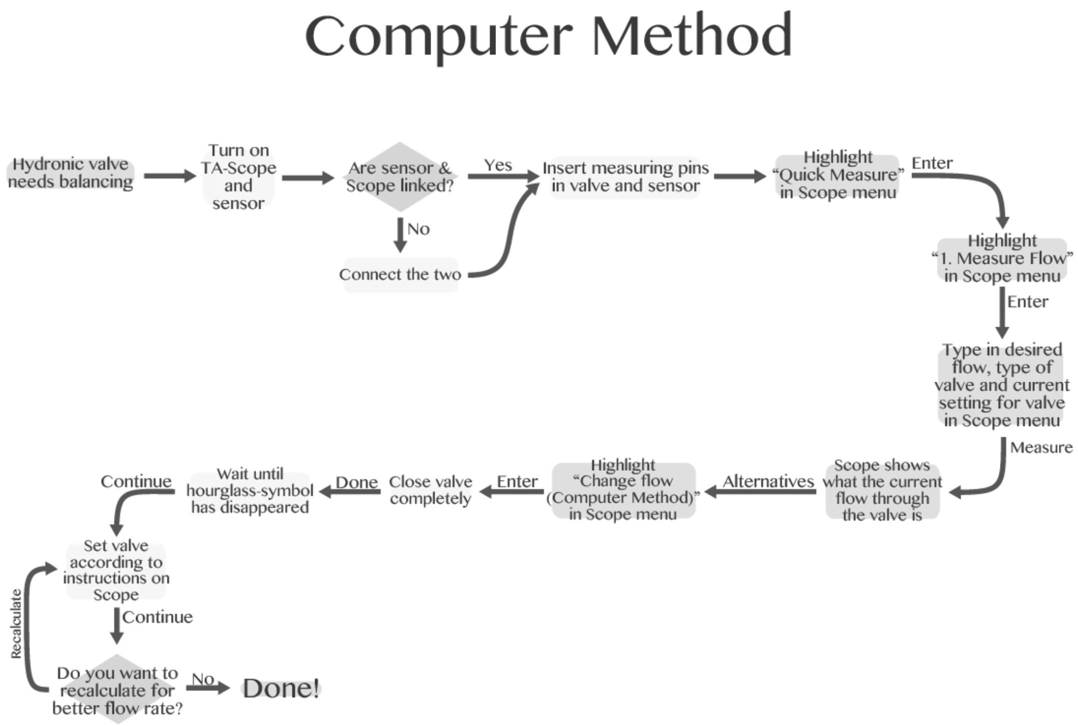


**Figure 10 Flowchart describing the Computer method.**

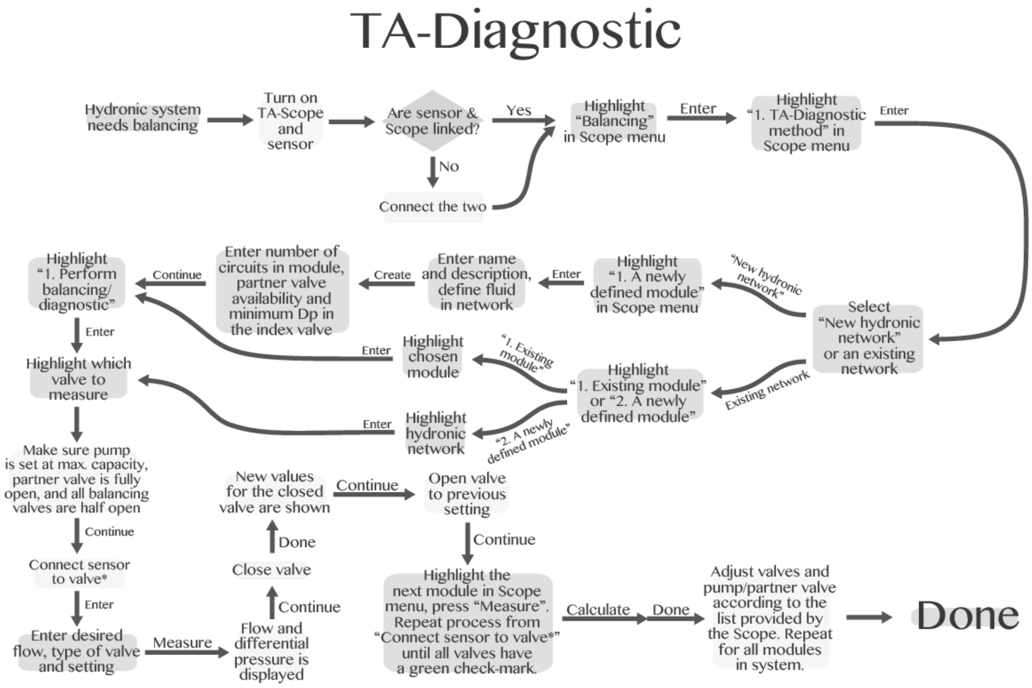


Figure 11 Flowchart describing TA-Diagnostic.

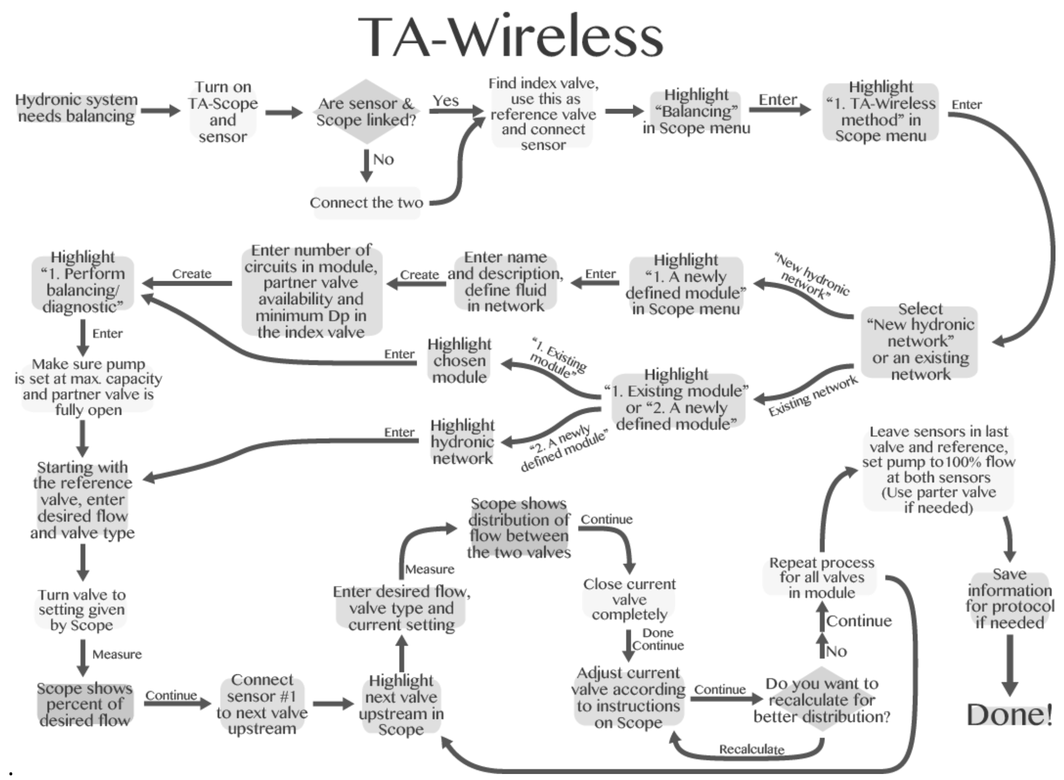


**Figure 12 Flowchart describing the TA-Wireless method.**

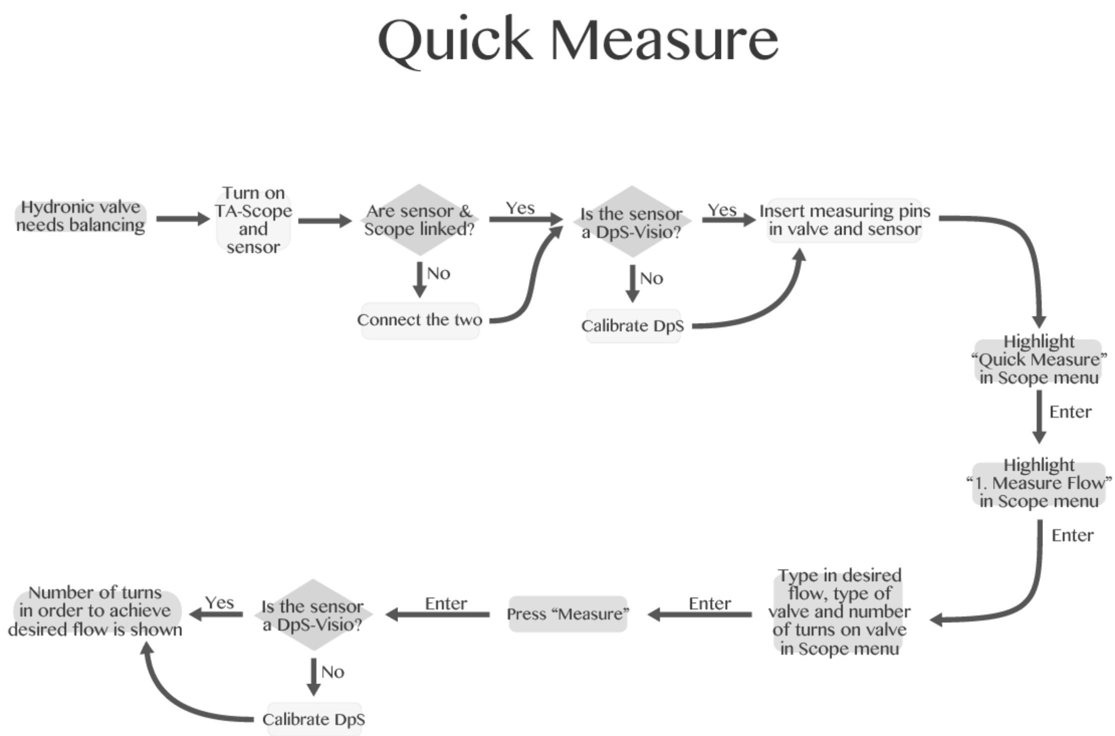


**Figure 13 Flowchart describing how to perform a quick measure.**

## 4. METHOD

The method chapter describes the full process and serves to explain the methods and steps taken throughout the project. The project was split into three main parts where the first phase was the data collection, where information was collected and analysed to build a basis for the project. The second phase was the ideation, where the collected data was turned into ideas for the product which was evaluated together with the team at IMI Hydronic Engineering. The third phase, the finalization, served to develop a final concept for the redesign of the TA-Scope. The project was furthermore conducted based on the human-centered design process, as described in 2.1.1 process.

### 4.1 Process visualisation

In order to make for an easier understanding of how this project was carried out, figure 14 shows a visualisation of the process used throughout the project.

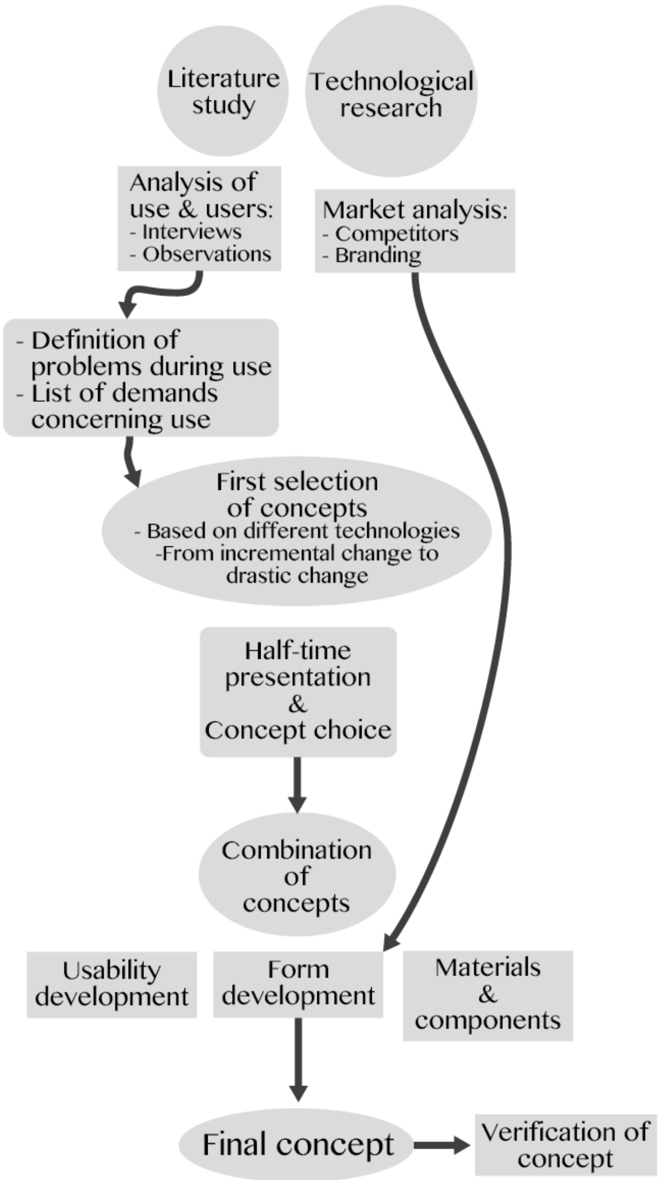


**Figure 14 Visualisation of the process used for this project.**

## 4.2 Data collection

The data collection phase was conducted to collect and analyse data from the users. This was done to identify user problems that could be solved through the redesign of the TA-Scope. The methods and steps taken are described in the following chapter.

