

QuickScale 2.0

The development of a user-oriented interface for a weighing tool utilized in on-site weight measurement. Aiding in forensic early post-mortem interval estimation.



Confidential Report

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The development of a user-oriented interface for a weighing tool utilized in on-site weight measurement. Aiding in forensic early post-mortem interval estimation.

By

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Preface

For the last two and a half years I have had the pleasure of working within the Innovation for Justice and safety group as a graduating master's student. In that time I have worked with and received help and support from, many remarkable people and I would like to thank each of them.

Kim Hutchinson for referring me to work on this project. Wouter Donders and Charlotte Kaanen for being shining examples of hardworking students. Anna Graell, Defne Unal, Josephine Leong Zhennian and Olivier ten Haven for thinking along and working together in the lab.

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Both John van der Dobbelsteen and Tim Horeman for providing me with both interesting and relevant jobs so I could provide for myself while finishing my graduation.

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During all the time I took to graduate I could rely on my partner, my family, my band, my sport, my friends and my housemates to be there when times were challenging, thanks for all the support.

Abstract

Post-mortem interval estimation (PMI) is a key part of forensic investigation. Accurately obtaining a PMI early in the investigative process improves the reconstruction of events, directs follow-up research and narrows down suspects in case of homicide. Currently, PMI is determined using Henssge's nomogram requiring ambient temperature, rectal temperature, an estimated body weight and an estimated correcting factor to account for the clothing of the deceased. These body weight and correcting factor estimates are subjective and can lead to errors of up to 14 hours from the actual PMI.

To improve the accuracy of the PMI Academic Medical Centre (AMC) in Amsterdam, TU Delft, the Dutch Forensic Institute and the Dutch police initiated the Therminus project. Using the Wilks Model [1] with specialised equipment can increase the accuracy of the PMI by up to a 15-minute margin of error under ideal circumstances and up to 3.2 hours under non-ideal circumstances.

For the Wilks model, the weight of the deceased remains an important input and the QuickScale was developed as a specialised tool to provide this information to forensic investigators at the crime scene. This report contains the development of the second iteration of the QuickScale, the QuickScale 2.0. Objectives of this development were:

1. To Finish the QuickScale prototype, design the modules needed for building in the electronics and for adding user-friendly, intuitive controls.
2. To design and conduct usability studies with forensic investigators and use the obtained information to further improve the QuickScale construction, electronics and usability.

Using a design analysis and usability engineering approach for the QuickScale design and user interface respectively. The QuickScale design was calibrated, and validated and possible improvements were identified. Three different user interfaces were developed and usability studies were conducted for groups of students and forensic investigators. New design requirements were derived from both the design analysis and usability studies.

The resulting QuickScale 2.0 design incorporated the user interface that resulted in the least user errors. It met 27 out of the total 30 design criteria and contains:

- An ambidextrous user interface.
- Correcting springs for the non-linearity of the load cell when measuring weights below 20kg.
- Handlebars with improved grip which can easily be extended to accommodate more users.
- Safety labels with an abbreviated guide on the field use and stickers indicating the controls

The un-met design criteria were an indicator of remaining battery life and the possibility that both units can display a difference in weight larger than 0.5 kgs, especially at the start of weight measurements. As this design still needs to be produced, it needs to be tested and evaluated. Special care should be taken when calibrating the QuickScale 2.0 and altering the calibrating method might be necessary. Furthermore, it is recommended to integrate the QuickScale 2.0 with other Therminus equipment in future evaluations.

All in all the QuickScale 2.0 is a user-oriented step toward more accurate post-mortem interval estimation.

Nomenclature

Post Mortem Interval (PMI) – Time passed after the death of an individual.

Specialised Transport Casket – A casket used in the transport of mortal remains that is insulated and can float on water, used in retrieval of mortal remains out of water.

Stretcher – A stretcher or brancard is used to support and transport mortal remains.

Carriage – A wheeled carriage underneath a stretcher aiding first responders and morticians in the transportation. This can often be adjusted to the desired height of the user(s).

Inertial Measurement Unit (IMU) – Component that measures position and acceleration.

Load Cell – Component that measures the forces pulling or pushing it

QuickScale Module – Refers to a single QuickScale unit

QuickScale System – Both QuickScale modules combined

FEM – Finite Element model

Usability – An umbrella term used to reflect convenience of use.

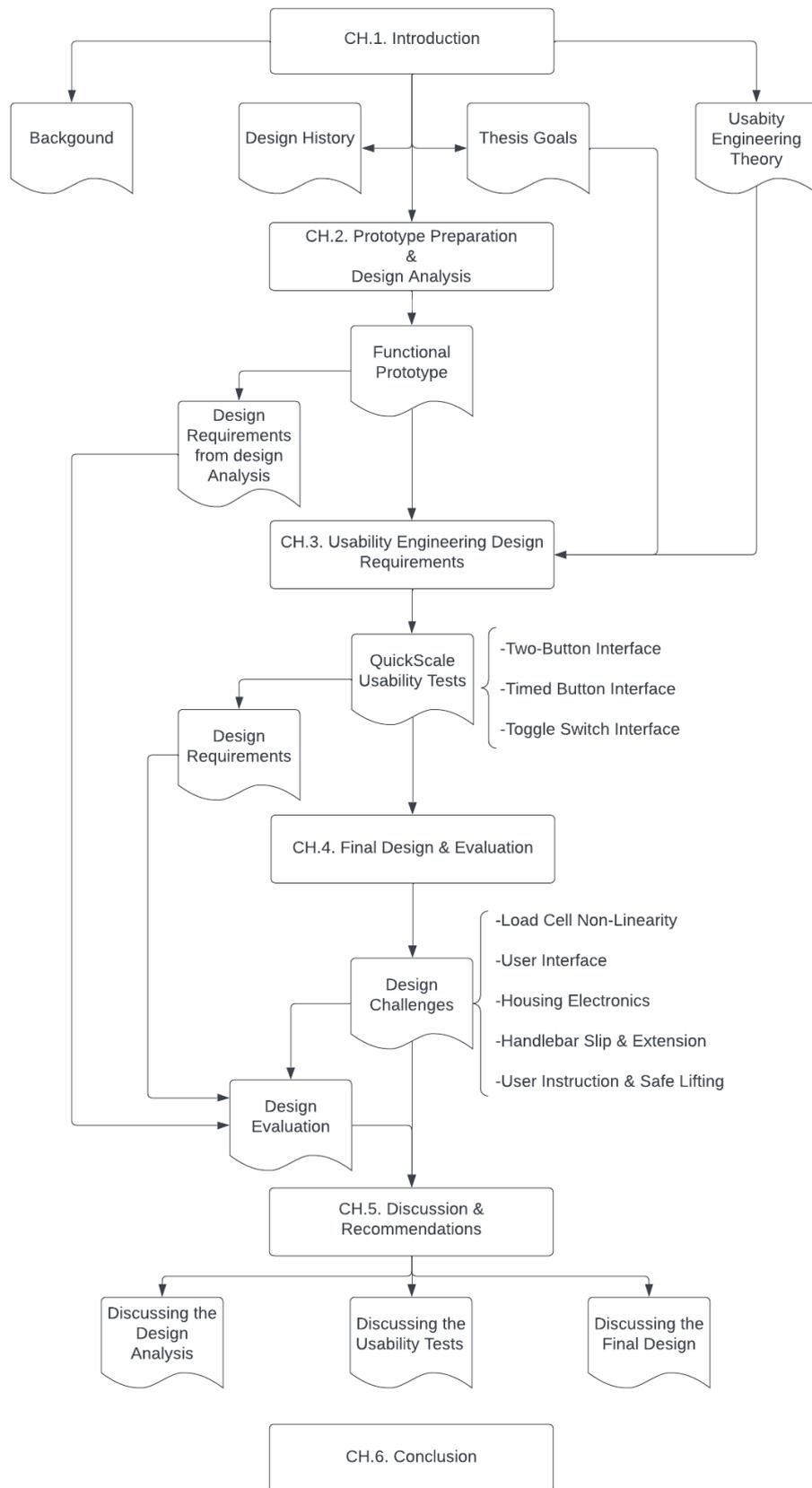
Usability Design – A design process taking both the user and the context of use into account when developing technology.

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Thesis Report Structure



1. Introduction

Background

In 2021, a total of 126 confirmed murders were committed in the Netherlands [2]. Besides these, the Netherlands has seen an increase in suicides in both 2020 (1823) and 2021 (1859) [3]. For these and other cases where the death of a person is involved a forensic investigation is carried out. Forensic investigation aims to determine factual information about the death of the individual and helps to ascertain if a crime was committed.

Estimating post-mortem interval (PMI) or, the time since an individual's death, is a key part of this investigation as it is necessary for an accurate reconstruction of the timeline of events leading up to the death of the individual [4]. This aids in narrowing down suspects in case of homicide and directs any follow-up research. Obtaining this information in a short amount of time improves the forensic investigation process as traces are fresh and perpetrators are still in a compromising situation [5].

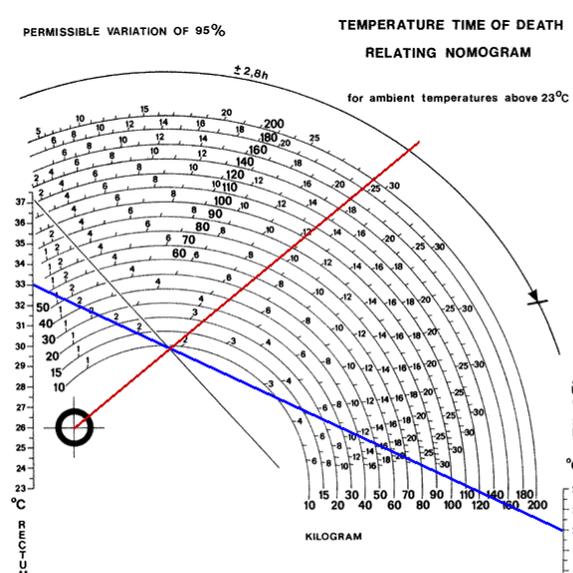


Figure 1.1: The Henssge Nomogram

Currently, the PMI is determined by Henssge's model using a nomogram (Fig. 1.1) this requires the forensic investigators to measure the ambient and rectal temperatures [6]. Besides these measurements, the investigators roughly estimate the weight of the mortal remains and judge whether a correcting factor for body heat loss through clothing applies. Applying this heat loss corrective factor is a subjective decision[7]. And using the nomogram requires the weight to be rounded to the nearest multiple of 10. Causing errors in the estimated PMI between 5.6 and 14 hours of the actual time of death [6]. To improve the PMI estimation and reduce this error the Academic Medical Centre (AMC) in Amsterdam, TU Delft, the Dutch Forensic Institute and the Dutch police initiated the collaborative Thermanus project. Thermanus aims to improve the accuracy of the PMI by using non-invasive thermometry

and a numerical model developed by Wilks et al. [7] for estimating the PMI. This model which combines measurements made by specialised equipment, can reduce the error of the estimated PMI to 3.2 hours [1]. With the potential to increase its accuracy to 15 Minutes when the input parameters are known with a high degree of certainty. For the Wilks model, an accurate measurement of the weight of the body remains an important variable as it relates to the amount of heat present in the body at the time of death.

After other evidence has been gathered, the mortal remains are placed on a stretcher in a body bag or a specialized transport casket [8]. The remains are transported to the mortuary for further investigation, here a weight measurement is made which refines the PMI estimate. The time this takes varies per crime scene and can be severely delayed by outside factors like traffic.

In 2019, L. Koopman et al. indicated that a suitable weight measurement system can be developed[9]. This system could accurately determine the weight of mortal remains on crime scenes with uneven ground, it was also integrated with current evidence-gathering practices. Next, the QuickScale prototype was designed, it needed to be operated, tested and refined. This prompted the question: can an intuitive user interface of the QuickScale prototype be developed with the end user in mind?

Design History

2017 - Project Thermanus commences

The NFI, AMC, and TU Delft aim to create a new approach for estimating PMI. This approach combines a FEM model of the deceased with characteristics of the surrounding environment. The Thermanus model has the potential to estimate the time of death with an accuracy of approximately 15 minutes.

2018 - BSc Technical Medicine Literature patent study and design report [9].

Aims to answer the question: "Is there a suitable weight measurement system which accurately determines the weight of mortal remains on a crime scene, and if not can it be developed?"

Goals:

1. Weighing should not require more than three steps: Bring the device, perform weight measurement, and return the device.
2. It will not contaminate the mortal remains.
3. Weighing should be completed within 5 minutes on top of regular procedures on the crime scene.
4. The measurement system is transportable by a forensic bus.
5. It should be easy to use and maintain.
6. It should be safe for both user and mortal remains.
7. The system should measure the weight with an accuracy of 1 kg.
8. The system should be portable i.e. max 23 kg.
9. The system should not deform during measurements.
10. It should not be damaged by chloride detergents.

Results:

"There is currently no weight measurement system directly applicable for measuring the weight of mortal remains on a crime scene." Development resulted in the initial proof of concept as seen in Fig. 1.3.

The proof of concept was a weighing device that meets the requirements of measuring within an error of 1.3% of the total weight. This stems from the requirement to measure the weight accurately within 1kg of the average Dutch man and woman. It meets the requirements to measure mortal remains on the crime scene. Further development was necessary to integrate its use with a stretcher and a user interface needed to be developed to display the measured weight and aid in the weight measurement.

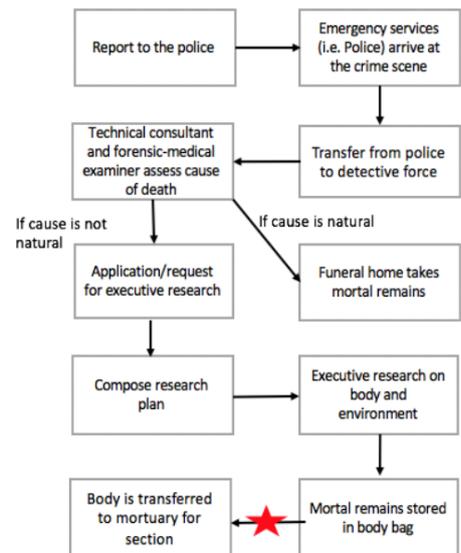


Figure 1.2: Flowchart of regular procedure on a crime scene, red star indicates timeframe for

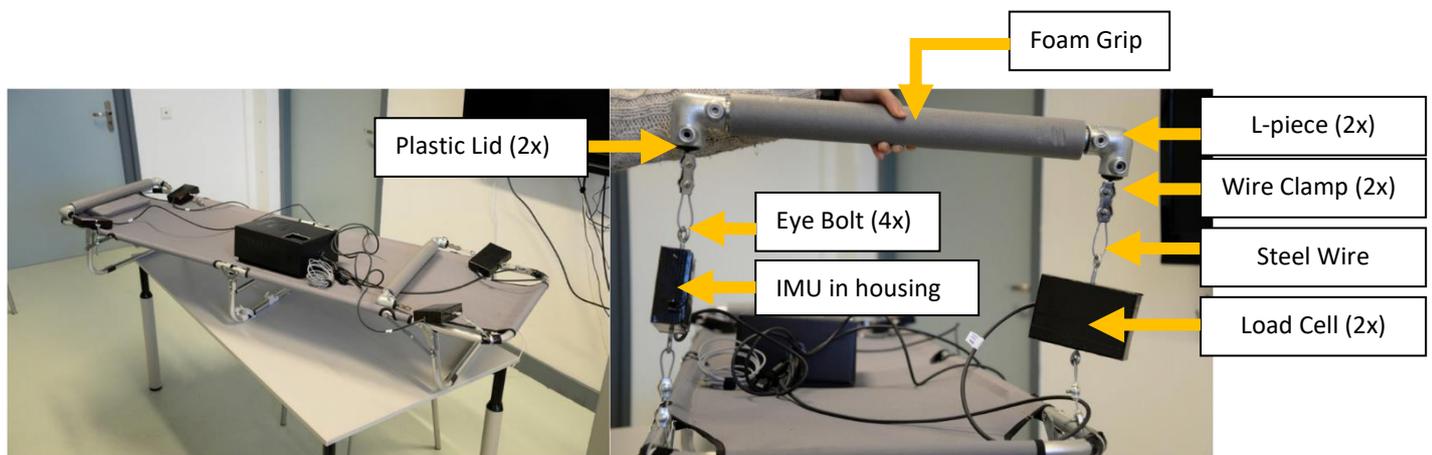


Figure 1.3: First Proof of concept of the QuickScale using two bars with an IMU and two load cells attached to each. Image adapted from "Rapport-Thermanus-NFI," L. K. T. Kos and A. M. E. v. Twist, 2019

2019/2020 - BSc Thesis Wing-Han Tang [10]

After the proof of concept, further development of the QuickScale prototype design was done by W.Tang [10] this next iteration was geared towards the implementation of the QuickScale as a device that integrates with the stretcher and carriage available to the end users. This was done by performing a function analysis, user environment study and target group research to collect design requirements. After these analyses, a new prototype design was created according to the collected design requirements.

Goals:

1. Assess different ways mortal remains can be weighed.
2. The QuickScale should be attachable to different carrying gear.
3. Multiple users should be able to use the QuickScale.
4. Avoid shear forces on the load cells.
5. Prevent torsion on the load cells.
6. Guarantee safety when the weight put on the QuickScale causes it to break.
7. Find a way to perform the weight measurement.
8. Keep the carrying gear stable during operation.
9. Keep the stretcher horizontal during operation

Results:

The chosen design uses a single load cell per QuickScale module, this would be attached between two bars (see fig 1.4B). The top bar will be held by users while the lower bar has hooks that attach to the gear carrying the mortal remains. In this report, that gear was ascertained to be a stretcher and a specialised transport casket[8]. The housing prevents shear forces on the load cell and guide rails between the inner and outer housing prevent clamping.

To accommodate for differences in carrying gear, the lower bars can be extended for stretchers with different widths. This was also designed for the possibility of carrying a specialised transport casket. Some mortal remains and carrying gear can be expected to be heavier than two users can lift. Therefore an option to extend the top handlebars was added. So four users can lift the QuickScale plus mortal remains and carry gear.

Of note is the user interface (see Fig 1.5). For safe use, this is designed with a depiction of the maximum weight that can be lifted above the display. It allows users, with a press of their thumb to save the weight and store it in the QuickScale. Appendix A provides an overview of these controls.

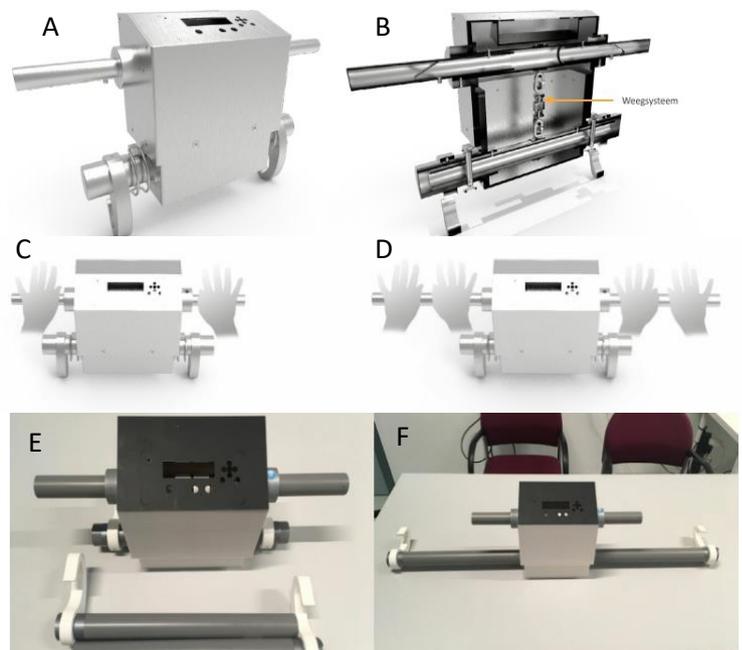


Figure 1.4- Top: CAD design and section view, middle: user carrying options, bottom: 3D-printed prototype in PLA. Image adapted from: "BSc-Thesis Weegapparaat-THERMINUS," W. H. Tang, BSc, Tu Delft, Delft,



Figure 1.5: User interface as envisioned by W. Tang. Adapted from: "BSc-Thesis Weegapparaat-THERMINUS," W. H. Tang, BSc, Tu Delft, Delft,

2020/2021 – Engineering of QuickScale Prototype by Maat Engineering [11].