### 4.2.1 Technical research

Technical research was vital to the final result as the size, shape and performance of the product largely depends on what components have been chosen. IMI Hydronic Engineering provided a TA-Scope that could be disassembled and used throughout the project. A list of parts with cost calculations were also provided to allow for a more in-depth analysis. In addition to this, an internet study was conducted to investigate and compare different technologies on the market.

### 4.2.2 User study

The user study was conducted with the goal of understanding the problems that the users faced with the TA-Scope. This was achieved through interviews and naturalistic observations with the users. The user studies were also complemented by partaking observations that were conducted on test rigs in the IMI Hydronic Engineering labs in Mölndal and Ljung.

*Interviews*

For this project, the large variety in geographical location of the users paired with the small target group, mainly made up of experts, made quantitative studies impractical and time-consuming. To achieve more and deeper answers and spend less time on finding users, qualitative interviews were therefore chosen. Furthermore, Opdenakker (2006) mentions phone interviews to be a good way of bridging the gap of a large variety in geographical location of the users. With these arguments, qualitative phone interviews were chosen as the method to use for all interviews. In addition, a semi structured approach was used. The strength of using a semi-structured approach is that it allows for probing of previously hidden problems while still allowing the interviewer to easily redirect the interview if it strays too far off topic (Wilson, 2014). Since IMI Hydronic Engineering had performed user studies in the past, the semi-structured approach was deemed the most suitable method, as it allowed for the potential of gathering new information that could previously have been missed.

Initially, a series of test-interviews were performed with the design team on IMI, and with friends related to the project. This was done to develop an interview guide for the semi-structured interviews. As this was very early in the project, focus was on formulating concise and clear questions that would lead to further discussions with the users, where useful information could be found.

The test-interviews led to the following interview guide:

- Have you used the TA-Scope?
- Does your company own one or several TA-Scope(s)?
- How often do you balance systems?
- What tools do you bring when balancing a system?
- How often do you use the TA-scope for the balancing of systems?

- How often do you charge the Scope? When, where and how?
- When you don't use the TA-Scope, what method do you use instead? Why?
- What are the problems in general when balancing a system?
- What problems have you encountered when using the TA-Scope?
- What are the biggest benefits of using the TA-Scope?
- What are the biggest cons of using the TA-Scope?
- What is the strongest reason for buying the TA-Scope?
- What would you say are the biggest reasons for not buying the TA-Scope?

The phone interviews were conducted by one project member on speaker phone, while the other one took notes.

As previously mentioned, the user group was limited to a small number of experts which made it difficult to achieve a large number of interviews. However, the ten interviews that were performed were deemed sufficient, as the information in interviews was frequently found to be repetitive. The interviews were approximately 30 minutes long and probing was used vigorously to spark spontaneous comments from the users. The interviewees were in the age span 43-58 and were all men. All interviewees further worked as consults and worked with the TA-Scope to a varying degree.

*Observations*

As this project was aimed at redesigning the TA-Scope, it was natural to perform observational studies of the already existing product, since this gave an opportunity to see where and how it is used. This information could then lead to a clear picture of what the current product is lacking, and thereby what problems the next product needs to address.

In order to extend the project group's knowledge on the subject of balancing hydronic systems, a series of observational studies were performed. For the first partaking observations, a test rig supplied by IMI Hydronic Engineering was used (See figure 15).

**Figure 15 Henrik using the TA-Scope to balance the test rig.**

One of the group members was given the task to act as a user of the product, while notes were taken by the other group member and the topic was freely discussed during use. An expert from IMI was present at all occasions, which made up for the fact that none of the group members were trained HVAC-professionals. As the goal was to simply learn more about the TA-Scope and the systems where it is used, it proved very helpful in this particular case, as all questions that arose could be answered by the expert.

The naturalistic observation was a field study at Volvo Penta, where a professional HVAC-worker and TA-Scope user worked with balancing a hydronic system. The field study was performed as a naturalistic observation, where the user had a system to calibrate while both project members were taking notes and asking questions when appropriate. This method was chosen as it gives a more realistic view of the problems that can occur during use, as the situation is not manipulated as it would be in a laboratory (Salkind, 2010). It was furthermore identified in the interview study that the users rarely used the built-in methods in the TA-Scope and instead used their own methods. This made a naturalistic observation even more suitable, since it could potentially lead to information about actual use in the field that was unaffected by an unnatural setting. In addition, as the observations were not controlled it was easier to spot problems with handling, and physical use of the product.

*Analysis*

The data collected in the user study was analysed through a deconstructed KJ Technique (Hanington & Martin, 2012). Instead of using sticky notes, a list with user quotes was made. These quotes were then silently categorized by both members into clusters and afterwards compared and interpreted. The quotes that were similar or identical were also simultaneously counted to help weigh the acuteness of the underlying problems and to identify low hanging fruits. The interpreted data was finally transferred to a list of requirements that was used as a live document in the iteration stages of the project to clarify the base for the final concept.

### 4.2.3 Competitor analysis

To allow for more accurate market placement of the product, a competitor analysis was performed using competitor websites, information from IMI Hydronic Engineering and targeted questions in the interviews.

*IMI Hydronic Engineering*

To narrow the scope and identify the strongest competitors on both a local and global level, interviews with IMI personnel were conducted. Information that had already been gathered from their customers in earlier user studies was also used to give a broader knowledge base to the analysis.

*Internet study*

An internet study was conducted to further specify the biggest competitors in the specific case of balancing instruments. In addition, technical specifications of the different tools on the market were compared to see how the TA-Scope measured up against other tools. The information gathered from the personnel at IMI Hydronic Engineering was vital to limit the scope and find the right information as balancing instruments for hydronic systems were frequently named the same as other similar tools that performed simple measurements rather than advanced calculations.

*Interview questions*

As previously mentioned in 4.1.2 User Study, the interviewees were asked several questions about what other products they had used to balance hydronic systems and what they thought of these products. These questions were specifically designed to get more information about the competitors on the market and to get information both regarding features that could be incorporated in the redesign of the TA-Scope and features that should be avoided.

### 4.2.4 Literature study

A literature study was performed to build a knowledge base around handheld devices. Ergonomics and anthropometry, that are described in 2.1.2 Ergonomics & Anthropometry, were subjects that immediately were identified as crucial for the further development of the concepts. Furthermore, literature on form, methodology, usability, materials and new technology was used throughout the project to make decisions. The literature required for this project was found in the library at Chalmers, on the Chalmers library website and on Google scholar.

## 4.3 Ideation

During the ideation phase, the data that was collected and analysed in the pre- study was used to create ideas around the product. The ideation phase was conducted using brainstorming as the main tool. The strategy was to use different technologies for interaction as a base for the ideation. The reason for this was that different interaction techniques were found to have a big impact on the possibilities regarding size and shape of the final concept. As an implication to using a varying degree of advancement in the technologies, the early concepts were automatically also led towards a varying degree of innovation.

The final stage of the ideation phase was a predetermined presentation with the team members and international leaders from IMI Hydronic Engineering. The focus of the entire ideation phase was therefore to produce a series of early concepts that allowed the company to steer the direction of the project towards the final concept.

### 4.3.1 Brainstorming & Brain sketching

Three separate brainstorming sessions with sketching allowed were performed, where touch function, buttons and voice recognition were the three interaction technologies that served as the base. These technologies were all used in similar products on the market and allowed for a wide variety of shapes, sizes and usage scenarios.

To specify how the limitations regarding the technological aspects affected the overall design: Using a touch screen allowed the screen and the buttons of the TA-Scope to be merged, and the shape could be altered to allow a bigger screen or a smaller product; Leaving the buttons as the main interaction point allowed smaller alterations in the overall shape of the product; Finally, using voice recognition for the main- or as a part of the interaction allowed similar changes as with the touch screen, as the buttons could be removed or at least be kept to a minimum.

Brainstorming and brain sketching were also used throughout the project to iterate on concepts as new information was gathered, which is in line with the human-centered design process, as previously shown.

### 4.3.2 Concept choice

Four concepts were presented to the team at IMI Hydronic Engineering to allow the company to steer the direction of the project in a structured way. First, the identified problems were presented thoroughly, backed by quotes, pictures and videos from the user study. The concepts were then presented accompanied by sketches. The sketches were handed out in printed form to the group and a discussion regarding each one followed. Finally, one of the concepts was chosen for further development in the finalization phase. The final decision was made by the team at IMI Hydronic Engineering in Ljung with the prior discussion as a base.

## 4.4 Finalization

During the finalization phase, the concept that had been chosen during the ideation phase was further developed and finalized both function wise and form wise. The findings from the pre-study and the literature study regarding ergonomics were used as a base for the choices regarding functionality and usability. The aesthetic design was finalized using a design format analysis, sketching and computer aided design (CAD).

### 4.4.1 Design format analysis

To get a better understanding of the semantic design cues in design for HVAC, a Design Format Analysis (DFA) was used. According to Warell (2006), the purpose of a DFA is to: “assess the relative weight of each element with respect to how visually characteristic the element is, compared to all other elements”. As handheld devices in the HVAC business were found to vary greatly in product expressions, focus was instead on finding the cues that represented the business in general. Therefore, other tools that were commonly used by the balancing technicians were added to the DFA. The reasoning behind this was that the redesigned device should have an expression that does not feel out of place when being used in the field. However, it does not mean that the product cannot reflect IMI Hydronic Engineerings brand, or that a visual cue (such as sharp corners, flat surfaces etc.) needs to be included because of its prevalence in the DFA.

### 4.4.2 Fish Trap Model

In order to explore the possible forms of the redesign, the Fish Trap model was utilized.

The Fish Trap model is a methodical approach used to generate and develop form concepts (Muller, 2001). Using the model means generating a large collection of design alternatives that are then meant to be analysed for usability. The first step in the model is to define the basic structure of the product, i.e. what components that are needed for the product in order for it to perform its task. These components are positioned and oriented differently in relation to each other, in many topological variants, giving what is called structural concepts.

The next step is to create formal concepts, which are different embodiments of the construction that support the components. This is again done in order to create a large selection of variants, this time called typological variants.

The final step is to create more detailed embodiments of the formal concepts, thus creating another large selection. This time around, manufacturing aspects are meant to be applicable to the concepts and the results concern different forms and shapes of the components in their already established configurations. For the purpose of developing the final concept, some modifications were added to the original version, in the form of free discussions regarding functionality during the process, allowing for cons to be disregarded faster and pros to be developed quicker. For the use of this model in this context, it was assumed that the display, PCB and battery would all be sandwiched on top of each other, in order to optimise space. Thus, all these three components were considered as one functional component.

The first step of generating topological variants therefore consisted of orienting and positioning the functional surface for eventual physical button/buttons. This was followed up with typological variants of the body of the product. Once a large selection had been formed, the next step was to create different forms and configurations for the buttons.

The focus with this process was not only regarding visuals and aesthetic appeal, but also largely on functionality. Discussions about pros and cons were, as mentioned, allowed during the process, and if an idea arose it was allowed to discard the process for a while. This meant a lesser risk of forgetting ideas that could prove meaningful in the end. While this approach differs from the original Fish Trap model, it was believed that a higher degree of freedom would allow for more developed ideas as a final result. The discussions regarded how the user would be able to interact with buttons from different angles, probable comfort in wearing the product and how other components such as inputs are possible to place in relationship to already established components.

### 4.4.3 Validation

A survey was performed with users from Europe to validate and extend the material found in the data collection phase, this was an iteration step to expand on the user context. The survey also served as a way of confirming the requirements list. The users that were asked were mainly from France, Belgium and Germany. The survey was in the form of a questionnaire written in English that was sent out by email, and a language barrier could therefore be present. The survey used open questions to allow the users to form their own answers. Furthermore, the questions were deduced from the discussion following the presentation with IMI Hydronic Engineering combined with comments that had been gathered from the Swedish users. The questions that were asked were:

1. How often do you charge the Scope? When, where and how?
2. How do you store the TA-Scope between uses?
3. Please thoroughly explain the steps you would normally take when balancing a hydronic system.
4. Have you ever broken a TA-Scope? If yes, how did it happen?
5. What are the problems in general when balancing a system?
6. What are the biggest pros and cons of the TA-Scope?
7. Is there anything that you feel is missing in the current TA-Scope?
8. Finally, do you have any other thoughts regarding the TA-Scope?

### 4.4.4 Evaluation

The evaluation of the usability of the final concept was performed as qualitative interviews with two members of the IMI Hydronic Engineering team that have used the TA-Scope in the field. This was due to the fact that no available users could be found, largely due to the geographical constraints mentioned in 4.1.2 User study. The interviews with the team at IMI Hydronic Engineering were performed in the same manner as the interviews during the initial data collection, as semi-structured qualitative interviews. However, these interviews were done face to face with the interviewees and a 3D-printed mockup up of the final concept was provided for the interviewees. This mockup was used to show placement on the arm and for the interviewees to get a feel for the size and form of the body, the size of the screen and the button placement. The questions used in the interviews were:

1. How do you feel about the size of the product and its different parts? (Buttons, screen, body)
2. How do you feel about the wristband? What will it need to feel secure and comfortable?
3. How do you feel about the functionality, considering the touch screen in combination with the built-in methods?
4. What problems can you see with the concept?
5. Additional thoughts?

An evaluation of the form of the final concept was performed by showing students at Chalmers University of Technology rendered pictures of the final concept, along with the 3D-printed mockup for size reference. The students were then asked to rank the level at which they perceived seven value words in the products form language. The ranking questionnaires were handed out on paper, and the evaluator had to rank the seven value words on a scale from 0 to 10. The value words were derived from the IMI Hydronic Engineering design manual, as well as from the brand analysis, and consisted of prevalent words that described desired expressions. Figure 16 shows the ranking system before the correct value words were added. The goal with this evaluation was to make sure that the new product had been finalised into a form with high ratings on these important value words.

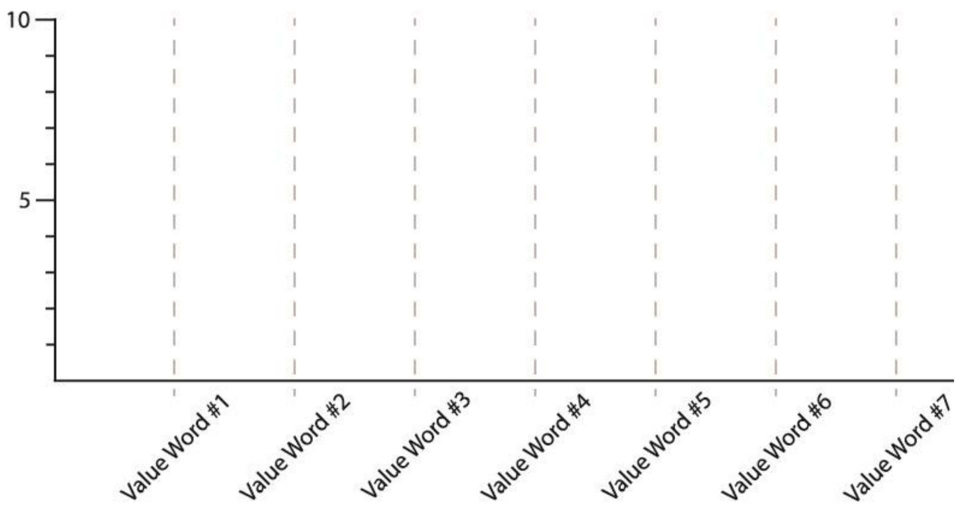


**Figure 16 The ranking system used to evaluate the form of the final concept.**

# 5. SEGMENTATION

The segmentation chapter describes the brand IMI Hydronic Engineering and maps and analyses the strongest competitors in the balancing instrument market. When designing any product, it is important to look deeper into the brand, to create a product that is coherent both with the products and the values and visions that the brand stands for and is associated with (Warell, 2006). The TA-Scope is a flagship product for IMI Hydronic Engineering and is often the only active interaction point with all the combined products from the brand that the users have. In addition to this, it was found in the interviews that the users are rarely the buyers when it comes to the TA-Scope. Combining these facts, it is therefore key that the users are presented with a positive, coherent experience that leads them to talk with the buyers, thereby solidifying IMI Hydronic Engineering as the leader in the segment.

## 5.1 Brand analysis

IMI Hydronic Engineering is one of the biggest competitors on the market when it comes to hydronic systems. The company presents themselves as a market leader with focus on technical expertise, quality, professionalism and reliability. Regarding technical expertise, short, technically focused product ads dominate where words like precision, efficiency and optimal are frequently mentioned. This is further accentuated by the clean, harsh lines of the company website, with a mainly monochrome color scheme and an industrial orange as the accent. The products come across as bulky and strong, with bold lines and visible metal parts dominating, which speaks of quality and reliability. The initial findings pointed towards IMI Hydronic Engineering being a conservative market leader with the main weight in Dominance and Expertise while leaning towards Cautiousness. However, as an accent to this otherwise traditionally industrial focus, innovation, tomorrow and smart are words that are frequently used on the first page of the website and in the new product ads. This gives an impression that IMI Hydronic Engineering are in a transition phase that leans more towards the archetype Freedom, than most competitors on the market. Having said this, IMI Hydronic Engineering still have a strong foothold in the more traditionally industrial archetypes of Expertise and Dominance.

In the brandmap (Leidenkrantz, 2017), IMI Hydronic Engineering is placed between Dominance and Expertise. Given as some parts of IMI Hydronic Engineering seem to be more traditionally cautious while some parts seem to lean more towards Freedom, a clash does occur. However, as the first page of the website showcases new products and would potentially showcase the redesign of the TA-Scope, Freedom will be the choice for this project. IMI Hydronic Engineering would however possibly need to clarify this for the overall brand at a later stage. The brandmap can be seen in figure 17 below.

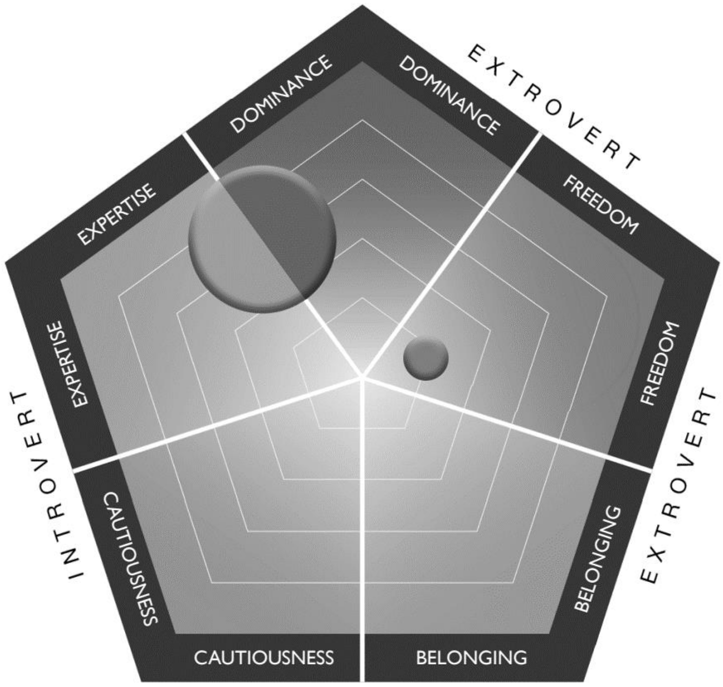


**Figure 17 IMI Hydronic Engineering placed in brandmap.**

## 5.2 Competitor analysis

The most important competitors that were identified by the team at IMI Hydronic Engineering, through the internet study and through data collected in the interviews were: Danfoss, MMA, Smart Balancing, Oventrop, Frese and Crane. What all these companies were found to have in common was that they had the balancing instrument hidden away on their respective websites. Instead their main focus was on selling valves, radiators and thermostats. This finding was also corroborated by the team at IMI Hydronic Engineering who noted that the same thing was partly true for them.

Regarding the products themselves, some dominant characteristics that were found included an initial impression of cheapness, a lot of plastic, outdated form language, simple forms and seemingly non-intuitive user interfaces. It was also found that several of the companies used the same rebranded plastic product from China, which partly serves as an explanation for these characteristics. All products contained elements of design for industry, where the colors were often bright yellow, orange or red and the forms were heavy and robust. However, in combination with the material choice of plastic, many products were instead found to take on a rather toy-like expression. This could be explained by the fact that tools designed for industry usually features metal parts and rubber handles as a contrast.

Some competitors were also found to offer mobile phone applications, which could be used with different models of smartphones. This solution offered a product that was significantly modernized compared to the pure balancing instruments that were found on the market.

## 5.3 Segmentation analysis

Based on the fact that most balancing instruments are outdated and hidden in technical documents on the company's websites, it seems like they are something that the companies have to be able to offer in connection to selling valves and other parts of hydronic systems, rather than something they want to have and put focus on. Even if the users in the interviews frequently mentioned the TA-Scope as the best tool on the market, it seems like it is more based on the fact that the competitors do not care, than the TA-Scope being the optimal balancing instrument. Worth mentioning is that IMI Hydronic Engineering are proud of the built-in methods and the accuracy and precision they can provide, but this does not guarantee that the tool itself is optimised.

Building on the previous paragraph, the consequence of balancing instruments not being the big money-making products in the industry is that the design is often overlooked. This is dangerous, as the balancing instruments often is the only touch point that the users of the main products, the valves, interact on a deeper level with throughout the lifetime of the combined products in the business. This opens up a great opportunity for creating the best visual touch point on the market, thereby promoting IMI Hydronic Engineering as the leader in usability and as the most up to date, modern company in the segment. As IMI Hydronic Engineering is already one of the market leaders and already acts like and present themselves as this archetypical category (2.4 Branding), this step would be natural and would match their other products and marketing strategies. IMI Hydronic Engineering already promote the brand as a synonym to quality, reliability and precision, and the TA-Scope should match all these values.

## 6. USERS & PROBLEMS OF USE

Given that the process of this project was based in human-centered design, identifying who the users were and what problems they had with the TA-Scope was a central part.

### 6.1 The users

The main group of users of the TA-Scope was found to be general HVAC-technicians that worked as hired consultants at construction sites during the later stages of the construction phase. The fact that these users worked as consultants also meant that they often performed more tasks than just balancing of hydronic systems, which lead to that they had rarely taken the time to learn the more advanced functions that the TA-Scope offer.

The other group was found to be experts, specialized in balancing hydronic systems. Because of this, they had the general idea that they knew how to balance without advanced tools helping them. They also mentioned that the methods and functions of the TA-Scope were designed for test rigs, that looked nothing like the real systems.

Both groups were found to mainly consist of older men and judging from the interviews it was clear that they had no personal interest in new technology or big changes.

### 6.2 Problems of use

Regarding the built-in methods of the TA-Scope not being used, one interviewee said:

*"The TA-method works great in a lab, but in reality, the partner valve is often missing. Companies cut costs by minimizing the amount of control valves and because of this the TA-method is useless".*

Another user said:

*"You have no control if you use the built-in methods since there is no way to tell if it is calculating correctly. It is like walking in the dark an entire day and in the end, you know if it worked or not".*

Instead of using the built-in methods it was found that the users most often made rough initial estimations and then went back and controlled the values. It was also mentioned that many sites had been pre-calculated by the employing company, which meant that the calibration process consisted of matching the valves with the set KV value and simply controlling that the initial calculations were correct using the TA-Scope. One of many ways to use the TA-Scope methods in the wrong way can be seen in Figure 18 below.