Based on the report of W. Tang, a short review of the idea & concept generation was carried out by B. Maat, after which engineering of a functional prototype began. The materials, internal structures, load load-bearing parts were engineered with the same design requirements as determined by W. Tang. Furthermore, several preferences were indicated by forensic investigators:

“The measuring instrument is lightweight, compact, robust, and high quality.” Additionally, human factors and safety design as stated in NEN-EN-IEC 62366 require that the QuickScale system cannot be used incorrectly. Finally, the QuickScale needs to be able to be produced in the workshop of TU Delft barring any standard parts that can be store-bought.”

Goals:

1. Perform a short validation analysis of the prototype design.
2. Make conceptual choices about structure, part forms, production, and materials.
3. Continue detailing, meanwhile, design choices are briefly documented.
4. Suppliers were to be consulted when this was deemed necessary.
5. Deliver 3D files, 2D drawings and structural analyses.
6. Deliver a concise assembly description so that functional prototypes can be made.

Results:

After validation, the detailed prototype of the QuickScale as engineered by B. Maat did not change the conceptual solution provided by W. Tang. Parts were added existing parts were changed to make the design robust and able to carry loads up to 171 kg.

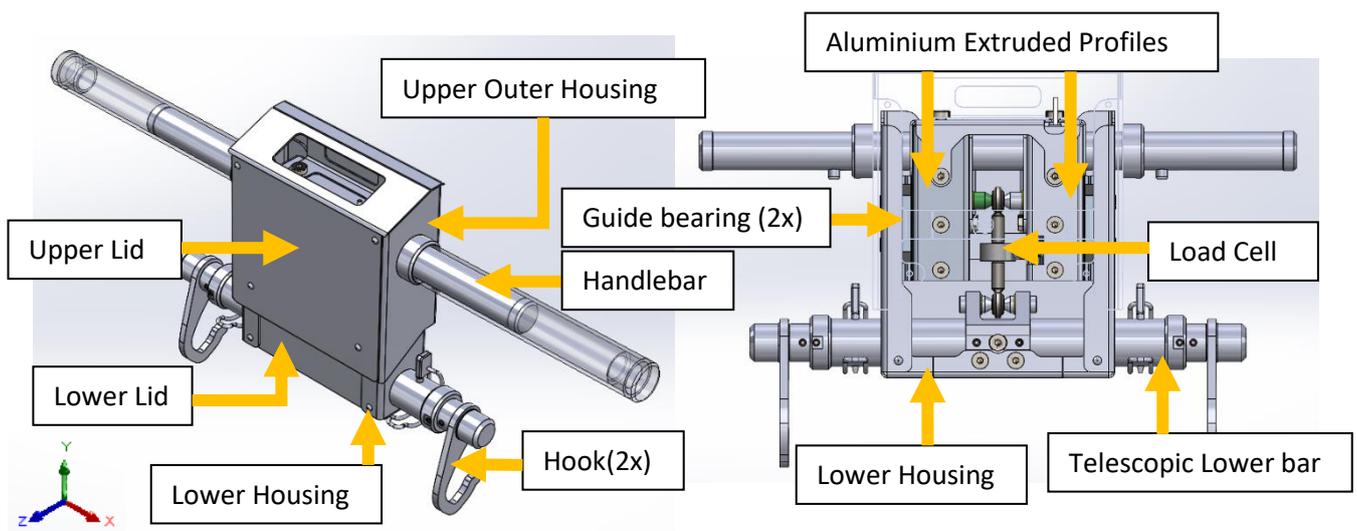


Figure 1.6: Left, CAD representation of the QuickScale prototype as supplied by Maat engineering.

Right, A front view without the Upper lid, lower lid and transparent upper housing

The lower housing (see Fig. 1.6) was suspended inside the upper outer housing. The lower housing was carried by the load cell and was guided along the y-direction by two bearings connected to aluminium extruded profiles. These parallel extruded profiles connect the load cell to the handlebar and the lower bar was attached to the hooks. The lower bar was engineered to be telescopic, the hooks can extend outward on separate bars in the x-direction. The report contains an assembly guide, however, no assembly drawings were added.

During the production a revision was made to the upper outer housing by Maat Engineering, as visible in Fig. 1.7, with the main difference being the centre jog, this was done to aid both production and assembly by keeping the load cell accessible and removing the need to overlap the hole between the two jogs. A separate part was added to connect both sides of the inner module in front of the weight cell as seen on the right in Fig. 1.7.

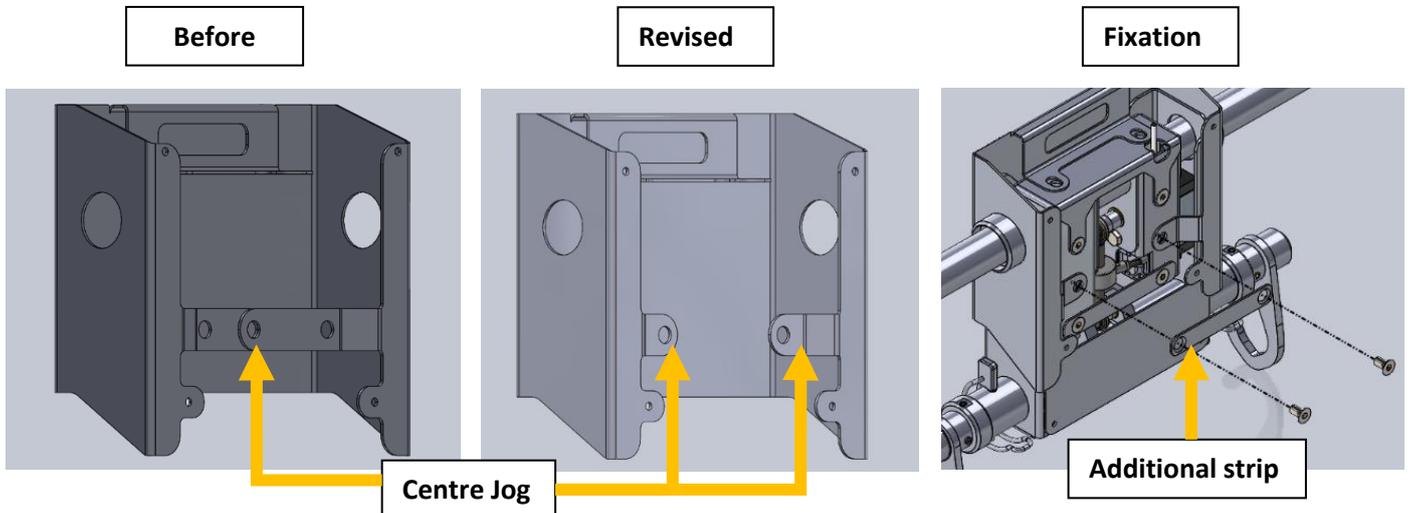


Figure 1.7: On the left the upper housing before revision, in the middle the revised upper housing is depicted, on the right the additional strip to fixate the part is shown.

2020/2021 – Electrical engineering of the QuickScale and software architecture

In parallel with the engineering of the QuickScale prototype, the electronic components needed to be selected and tested. This was done by A. van Dijke and A. Loeve. After analysing the functions the QuickScale modules needed to perform and relating them to the workflow of its users, the goals of the software were defined and software addressing these goals was provided.

Goals:

1. Define the function overview of the QuickScale.
2. Select the necessary electronic hardware for the QuickScale prototype.
3. The precision of the weight measurements is 0.1kg, averaged over a sample of 5 measurements.
4. Build a test set-up to verify the hardware and software.
5. Provide a schematic so the circuit can be reproduced.

Results:

Chosen hardware

- An Arduino UNO
- HX711 Load Cell amplifier
- BNO055 IMU
- nRF24L01 Radio Module
- LCD Display (20x4)
- four different coloured buttons
- Connected as shown in Fig. 1.8.

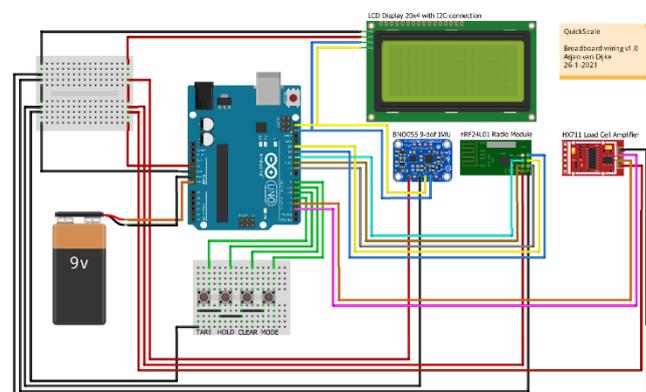


Figure 1.8: Electrical component schematic by A. van Dijke.

A block diagram was used to identify the functions and calculations the QuickScale system needed to perform. In short, a QuickScale module measures the force on the load cell and the inertial measurement unit (IMU) measures the angle at which this force is directed. This is then

converted into the vertical component of the force. The module communicates this value to the other unit, and the other QuickScale module sends its own calculated vertical component. Upon receiving the vertical component weight, it sums both. This weight is updated constantly and displayed.

The desired workflow has the user perform the following functions with the QuickScale: After enabling the QuickScale, both units will start to establish a wireless connection, this is called PAIRING. If the user decides they want to use a single module, they can press the MODE button during PAIRING to stop this connection. Whether a single or both units are used, the order of operation is that users first zero the scale by using the TARE function. This is followed by lifting the weight attached to the QuickScale, the weight can be read on the display at all times. After the weight is completely suspended the displayed weight can be frozen by using the HOLD function. If the user(s) wish to re-tare or un-freeze the display, they can re-enable those functions or they can use the CLEAR function.

Before this point in the development there used to be a preference for storing the measurement in the QuickScale, so it could be recovered later. This was later deemed unnecessary and undesirable by the Terminus committee as it could be prone to errors in the workflow.

Thesis Goals

After both the mechanical and electrical engineering for the QuickScale prototype was concluded the parts for the prototype were ordered and the mechanical assembly of a single QuickScale Module was completed (see Fig. 1.9).



Figure 1.9 – Left: Parts of the QuickScale Prototype, Right QuickScale as assembled by A. Loeve. <https://youtu.be/fox72cxyuJI>

The currently selected electrical components needed to be fitted inside the housing of the QuickScale so the prototype could be prepared for use in tests. Besides this, an intuitive user interface needed to be developed and made fully functional in the next version of the QuickScale. This next version should add the context of the user, flaws in the design need to be found and addressed in the next iteration of the QuickScale.

Problem Statement

“There is a need to further develop and refine the QuickScale prototype. Specifically, the integration of electronics and the design of a user-friendly control interface. User studies with forensic investigators need to be conducted to gather feedback and evaluate the construction, electronics, and overall usability of the QuickScale.”

Goals

1. Finish the QuickScale prototype, design the modules needed for building in the electronics and for adding user-friendly, intuitive controls.
2. Design and conduct user studies with forensic investigators and use the obtained information to further improve the QuickScale construction, electronics and usability.

Subgoals

- Complete the mechanical assembly of the QuickScale Prototype.
- Design the parts which accommodate the electronics.
- Calibrate the prototype.
- Validate the prototype.
- Conduct user tests with forensic investigators.
- Use the results of the user tests to design an intuitive user interface.
- Use the obtained information to improve the usability, electronics and construction.

The QuickScale in a usability design theory context

To aid in assessing the usability engineering effort and to provide a framework within the usability tests the NEN-EN-IEC 62366 part 1 and 2 were consulted. These norms discuss the application of usability design to medical devices. NEN-EN-IEC 62366-1 focusses on the levels of risk and safety associated with the users and patients due to usability problems.

The main risk for the use of the QuickScale is that it can drop or tip over the “patient” during use. The term patient does not strictly apply to the QuickScale but there is the matter of preservation of evidence and the bodily integrity of the deceased. While the risk to the users can be assessed as fairly low, the users of the QuickScale are still at risk of foot injury by dropping a heavy load. This needs to be taken into account during the usability testing as well as lifting ergonomics.

According to NEN-EN-IEC 62366 part 2 the usability tests for user interface aid in formulating specific design requirements for the user interface by using iteration cycles of conceptualization, implementation and evaluation cycles (Fig 1.10). In these cycles, end users are involved in the development process by performing evaluations during production (formative). The more the end users start to use the device in the intended user environment, the more representable these evaluations get as an indication of how users will experience the finished product in the field. At the end of the development process, a summative evaluation should take place for a final residual risk assessment.

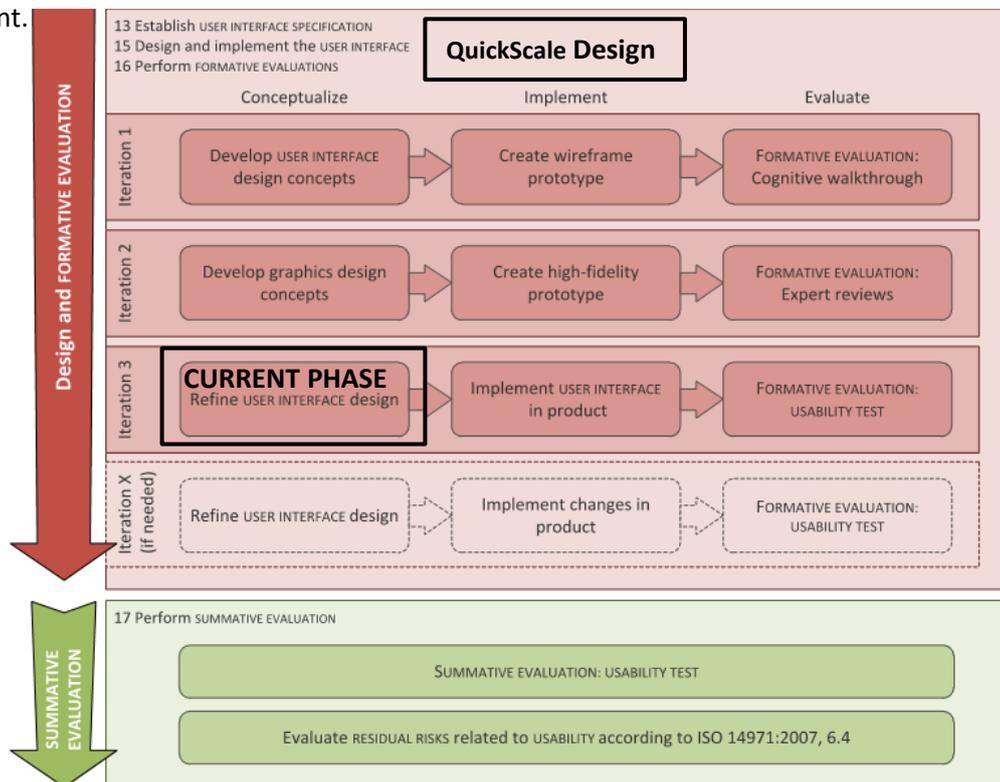


Figure 1.10: The development overview provided by EN-EN-IEC 62366-2 depicts cycles of development, implementation and evaluation that are at the core of usability engineering. image

A usability test consists of observing the performance of users controlling a device during tasks in similar conditions as the context in which it is to be used. A test script should be developed and a moderator should conduct the tests according to this script. These usability test sessions can be recorded through audio or video for later analysis or to confirm data collected during sessions.

Table 1-1 Cumulative probability of encountering a usability problem, Image from NEN-EN-62366-2

USABILITY defect probability of occurrence	Number of test participants (Values in # participants)													
	1	2	3	5	6	7	8	10	15	20	25	50	75	100
1,0 %	1	2	3	5	6	7	8	10	14	18	22	39	53	63
3,0 %	3	6	9	14	17	19	22	26	37	46	53	78	90	95
5,0 %	5	10	14	23	26	30	34	40	54	64	72	92	98	99
10 %	10	19	27	41	47	52	57	65	79	88	93	99	100	100
15 %	15	28	39	56	62	68	73	80	91	96	98	100	100	100
25 %	25	44	58	76	82	87	90	94	99	100	100	100	100	100
50 %	50	75	88	97	98	99	100	100	100	100	100	100	100	100
75 %	75	94	98	100	100	100	100	100	100	100	100	100	100	100
90 %	90	99	100	100	100	100	100	100	100	100	100	100	100	100

Chances of defects occurring during usability tests, in percentages

To determine the number of usability test participants required, a supplementary table provided by NEN-EN-IEC 62366 2 can be used, see Table 1-1. This table depicts that the likelihood that a usability defect is encountered during usability tests increases as the number of test participants increases.

Tests with 10 to 15 participants are common, as the probability of detecting at least one usability defect that occurs 15% of the time lies between 80 and 91 per cent. Defects with a lower probability of occurring can still slip by, but there is also the matter of diminishing returns. Assuming the same test duration, it will take more time to process a larger number of participants. During these user tests, participants are more likely to run into usability defects with a high probability of occurring. However, after these defects are known, every new participant is just as likely to encounter this same defect. This means that without changing the test, or the design, most time will be spent observing participants encountering usability defects which are already known. Taking this into account, 12 participants seems to be a sweet spot between identifying usability defects and the diminishing returns of participants (see Fig 1.11).

The results from formative tests are mostly qualitative. However, the number of user errors provides valuable feedback on the user-friendliness of the design. User errors can consist of simple mistaken button presses to procedural errors in the scenario like mixing up the order of operations. Besides counting user errors there are other methods of evaluating the usability of the QuickScale. This can be done by evaluating the user experience by interviewing the participants or providing them with a questionnaire.

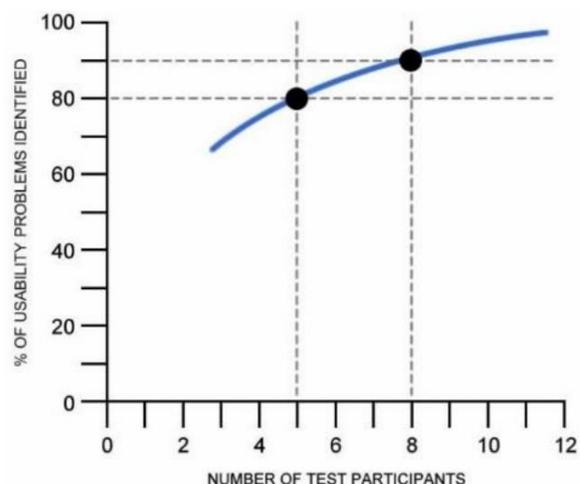


Figure 1.11 Graph indicating the probability of finding design flaws is not increasing around 12 participants. Source: Human factors engineering for medical devices S.Paus-Buzink

2. Prototype Preparation & Design Analysis

Methods

Functional prototype preparation

The mechanical assembly of the QuickScale was done according to the instructions supplied by Maat Design and Engineering [11]. Assembly drawings were drawn (see Fig 2.1), these are provided in Appendix B. After this an electronic circuit was set up according to the drawing provided by A. Reve in the design history (fig. 1.8).

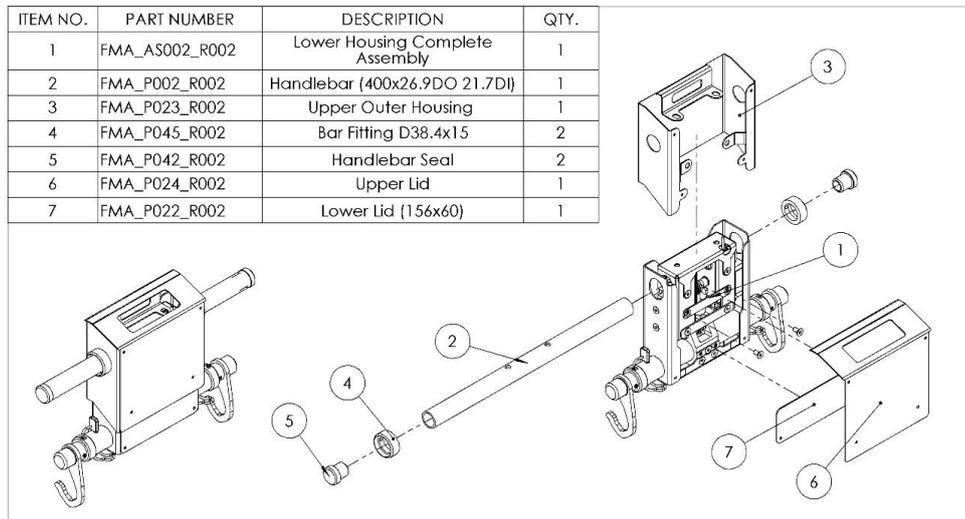


Figure 2.1: Final step in the assembly of the QuickScale Prototype for the assembly drawings of the lower housing assembly see appendix B.

Changes to the prototype

Some parts were not used in the assembly, as seen in Fig 2.4.

1. The spring-loaded pins were left out as the ones purchased for the design were too small to securely lock the extended handles.
2. The security pins were not used because, during the later experiments, it was necessary to adjust the distance between the hooks, as the width of the stretchers used varied.
3. To keep the inside of the prototype accessible the blind rivets on the outer lids were not used. Instead, the holes were threaded with M5 thread and M5x12 bolts were used.

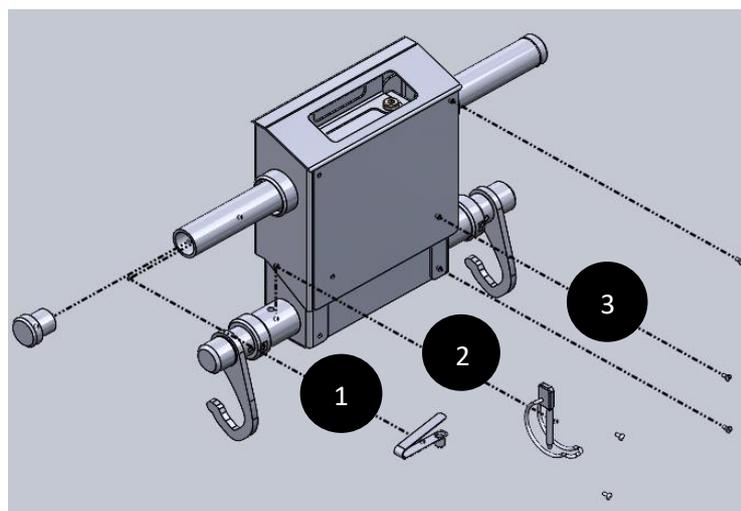


Figure 2.2: Numbered parts not used in prototype:
1-Spring loaded pins, 2-Security pins, 3-Blind rivets.

To complete the prototype, modular 3d-printed PLA parts were designed to fix the electronics in the housing of the mechanical assembly. These were reliable enough to use for the prototype, easy to iterate and allow for the flexibility to integrate purchased parts like nuts, bolts and electronics.

First User interface development

To be able to operate the prototype an initial user interface needed to be developed. When taking the design history into account, the design of the prototype requires two users to lift the QuickScale using the handlebars. Both to perform the taring of the QuickScale and to perform the weight measurement. This means that during these operations the hands of the users are occupied with lifting so these operations need to be executed by buttons that can be used during lifting. This could be either triggers in the handle or

Design Analysis

After the prototype was prepared it was evaluated. The QuickScale prototype was used in unstructured pilots and mock-ups using a stretcher and weights. These tried to simulate the weighing of mortal remains to get a feel for the handling and to discover potential flaws. During these pilots, any shortcomings expected to be influencing the design of the user interface and controls were registered and these were translated into design requirements.

Design Requirements

During the assembly of the prototype new requirements for the design were encountered. These are the result of constraints of the placement of electronics and the functioning of the device as intended by those who worked on the design previously. These were added to the design requirements that were established before prototype assembly. The design requirements that are relevant to the design of the user-interface and the usability of the next version of the QuickScale were taken into account. To see all the design requirements as previously formulated by W. Tang see Appendix D.

Results

Functional prototype preparation

3D-Printed Part Design

Figure 2.3 provides an overview of the 3D-printed parts with the placement of the electronics.

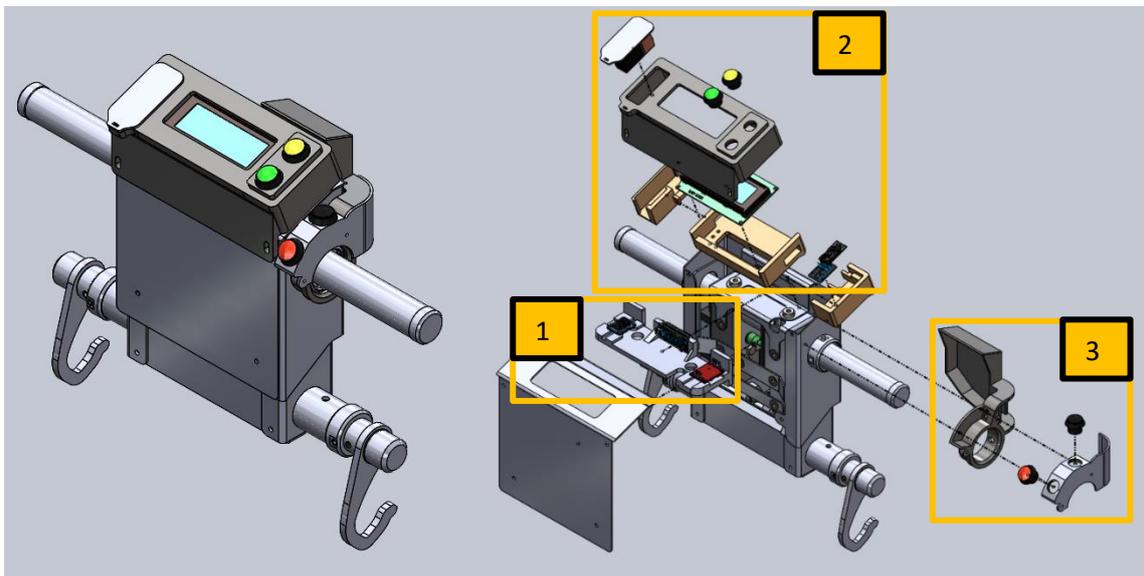


Figure 2.3: Depicted on the left is the CAD model of QuickScale prototype. In the exploded view on the right, three subassemblies are highlighted. 1-The inner electronics fastener, 2-The outer housing subassembly, 3-The operating handle subassembly

1. Inner electronics fastener:

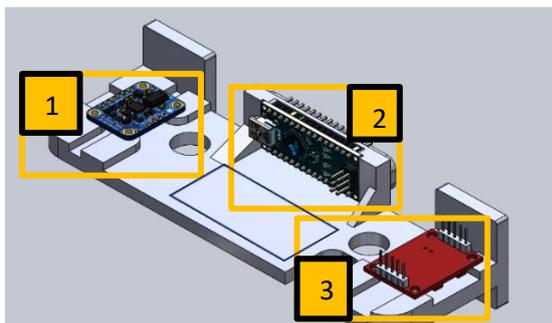


Figure 2.4: Inner electronics fastener, 1-The Adafruit BNO055 IMU, 2- Arduino Nano and 3-HX711 load cell amplifier.

The inner electronics fastener contains an Adafruit BNO055 IMU, an Arduino Nano and an HX711 load cell amplifier (see Fig 2.4). Of note is the robust fixation of the BNO055 IMU as changes in orientation during the booting of the IMU can result in the misaligning of its calibrated coordinate system. The inner electronics fastener is made of PLA with a 20% fill, the part is flexible enough to slide into place when both the hex bolts on top of the lower housing assembly (see Fig 2.1) are removed. The open space in the middle is used to install a breadboard connecting the components.

2. Outer housing assembly:

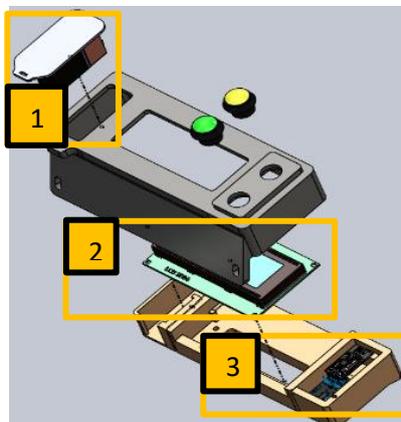


Figure 2.5: The outer housing subassembly, 1- Battery, 2-2004 LCD screen, 3-nRF2401

As the 2004 LCD screen did not fit inside the metal housing an external housing was made which fit on the housing of the QuickScale prototype (fig 2.5). This was also used to place the nRF2401 radio transceiver and its power adaptor as these needed to be outside the metal housing to send and receive wireless radio signals. This part also contains the battery compartment for the prototype and the buttons with the 'clear'(green) and 'mode'(yellow) functions. The 3D-printed parts were designed to be separable so it was easy to iterate and make adjustments e.g. for cables. One such adjustment was the addition of an On/Off switch integrated through the outer housing.

3. Operating handle subassembly:

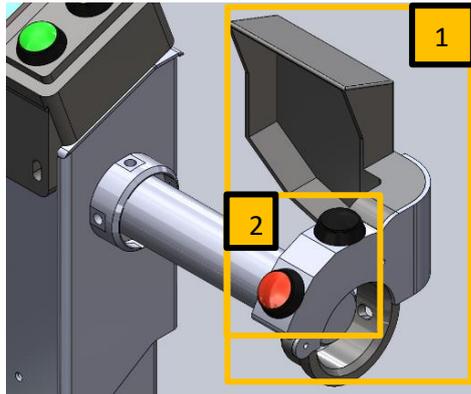


Figure 2.6: Operating handle subassembly, 1- Cable guide to handle, 2-Hold and Tare Buttons.

This assembly holds the buttons that were to be used during the trial prototype use, the red 'Tare' and black 'Hold' buttons (see Fig. 2.6). These buttons were placed on the handle so they were within reach during the operation of the Quickscale. To prevent damage to cabling running to the buttons in the handle a cable guide with a protective cover was added to the design. This operating handle is fastened tight against the housing by replacing the set screw in the handlebar fitting with a longer variant.

Design Analysis

After the assembly of the prototype was complete and the electrical components connected, the design was used in pilots to assess the ease of use of the device and its user interface. Several points which can be improved were identified regarding the prototype so far.

1. Zeroing with mortal remains on the stretcher

When using the QuickScale prototype, a user requires two functions that alter the weight shown on the LCD screen. The 'Tare' function zeroes the weight in the display and the 'Hold' function freezes the weight shown in the display.

A potential defect is that both of these functions can be executed during any part of the weight measurement. A user might accidentally use the taring function when they want to freeze the weight in the display. This is a particularly unwelcome error as this would require the unloading of the mortal remains from the stretcher so preventing or minimizing this error would be beneficial.

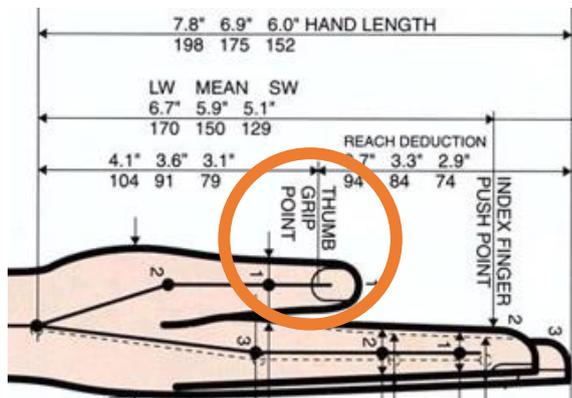


Figure 2.7: Thumb grip point defined in the middle of the distal thumb phalanx.

2. Button placement

When developing for operators of devices, Dutch engineers and designers can rely on the DINED ergonomics database [12] for anthropometric data. However, in the case of the QuickScale, this database was unhelpful. In determining where to place the buttons as a thumb grip point (fig.2.7) is not available in this database. Other anthropometric information can be found [13] but not specific to the Dutch population which is in general a taller population, with larger hand proportions. Developing a user interface with buttons placed within reach of the smallest end users but without obstructing the thumbs of the large end users would be beneficial.

3. Safe lifting posture

When using the QuickScale in the envisioned workflow, two or four users measure the weight of mortal remains. In this situation, these users likely lift a total weight of 105 kilograms consisting of 84kg for the average Dutch male plus 8 kg of the stretcher plus 13 kg of the QuickScale itself excluding clothes. This is a potential danger and well above the maximum safe lifting limit with two persons displacing 50kg established by the Dutch labour inspectorate [14]. To prevent injuries, operators of the QuickScale should be made aware of safe lifting practices and when lifting mortal remains heavier than 100kg should be encouraged to lift with 4 people as this equates to each pair lifting 50kg.

4. Managing batteries

When using batteries to power devices, replacing batteries in the field becomes a requirement. The QuickScale prototype uses two 9Volt batteries and currently does not display how much battery life is left. A potential downside is that batteries might run out in the field and operators need to be able to swap these batteries. A fool proof way to power the QuickScale and/or an accessible battery port so the batteries of the QuickScale can be swapped is desirable.

5. The user in control of the measurement

During the normal operation of the QuickScale, as a feature, both units can perform the steps to execute a weight measurement. This means that both users can execute the 'Tare' and 'Hold' functions. However, this can be confusing if both operators try to perform these steps at the same time. Taring values would get overwritten, and weight could get unfrozen in the display. As second button presses either re-initiate the Tare function or release the held weight. It would be beneficial if the QuickScale clearly communicated to the users that one of them should be in control of the measurement.

6. Ambidextrous design

When the initial user interface was developed for the functional prototype, the user interface was only developed for right-handed users. Considering that there likely will be left-handed end-users and that these need to be able to control the QuickScale just as easily. The next version of the design should address this and there should be no difference between the controls for both left and right-handed users to operate the user interface.

7. Slipping grip

When lifting repeatedly with the QuickScale, users find that the handlebars they use to lift the stretcher become more slippery as their hands get sweaty. The handlebars used to grab and hold the QuickScale are fashioned out of an AISI 316L steel pipe. This surface is smooth and when users have wet hands this can cause bars to slip out of the hands of users while lifting. This can cause injury, as the stretcher carrying mortal remains can fall on the feet or legs of operators. Therefore the QuickScale should be made in such a way that it does not slip out of the grip of users, even in wet conditions.

8. The difference in weight shown on the displays of both units

When using the QuickScale for weight measurements, both units calculate the weight they measure and send this to each other. However, the displayed weights on the LCD screens of the units can differ. The differences in measured weights of both units can be explained by the radio communication delay between both QuickScale units. Both the measured and received weights are averages of about 10 measurements per second. Because both units alternate in sending in these vectors values do not overlap, certainly just after lifting and shifts in weight. Therefore both units can differ in their averaging of the measured weight. These differing values should disappear when the time the weight is suspended is increased. However increasing the time too long, say for 1 minute can result in inaccuracies due to sensor drift.

This can confuse users and from the displayed weights, it isn't clear which unit displays the weight that is the most accurate. Therefore it would be beneficial if Both user interfaces don't show a difference in measured weight. Or if this isn't possible, only a minimal difference in the measured weight.

Design Requirements

For the next step in the design of the QuickScale, criteria were collected from the functional prototype preparation and the design analysis these are depicted in Table 1. Some previous design requirements formulated by W. Tang, which were also the basis for the prototype design by Maat Engineering, have not been met. These are still relevant for the next step in the design and were also added to Table 1. For a complete overview of the design requirements formulated by W.Tang, see Appendix C.

Table 2-1: Design Requirements after design analysis and prototype preparation.

Abbreviation	Description	Source
DAR-D	Device	
DAR-D-1	The electronics fit within the metal housing	Functional Prototype preparation
DAR-D-2	The device housing allows for wireless radio communication	Functional Prototype preparation
DAR-D-3	The device indicates it needs to remain still during set-up to prevent the wrong calibration of the IMU.	Functional Prototype preparation
DAR-D-4	The device should allow for an easy change of batteries.	Functional Prototype preparation
DAR-D-5	The device is made in such a way that it does not slip out of the grip of users, even in wet conditions.	Design analysis
DAR-D-6	The device informs users about safe lifting practices.	Design analysis
DAR-D-7	The device shows how it should be held	Process diagram by W.Tang
DAR-D-8	The device shows how it should be attached to the stretcher or other device used for carrying the mortal remains.	Process diagram by W.Tang
DAR-D-9	The device must be able to be used by both two and four persons simultaneously	Task/target group research by W.Tang
DAR-UI	User Interface	
DAR-U-1	The user interface should be operable by both left and right-handed users.	Design analysis
DAR-U-2	The placement of buttons on or in the handles should be within reach of the users with the smallest thumb grip. Without obstructing the reach of users with a larger thumb grip.	Design analysis
DAR-U-3	The user interface is unambiguous about who is in control of the weight measurement.	Design analysis
DAR-U-4	Both user interfaces do not show a difference larger than 0.5kg in measured weight.	Design analysis
DAR-U-5	The user interface informs the user about the amount of battery charge.	Process diagram by W.Tang
DAR-U-6	The control panel is within reach during lifting and carrying of the bed	Process diagram by W.Tang
DAR-U-7	The display screen is readable during the carrying of the bed	Process diagram by W.Tang
DAR-U-8	The measurement value can be frozen in the display.	Task/target group research by W.Tang – Adjusted for this report
DAR-U-9	There must be a possibility to take a photo of the measurement value with another camera.	Task/target group research by W.Tang – Adjusted for this report
DAR-WM	Weight Measurement	
DAR-WM-1	The device must be able to measure weights from 8 to 171 kg with an accuracy of 1.3%	Research on measuring range by W.Tang
DAR-P	Preferences / Nice to have	
DAR-P-1	The parts must be purchased parts	Process flow research by W.Tang
DAR-P-2	Using the device feels intuitive and new users experience few errors which can be corrected for by experienced users.	Client preference
DAR-P-3	The device should incorporate measures to prevent accidental or unintentional zeroing of the weight of the mortal remains.	Design Analysis

3. Usability Engineering Design Requirements

Materials & Methods

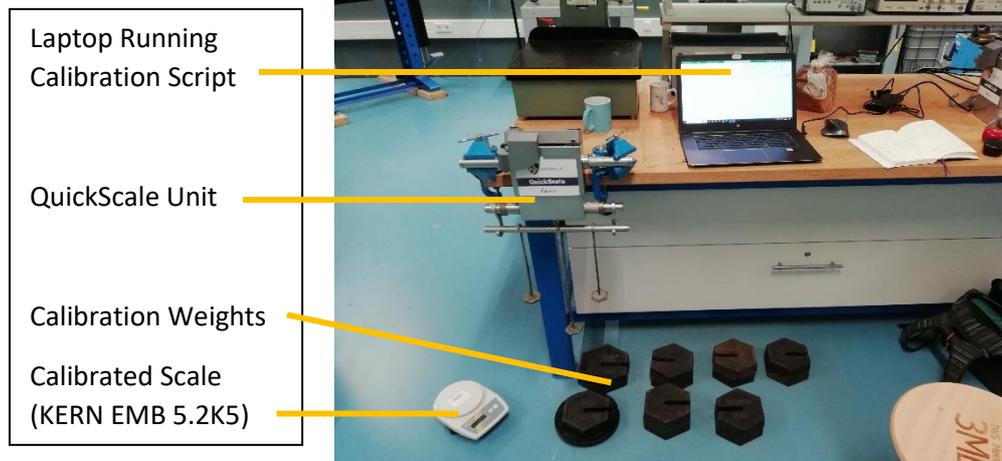


Figure 3.1: Calibration setup.