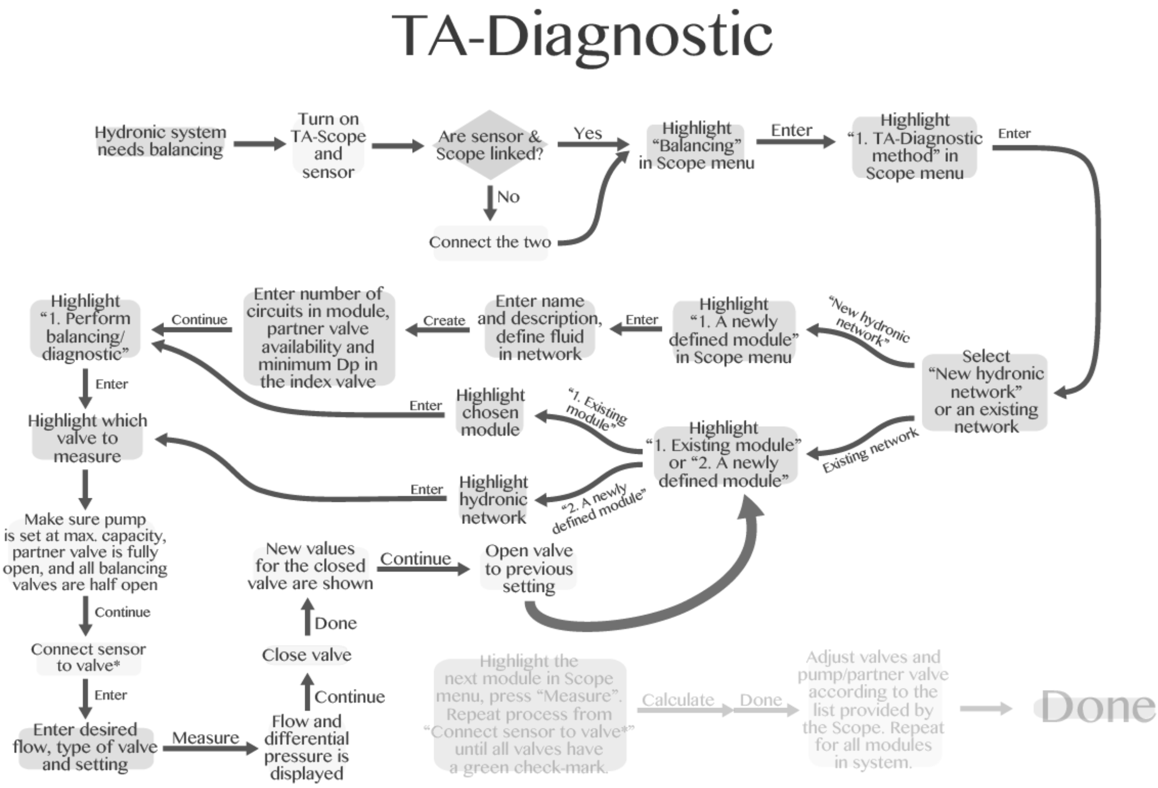


**Figure 18 Flowchart showing one of the many ways that the methods can be used in an incorrect way.**

Another recurring comment from the users was that drops from ladders onto concrete floors happen frequently and that the TA-Scope had a tendency of not being able to sustain these falls in their extremes. The need for service after drops meant that companies often had to rent a spare tool and one interviewee said that the tool had to be much more durable. However, the users also said that the durability of the TA-Scope was above their initial expectations and that it handled drops from 1-2 meters well. When analysing all the comments and probing the users regarding durability, it was found that the TA-Scope performed better than all competitors regarding durability and that the users overall were happy with the current performance.

The competing products were often applications in smartphones, which not only provided less durability, but also meant further complications when the device broke; the smartphones were often meant for private use, communication and other tasks alongside calibrating hydronic systems. Most users also said that they preferred using a tool designed for balancing hydronic systems, rather than using their private- or company smartphone. Users also mentioned in the interviews that the touch function was not fully viable in connection with glycol.

Furthermore, it was mentioned that a frequently occurring problem was systems containing a water and glycol mixture. This problem is also related to the use of smartphones, as they are generally not washable leading to glycol being transferred to other personal belongings and clothes. The glycol was also stated to have a negative impact on touch screens. Therefore, IP-classification 64 was deemed necessary and to allow rougher cleaning with water jets, IP-classification 65 was found to be optimal.

A set of smaller problems that were brought up less frequently were:

- One user mentioning that the work environment was sometimes dark and that a backlit keyboard would be preferred for these situations.
- Regarding the user interface, all included interviewees asked for more valves from competitors to be incorporated into the TA-Scope. It was further mentioned that competing tools like the Smart Balance performs better in this regard.
- Better back-up functionality was sought after, as large quantities of important information was often lost when crashes occurred.
- The function where the valve type is chosen was mentioned to be frustrating as it did not remember the last valve that was controlled and kept the setting.
- Finally, better reach of wireless signal was sought after as the relay unit for radio amplification was never used due to it being difficult to set up.

### 6.2.1 Observation

As already touched upon previously, durability was a frequently mentioned problem with the TA-Scope. This became even clearer during the observation at Volvo Penta in Gothenburg. The technician had brought two TA-Scopes to the work site with the reason being that they break too often to be relied upon. The user also mentioned that a lot of travel and overnight stays away from the home office was part of the job, and breaking the tool therefore involved the risk of wasting a full day of work before a new one could be sent.

In connection with the fact that the user had brought two TA-Scopes, a new problem could be identified. As the TA-Scope has to be paired with the DpS-Visio using a USB-cable the first time it is used, the user had trouble starting up the tool since the spare tool was accidentally used. It was also apparent that the user did not know about this fact and needed help to understand the problem, which could potentially cause a lot of wasted time and frustration when help is not readily available.

The most interesting finding during the observation was how poorly a lot of the valves are placed. As can be seen in figure 20, some valves were placed above roof tiles and close to beams, which made them difficult to reach and even harder to visually inspect. The technician mentioned that he often used his cellphone camera and a flashlight for these valves and voiced a concern that the TA-Scope did not allow these features.

When further analysing the interviews and combining the comments with what could be seen during the observation, it became clear that it was the use pattern of the TA-Scope that made it prone to suffer drops. Since the bulky product was frequently squeezed into pockets as the technician needed a free hand to use another tool, the risk of frequent drops was obvious. Furthermore, several users mentioned that the straps that could be used with the TA-Scope was annoying, as the tool was too bulky to have hanging around.

### 6.2.2 Work environment

One of the major problems that came up during both the interviews and the observation was valve placement. All of the people that were asked agreed that valves are often placed in inconvenient ways, and that this makes the job more difficult. The valve placement is obviously connected to where pipes are placed in buildings, and pipes are likely to be placed high up on walls to not interfere with people or furniture.

Furthermore, it is common to place a radiator under windows or skylights to deal with cold drafts that might occur. As a result of this, valves tend to be situated close to ceilings where reaching them leads to the need of a ladder, step stool or in some cases even a skylift. Another aspect that makes balancing more difficult is the fact that once the space where the valve will be placed is decided, it is not always angled in a way that leads to easy access. Sometimes the valve will face a wall or be hidden in a tight space.

A comment from the pre-study that might give explanation to this is that "everything has to do with money when building, which means everything has to be done as fast as possible". This means that valve placement is not always optimised for the person that will deal with the balancing. A quick glance at the Chalmers Campus reveals that valve placement can indeed lead to problematic situations, as seen in figure 19.

**Figure 19 Examples of valve placement at Chalmers.**

As previously mentioned, these situations mean that the user needs to be able to use the product with one hand, in order to hold on to something else so as not to fall. But more issues can be found. The most challenging valve placement found during observations was at Volvo

Penta, where photographs were unfortunately prohibited. However, figure 20 illustrates this placement.

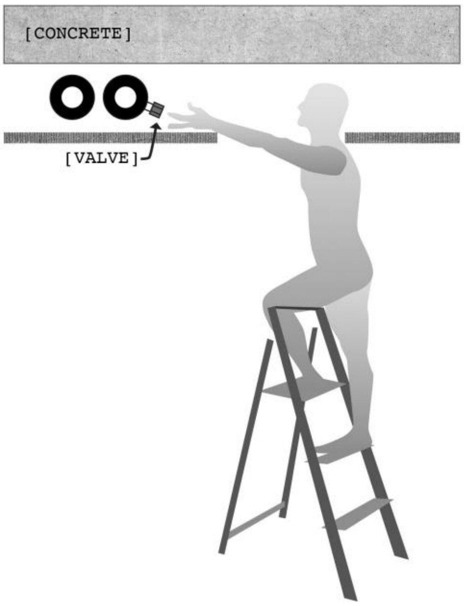


**Figure 20 Illustration of valve placement at Volvo Penta.**

As can be seen, the valve is placed on a pipe that is hidden in a space between the inner ceiling and the actual concrete ceiling. This means that the valve is at least 2.7 meters over the floor in a space with no lighting. Furthermore, the tiles were placed in a way that meant that the easiest way of gaining access to the valve was to lift out a tile that was at arm's length distance from it. The observed user noted that this type of placement is not good at all, but unfortunately not uncommon either. The balancing is then dealt with by standing on a step stool, reaching into the tight space to see valve type and setting. If needed the valve is adjusted by hand, as per usual.

## 6.3 Ergonomics & Anthropometry

Concerning comfort in the use of hand tools, it was found that literature dealing with this is in regard to tools where force needs to be exerted in order to perform a task. It was found in the observation and testing of the TA-Scope that no force needs to be exerted when using the product. Turning a valve or inserting measuring needles into a valve are likely the two activities that would require the most force, but both of these were outside the scope of this project.

Regardless, a RULA was conducted, which was used to analyse the posture seen when using the Scope during the observation. The posture is simply “standing with both feet on the ground, holding up the TA-Scope with one hand and looking on the display”. The RULA concluded that the Scope would have to weigh 2 kilograms before any further investigation into potential harmfulness is needed. The complete RULA can be seen in picture 21 below.

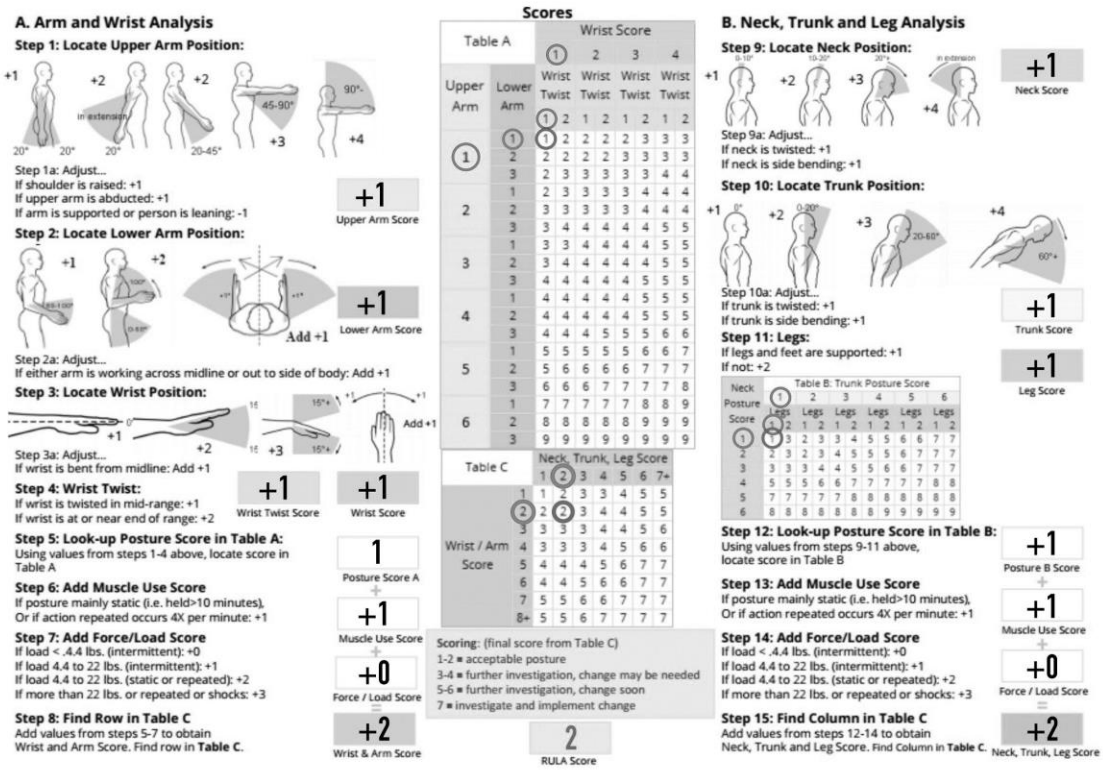


**Figure 21 Rapid Upper Limb Assessment (RULA) of TA-Scope use.**

So, without the weight of the product creating a harmful load, and without the use of the product creating harmful conditions, the focus lands on creating a product that is as comfortable as possible within these boundaries. This is corroborated by Kuijt-Evers (2007), who adds that it is not necessary to focus on comfort for users that do not employ their tool often or for extended periods of time. This is very descriptive of the situation observed in this thesis.

This does not mean that comfort is to be discarded completely however. There are still ways to make sure that the use is as comfortable as possible. For this, Kuijt-Evers (2007) proposed a flowchart that designers can use in order to systematically deal with aspects that can be an issue. The flow chart can be seen in figure 22. It is worth noting that Kuijt-Evers (2007) adds that the flow chart needs to be validated with other hand tools than screwdrivers and scissors, and that designers should evaluate the flowchart themselves.