Calibration

The QuickScale modules use a Futek LCM300 load cell with an HX711 load cell amplifier. Before use the QuickScale needs to be correctly calibrated. The calibration of the LCM300 load cell was carried out by Futek themselves [15] and the LCM300 is linear between 20 and 450kg. Because the QuickScale as a device was built around these load cells interactions with other parts cause friction, deform or absorb stress in an unknown manner. It is necessary to find the correct calibration factor per unit: A single QuickScale module calibration factor can be understood as gain that multiplies the input voltage measured by the HX711 load cell amplifier to get an expression of the total weight measured in kg. A variable offset value representing the weight of the QuickScale is subtracted, after which the weight in kg is output by the Arduino.

Before calibration, the available weights were measured using a KERN EMB 5.2K5 digital scale to find any inaccuracies in the calibration weights used. Then after zeroing a QuickScale module with just the attached hangers, the weights were placed on these hangers up to a total of 45 kg. The calibration factors of the two QuickScale modules were determined by measuring the output weight at known weights. The output weight can be adjusted by increasing or decreasing the calibration factor. This was done until the weight registered by the QuickScale reflected the known weights. The calibration factors corresponding to the output weights were registered. This process was repeated three times per unit after which the collected calibration factors were then averaged. After the calibration factor for each unit was applied calibration curves were made to evaluate their performance. An example of a calibration curve and its components are shown in Fig. 3.2.

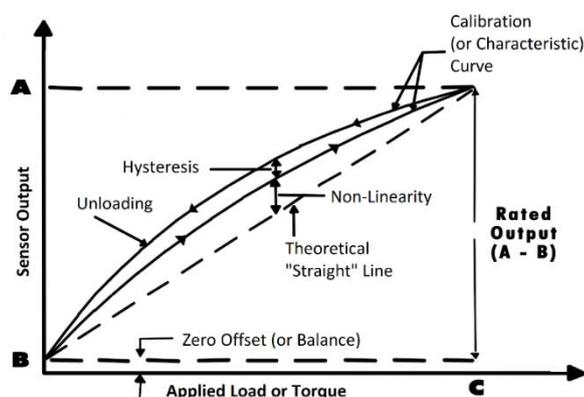


Figure 3.2: Components of a calibration curve, image adopted from of FUTEK.

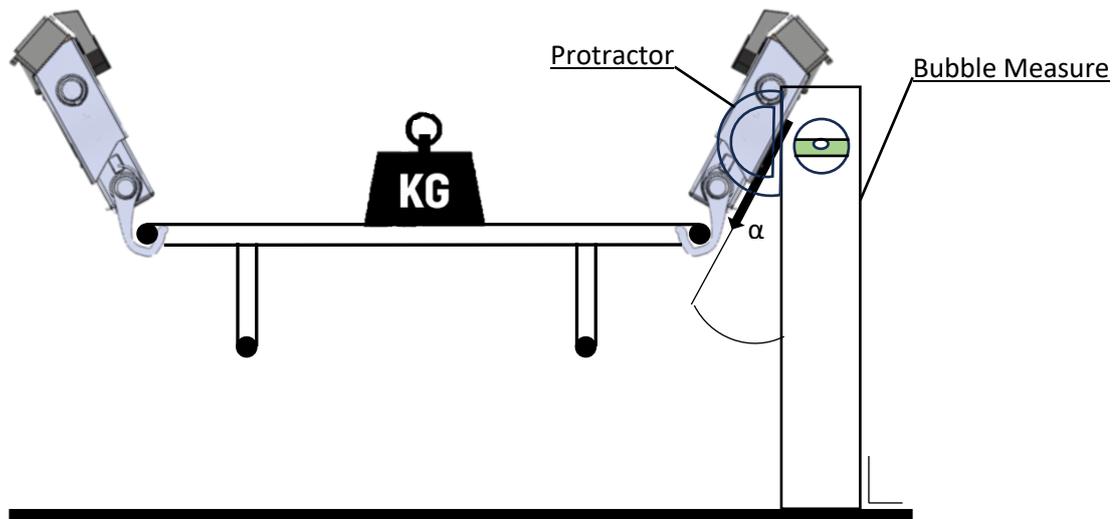


Figure 3.3: QuickScale angle validation set-up.

Validation

For the validation of the QuickScale modules, two volunteers were asked to repeatedly use the QuickScale and lift a stretcher loaded with 70, 80 and 90kg. This needed to be carried out quickly to minimize the time the assistants would be lifting. Therefore, instead of precise angles, angle ranges were used. These ranges were: 0-5 degrees, 10-15 degrees and 20-25 degrees. The angle Alpha was measured using a straight bubble measure in contact with the ground and a protractor as seen in Fig. 3.3. First the bubble measure was placed in contact with the ground and the side of the handle, and the protractor was put on the side of the bubble measure, the leg of the protractor was then aligned with the angle of the housing. Second, the assistant is either told to take a step to the back or to the front until the QuickScale's orientation was within the desired angle range. Third, this is repeated for the second assistant holding the other QuickScale module. Fourth, the hold function is enabled to average the weight and freeze it in the LCDs of the two QuickScale units. The depicted weights were then noted and compared to the known weight put on the stretcher.

QuickScale usability experiments

As a result of the design analysis, a possible use error around the weight measurement was identified: The accidental and unintended taring of the mortal remains on the stretcher. To minimise the risk of this use error during the operation of the QuickScale and aid in the next iteration of the user interface a usability engineering design approach was used. In this approach, three different versions of the user interface necessary to perform a weight measurement were implemented in the prototype: "The two buttons", "The timed button" and "Toggle switch" were evaluated by performing usability experiments.

Two buttons:



Figure 3.4: The two-button control configuration

The two-button configuration (see Fig. 3.4) was the original control user interface developed for the functional prototype preparation. Each button executes one function, red tares the QuickScale, and black freezes the weight in the display. The design of this configuration places the red tare button and the black hold button within reach of the right thumb of the operator. With instructions available, the Two-button configuration could be a viable, straight forward, user interface for the QuickScale.

Timed button:



Figure 3.5: The single timed button configuration.

The Timed button configuration (see Fig. 3.5) was a single button within reach of the thumb of the operator. The button executes both the tare and hold functions depending on the time the button was held before being released. Inspired by the operation of most kitchen scales, it aims to improve the ease of use by familiarity with kitchen scales.

A short tap initiates the tare function and holding the button down and releasing it after 2.5 seconds initiates the hold function freezing the weight in the display.

An instruction sticker with colours matching the quick start guide and the time necessary to depress a button was added. Participants needed to tap the button (0.5 seconds) to initiate the 'Tare' function and needed to hold the button (3 seconds) to freeze the weight in the display.

Toggle switch:



Figure 3.6: The toggle switch configuration.

The toggle switch configuration (see Fig. 3.6) houses one toggle switch and a button within reach of the operator's thumb. The toggle switch indicates and enables either the tare or the hold function, when the white button is pressed the function is executed. This aims to make the operator think before executing a function by adding an extra step in the operation. This pause and the fact that both functions are required to complete a measurement could help deduce which step is next in weight measurement. To prevent the wrong position from being selected, an information sticker is placed around the toggle switch which communicates to the user which function the white button executes.

The QuickScale usability experiments were designed as a formative evaluation of these three user interfaces. The goal of this evaluation was to assess how intuitive and easy to use each user interface was and which user interface participants preferred. Besides this, the usability tests were used to discover flaws in the current design and to collect anthropometric data to aid in the dimensioning of the handlebar and placement of buttons.

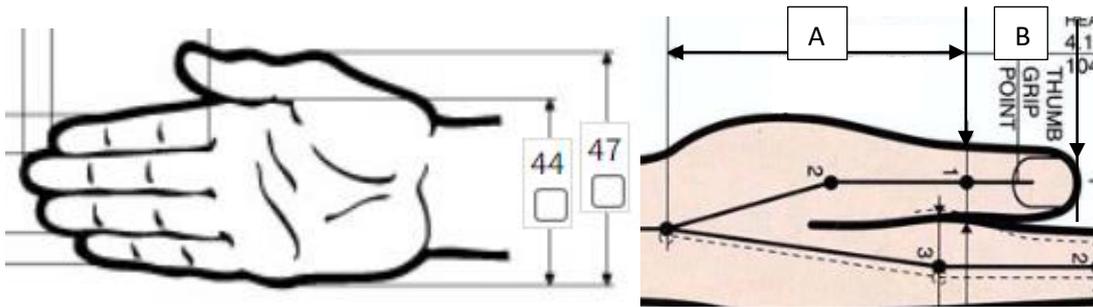


Figure 3.7: Anthropometric hand data collected.

The anthropometric data that was collected is depicted in Fig. 3.7. It concerns the total width of the hand (47). The hand palm width (44). The thumb grip point was measured by adding the distance between the crease of the wrist and the proximal thumb phalanx (A) to half the length of the distal thumb phalanx (B). So:

$$\text{Thumb Grip Point} = A + \frac{B}{2}$$

These measurements were collected from the participants' bare hands. But during the usability test participants would wear nitrile gloves as they would while operating the QuickScale on a crime scene. The device was handed over to two participant groups: students and personnel from the Dutch forensic unit. After the anthropometric data of all participants was collected, they were given an instruction video in which the instructions about button use were left vague on purpose. and a quick start guide as seen in Fig. 3.8 which they could consult during the experiment.

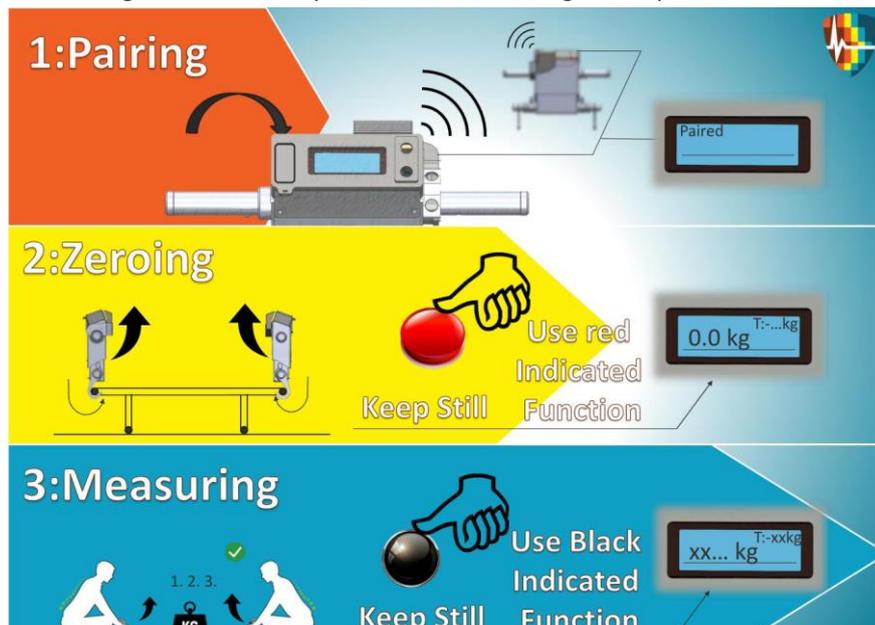


Figure 3.8: QuickScale quick start guide.

In evaluating the user experience of the QuickScale a combination of a post-task and a post-test assessment of usability was used. The post-task assessment consisted of capturing the impressions of the participants after they used two different user interfaces by a single ease question (SEQ). Participants were asked if they preferred the current user interface or the previous user interface. The post-test assessment consisted of a standard questionnaire based on the system usability score (SUS) in which participants answered questions regarding their experience.

Experiment Design

The usability tests were performed on two different groups of 12 participants, one group of student participants and another group of forensic investigators. The goal for the participants was to complete multiple weight measurements using the different QuickScale user interfaces with the help of an assistant, while the researcher recorded their use errors and the number of times participants checked the Quick Start guide. This was done using a data collection form, included in Appendix E. The experiments were structured as follows:

1. **First Encounters:** The goal of the first part of the experiment was to find out how intuitive each designed user interface was to use. Users had first encounters with each user interface. To reduce the effect of the order, the user interfaces were presented in different orders to different participants. This order was determined by a Latin-square, meaning that the three user interfaces were arrayed over the participants as seen in Table 3-1:

Table 3-1: Latin square of six participants and the orders in which each is to use the different user interfaces.

Participant Nr.	First User interface	Second User Interface	Third User interface
1	Two Button	Timed Button	Toggle Switch
2	Two Button	Toggle Switch	Timed Button
3	Toggle Switch	Two Button	Timed Button
4	Toggle Switch	Timed Button	Two Button
5	Timed Button	Toggle Switch	Two Button
6	Timed Button	Two Button	Toggle Switch
This array repeats every six participants			

They were asked to perform weight measurements with each user interface during which their use errors were recorded, to see how confident they felt in using the QuickScale the number of times they consulted the Quick Start guide was recorded as well. If a participant was checking the QuickStart guide more than users on average it could be inferred that they did not feel confident in using the QuickScale. After the participants were done using their second and third user interfaces they were asked which they preferred over the other.

2. **Learning Curve:** The goal of the second part of the experiment was to identify the learning curve. Participants were asked to perform successive weight measurements with each user interface to see how their mastery of the controls over time developed.

After the weight measurements, the participants were asked to fill out a post-study, systems usability questionnaire (SUS)[16]. This is a standardised questionnaire that was slightly adapted for the QuickScale usability tests.

Adapting the system usability score for the QuickScale

The SUS questionnaire is a standardised form based on 10 questions asking about their experience using a system or device, these questions are listed below in fig 3.9.

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

Figure 3.9: The standardised questions of the system usability score method.

The answers to the questions are scored as follows:

1-Strongly Disagree, 2-Disagree, 3-Neither Agree nor Disagree, 4-Agree, 5-Strongly Agree.

By answering the questionnaire, the participants provide an impression of the device's usability. To generate a system usability score per participant, a five-point Likert scale is used. In using this scale 1 was subtracted from the odd-numbered questions while the scores of even questions were subtracted from 5. This is done to account for the positive or negative phrasing of the question.

This result is then multiplied by 2.5 to generate the system usability score ranging between 0-100. While not a percentage, this is done to broaden the range of the scores. Higher scores represent a better user experience than lower scores.

The standard questionnaire was adopted in such a way that instead of 'system' the questionnaire mentions 'QuickScale' and the first question was changed from:

1. I think that I would like to use this system frequently.

To:

1. I think that the QuickScale accurately obtains the weight of a body and does this quicker than first transporting the mortal remains to the morgue.

This was done because "I think that I would like to use this system frequently" is phrased positively however, frequently using the QuickScale would mean that the user would frequently weigh mortal remains on a crime scene. And this framing can reasonably be expected to be negative. The adapted questionnaire is included in Appendix E.

Because usability scores by themselves provide no reference to the actual usability of a system. A scale to interpret the score, the Sauro-Lewis grading scale, was used, see Table 3-8. This is a standardized scale and is used to interpret the usability score of a system by scoring it like an exam A+ and 100% being the highest scores. The developers of the Sauro-Lewis scale recommend that before implementing a device the SUS should at least be an average of 80 so an A- or 85% [17].

Table 3-2: The Sauro-Lewis Scale, Generalized Usability Scores for grading a system.

SUS Score Range	Grade	Percentile
84.1–100	A+	96–100
80.8–84.0	A	90–95
78.9–80.7	A-	85–89
77.2–78.8	B+	80–84
74.1–77.1	B	70–79
72.6–74.0	B-	65–69
71.1–72.5	C+	60–64
65.0–71.0	C	41–59
62.7–64.9	C-	35–40
51.7–62.6	D	15–34
0.0–51.6	F	0–14

Changes for forensic unit usability tests:

Three changes were made for the participants of the forensic unit (FU):

1. Due to time constraints, only the two buttons and the toggle switch control interfaces were tested. These were selected as they had the least user errors in the student usability tests.
2. The time it takes to execute the 'Tare' function was shortened. This was done by decreasing the array size of the measurements the QuickScale makes as soon as the tare function is enabled.
3. In the "Learning Curve" part of the experiment, FU participants were asked to perform two weight measurements in a row instead of three.

Usability Design Requirements

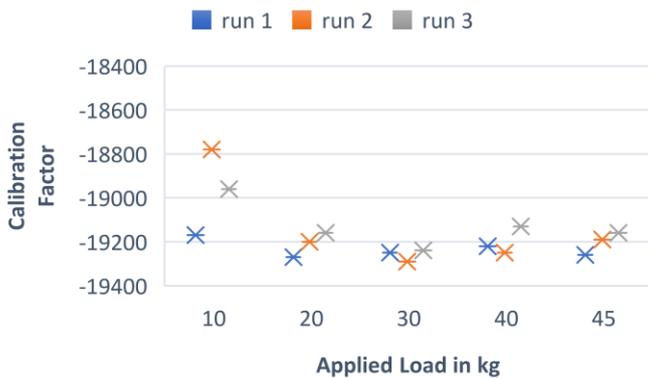
During the adaptation of the prototype new requirements for the design were extracted. These are the results of implementing the desired features and functions of the device and both the student and forensic unit usability tests. These were added to the design requirements that were established during the design analysis.

Results

Calibration

For each unit, three calibration runs were executed. The calibration factors were adjusted until they were accurate up to 0.1 kgs. For example, when the output would fluctuate between 12.35 and 12.45 it was deemed calibrated for 12.4kg. During the calibration, the available weights went up to 45kg.

Calibration Factors Unit 1



Calibration Factors Unit 2

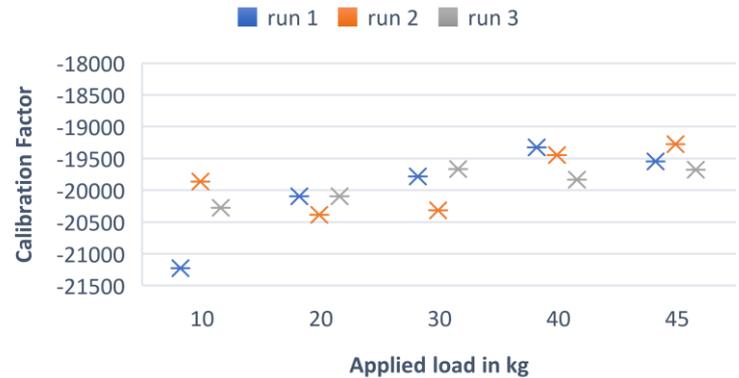
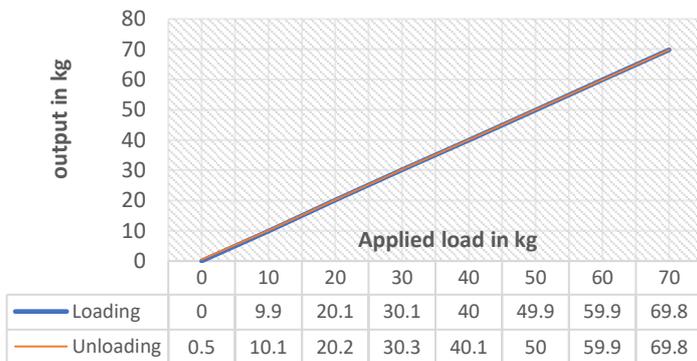


Figure 3.10: Calibration factors for both QuickScale units found to display the correct applied load.

After finding these calibration factors corresponding to the applied loads the calibration factors found between 20 and 45kg were averaged. Calibration factors under 20kg were not used as the load cell is not accurate within this range as the LCM300 is linear between 20 and 45kg.

The averaged calibration factors were: -19214.6 for unit 1 and -19825.7 for unit 2.

Calibration Curve unit 1



Calibration Curve unit 2

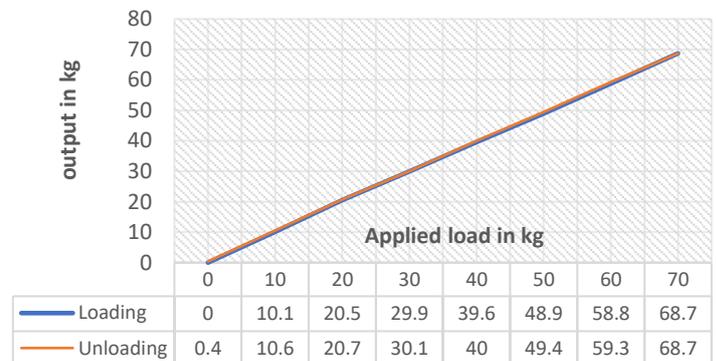


Figure 3.11: Calibration curves of both QuickScale units.

To evaluate these calibration factors, calibration curves for each of the QuickScale units were made with their corresponding calibration factors see Fig 3.11. Unit 1 has an error of 0.28%, unit 2 has an error of 1.8%. Both calibrated QuickScale units display little hysteresis, 0.5 and 0.4 when all weight is removed.

Validation

The validation results are presented in Table 3-2, during 90kg measurements results indicated by the orange cells of table 3-2, the taring of the stretcher was inaccurate. The stretcher weighed 13.8kg and the weight the QuickScale tared during those runs was 12.8kg. To depict what was measured, this 1kg was not corrected for in the table. However, considering that the weight of the stretcher was known when corrected for this kg of difference result was within 1.3% error as per DAR-WM-1 in Table 2-1.

Table 3-3: Results of the displayed weight measurements with both the units held at the indicated angles.

Reference weight	Angle 0-5deg		Angle 10-15deg		Angle 20-25deg	
	Unit 1	Unit 2	Unit 1	Unit 2	Unit 1	Unit 2
70.0 kg	69.9	69.7	69.3	68.34	68.6	68.94
80.0 kg	80	80.14	79.3	79.4	78.8	78.7
90.0 kg	89.7	89.8	88+1	88.02+1	88+1	87.82+1

QuickScale usability experiments

Hand anthropometry data:

After performing a Jarque-Bera test on the collected anthropometric samples and finding no p-value smaller than 0.05 it was assumed that the collected anthropometric data was normally distributed.

Table 3-4: Anthropometric data of student and forensic user participants.

Student data	-S. Deviation	Mean	+S. Deviation
Palm width (44)	71 mm	80 mm	88 mm
Hand width (47)	87 mm	97 mm	107 mm
Wrist crease - Head proximal phalanx 1 (A)	79 mm	85 mm	91 mm
Length distal phalanx (B)	28 mm	32 mm	36 mm
Calculated thumb grip point (= A + (B/2))	94 mm	101 mm	108 mm
Forensic Unit			
Palm width (44)	75 mm	82 mm	88 mm
Hand width (47)	91 mm	100 mm	108 mm
Wrist crease - Head proximal phalanx 1 (A)	75 mm	86 mm	97.43 mm
Length distal phalanx (B)	27 mm	31 mm	35mm
Calculated thumb grip point (= A + (B/2))	89 mm	102 mm	114 mm

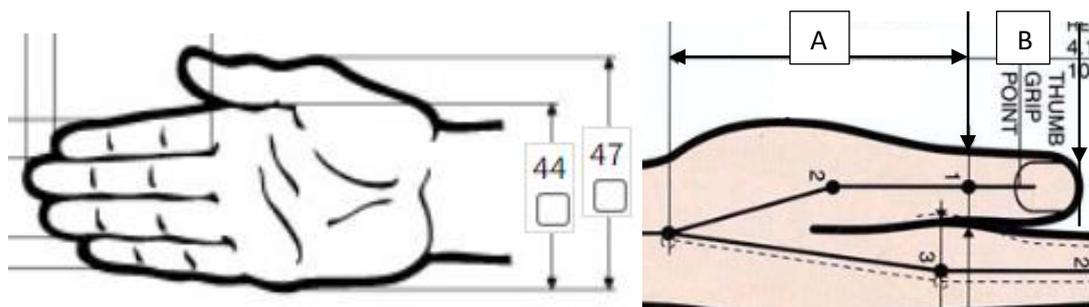


Figure 3.12: Depicting the measured hand dimensions.

Use Errors & Quick Start Guide Checks

The total number of use errors and quick start guide checks per user interface during the first time and continued use are displayed in Table 3-3 for the Student participants and in Table 3-4 for the forensic unit participants.

Table 3-5: Total numbers of use errors and quick start

User Interface	First Time Use				Continued Use					
	# Use Errors	Median	# Guide checks	Median	Use Errors			Guide Checks		
					R1	R2	R3	R1	R2	R3
Two-Button	13	0	11	0.5	3	2	1	3	1	0
Toggle Switch	15	0.5	10	0	7	3	4	0	2	0
Timed Button	24	1.5	23	0.5	2	2	2	0	0	0

Table 3-6: Total numbers of use errors and quick start guide checks for 12 forensic unit participants.

User Interface	First Time Use				Continued Use			
	# Use Errors	Median	# Guide checks	Median	Use Errors		Guide Checks	
					R1	R2	R1	R2
Two-Button	5	0	10	0	0	2	4	1
Toggle Switch	15	0.5	13	0.5	4	3	0	0

To gain insight into the distribution of use errors amongst the participants, in Fig 3.14 and Fig. 3.15, the spread of first-time use errors and quick start guide checks per user interface is displayed in box and whisker plots. For reference, a legend and description is displayed in Fig. 3.13.

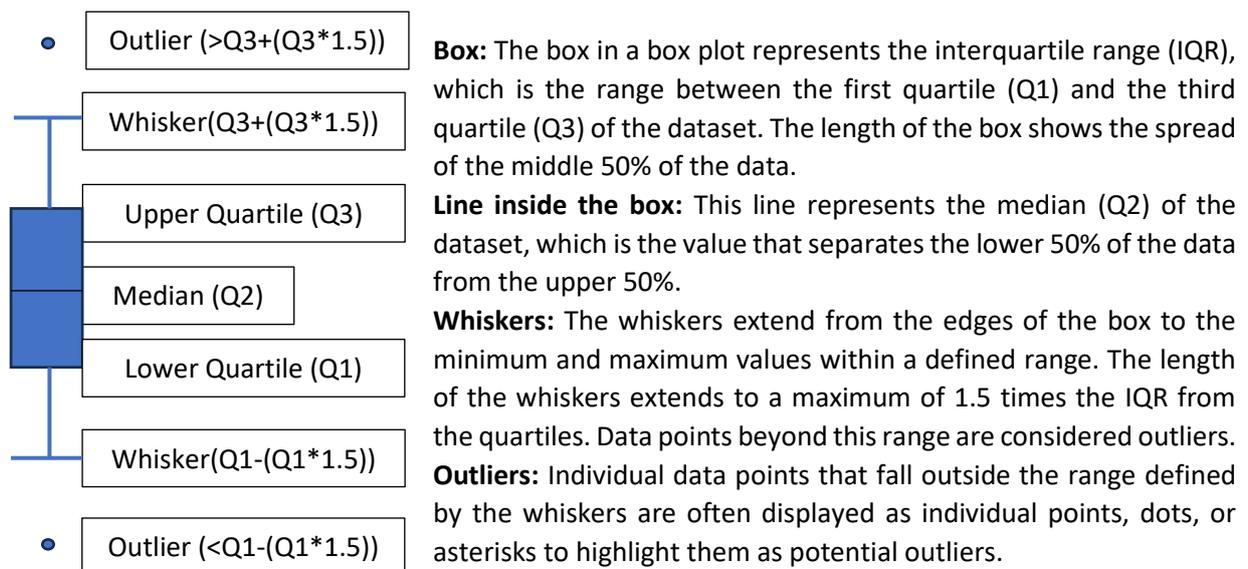


Figure 3.13: Box plot representation of data.

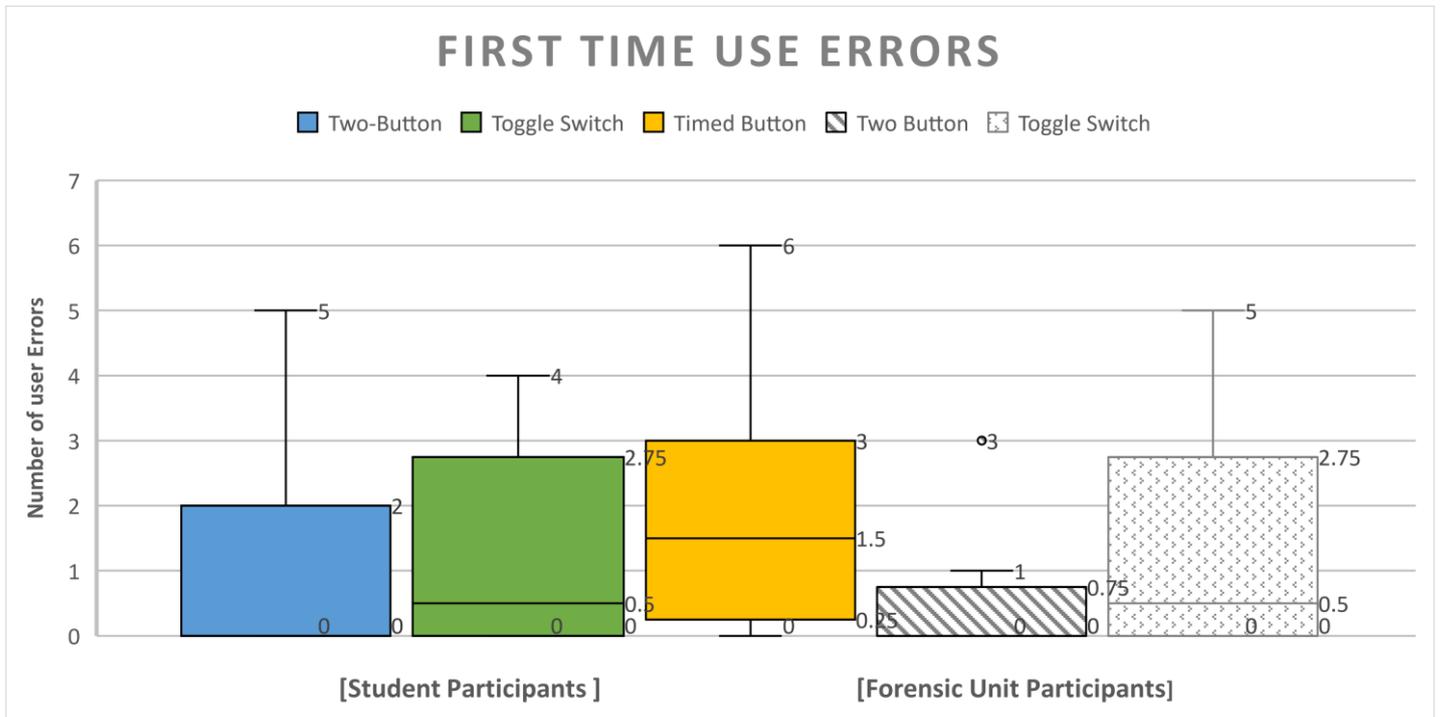


Figure 3.14: Box Plots depicting the first time use errors made per user interface.

As depicted in Figure 3.14, during their first times using the Two-Button interface, both participant groups had a median use error of zero. The forensic unit participants made fewer errors in total. Indicated by the difference in the interquartile range of 1.25 (2-0.75). While not ahead by much, this was promising for the Two Button configuration.

The box plots of both participant groups for the Toggle Switch were similar, except for a rounding difference of 1 (5-4) in the upper whisker. While the forensic participants did not use the Timed button user interface. In the student participant group, the timed button interface scored the worst out of all user interfaces, indicated by the median of 1.5 and upper quartile of 3.

FIRST TIME USE QUICK START GUIDE CHECKS

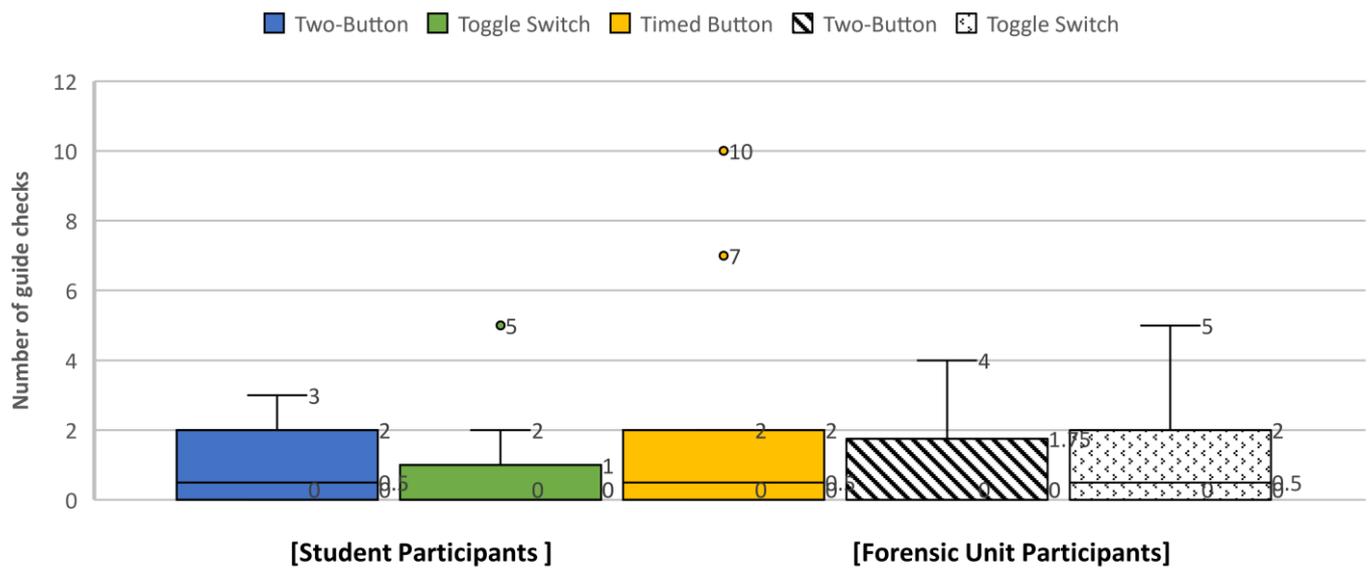


Figure 3.15: Box plots depicting the times participants consulted the Quick Start guide.

The median of less than 1 Quick Start guide checks also indicates that participants felt confident during the use of the QuickScale, see Fig 3.15. However, three outliers show that one student participant lost their confidence when confronted with the toggle switch user interface and two student participants didn't feel confident using the timed button user interface. These participants did not get agitated in the experiment they just took their time to make sure they understood the user interface and referred back to the quick start guide as often as 10 times .

Considering the learning the curve part of the usability tests

The spread of use errors was very small in the continued use part of the usability tests. The results of the forensic unit are skewed to participants having 0 use errors with the exception of two users. Considering the student participants, in most cases when a use error was made the participant knew they made an error. When correcting for two student users participants not using the hold the function to freeze the weight in the display this spread is also skewed towards 0.

Questionnaire results:

After the usability tests participants were asked to indicate a preferred user interface. Some participants found it hard to choose a single interface as they saw benefits to each interface. However the participants were asked to pick a single user interface .

Table 3-7 Student participants' preferred user interfaces.

5	Student participants indicated they preferred the Two-button interface.
3	Student participants indicated they preferred the Toggle-switch interface.
4	Student participants indicated they preferred the Timed-button configuration.

Table 3-8 Forensic user participants' preferred user interfaces.

7	Forensic unit student participants indicated they preferred the two-button interface.
5	Forensic unit participants indicated they preferred the flip-switch interface.

Interestingly, the preferences are quite closely grouped. With not a very clear "winner" so to say, repeatedly participants said that they 'got the point' of their non-preferred user interfaces.

System Usability Scores

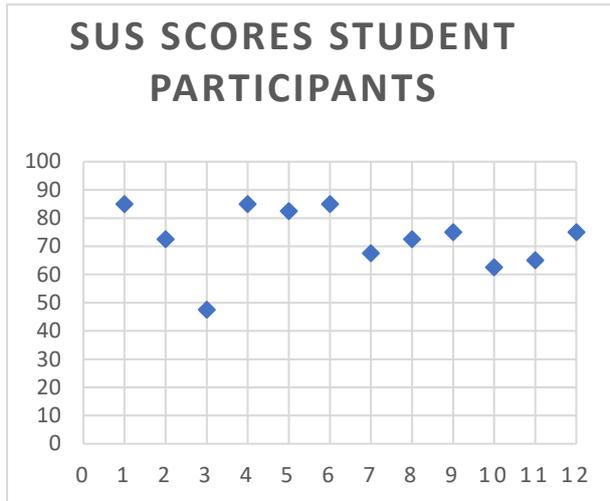


Figure 3.17: System Usability Scores of 12 Student participants.

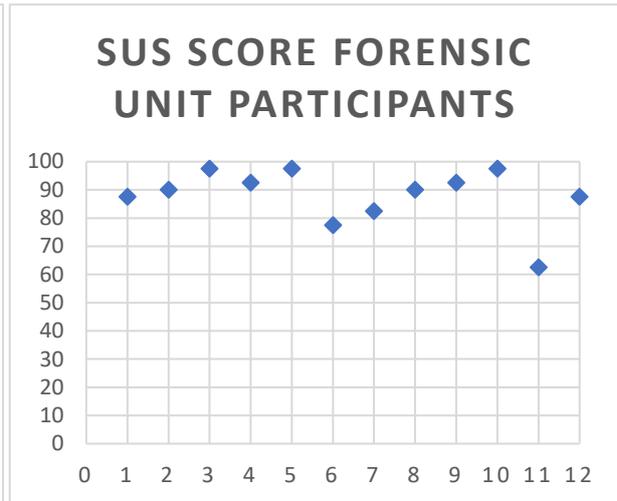


Figure 3.16: System usability scores of 12 Forensic unit participants.

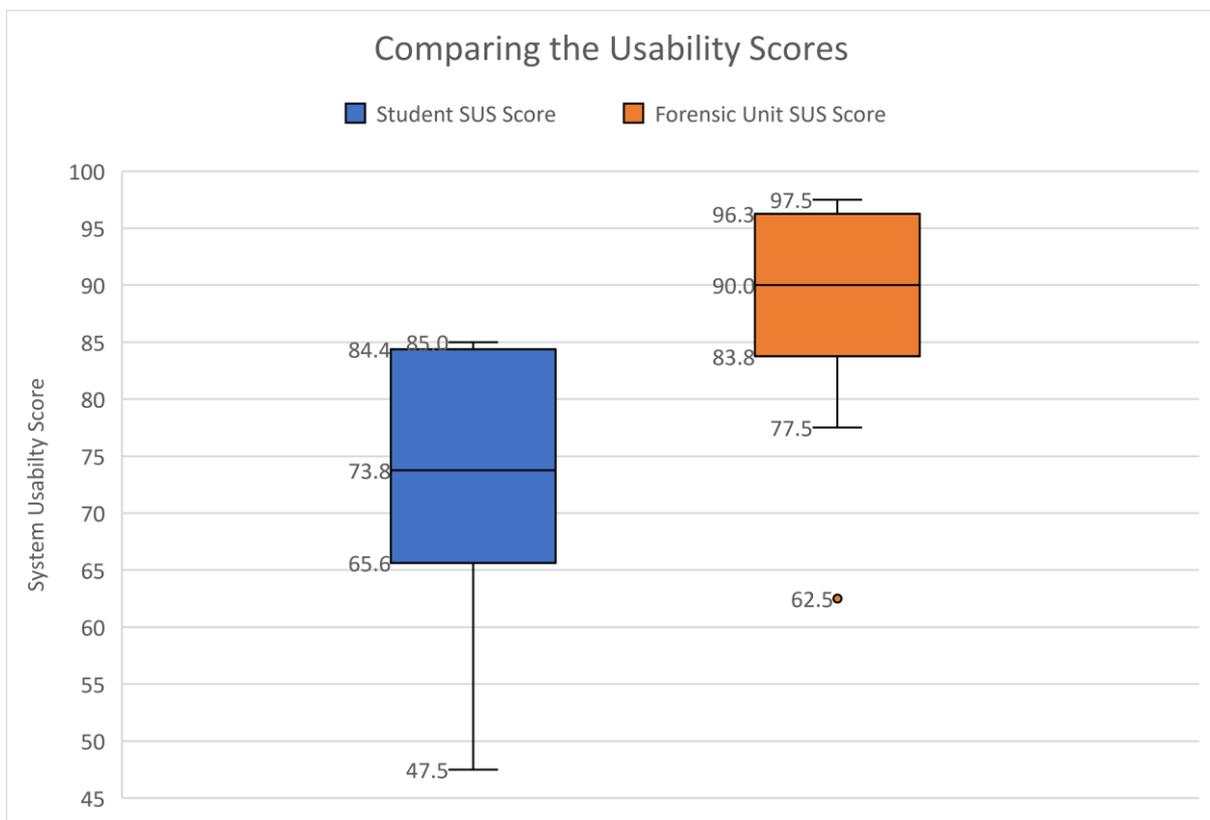


Figure 3.18 Box plots indicating the spread of the QuickScale Usability scores of Student and Forensic Unit Participant groups.