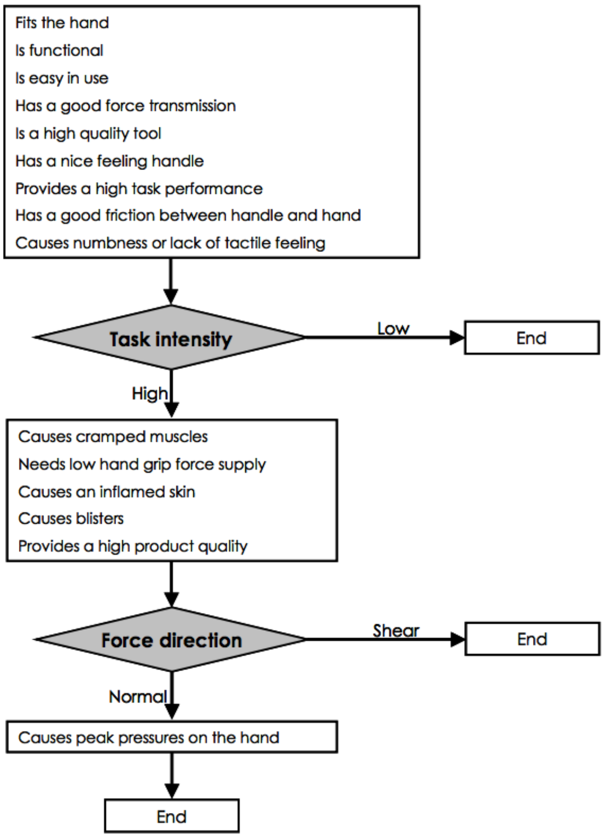


**Figure 22 Flowchart for dealing with comfort issues in hand tools (Kuijt-Evers, 2007).**

This flowchart, put into this context, would result in only overseeing the first set of aspects, since we have already established that the task intensity is low. In addition, it was concluded in the RULA analysis that the force transmission is negligible. The other aspects, however, are fitting to review in order to establish whether or not the comfort of the final product is where it needs to be for satisfaction.

## 6.4 Problem analysis

The main problems that were found with the current TA-Scope were:

- Functions and methods not being used
- Potential fall damage
- Valve placement

Out of these problems, functions and methods and durability were the two main problems that were directly connected to the product and that could be solved at the core issues. Therefore, the natural areas to work with were found to be usability and durability.

Usability in this case means that the methods should be easy to understand and use, and that it should present the user with an intuitive help when balancing systems. This is important not only for the users, but also for IMI Hydronic Engineering. As mentioned in 3. The TA-Scope, the methods are what gives the TA-Scope its precision in settings to reach the promised benefits regarding energy savings and optimal indoors climate. When pairing this with the conclusions in 5.3 Segmentation analysis, where precision is mentioned as one of the key values for the IMI Hydronic Engineering brand, the problem becomes clear. If the methods cannot be made more attractive to the users, the TA-Scope cannot stand for precision.

Usability is also important for the added sense of reliability and durability. As mentioned in 6.2 Problems of use, one problem is that large quantities of information have frequently been lost when the TA-Scope has crashed, which has been found to be related to both fall damage and software crashes in general. According to Kuijt-Evers (2007), reliability is one of the factors related to comfort in hand tools, as a user has to feel the ability to trust the tool in order to perceive it as comfortable. To first add a backup function and then also develop the user interface to give the user a sense of security that information is continuously backed up would meet both these values.

Durability was singled out as important due to the fact that repairs and service often are time consuming and forces the user to rent a new TA-Scope while waiting. This is problematic with the current TA-Scope, as a broken tool often means that the user loses information that is needed for ongoing projects. If the brand IMI Hydronic Engineering is to stand for reliability and quality, these issues has to be dealt with in the redesign. The most pressing concern was found to be fall damage related to work on ladders and sky lifts. As it is almost impossible to design products that can withstand these falls, focus was decided to be put on reducing the risk of falls completely.

## 6.5 List of requirements

In order to establish a clear picture of what the final product would have to improve upon, a List of requirements was created. This list was used as an evaluation tool for the final concept.

The list contains requirements taken from interviews, observations, testing and general discussions around current problems with the product today. The content was revised in collaboration with IMI Hydronic Engineering, in order to ensure that it was necessary and/or desired in the future. The list of requirements can be seen in Table 2 below.

| Type of demand | Requirement | Type of measurement | Target measurement | Method of evaluation | Origin |
|---|---|---|---|---|---|
| Functional | Perform calculations for balancing valves in hydronic systems | Binary | Yes | Functional check | Product category |
| Functional | Convey calculations to the user | Binary | Yes | Functional check | Product category |
| Durability | Avoid damage due | Subjective | Yes | Prototype testing | Observation & |

| | | | | | |
|---|---|---|---|---|---|
| | to being dropped | | | | interviews |
| Durability | Avoid damage due<br>to particles and/or water | IP Classification | 65 or higher | Prototype<br>testing | Observation |
| Durability | Avoid damage due to wear | Subjective | Yes | Prototype<br>testing | Interviews |
| Durability | Withstand repeated drops<br>onto concrete | Height<br>&<br>number of drops | 1.5 m<br>&<br>>10 drops | Prototype<br>testing | Observation<br>&<br>interviews |
| Functional | Allow for connection via<br>cables and bluetooth | Binary | Yes | Functional<br>check | Product<br>category |
| | | | | | |
| **Type of wish** | **Requirement** | **Type of measurement** | **Target measurement** | **Method of evaluation** | **Origin** |
| Durability | Not allow for dirt buildup | Radii of concave<br>edges | >3 mm | Functional<br>check | IMI |
| Functional | Allow for equally simple<br>balancing for all types<br>of valves | Number of valves<br>included in database | All that are being used | Functional<br>check | Observation<br>&<br>interviews |
| Functional | Allow for back-up of data | Binary | Yes | Functional<br>check | Interviews |
| Functional | Allow for use in dark<br>environments | Binary | Yes | Functional<br>check | Observation |
| Functional | Not allow for added time<br>to balancing process | Seconds | 0 | Functional testing | Reasoning |

| | | | | | |
|---|---|---|---|---|---|
| Functional | Allow for errors to be detected | Binary | Yes | Functional check | Interviews |
| Functional | Avoid problems with glare on screen | Subjective | Yes | Functional check | Observation |
| Functional | Allow for simple connecting of Scope and a DpS | Subjective | Yes | User testing | Observation |
| Functional | Warn user when a filter is getting clogged | Binary | Yes | Functional check | Interviews |
| Ergonomics | Allow for one handed use | Binary | Yes | Functional check & User testing | Observations & interviews |
| Ergonomics | Avoid pressure points or sharp edges on contact surfaces | Binary | Yes | Functional check | Theory |
| Aesthetics | Convey durability & precision | Subjective | Yes | User test | IMI |

**Table 2 List of requirements**

## 7. EARLY CONCEPTS

The early concepts were created as a base for discussion with the team at IMI Hydronic Engineering to achieve a final concept choice that could either be one of the concepts or a combination of them all. As mentioned in 4.2.1 Brainstorming/Brain sketching, the strategy behind the early concepts was to use different technologies for interaction to achieve a varying degree of innovation in the concepts. As a result, the early concepts ranged from incremental changes to a complete redesign with more innovative ideas shining through.

### Redesign for durability

The main focus for this concept would be to deal with the top problem as seen in the pre-study; breaking the product. It would be focused on adding material to soften drops onto hard floors and choosing the top materials regarding shock resistance.

This does not necessarily mean that other aspects would be ignored, but that in the case of “one or the other”, durability would always be prioritised. It is still possible to slim down the design and make sure that it is easier to use.

The concept is shaped to ensure maximum impact surface when dropped, which means that there are no sharp edges or corners in the design. It would still have a keypad and a screen, as well as connectors for the different chords. Figure 23 shows an early sketch that was used as discussion material for meetings with employees at IMI Hydronic Engineering.


**Figure 23 Concept sketch, redesign for durability.**

**Voice recognition**

By utilizing voice recognition as the main form of interaction with the product when it comes to entering numbers, the keypad can be removed, allowing similar changes in form to the touch screen concept. The concept allows the product to be slimmed down, while maintaining high impact resistance. This is due to the fact that the screen would not have touch function, which means that it can be covered with thicker, more durable transparent materials than glass.

In this concept, four buttons are kept from the original TA-Scope to allow easy navigation through the menus. These buttons could also be used for entering numbers when working in for example loud environments, or areas where voice recognition is not allowed. Figure 24 shows an early sketch that was used as discussion material for meetings with employees at IMI Hydronic Engineering.


**Figure 24 Concept sketch, voice recognition.**

**Touch Screen**

Utilizing a touch screen for the redesign of the TA-Scope would allow for the keypad to be integrated into the software interface of the product. This means that the product can be made smaller, which gives the added benefit of being easy to handle while balancing valves. A touch screen product can attain just as high IP classification as the current TA-Scope and works well in unlit environments as the interface is always lit up.

The concept is not unlike today's smartphones but will need thicker edges to protect the screen from breakage when dropped. As a concept, it does not take the prevention of fall damage into account further than that, but it is versatile enough that other partial solutions might be added to it. With this concept it is possible to make the screen larger, in order to increase the size of symbols and letters to aid in understanding and reading. At least one physical button must be provided as the “power on”-button and maybe a “main button” would be needed as well.

Disadvantages for this concept would be that a larger screen leads to a higher probability of the product landing on the screen and breaking it when dropped. Furthermore, capacitive touch screens are not known for working well in wet conditions.

The concept is aimed to give the user a unit that only needs one hand to be maneuvered, that is slim and easy to stow away and pick up again. Figure 25 shows an early sketch that was used as discussion material for meetings with employees at IMI Hydronic Engineering.


**Figure 25 Concept sketch, touch screen.**

**Smart watch**

The smart watch concept utilizes a watch strap to avoid drops altogether. This allows the product to be slimmed down, as less shock resistance is needed in the outer casing. The watch is designed with the same IP classification as the TA-Scope, which means that it can withstand the environment that the users are working in.

Regarding usage, the main interaction of the product is solved through a smart crown that allows the user to both rotate through numbers and click to accept. Two complimentary buttons are provided that allows the user to either accept or reverse a command. Because of the change in interaction from the TA-Scope, the user interface is minimized to increase the simplicity of the product. This is done through removing all methods and other functions that were found to be rarely used in the pre-study.

The watch is furthermore fitted with a rotatable strap, which allows it to be positioned on either side of the arm to allow for safe use on ladders. When positioned to be read from the anterior side of the arm, it allows the user to hold the ladder while using the product.

The smart watch concept is targeted towards simplicity and simplifies the use of the balancing instrument. It is furthermore focused on complimenting the style of use that was found to be most common in the pre-study, where rough initial measurements followed by control measurements was the preferred method. Figure 26 shows an early sketch that was used as discussion material for meetings with employees at IMI Hydronic Engineering.


**Figure 26 Concept sketch, smart watch.**

## 7.1 Concept choice

Leading up to the finalization phase, the concepts were presented to the team at IMI Hydronic Engineering. The reason behind the presentation was to get insights on which direction the project should take for the final redesign of the TA-Scope and what level of innovation that would be interesting for the company.

The winning concept was the Smart Watch, based on the reduced risk of drops, thereby increasing durability. By designing a wearable device, it also meant that two hands could be used when climbing ladders. However, the team did not feel ready to disregard any of the built-in methods in the TA-Scope and felt that rather than decreasing functionality of the product, more should be added. The analysis regarding these points was in line with the proceedings in 5.3 Segmentation analysis. As the IMI Hydronic Engineering brand stands for quality and precision and the methods are what enables these values, keeping the methods are more important than simplifying the product for the users. Furthermore, this was also in line with the fact that the users were rarely the buyers in the case of the TA-Scope, as had been found during the user study. As the buyers were found to be more interested in the most precise and durable tools on the market rather than the most user-friendly ones, the decision made even more sense. Finally, IMI Hydronic Engineering has put considerable investments into developing these methods that are unique for them and discontinuing these methods might be seen as the investments going to waste.

Based on these points, the Smart Watch concept was reevaluated and discussed. The final decision was to go for a larger wearable device than the initial concept, which was needed to house the necessary batteries and parts to allow for the same level of functionality as the TA-Scope. The new concept was given the working title “Wrist Computer” to reflect the increase in technical functionality and size compared to the Smart Watch. As the delimitations of this project included programming and details regarding the software, increasing the usability of the user interface was therefore deprioritized and limited to suggestions left as a further recommendation to IMI Hydronic Engineering.

## 8. FINALIZATION

Once the Wrist Computer concept had been decided on for further development, the project went into a finalization phase. This phase consisted of a wide focus on ensuring that the final concept had taken as much information from the user studies and competitor analysis into account, as possible. In accordance with IMI Hydronic Engineering, construction details such as how to ensure IP Classification, how to make the construction is stiff enough etc., were left for the company's own designers. In doing so, the final concept was only aimed at finding the optimal solutions, and any changes needed due to price of components or manufacturing aspects were not considered. In short, the goal was to make all features of the concept optimal and IMI Hydronic Engineering would later realize the concept as closely as they themselves saw fit.

### 8.1 Form development

As a first step in the finalisation of the form language of the new product, a Design Format Analysis (DFA) was used. This was done to ensure that the product would fit in the context of use. The common design cues that were found for tools and handheld devices used in the HVAC industry can be seen in figure 27 below. The wrench on the top of the DFA was found to have the highest score regarding general design cues in the selection.


**Figure 27 The DFA performed on tools and devices from the HVAC industry.**

The most distinct features that covered the whole range of products were bright warning accent colors, distinct split lines between different materials and compact forms. Many also had a combination of soft and hard form, with soft indicating grip and hard indicating functional parts. When looking at other products outside the design format analysis, these features were found across products from both the HVAC business and the industrial segment in general which supported the results further. However, when looking at concept drawings of the next generation of products, it was found that the bright warning colors were used much more sparingly. This led to the decision of using the design format analysis as a reference, not a template. The goal was to have something to evaluate forms against to make sure that the product would aesthetically fit into its environment, without being locked too much into the aesthetic of other tools in the segment. Examples of concepts can be seen in figure 28 below.


**Figure 28 Concepts used as inspiration for further development (Left: Hu, 2011, right: Umeå Institute of Design, 2014).**

In order to create new, potential forms for the Wrist Computer, the previously mentioned, modified Fish Trap was used. The modification in question was permitting free discussions during the process, and the Fishtrap quickly led to an abundance of discussions as different structures and forms were generated. Figure 29 below shows a selection of the sketches produced during this phase. Each sketch shows changes that were made with regards to the shape of the product body and the configuration of buttons. This illustration shows the reader how the sketching process worked; functional components/surfaces have differing orientations, there are six different structures and four different variants of physical buttons on each concept. For each new sketch, discussions ensued that dealt with the pros and cons of the new configuration. The DFA was constantly at hand during the discussions and was used to methodically evaluate which sketches had the potential to fit into the HVAC environment. It was quickly found that too ornate buttons with complex profiles made the sketches look sporty, round buttons were too reminiscent of toys, a tightly packed group of buttons had the tendency to be hard to read and looked outdated. Placing the buttons on the same surface as the screen and having quite small radii on the corners was the most promising, since this made the product look precise and more professional than other configurations.

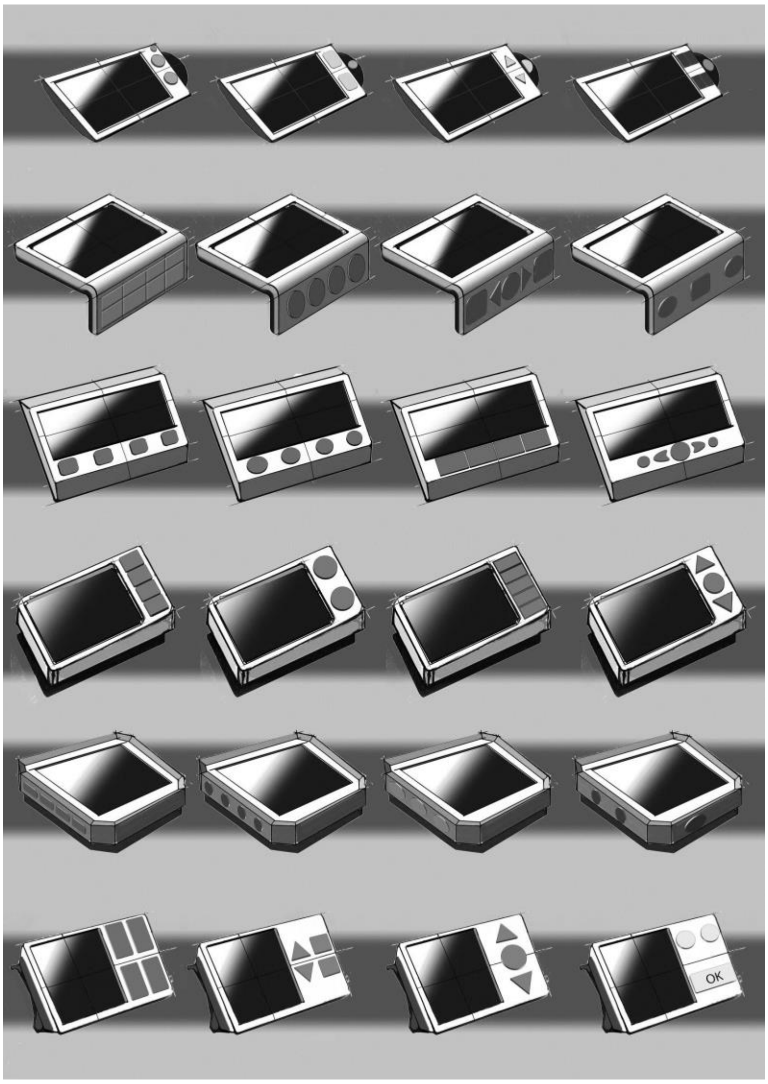


**Figure 29 Illustration of the sketch process.**

With these aspects in mind, the Fish Trap resulted in configuration of buttons, overall form of body and size of the product being decided on, and moulded into one concept that was developed further. This concept also incorporated the most important features from the discussions during the Fish Trap, which were:

Angled sides towards the bottom of the product was found to allow for a smaller contact surface with the user's arm in comparison to the size of the touch screen, as a consequence of the geometry. This means less of a feeling of wearing a bulky device with a larger screen, something that is considered a positive feature, since a larger screen allows for higher readability of the interface. Furthermore, the angled sides provide room for the user to move his/her hand more freely. The top sketch in figure 30 illustrates this concept. This was considered a major advantage for this form, since a regular wristwatch and its crown have a tendency to press against the user's wrist, sometimes leaving the user with cuts or marks. Since this product is considerably bigger than a wristwatch, trying to minimise the users feel of restriction and/or clumsiness was a high priority. The final added bonus with the angled sides comes in the form of being able to grip the body of the product to gain leverage when pressing buttons. There is no intention to have a high resistance in the pressing of the buttons, but this possibility will either be considered a nice feature or not be used, there is no risk of it being distracting.


**Figure 30 A collection of early sketches of the final concept.**

Another feature decided on during the Fish Trap sessions, was to give the form a soft edge towards the back of the user's hand. The reason for this being the same as the angled side: to minimise pressure on the hand during extension. These form discussions quickly lead to a discussion about the material of the product. To further minimise potential pressure, a soft rubber or silicone, with a hard polymer core (See figure 31), was found to be a viable solution. Some soft rubbers have the desired qualities of being soft, enduring water and dirt as well as standing up to some more harsh chemicals, making for a great fit in this context. Rubber also has the added bonus of being possible to use in pressure fits, thereby aiding in attaining the desired IP Classification. The material discussion resulted in the use of Cambridge Engineering Selector (CES), in order find a suitable material. When looking at the material library, all elastomer types were found to be suitable for the product. However, polyurethane was found to be relatively cheap and versatile when it came to surface structure. It also had high scores in manufacturing in all production methods commonly used. In addition, it was also found to be frequently used in smartphone shells designed for shock resistance. Finally, an internet search proved that currently popular fitness trackers, such as the Fitbit, successfully use elastomers (Fitbit, 2018) in a design that is meant to be non-intrusive for the user while performing athletic activities, leading to the conclusion that polyurethane or similar polymers are optimal materials for the outer surfaces.

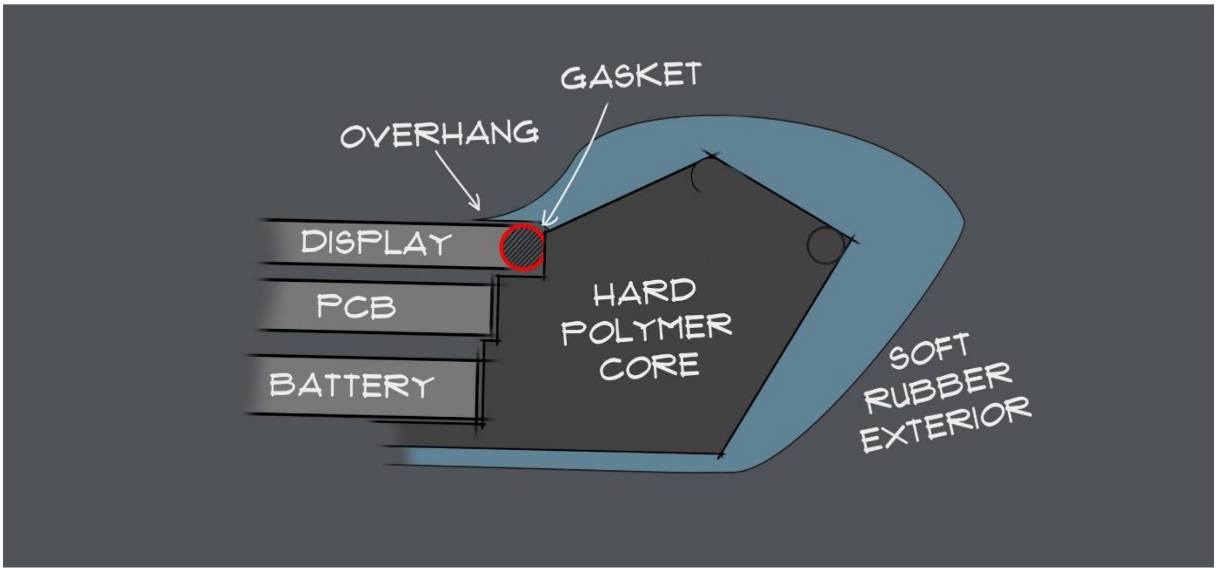


**Figure 31 Early construction sketch of final concept.**

## 8.2 Functional development

### Screen

As previously mentioned, the Wrist Computer is intended to be worn on the wrist, and because of this one key aspect was to reduce its size, especially compared to the TA-Scope, to minimise restriction and clumsiness. In the new concept, the most radical change that deals with this issue is the addition of a touch screen, which allows for most of the physical buttons to be removed from the product, leading to a smaller product. The use of a touch screen also produced other benefits; there are quite few mobile products on the market today that feature screens without a touch function. This means that a product that does not feature a touch function is running a high risk of being considered out of date, which could lead to an overall poor user experience. Secondly, touch screens are backlit. This means that the entire problem with working in dark environments naturally becomes easier. Had the concept utilised physical buttons, they would have needed extra lights to ensure that working in dark environments would be trouble free. This means that either the keypad would use extra energy from the battery, or that this feature would need to be turned on/off which would add extra steps during use.

The chosen screen was a 4” touch screen with an aspect ratio of 4:3. The modern, more elongated screens with an aspect ratio of 18:9 were found to be mainly adapted for smartphones, as they were most frequently used in a standing position. As opposed to this, the final concept was decided to be used in a lying down position, as it allowed for the screen size to be maximized on the given surface, the arm. However, when tested on programme colleagues from Chalmers, total product length started becoming hindering for the user after around ten centimeters. With these facts combined, an aspect ratio of 4:3 allowed the screen to be short enough for the wrist to extend freely, and wide enough to allow for maximum work space. The measurements can be seen in figure 32 below.

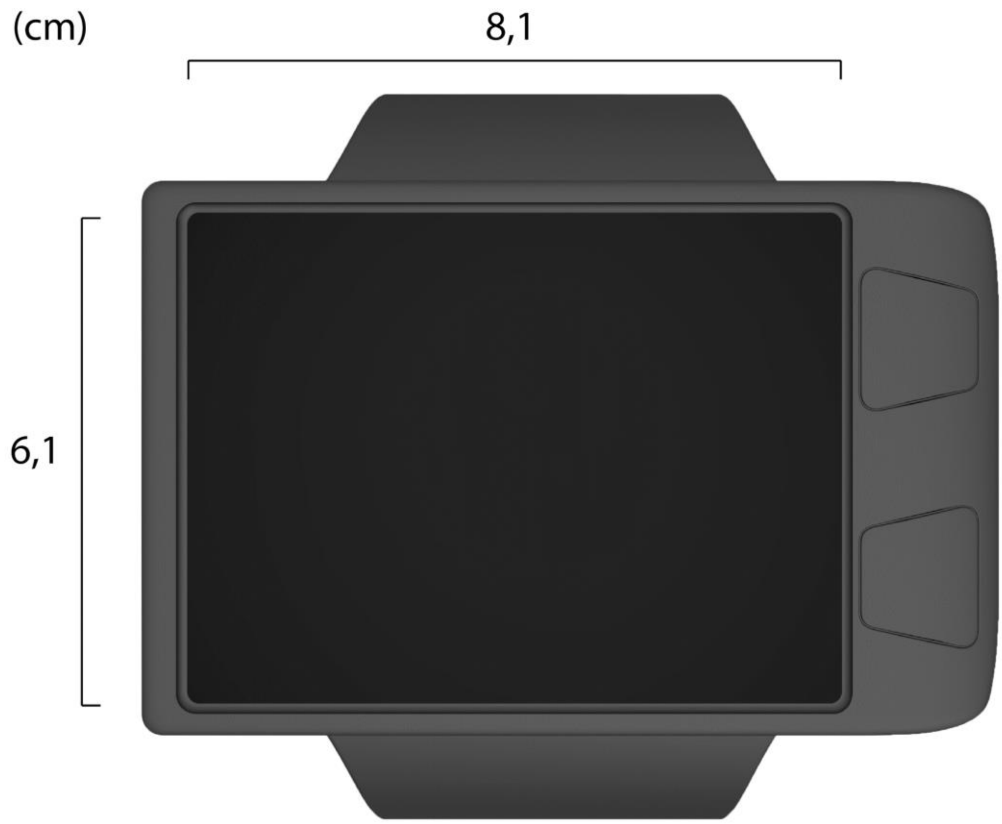


**Figure 32  Measurements for touch screen.**

The cons of a touch screen in the context “professional tools in HVAC” is first and foremost the lack of durability. The touch screens contact surface is made from glass, which can shatter. There are a lot of different types of scratch and crack resistant glass types in the smartphone business, but ultimately, IMI Hydronic Engineering must decide what choice makes the most sense. The recommendation from this thesis is simply whatever is the most crack resistant. In the specific case of hydronic systems, glycol has also been found to pose a problem, since it can stick to the screen and inhibit use. However, the recommended IP65 Classification means that the user can simply wash any potential glycol off with water.