In Figures 3.16 and 3.17 the usability score per participant is displayed. In Fig. 3.18 the spread of the QuickScale usability scores given by both participant groups. The median score of the the forensic unit participants was 90 while the median score of the student participants was 73.8.

In the forensic unit, 50% of the participants scored the QuickScale between 83.8 and 96.3 while 50% of student participants scored their use of the QuickScale between 65.6 and 84.4.

The usability tests that the forensic users performed were slightly different from the student usability tests. Adjustments were made to the usability tests to decrease the time to completion, this can influence the user experience.

In general, higher SUS scores are better but by themselves, these scores don't give insight into the performance of the system. Therefore, in interpreting the usability scores a scale is provided by Lauro-Sewis. For readability, this scale is depicted again below in Table 3-9

Table 3-9: The Sauro-Lewis Scale, Generalized Usability Scores for grading a system.

SUS Score Range	Grade	Percentile
84.1–100	A+	96–100
80.8–84.0	A	90–95
78.9–80.7	A–	85–89
77.2–78.8	B+	80–84
74.1–77.1	B	70–79
72.6–74.0	B–	65–69
71.1–72.5	C+	60–64
65.0–71.0	C	41–59
62.7–64.9	C–	35–40
51.7–62.6	D	15–34
0.0–51.6	F	0–14

The median user experience of the student participants (73.8) can be scored with a B-, which is disappointing as the method recommends a threshold of a usability score of 80 before implementation. On the other hand, the median user experience of the forensic unit participants (90) scores well above that with an A+. Which is good enough to be implemented according to the Sauro-Lewis scale.

Analysing the student usability test findings:

1. Accidental Button Presses

During the operation of all user interfaces. When some users lifted the QuickScale and stood up straight they held the QuickScale in front of their hips. As they did this the hips would make contact with the QuickScale and accidentally press the button situated at the front See Fig 3.19



Figure 3.19: Circled Buttons pressed with hip.

They would not notice this and later register that they were re-taring or had released the held weight without meaning to. It would be beneficial if buttons were dimensioned so as not to protrude outside the handlebars or housing so these buttons can not be depressed by accident.

2. Hard-to-reach buttons

When operating the black hold button and the toggle switch user interfaces, participants with a small thumb grip range (<94mm), remarked that the buttons on top of the user interface were hard to reach. These buttons are depicted in Fig. 3.20

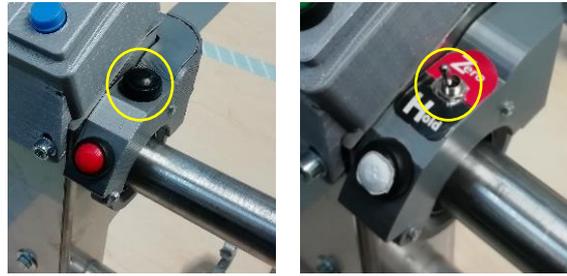


Figure 3.20: Circled buttons on top that were hard to reach

For the next design of the QuickScale it would be beneficial if all buttons are comfortable to reach, i.e. are well within the reach of the end users' fingers

3. Time before 'Tare' completion

The time that it takes to zero the weight of the stretcher is perceived as too long. For reference, on average most time it took was between 10 and 30 seconds. However as it is hard to stand exactly still, this could take up to 1 minute or longer. Student participants showed impatience or stated their displeasure lifting the stretcher while waiting for the device to tare. Therefore, minimizing the time it takes to Tare the QuickScale, without a loss of precision would be beneficial for the next version of the QuickScale.

4. Instruction Stickers

When users felt doubt about the next action they should take in the user tests, they studied the instructions sticker present on both the Toggle Switch and Timed button user interfaces. Later they remarked that these instruction stickers in direct view of their hands were helpful.



Figure 3.21: Information stickers Indicating functions.

5. Indicating 'Tare' and 'Hold' Functions

When using the QuickScale 'Tare' and 'Hold' functions. The text 'Taring' and 'Hold' would be displayed in the upper left corner of the LCD Screen. Just as the tared weight was displayed in the upper right corner, see Fig 3.22.

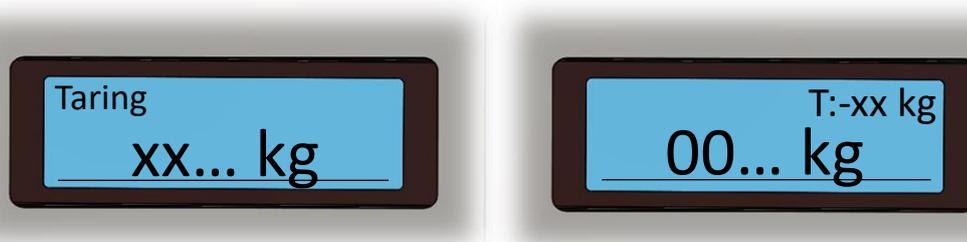


Figure 3.22: Left, Taring action visible in top left corner of lcd screen, Right Tared weight is displayed in right corner lcd screen.

However, this was only noticed by 5 out of 12 participants during the student participant usability tests. It would be beneficial if these functions were indicated better in the next version of the QuickScale.

6. QuickScale Battery life

At the start of the second day of the student usability tests, the batteries of the QuickScale ran out. This meant that the batteries had lasted about 72 measurements and the batteries were quickly replaced. However, no indication of the current battery life was present on the display of the user interface.

Analysing the forensic unit participant usability test findings:

1. Default number of users

When questioning forensic unit participants about their experience in lifting the QuickScale. Participants commented that lifting average mortal remains with two users would be challenging. This poses a question, as the standard amount of users the QuickScale was designed for is two and as an option, the QuickScale can be made to accommodate 4 users. Taking this into account for the next version of the QuickScale meant that it should be as easy as possible to extend the QuickScale and besides. It would be beneficial if the standard work instruction encourages users to use the QuickScale with 4 users.

2. Readability of the display

When a forensic unit participant who was far-sighted used the QuickScale, they commented that they couldn't read the display without glasses. While the readability of the display was not a problem for the other participants it would be nice to have a way to adjust the size of the text in the next version of the QuickScale, but as this is only commented on by a single participant and should be easy to prevent or work around, it should not be a design criterion.

3. Lifting Posture

The lifting posture of 10 out of 12 forensic user participants was quite poor, they rounded their backs in lifting the QuickScale. They also held their arms out in front of them, this was possible because the weight used to measure did not challenge them. Only participants experienced in weightlifting performed the lifting of the QuickScale with the correct form. In the next version of the QuickScale special care should be taken to try to inform users about correct lifting posture.

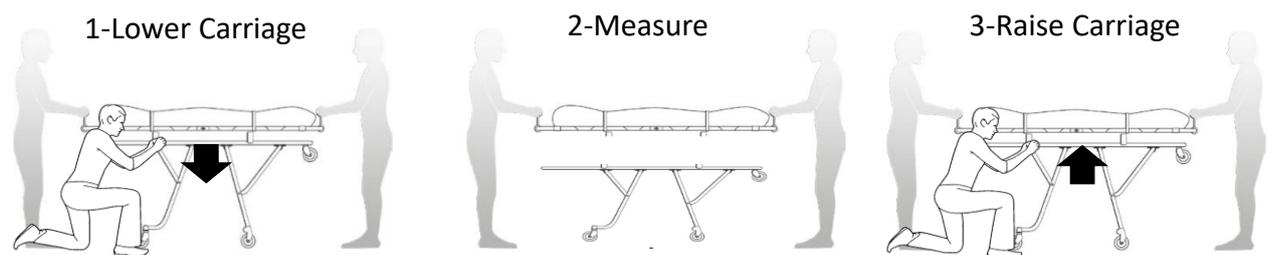


Figure 3.23: Steps indicating the workaround in which users of the WQuickScale don't have to lift the device off the ground. Images Adapted from Canada.ca and W.Tang

A suggested workaround for the bad lifting posture is the possibility of collapsing the carriage under the stretcher and letting the stretcher hang instead of having to lift it, see Fig 3.23. This prevents users from having to lift the QuickScale from the ground up. But does require a third person present for lowering the carriage and, raising it if necessary.

4. Bodies Obstructing View

During the Forensic participant's usability tests, 2 participants had trouble getting a direct line of sight on the display due to their bellies being in the way. These participants would try to read the display and in doing so compromise their posture while lifting. They would push their arms out to the front, while ideally in this situation participants should step back. This might also be a result of the lifted weight being too low. It would be beneficial for the next version of the QuickScale to inform users to communicate when they can not view the display and use the weight displayed by the accompanying QuickScale unit from their partner.

5. Integration with body bags

During the usability tests and after reviewing comments made on questionnaires users indicated that they would like a possibility to integrate the use of the QuickScale in combination with a body bag. However, this finding contrasts with the target group research performed by W. Tang. The body bag might get damaged by attaching it to metal attachments and besides this, the contents are likely to shift in the body bag risking damage to the mortal remains and destroying evidence. Therefore this is not considered beneficial to the next version of the QuickScale.

Usability Design Requirements

Table 3-10: Post Usability tests Design Requirements.

Abbreviation	Description	Source
UDR-D	Device	
UDR-D-1	The device handlebars promote a safe lifting posture which keeps the back straight and doesn't require rotating the shoulders and wrists.	Forensic unit usability tests
UDR-D-2	The device handlebars allow for easy extension to lift with four persons in a safe manner.	Forensic unit usability tests
UDR-D-3	The device encourages operation by four persons.	Forensic unit usability tests
UDR-UI	User Interface	
UDR-UI-1	There is a battery indicator present indicating an empty (<33%), half full (<66%) and full battery.>66%)	Student usability tests
UDR-UI-2	Buttons are dimensioned so as not to protrude outside the handlebars or housing to prevent accidental button presses.	Student usability tests
UDR-UI-3	The button placement is within the calculated thumb grip point of the forensic user participants of the usability study. (89mm) without obstructing users having longer thumbs.	Student usability tests and forensic unit usability tests
UDR-UI-4	The display can be read in dark outdoor and light indoor conditions.	Forensic unit usability tests
UDR-UI-5	The tare function, zero's the weight displayed on the user interface within 2 seconds.	Student usability tests
UDR-UI-6	An instruction is present in the user interface indicating the order of first taring and then holding.	Student usability tests and forensic unit usability tests
UDR-UI-7	An instruction is present on the outside housing of QuickScale. Indicating the steps for weight measurement.	Forensic unit usability tests
UDR-UI-8	A clear indicator audibly and visibly depicts the function that the QuickScale is performing.	Student usability tests
UDR-P	Preferences / Nice to haves	
UDR-P-1	An optional work instruction booklet accompanying the QuickScale is made available for letting the stretcher hang between the operators until a weight measurement is completed	Forensic unit usability tests
UDR-P-2	The device promotes taking up a wide stance and lifting like performing a deadlift.	Forensic unit usability tests
UDR-P-3	The size of the text on the LCD screen is depicted large enough so someone who isn't near or far-sighted can clearly see the depicted text from an armlength away.	Forensic unit usability tests
UDR-P-4	The display on the user interface remains within the user's direct line of sight at all times, even when obstructed by clothing or body parts.	Student usability tests and forensic unit usability tests

4. Final design and evaluation

This chapter focuses on the final design and evaluation of the newest iteration of the QuickScale. The QuickScale was broken down into components each with its engineering challenges, and potential solutions were assessed. The results section of this chapter portrays the selection design solution based on the earlier defined design requirements.

Methods

For the final design, the QuickScale prototype was further refined by dividing the design effort into separate design challenges. For each design challenge, the relevant design requirements were collected and converted into evaluation criteria. Multiple solutions were presented for each design challenge, providing a range of potential options for consideration. Each solution was chosen using a morphological chart and iterated upon.

Load-Cell Non-Linearity

During the calibration and validation, inconsistent behaviour in the weight depicted on the QuickScale when measuring below 20kg shows non-linear behaviour.

Table 4-1 Design Requirements relevant for load cell non-linearity.

Abbreviation	Description	Source
Design Analysis Requirements		
DAR-WM-1	The device must be able to measure weights from 8 to 171 kg with an accuracy of 1.3%	Research on measuring range by W.Tang

Possible Solutions:

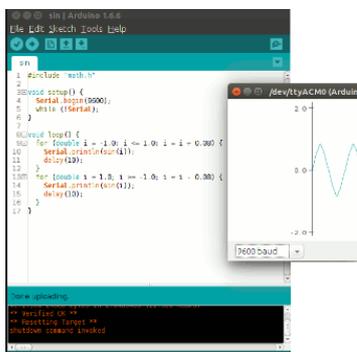


Figure 4.1: The Arduino Interactive Design Environment

1. Software solution

Attempting to map the nonlinearity in the zone below 20kg and correcting for this in the software. This could potentially be done by fitting a polynomial after testing. Then adjustments need to be made to the calibration factor in the Arduino Script.

Another possibility is to have a separate mode on the QuickScale in which the user indicates that the measured weight will be below 20kg. This mode alters the calibration factor to better reflect the weights in this region.

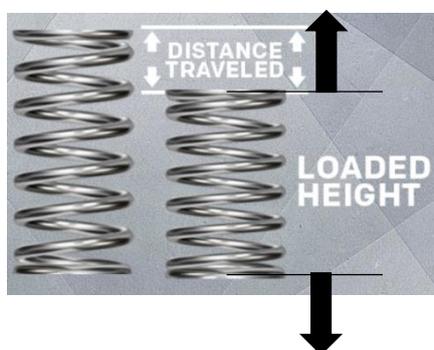


Figure 4.2: Springs under compression
Image adapted from stockspringscatalog.com

2. Pre-load

Pre-loading the QuickScale load cell. This can be done by compression springs inserted between parts of the QuickScale connected to both ends of the load cell.

3. Different Load Cell

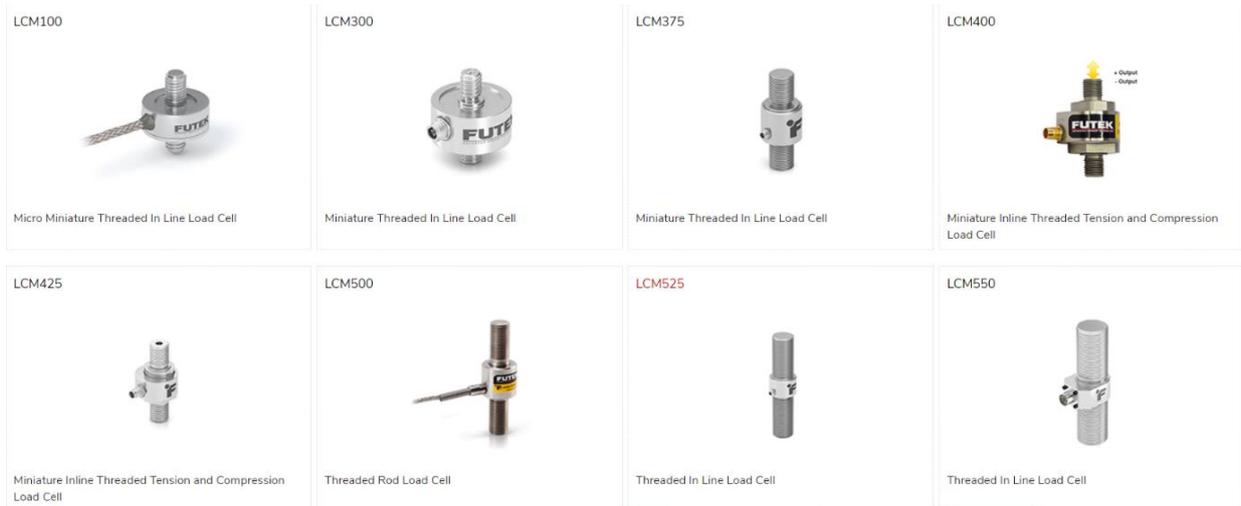


Figure 4.3: In-line load cells available from the Futek website www.Futek.com

Another possible solution is changing the load cell to another with a linear range under 20 kg, FUTEK supplies other load cells as visible in fig. 4.3. Other providers of load cells which could also provide the load cell for the next QuickScale version.

User Interface

For the final design of the user interface, input from the usability tests was used.

Table 4-2 Design Requirements relevant to the User Interface

Abbreviation	Description	Source
Design Analysis Requirements		
DAR-U-1	The user interface should be operable by both left and right-handed users.	Design analysis
DAR-U-2	The placement of buttons on or in the handles should be within reach of the users with the smallest thumb grip. Without obstructing the reach of users with a larger thumb grip.	Design analysis
DAR-U-6	The control panel is within reach during lifting and carrying of the bed	Process diagram by W.Tang
DAR-U-7	The display screen is readable during the carrying of the bed	Process diagram by W.Tang
DAR-U-8	The measurement value can be frozen in the display.	Task/target group research by W.Tang – Adjusted for this report
DAR-U-9	There must be a possibility to take a photo of the measurement value with another camera.	Task/target group research by W.Tang – Adjusted for this report
DAR-P-2	Using the device feels intuitive and new users experience few errors, which can be corrected for by experienced users.	Client preference
DAR-P-3	The device should incorporate measures to prevent accidental or unintentional zeroing the weight of the mortal remains.	Design Analysis
Usability Design Requirements		
UDR-UI-2	Buttons are dimensioned as not to protrude outside the handlebars or housing to prevent accidental button presses.	Student usability tests
UDR-UI-3	The button placement is within the calculated thumb grip point of the participants of the usability study.	Student usability tests & Forensic unit usability tests
UDR-P-4	The display on the user interface remains within the user's direct line of sight at all times, even when obstructed by clothing or body parts.	Student usability tests & Forensic unit usability tests

Possible Solutions:

Three possible concepts were tested during the usability tests, as a result of these tests the Two-Button concept resulted in the least user errors. This concept will be used in the final design. Furthermore, the results from the anthropometric data collected during the usability tests are to be used in the detailing of the button positions.