**Buttons**

The number of physical buttons has been decreased from 23 to only 3. The first button is the on/off button situated on one of the long sides. This decision was made so that it did not interfere with the symmetry of the top surface, or the soft side that is potentially in contact with the user’s hand, while still being easy to reach with the free hand.

On the subject of symmetry, the two buttons on the top surface (Forward/Go/Measure and Back), are designed to allow for both right handed and left-handed users. The idea is to include right handed and left-handed mode in the main menu of the new product, and the form of the buttons mean that changing this will maintain easily understood buttons. The buttons are therefore shaped as relatively square arrows, pointing in opposite directions. The interface is kept very clean and easy to understand as a result, and the design was considered to communicate a sense of precision and durability. As a result of mockup testing, the buttons were scaled up from the original design, to accommodate for large finger tips. All other functions, such as scrolling through lists and changing settings will be easier to perform using the touch screen.

**Strap**

The strap that is used in order to secure the product on the user's wrist has a generous width in order to ensure stability against the user's arm. For the Wrist Computer to be perceived as a simple and sleek solution, it was also deemed necessary to find a strap that was simple enough to use that it would not cause an inconvenience for the user. This means that it has to be easy to put on when you are wearing a jacket or a t-shirt, and it should not matter how thick your arm is. Furthermore, this design might very well lead to a scenario where a user finds his or herself on top of a ladder without having attached the product to his or her wrist. This means that in order to safely put on the Wrist Computer, it needs to be possible to do with one hand.

This conclusion lead to a rubber strap equipped with magnets. One side of the strap has recessed magnets, the other protruding magnets, thereby making sure the trap does is not allowed to slide open. The magnets pulling on each other results in a strap that closes itself securely when the user brings both sides of the strap in the vicinity of each other.

**Connections**

Instead of keeping the four connections of TA-Scope, the recommendation for the new product is to cut down to one, a USB-C. The reason for this is that keeping the number of connections low minimises the risk of fluids or dirt getting in contact with the electronics. A USB-C is also possible to connect "upside down", leading to less struggles with inserting contacts. The connection is placed in the centre of the back surface of the Wrist Computer, for aesthetic balance. Since the rubber flaps that sealed connections on the TA-Scope have worked previously, a similar solution is used again, the only modification being a larger gripping surface.

**Flashlight**

Finally, it was decided not to add a flashlight to the new product, even though this was expressed as desire from users. The reason for this is that if the flashlight was integrated, a right-handed user would use the right hand to turn on the flashlight on the product and let go of a potential ladder (or railing etc.) in order to shine in the right direction. If a flashlight is instead something that the user keeps in a pocket or utility belt, the right hand can simply fish it out, turn it on and direct it. This means there is never a need to let go of a grip that is potentially protecting the user from falling.

## 8.3 Evaluation

**Demands**

When comparing the final concept with the list of requirements that was established in 6.4 List of Requirements, the added benefits of the new concept become quite apparent. First off, the concept will of course be able to perform calculations and convey information to the user. The next requirement, however, is where the new features come into play;

"Avoid damage due to being dropped" is quite clearly dealt with, in that the new concept is secured to the user during balancing. Instead of having the old TA-Scope to put down and pick up, the new product is less clumsy and fits in a pocket if needed. Most importantly, the concept allows for both hands to be free when dealing with other aspects of balancing, without the risk of a drop.

As previously mentioned, a higher IP Classification has been found to be needed, but the construction ensuring this as well as the withstanding of repeated drops is left for IMI Hydronic Engineering. This higher IP Classification also means that dirt build-up can be avoided by rinsing the product, but the new design has also avoided narrow corners and small radii where dirt is able to get stuck.

Furthermore, the concept has fewer buttons and connections that can break and the fact that it is less clumsy and takes up less space means that it avoids damage due to wear to a higher degree.

Since the touch screen itself emits light, it allows for use in dark environments and avoids problems with screen glare by counteracting incoming light. The fact that the product is worn by the user allows for one handed use.

Finally, as can be seen, and has been previously discussed, the overall design of the form and the material choices means that no pressure points or sharp edges on any contact surfaces are added. The remainder of the demands are connected to the software in the product and the DpS-Visio and are therefore left as recommendations for the later development of the touch screen interface.

**Interviews**

A picture of the mockup that was used in the interviews can be seen in figure 33 below.

**Figure 33 3D-printed mockup in carbon reinforced plastic.**

When asked about initial thoughts of the mockup, both users mentioned that having the product on the wrist felt weird and that it could be in the way when working in tight spots. However, both interviewees also changed their minds more and more during the course of the interviews, indicating that the biggest issue regarding the first reaction was the big change when compared to the handheld TA-Scope. As an example, one of the users started the interview by saying “This could be worse than the product today” and ended with “It is very exciting”. This could mean that the product needs to be introduced to users in a way that allows for them to get used to the new features in their own pace, in order to be accepted as a preferred alternative to the TA-Scope. Perhaps an introductory presentation and short course in how to use the new product would aid in this.

When asked about the size of the product and how it felt when worn on the arm, the users said that they would like the entire product to be smaller, to not be in the way, but at the same time have the screen bigger, to allow easy reading and interaction. Both users did however agree that the present compromise was good. This finding lead to the thickness of the product being revised. Since the design is aimed at optimising the size of the screen in comparison to the rest of the product, the concept still maintains the angled sides but the initial thickness of slightly above 20 mm was reduced to 15 mm. This measurement was considered less intrusive and bulky by the users, and the hopes are that this will reduce problems with working in the tightest spots.

Regarding the size of the buttons it was mentioned that they could be a bit larger to make finding them when not looking easier. One user also said that he would like a third button for the function “go”, or “ok”. Minimizing the number of buttons, however, was a conscious design choice. It is meant to remove problems with multiple buttons doing the same thing in parts of the current user interface. Therefore, a third button was deemed unnecessary for the new product. However, the buttons were made bigger towards the final version of the concept.

When considering the strap for the product, the users said that a wide band would be optimal, as it would give the best possible stability when worn on the arm. However, the issue of the watch being in the way in tight spots was brought up again. One proposal from the users was to design the product so as to make it possible to remove it from the wrist band and use it as a normal handheld. The strap was decided to be made wider than the original sketches to increase the stability. However, the question of being able to remove the product from its strap had previously been discussed during the project and rejected. This was due to the fact that the possibility could lead to the product being misused to a wide extent, causing unnecessary drops. As the product was also designed to be used on the wrist, using it as a handheld would be subpar to other alternatives. When asked how often both hands are used to reach into the tight spots, however, it became apparent that most of the time only one hand would be used. This hand is most often the strongest hand, i.e. the hand that will not be wearing the Wrist Computer.

The reduction of connections (from 4 to 1) was considered to be helpful in establishing the first contact between the balancing instrument and the DpS-Visio. One connection that is rotationally symmetrical means that users automatically understands where to connect the DpS-Visio the first time, and this wish from the list of requirements is considered fulfilled to the highest degree possible. However, the first time a user connects the two products is the only time a physical connection is needed. Therefore, the next interface should make sure that the Bluetooth connections needed after first use are easy to establish as well.

As the positioning of valves unfortunately is something that cannot be affected by any party involved in this project, making a product that is as thin as possible is the main factor that can deal with problems related to this. The concept as it existed before the morph, would have led to a product that was possible to reduce the size of even further, but as mentioned, IMI Hydronic Engineering chose to keep the methods. This is what creates the need of a larger product and, by extension, a potential problem with these tight spots. As the reduction of thickness might not be enough for users to avoid scratching and banging the product into pipes and walls, the demands on scratch and crack resistance for potential contact surfaces (body and touch screen) are higher than initially thought. Obviously, the body of the wrist computer will not crack since it is a soft polymer, and scratches will not influence the function, but the screen will be harder to read if it has a tendency to get scratched or cracked. Again, it is up to IMI Hydronic Engineering to decide on the price range of the materials, but scratch and crack resistance should be considered two of the most important properties for the screen at the very least.

**Form**

In order to ensure that the TA Wrist had achieved a form language that communicated the desired values, the previously mentioned evaluation questionnaire was created. Seven value words were derived from the design manual as well as the brand analysis and were chosen for their prevalence and how important they were deemed. The important excerpts from the design manual read as follows:

*"The design should focus on expressing exactitude and competence. The choice of shapes, materials, colours, surfaces and graphics are made with this in mind."*

*"Unnecessary details, complex shapes and over designed features should always be avoided to create an evident and clear product and to avoid confusing the user."*

*"Clean, clear sweeping surfaces with low but stretched curvature meets edges that generally has a small radius. This combination expresses strength and precision."*

*"Avoid intense colours."*

*"Precision, competence, functionality, professionalism, reliability, comfort and energy-efficiency are also important keywords. The products offered by the company must express these words. "*

*"Low-voiced, subdued."*

*"Fresh, up to date."*

From the brand analysis it becomes evident that reliability and precision are two of the most important factors for IMI Hydronic Engineering.

With this in mind, the final evaluation questionnaire was created, with seven value words that reflect the most important aspects to communicate with the new product. The list of value words are as follows:

1. Precise
2. Durable
3. Robust
4. Reliable
5. Efficient
6. Quality
7. Innovative

Students at Industrial Design engineering were asked to rank their perception of the value words and the rankings were compared to a goal ranking. The goal ranking clearly states that while all words are important to receive a high ranking on, quality is the most important. The reasoning behind this is that precision, reliability and efficiency are highly affected by later use and can be raised in ranking by a great digital interface. Durability and robustness are also highly affected, but by the physical use. How innovative the new product was perceived was added as a comparison with the current TA-Scope, to ensure that the TA Watch would be perceived as having a more innovative look. Figure 34 shows the rankings, with the goal ranking in the thicker black line.

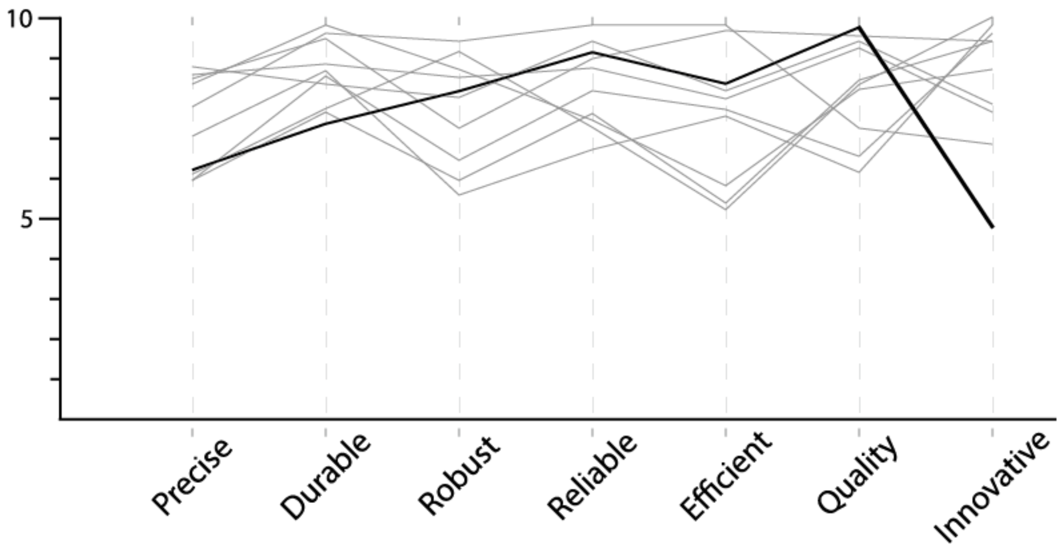


**Figure 34 Rankings from student evaluation.**

The ranking showed that high levels of precision and durability had been achieved with the form, almost exclusively higher than the goal levels. Perceptions of the level of robustness were quite scattered around the goal level, but all ratings were quite high. Although reliability, efficiency and quality were somewhat lower than the goal values, ratings are still high and considered satisfactory. Finally, the levels of innovation showed that a lot of progress has been made on improving the form language of the TA-Scope.

## 9. TA WRIST

The final concept is called TA Wrist and is a completely new type of product on the balancing instrument market. It is designed for the specific task of balancing hydronic systems, but at the same time draws inspiration from consumer products in the portable electronic device segment, to bring the product more towards the archetype freedom and leave cautiousness behind.

**Figure 35 Rendering of the TA Wrist**

### Expression

The bright warning accent colors have been toned down but are still visible in the user interface. This creates an overall expression that is more similar to products found in the modern portable electronic device segment while still indicating that it is a tool. This creates a meeting that handles the previously mentioned conflict between the archetypes Cautiousness and Freedom. The distinct split lines can be seen around the buttons, which otherwise follows the shape of the product, creating a solid and compact form. The tilted sides have been kept from the original TA-Scope, giving the product a slimmer look that speaks of precision.

**Figure 37 Tilted sides showing a slimmer, precise look**


**Figure 36 User interface in bright warning accent colour**

**Size**

The size of the TA Wrist is 10 by 6,5 cm and it utilizes a 4-inch touch screen. The size has been tested with users to allow for maximum screen size with the lowest possible restriction of movement for the hand.


Figure 38 Measurements of the TA Wrist

**Connections**

The handling of the TA-Scope has also been simplified by reducing the amount of ports to a single USB-C, that combines the functionality of charging, connecting to a computer and connecting to the DpS-Visio. Temperature measurements were found to be rarely used but could easily be made possible by simply redesigning the thermometer to work either by USB-C or by wireless connection.

Figure 39 Rendered back-view showing USB-C port

### Interaction

By introducing a touch screen in the TA Wrist, the possibilities regarding user interfaces have been brought up to date, as it allows for the use of open source operating systems like Android to be used to their full potential. The TA Wrist is also considerably smaller than its predecessor due to the fact that most of the buttons have been removed since they are no longer needed. A touch screen is also baseline for almost all portable electronic devices today and was therefore seen as a necessity to increase the perceived value of the product in the eyes of the end users. By making the screen the center point for the interaction, the problem with dark areas is also solved, as the screen will be backlit.

Regarding the buttons, two interaction buttons were kept in the design. These buttons are shaped to indicate a forward and backward action that translates to “go, ok, yes or next” and “no or back”. The main function of the buttons is that they allow for some interaction with the TA Wrist when the user cannot look at the screen, but they also speak of a robust tool as opposed to the touch screen. The buttons have been made rotationally symmetrical to allow for use on both arms through a left or right hand mode in the software. Finally, an on and off button is located on the side of the TA Wrist. This button is used to start and turn off the product, but also to lock the screen when the product is not used, to conserve batteries.

**Figure 40 Buttons and touch screen**

### The strap

As the users often wear jackets and long-sleeved shirts on the sites, and also often change clothes depending on the climate, it was important to design the TA Wrist to allow for easy repositioning. This has been done through the use of a band equipped with magnets, which allows the user to remove the product in one movement. The band has been made wider than normal smart watches to provide increased stability and to increase the contact area for the magnets, to ensure that it cannot fall off unintentionally. It has also been made extra long, to make positioning on the outside of jackets possible.

**Figure 41 Band of the TA Wrist**

**Figure 42 Band with magnets**

### Ergonomics

The TA Wrist has been designed with ergonomics based on anthropometric data from the HVAC business in mind. The generously rounded corners remove all potential pressure points for the user. The exaggerated tilt towards the hand allows for free movement without restrictions and the material has been specifically chosen with comfort in mind.

**Figure 43 Exaggerated tilt towards the hand**

### Materials

The exterior of the TA Wrist is made out of polyurethane, which provides similar properties regarding chemical resistance, water resistance, shock resistance, durability and feel as natural rubber, while being very easy to form and cheap to manufacture. The same material is often used in activity bands and watches due to its durability, comfortable texture and as mentioned, its water resistance. Polyurethane further provides an expression of robustness and durability due to its visual similarity to rubber, which draws the mind to car wheels and power tool handles. To provide stability for the product, a harder polymer will be used as a core. A multitude of polymers would be suitable for this application and which one to choose largely depends on the factory where it will be produced.

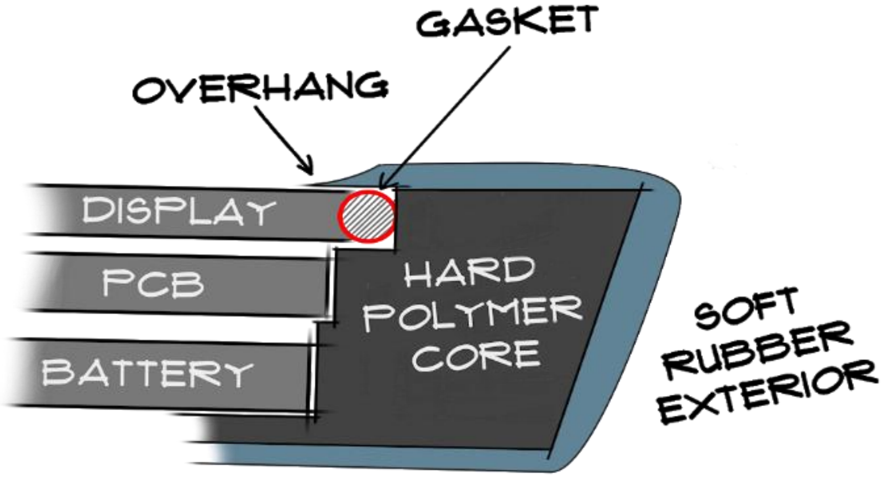


**Figure 44 Material choices and conceptual build**

### Context of use

When compared to handheld instruments, the TA Wrist adds another dimension to the usability of the product, as the user will always have both hands free when not directly interacting with the instrument. This advantage in usability goes beyond the product itself and adds positive changes to the actual context of use.

**Figure 45 Rendering of final concept**

## 10. DISCUSSION

The purpose of this project was to redesign and improve the balancing instrument TA-Scope for the users, through a human-centered design process. Improving, in this case meant creating a product that was adapted to the environment in which it was being used. It should be designed for the end user to allow for a high usability in practice. Furthermore, the product should reflect the values of the brand, IMI Hydronic Engineering, to meet the needs of the buyers and increase the perceived value for the end user.

The TA Wrist is a product of a human centered design project and is therefore designed with the end users in mind. The product has also been adapted to the environment in which it is being used through the choice of materials, IP Classification and through design features that solves the issues regarding durability. Regarding the physical product, usability has been thoroughly thought through. However, the main part of the usability regarding the concept would fall under the software category, which was a delimitation of this project set by IMI Hydronic Engineering. Having said this, regardless of how the new software will be designed, the TA Wrist offers better preconditions for this area as well, seeing as the touch screen allows for modern operating systems like Android to be used as a base. The TA Wrist has been designed with the brand values of IMI Hydronic Engineering in mind and captures the key values that the brand stands for both regarding aesthetics but also through its durability and effectiveness. Finally, given that the TA-Scope was considered outdated, largely due to its lack of modern technology, the perceived value of the product has been increased. This has been done mainly through making the product smaller and introducing a touch screen for the interaction. Through these arguments, the purpose of the project is altogether seen as fulfilled, although the brand and the buyers in some parts had a bigger impact than the end users.

One key point that affected the purpose is that the influence that the brand IMI Hydronic Engineering had, became significantly more powerful than originally thought. In order to meet the demands from the brand and the buyers, the TA-methods were kept as a feature in the TA Wrist. This went against what was found in the data collection phase when interacting with the users. As this delimitation was not in the initial project scope from IMI Hydronic Engineering, a conscious choice had to be made about whether to focus on the usability for the end users or what was important for the brand. In the end it was decided to keep the methods intact, to make the concept plausible for, as well as accepted at, IMI Hydronic Engineering. The direct compromises that had to be made included size and form changes and changes to the interaction with the product, since the methods required a bigger screen to keep a high usability. This also partly explains why the evaluation pointed towards the product being a bit too bulky and why concerns regarding the product getting stuck in tight spaces were raised. As many other professional tools and instruments can be equipped with similarly distinguishing functionality as the TA Scope, it is important to note that a degree of flexibility is needed when redesigning popular products. It is not always possible to take information from user studies, form a concept that deals with the found issues, and hope that this concept is approved by the company. There are always other aspects that will influence how much of the concept is possible to realise. Therefore, flexibility when dealing with feedback, and being open enough to incorporate parts of it into your design, will in some cases lead to happier company. This flexibility does not, on the other hand, mean that a designer should not give clear arguments as to why there might be a better redesign proposition to go with.

Given that there are no other wrist-worn balancing instruments on the market, this project is somewhat groundbreaking. It allows for a possibility for IMI Hydronic Engineering to be first on the market with a new type of product. However, a possible problem with the introduction of this new instrument is that people do not always see the benefit of big changes. The TA Wrist could be a hard sell to the stereotypically conservative HVAC market. It would therefore be important to put resources towards marketing, in order to reach out to the users and allow them to become accustomed with the product.

The resulting concept, the TA Wrist, is a product of a project with a human-centered design approach and is therefore directly linked to the problems that the end users have. The fact that the users themselves have shaped the project means that the end result is automatically highly relevant. However, delimitations from the company did force the decision regarding one of the main findings in the project, the methods not being used. This point would need to be revised further if the product is to become fully optimized for the end users.

Continuing with the data collection phase of the project, the interviews that were performed were quite few in numbers compared to many other theses on similar subjects. According to Statistiska Centralbyrån (2016), there were around 20 000 HVAC-workers active in Sweden in 2016. However, only a handful of experts in this group were found to perform balancings of hydronic systems at all, and even fewer worked with it full time. Given that the users were trained experts they did however have thorough knowledge of how the systems and surroundings functioned, which, in combination with the fact that answers were found to be repeated frequently, is why the interviews are deemed sufficient for the project. The interviewees were also exclusively from the Swedish market, which was found to influence the result when discussing with the European leaders from IMI Hydronic. One problem that might have influenced the results in the observation study is the fact that the users were aware of that they were under observation. This applies to all observations, both with the actual user at work and on the test rigs. During the observation at the test rigs the situation and the hydronic systems were furthermore optimal, as the balancing was performed in a laboratory. As the valves were placed close to each other and in sight, it did not give much information about the actual context of use, and conclusions about how the product was used were difficult to verify against real life situations.

**Further recommendations**

As mentioned, the problem with users not actually using the built-in methods still remains. One recommendation for IMI Hydronic Engineering would therefore be to evaluate the possibility of remaking the user interface to find a sweet spot between ease of use and precision and thereby increase the usage of the methods. In a first step, this could be done through incorporating a model for big data collection in the next version of the TA-Scope to track exactly how the product is being used in the balancing process. Updating the user interface would furthermore be a necessity to allow for the use of a touch screen, but since this was outside the scope of this project, it is left for a future project.

To give an accurate representation of how the final product would perform in practice, the prototypes would need a working interface connected to a touchscreen. Unfortunately, this proved impossible to manufacture within the timeframe of this project. An attempt to evaluate the concept towards the European market through an internet questionnaire was made. However, it became clear that using this questionnaire as the survey method was too shallow, and it gave little tangible results. Therefore, another recommendation to IMI Hydronic Engineering would be to produce prototypes to test with the actual users during a longer period of time, to verify and possibly tweak the solutions in this project accordingly. This would of course allow them to test the prototype abroad as well and maintain the human-centered approach throughout the entire venture of creating the new product.

## 11. CONCLUSION

The most important finding in the course of this project was that handheld balancing instruments present issues regarding reliability and durability, as drops from significant heights and harsh conditions are very prevalent during use. In combination with the fact that all data from performed balancings are kept on a hard drive in the TA Scope, valuable data is constantly at risk of being lost. Should this happen, many hours of work might go to waste. Furthermore, the balancing instruments are used in dirty and wet environments where poor lighting and visibility can often cause problems both regarding readability of the instrument, but also in the general environment. Finally, the methods that have been developed for the TA Scope are not used by the end users. Instead, they prefer using their own expertise and prior experience as guidance to finding balance in the hydronic networks. However, as the methods are what ties the product to the brand value of precision, they pose a conflict of interest between IMI Hydronic Engineering, the buyers, and the end users. This conflict influenced the results of this project greatly and IMI Hydronic Engineering and the buyers were prioritized over the end users in this instance. To some extent, this decision deviates from the purpose of the project and the human-centered design approach. However, as the main research question of this project was how the optimal balancing instrument should be designed for both the end users, the buyers and the brand IMI Hydronic Engineering, the TA Wrist is seen as a successful redesign for all parties involved.

The finalized concept is a redesigned balancing tool that truly has been adapted to the environment that the users work in. This has been done through the implementation of several design features that solve the issues found when interviewing and observing users. Regarding the high usability in practice, this has been achieved through working with ergonomics, form, technology and through the fact that the redesigned product is worn on the wrist. When compared to other, handheld instruments, the TA Wrist adds another dimension to the usability of the product, as the user will always have both hands free when not directly interacting with the instrument. This advantage in usability goes beyond the product itself and adds positive changes to the context of use for the end users. Through its design, the TA Wrist is a statement to how HVAC tooling can be brought up to the standards of modern portable electronic devices.

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