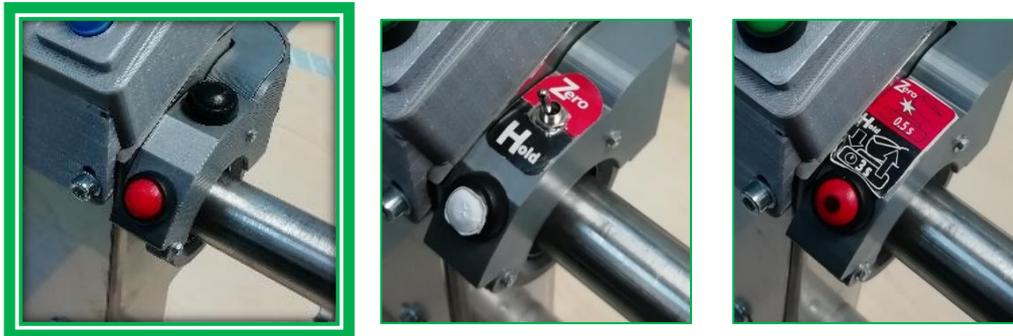
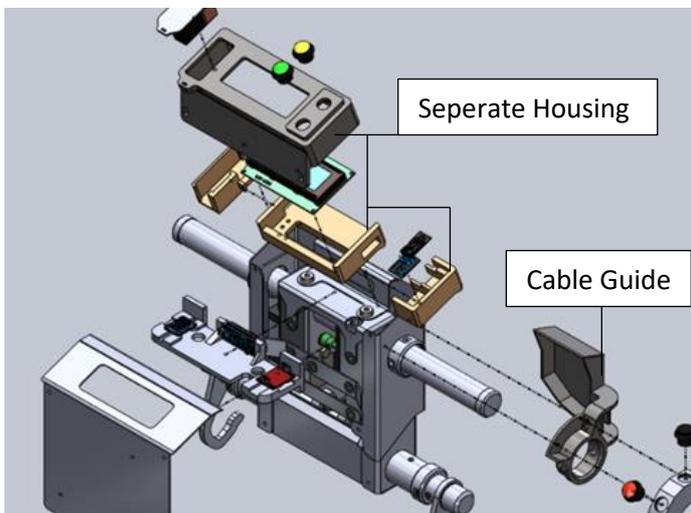


Figure 4.4: The Two Button, Toggle Switch and Single Button concepts

Housing the Electronics



During the functional prototype preparation, the electronics could not be placed within the metal housing, requiring a separate housing and cable guides to be developed (fig4.5). In the final design, this can be remedied.

Figure 4.5 Overview of the electronics placed within the QuickScale.

Table 4-3 Design Requirements Relevant to Housing the Electronics

Abbreviation	Description	Source
Design Analysis Requirements		
DAR-D-1	The electronics fit within the metal housing	Functional Prototype preparation
DAR-D-2	The device housing allows for wireless radio communication	Functional Prototype preparation
DAR-D-4	The device should allow for an easy change of batteries.	Functional Prototype preparation
DAR-U-7	The display screen is readable during the carrying of the bed	Process diagram by W.Tang
DAR-U-8	The measurement value can be frozen in the display.	Task/target group research by W.Tang – Adjusted for this report
DAR-U-9	There must be a possibility to take a photo of the measurement value with another camera.	Task/target group research by W.Tang – Adjusted for this report
DAR-P-1	The parts must be purchased parts	Process flow research by W.Tang
Usability Design Requirements		
UDR-UI-2	Buttons are dimensioned so as not to protrude outside the handlebars or housing to prevent accidental button presses.	Student usability tests
UDR-UI-3	The button placement is within the calculated thumb grip point of the participants of the usability study.	Student usability tests and forensic unit usability tests
UDR-UI-4	The display can be read in dark outdoor and light indoor conditions.	Forensic unit usability tests

Possible Solutions

1. Enlarging Available Volume

Creating the required space available space within the housing of the QuickScale required reconfiguring the sheet metal parts. Both the outer housing and the upper lid were the two parts that would influence the available volume indicated in Fig.4.6 the most. Both these parts could be extended in the vertical direction as depicted in Fig 4.7 without compromising other components. The only downside to increasing the size of these parts is that there is likely to be an increase in the total weight of the QuickScale.

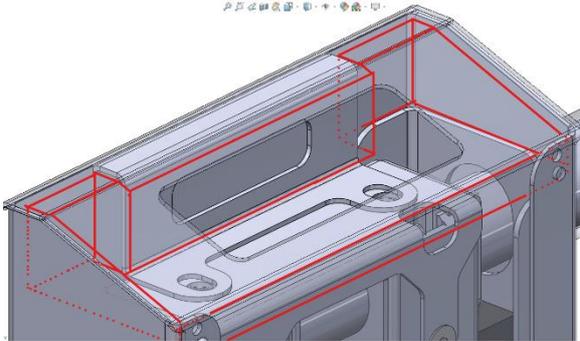


Figure 4.6: Available space for electronics under the lid in the first QuickScale prototype.

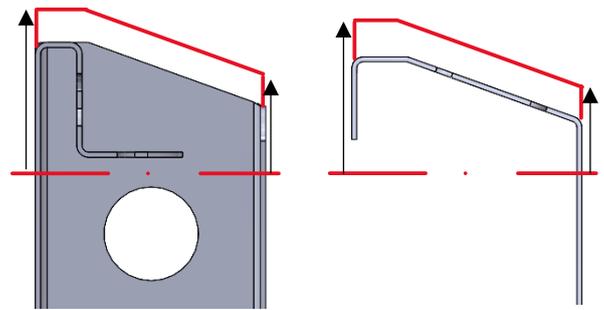


Figure 4.7 Increasing the length of the outer housing (left) and the upper lid (right) parts of the QuickScale.

2. Custom PCB Design

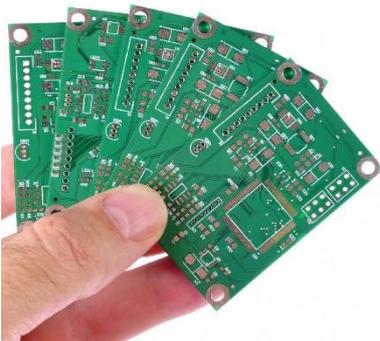


Figure 4.8 Custom Designed Printed Circuit Boards. Image adopted from axonim.com

Instead of connecting all the components using a breadboard and cables, the use of a custom printed circuit board (PCB) could greatly increase the amount of space available for the necessary components. This does require the development of a custom PCB which connects all the electrical components. The trade-off in making a custom PCB is a loss of versatility, a PCB can not be altered unless it is redesigned and re-ordered. Meanwhile, the use of a breadboard and jumper cables offers flexibility and room for error.

Handlebar slip and extension

The handlebar assembly is what users will hold during the lifting of the QuickScale. It integrates with the user interface and can be extended to allow four users to lift the QuickScale. To dimension the new length of both the handlebar and its extensions the anthropometric data from the usability tests was used.

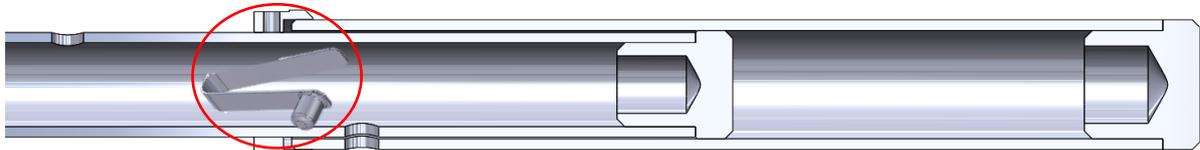


Figure 4.9 Cross section view of the handlebar extension with dislodged button.

There was a slight problem with the use of a button on a spring to connect the extension, which was that the spring could be depressed too much and this caused the button to dislodge, see Fig 4.9.

Table 4-4 Design Requirements Relevant to the Handlebar Redesign.

Sign:	Description	Source
Design Analysis Requirements		
DAR-D-1	The electronics fit within the metal housing	Functional Prototype preparation
DAR-D-5	The device is made in such a way that it does not slip out of the grip of users, even in wet conditions.	Design analysis
DAR-D-9	The device must be able to be used by both two and four persons simultaneously	Task/target group research by W.Tang
DAR-U-1	The user interface should be operable by both left and right-handed users.	Design analysis
DAR-U-2	The placement of buttons on or in the handles should be within reach of the users with the smallest thumb grip. Without obstructing the reach of users with a larger thumb grip.	Design analysis
DAR-U-6	The control panel is within reach during lifting and carrying of the bed	Process diagram by W.Tang
DAR-U-7	The display screen is readable during the carrying of the bed	Process diagram by W.Tang
Usability Design Requirements		
UDR-D-1	The device handlebars promote a safe lifting posture which keeps the back straight and doesn't require rotating the shoulders and wrists.	Forensic unit usability tests
UDR-D-2	The device handlebars allow for easy extension to lift with four persons in a safe manner.	Forensic unit usability tests
UDR-UI-2	Buttons are dimensioned so as not to protrude outside the handlebars or housing to prevent accidental button presses.	Student usability tests
UDR-UI-3	The button placement is within the calculated thumb grip point of the participants of the usability study.	Student usability tests and forensic unit usability tests

Possible Solutions:

To provide the grip it was decided to apply a knurling surface finish on the handlebars and their extensions. There were multiple ways to connect the extension.

1. Bayonet lock



Figure 4.10 Example bayonet lock, Image adapted from kwdesign.co.uk

A radial lock which can be fastened and loosened with minimal effort by twisting the extension. The appeal of this type of lock is that it doesn't need machined thread, requiring the handlebar extensions only to be milled. If the pipe for the handlebars is bought with the right outer diameter and inner diameter then milling is the only required machining for this part. It also does not require additional parts like springs. It is also quite intuitive as many applications with bayonet locks exist e.g. garden hoses, faucet caps etc. End users are likely to be familiar with these types of connections.

2. Bar Insertion



Figure 4.11 Extension bars available on homedepot.com

Removing a lid and inserting a bar of equal diameter, using a push-fit lock, or using a square-shaped connector. This requires additional parts to be machined it is however arguably even easier to use than the bayonet lock as there is not even a twisting motion required to extend the handlebars. Downsides of this type of connection are: First, Some new locking mechanism is required to keep the connection between these parts. Second, forces are concentrated in this connection. Finding the safe dimensions of this connection would require a finite element analysis. And the outcome needs to be part of any risk analysis.

3. Improved spring

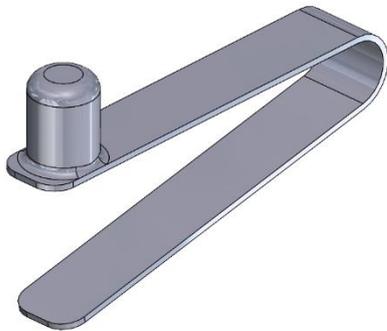


Figure 4.12 Spring loaded pin

Using a stronger spring in the current design could solve the problem of the dislodging spring-loaded pin. It is however hard to repair if the issue persists, as the lid of the handlebar is press fitted. This means that if the spring dislodged in the field (as seen in Fig. 4.9) it would be hard to repair without tools.

User instruction and safety

Part of the user interface is the information displayed to users which instructs in its use. This can be displayed on the LCD screen or a static instruction can be displayed on the housing.

The QuickScale must contain user instructions in which the user is informed about safe lifting practices and how other equipment can aid them in the completion of weight measurements.

Users are to be informed about the following:

- They need to lift safely from their legs and straight backs
- The QuickScale is to be used with multiple people, two or four.
- Only one person is in control of the measurement
- Keeping the QuickScale units stationary during start-up
- The functions of the buttons on the user interface: **Zero** and **Hold**

The order of operations results in a successful weight measurement.

1. Place on the floor, Turn on, PAIR, and choose 1 person to perform the measurement
2. Position Carriage & TARE stretcher
3. Load Mortar remains on the stretcher, Take up a wide stance and LIFT
4. Freeze Weight in Display until a picture is taken

Table 4-5 Design Requirements Relevant to user instruction and safe lifting

Sign:	Description	Source
Design Analysis Requirements		
DAR-D-1	The electronics fit within the metal housing	Functional Prototype preparation
DAR-D-3	The device indicates it needs to remain still during set-up to prevent the wrong calibration of the IMU.	Functional Prototype preparation
DAR-D-5	The device is made in such a way that it does not slip out of the grip of users, even in wet conditions.	Design analysis
DAR-D-9	The device must be able to be used by both two and four persons simultaneously	Task/target group research by W.Tang
DAR-U-3	The user interface is unambiguous about who is in control of the weight measurement.	Design analysis
Usability Design Requirements		
UDR-D-3	The device encourages operation by four persons.	Forensic unit usability tests
UDR-UI-6	An instruction is present in the user interface indicating the order of the tare and hold functions.	Student usability tests and forensic unit usability tests
UDR-UI-7	An instruction is present on the outside housing of QuickScale. Indicating the steps for weight measurement.	Forensic unit usability tests

Possible Solutions:

1. Laser Engraving



Figure 4.13: Laser engraved sheet metal, Image adapted from laser-cutz.com.

During the fabrication of sheet metal parts, the laser can engrave the surfaces with instructions for the weight measurements. This would add slightly to the production time however, as a positive the instructions would be very robust and hard to remove.

2. Stickers with information

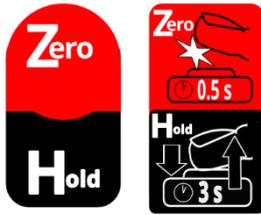


Figure 4.14 Example stickers used for the usability tests

Much like during the functional prototype preparation instructions can be printed on stickers and stuck on the QuickScale. Additional measures can be taken to add to the robustness of the stickers like adding a layer of transparent film. Stickers would be easy to replace as well. Changes to these stickers can also be easily made if the user interface changes in the future.

3. Modified Handlebar Shape



Figure 4.15: An Olympic Curling Bar available from e-bay.com.

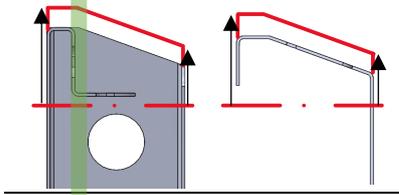
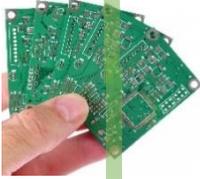
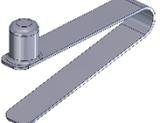
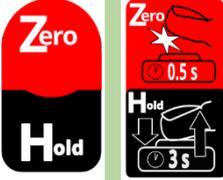
The handlebars can also be used to invite a certain posture of lifting. The shape of the handlebars can be altered for example the Olympic curling bar to promote a certain posture during lifting. The downside is that besides this instruction will still be necessary.

Results

Morphological Chart

Table 4-6 contains the morphological chart, summarizing the design challenges and the possible solutions presented in the method of chapter 4 (pages 39-47). Through the morphological chart the design decisions that lead to the redesign are listed in the 'Reasoning' column of Table 4-6. that were adjusted to meet the design requirements established in the design analysis and usability studies.

Table 4-6 Morphological Chart Final Design

Design Challenge	Solution 1	Solution 2	Solution 3	Reasoning
Load-Cell Non-Linearity	Software 	Different load cell 	Pre-Load 	<p>The current chosen load cell is appropriately selected for the loads that can be expected. Using software will not work as the error outside the linear range of the load cell (20 to 460kgs) is not constant.</p>
User Interface	Two-button 	Toggle Switch 	Timed Switch 	<p>The results of the usability tests show that the two-button configuration has the least user errors and among end users, there is a preference for this configuration.</p>
Electronics Housing	Modify Housing 		Custom PCB 	<p>Due to the limited space available and the required accessibility for the battery, both are necessary. Besides this, the metal housing will already need to be altered to accommodate the user interface.</p>
Handlebar grip & including extension	Bayonet lock 	Bar Insertion 	Improved Spring 	<p>Interference with cabling & more parts (which can get lost). A thread could also be used but might be slightly less user-friendly and unnecessary. Finally, the improved spring would not eliminate the possibility of the spring dislodging.</p>
Instruction & Safety	Laser engraved 	Stickers 	Modify Handlebar shape 	<p>The sticker can get replaced, etching can damage permanently and a curled handlebar shape cannot be extended.</p>

Final Design of the QuickScale 2.0

Through design choices, usability tests and an iterative process a new version of the QuickScale was designed, the QuickScale 2.0. (fig 4.16) This design incorporates both the lessons learned from the design analysis and the results from the usability tests. In this part of the report, the resulting design solution per challenge is detailed. An image depicting the changed parts and a short motivation of the adjustments made.

More detailed assembly drawings and technical drawings of the adjusted parts are provided in Appendix F.

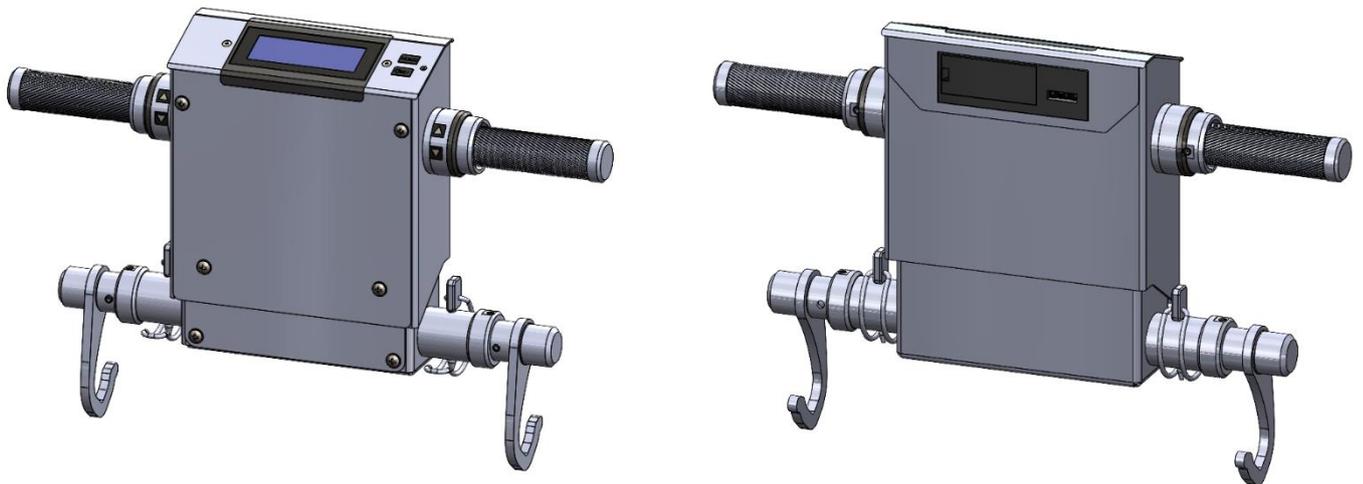


Figure 4.16: The QuickScale Version 2.0 Design

Load-Cell Non-Linearity:

As seen in Fig 4.17 springs were placed between the Aluminium extruded ITEM profile and a separate U-shaped sheet metal part. Furthermore, a spring guide was designed with one end threaded to be inserted in the ITEM profile. This spring guide aids in the assembly of the QuickScale by allowing the spring to be secured in its compressed state when assembling the QuickScale. After the assembly of the lower housing, the spring guide with the compressed spring can be connected to the U-shaped part and the security pin removed. Then the spring is at its intended operating length.

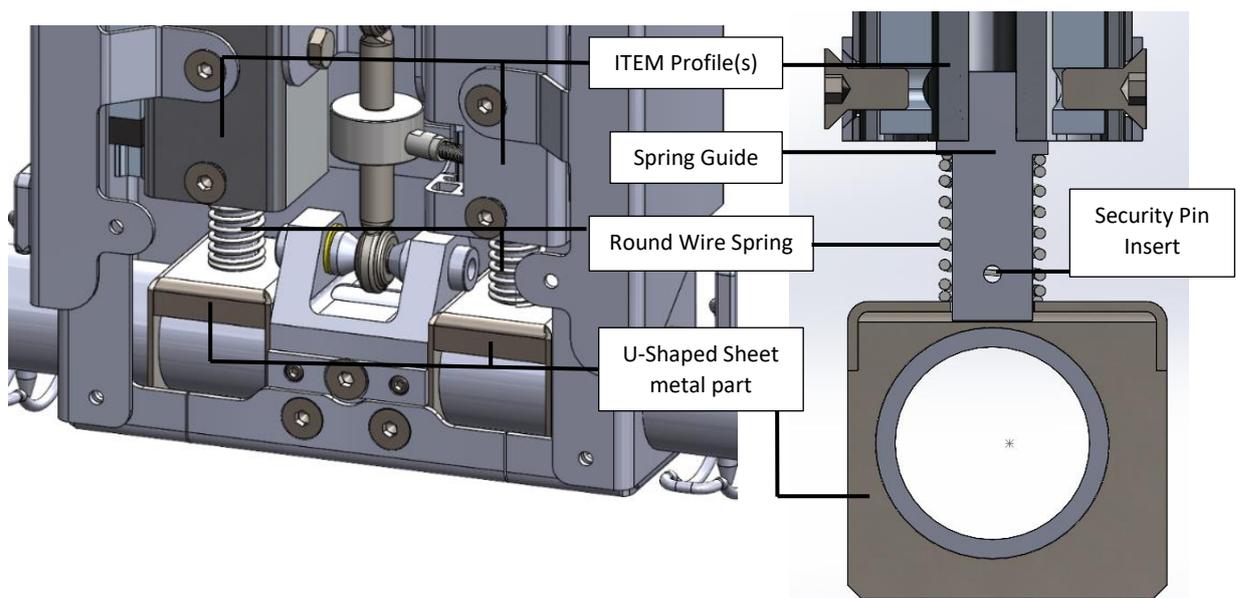
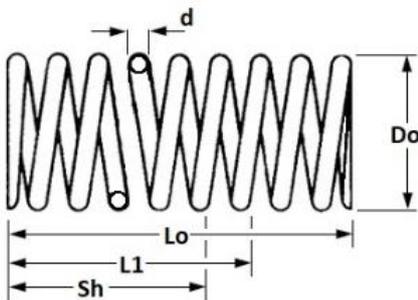


Figure 4.17:Left, two compression springs inserted between the module and ITEM profile put the load cell under pre-tension. In the right image the spring guide is visible.

Spring Selection Calculation

1. The necessary pre-load on the load cell is 20kg. As below the 20 kg the QuickScale wasn't accurate enough as seen during the calibration and validation.
2. When suspended, the lower housing of the module hangs by itself weighing around 3.5kg this leaves $20 - 3.5 = 16.5$ kg to apply on the load cell.
3. 16.5kg equates to 161.865 Newton in force. This force is applied by using 2 springs, so the working load per spring needs to be 80.93N.
4. Using the catalog available on <https://www.amatec.nl/nl/> further detailing for spring selection could be done. The type of spring is a round wire, compression spring with ground flat ends. The first search criterion was a working length (L1) of around 20 mm, at this length the spring needs to apply 80N of force. The closest matches of this type were a couple of springs with P1 of 80.07N.



5. Next is determining the outer diameter of the spring, the diameters can be 15,24 and 18,29. 15.24mm was chosen as the diameter of 18.29 would conflict with nearby parts.

6. The spring selected for the QuickScale 2.0 is the Amatec [C0600-063-1500M](https://www.amatec.nl/nl/) this spring has the following characteristics:

d:1.6	Sh:13,36	N/mm:4.20
Do:15.24	Lo:38.10	Material: Steel
Di:12.04	L1:19.05	P1:80.7N

Figure 4.18: Spring Dimensioning, Figure adapted from Amatec.nl

User Interface

Through the usability tests before the user interface design was determined. In its application, the two-button interface was mirrored on the other handle to allow both right and left-handed users. The material of the button housing should be made from either AISI 316 Stainless steel or chlorine-resistant polymer like (Chlorinated) polyvinyl chloride (PVC). The wiring for the min push buttons should be properly insulated when using metal for the button housing. The button covers should be made from a fluoroelastomer for the same chemical resistance. One of the advantages of using these flexible buttons is that they provide tactile feedback when operators press the button. The arrows depicted on the buttons serve as placeholders for symbols on the buttons.

The damper is necessary to prevent damage to the button housing as the handlebar will deform when the QuickScale is loaded and unloaded.

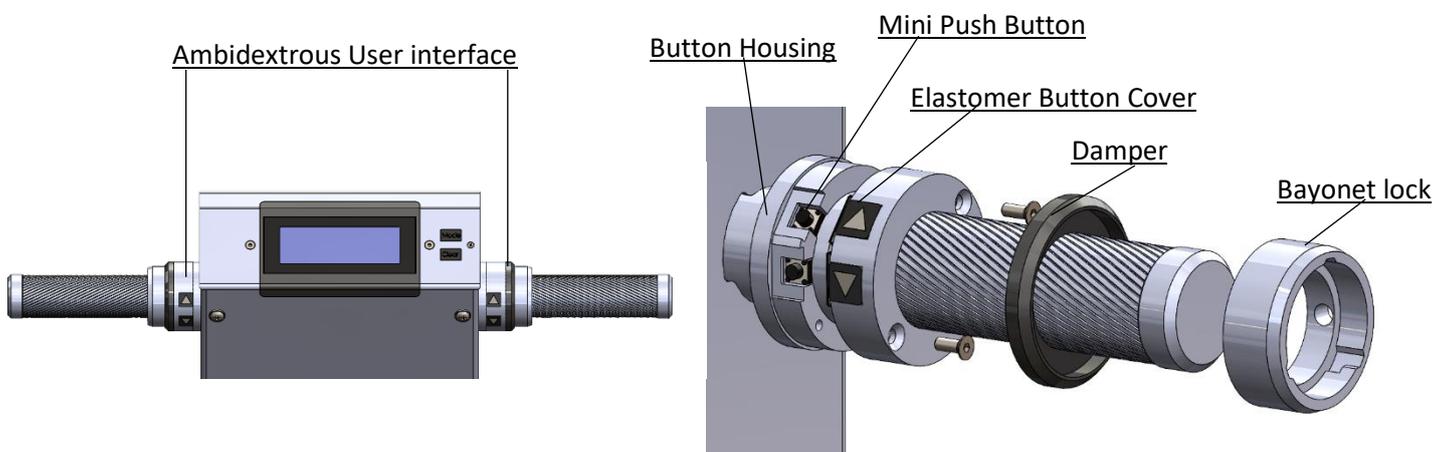


Figure 4.19 Distant and exploded views of the user interface

Housing the electronics

For the new design, two separate assemblies of the electronics will be combined to allow for full functionality. The front lid of the assembly was adjusted to accommodate an intermediate part. This part houses the elastomer button cover for the clear and mode buttons and connects the LCD screen and the lid. A desire was indicated that this would be flush with the surface so this was adjusted in the final iteration of the design. The intermediate part (see Fig 4.20) should be made from a chlorine-resistant polymer like (Chlorinated) polyvinyl chloride (PVC) or polyether ether ketone (PEEK) or be covered in a Teflon (PTFE) sheet as the mechanical properties of these materials won't be affected by chlorine-based detergents.

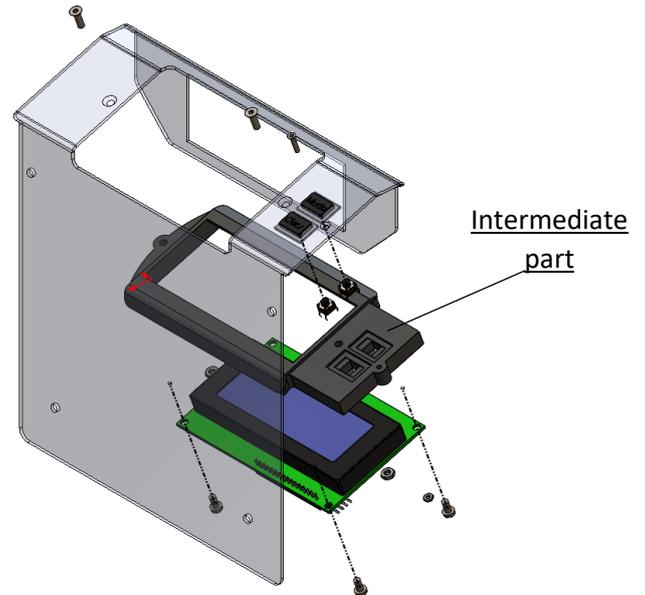


Figure 4.20 Front LCD Assembly

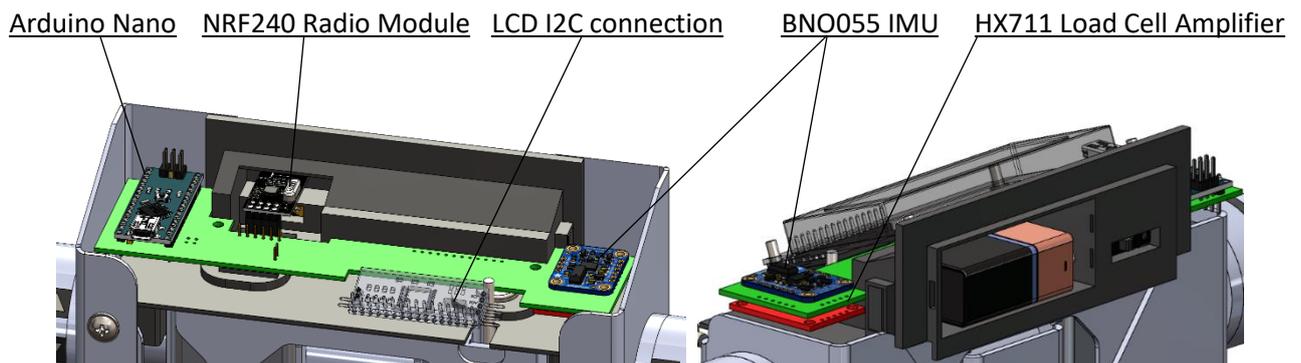


Figure 4.21 View of the Inner Electronics

The electronic components that are not connected directly to the outer lid (see Fig 4.21, Fig 4.22) can be installed on a PCB separately and connected to the electronics module.

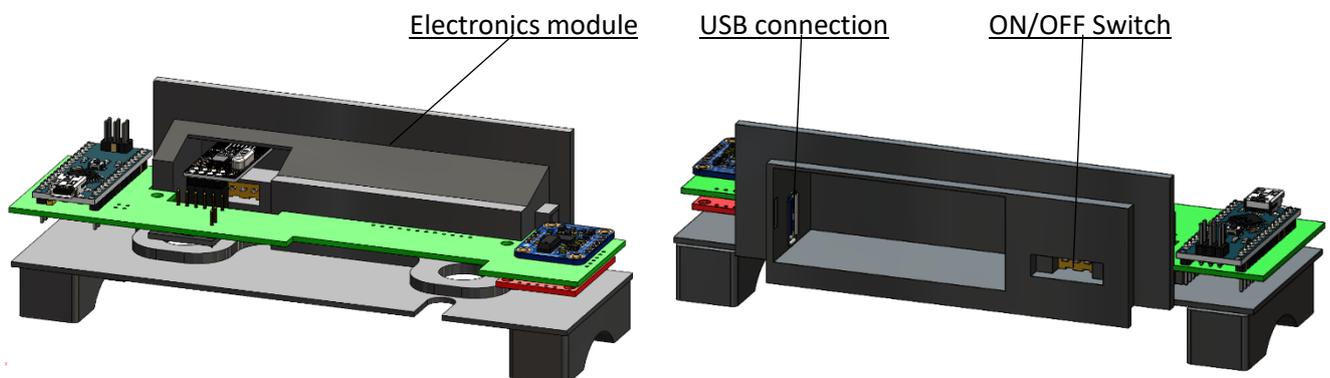


Figure 4.22 The PCB and Electronics module.

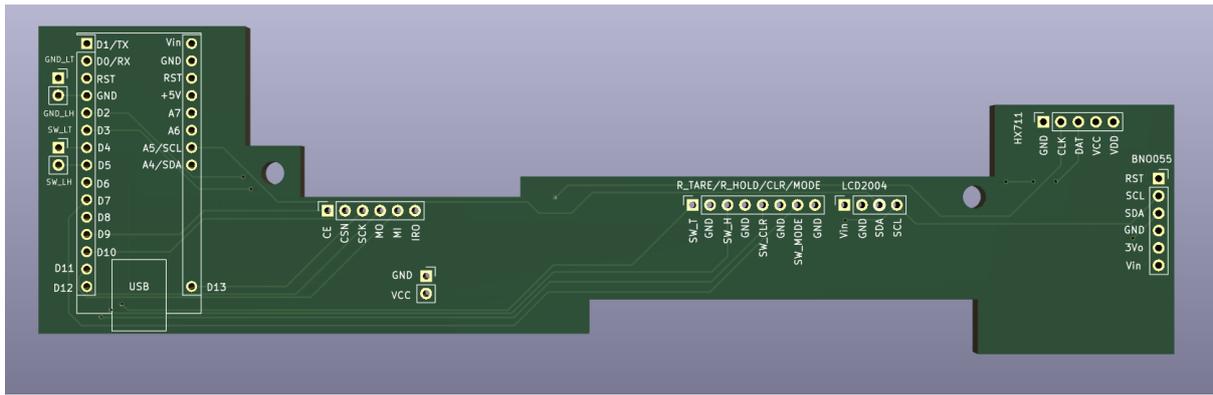


Figure 4.23: Render of finished printed circuit board for the QuickScale 2.0

The printed circuit board was designed to fit in the available space with all the electrical components attached. For details on the schematic and pathing see appendix G.

Handlebar slip and extension

The handlebars integrate with the user interface and are used to lift the QuickScale either with two or four persons. Both the surface of the handlebars and the surface of the extensions should be knurled to provide additional grip for the users, see Fig 4.24. Additionally, because the user interface slightly decreases the space available for hand placement, both the handlebar and the handlebar extensions have been lengthened by 30mm on each side.

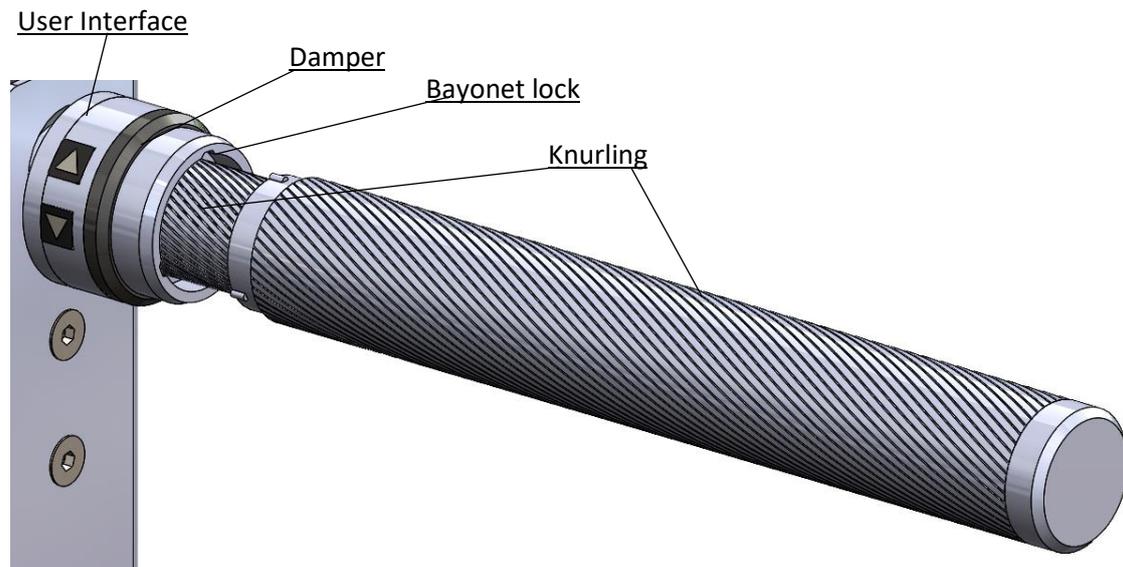


Figure 4.24 Handlebar extension

Instruction & Safe Lifting



Figure 4.25: Stickers placed on the QuickScale

The stickers in Figures 4.24-4.26 were developed based on the Quick Start guide used during the usability experiments. The step which was added is “step 0. Communicate” The idea behind this step is that the users of this device take a moment to assess the situation before they use the QuickScale. Furthermore, using extensions and lifting with four people would cause the operator to have their thumb out of reach of the user interface. To amend this the operator should lift with a mixed grip, reversing their dominant hand to control the QuickScale. The sticker on the handle can cover the elastomer button covers and be sealed with chemically resistant sealant and/or chemically resistant tape.



Figure 4.26: On the left: Example Instruction Sticker and on the right a standard CAUTION sign available on: mysafetysign.com

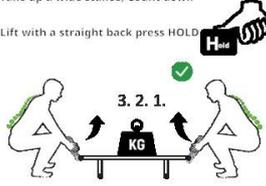
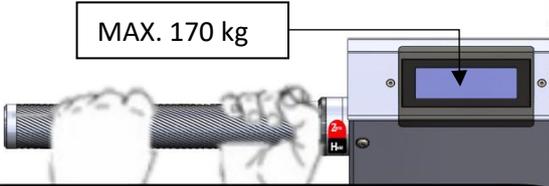
<p>0. Communicate</p> <p>Decide who is controlling the measurement.</p> <p>Ask for help if expected weight exceeds 100kg</p> <p>Extend handles when four persons are lifting.</p> 	<p>1. Pair</p> <p>Place QuickScale on FLOOR then turn on.</p> <p>Wait until 'Paired' is visible in the displays.</p> 
<p>2. Zero</p> <p>Put Carriage at desirable height, Hook QuickScale</p> <p>Lift the Stretcher and press ZERO</p> <p>Lift until 0 is in display</p> 	<p>3. Measure</p> <p>Load mortal remains on stretcher</p> <p>Take up a wide stance. Count down</p> <p>Lift with a straight back press HOLD</p> 
<p>When lifting with Extensions</p> <p>Controlling the QuickScale requires a mixed grip</p> <p>MAX. 170 kg</p> 	

Figure 4.27 Example sticker to be placed on the lid of the QuickScale

Evaluation

Table 0-1 Evaluating the Design Analysis Requirements

Sign:	Description	Result
DAR-D	Device	
DAR-D-1	The electronics fit within the metal housing	Achieved
DAR-D-2	The device housing allows for wireless radio communication	Achieved
DAR-D-3	The device indicates it needs to remain still during set-up to prevent the wrong calibration of the IMU.	Achieved
DAR-D-4	The device should allow for an easy change of batteries.	Achieved
DAR-D-5	The device is made in such a way that it does not slip out of the grip of users, even in wet conditions.	Achieved
DAR-D-6	The device informs users about safe lifting practices.	Achieved
DAR-D-7	The device shows how it should be held	Achieved
DAR-D-8	The device shows how it should be attached to the stretcher or other device used for carrying the mortal remains.	Achieved
DAR-D-9	The device must be able to be used by both two and four persons simultaneously	Achieved
DAR-UI	User Interface	
DAR-U-1	The user interface should be operable by both left and right-handed users.	Achieved
DAR-U-2	The placement of buttons on or in the handles should be within reach of the users with the smallest thumb grip. Without obstructing the reach of users with a larger thumb grip.	Achieved
DAR-U-3	The user interface is unambiguous about who is in control of the weight measurement.	Achieved
DAR-U-4	Both user interfaces do not show a difference larger than 0.5kg in measured weight.	At the start of the weight, the measurement difference is likely greater than 0.5kg. And can remain if users move the Quickscale.
DAR-U-5	The user interface informs the user about the amount of battery charge.	A readout on the LCD Needs to be developed.
DAR-U-6	The control panel is within reach during lifting and carrying of the bed	Achieved
DAR-U-7	The display screen is readable during the carrying of the bed	Achieved
DAR-U-8	The measurement value can be frozen in the display.	Achieved
DAR-U-9	There must be a possibility to take a photo of the measurement value with another camera.	Achieved
DAR-WM	Weight Measurement	
DAR-WM-1	The device must be able to measure weights from 8 to 171 kg with an accuracy of 1.3%	Research on measuring range by W.Tang
DAR-P	Preferences / Nice to have	
DAR-P-1	The parts must be purchased parts	Process flow research by W.Tang
DAR-P-2	Using the device feels intuitive and new users experience few errors which can be corrected for by experienced users.	Achieved
DAR-P-3	The device should incorporate measures to prevent accidental or unintentional zeroing of the mortal remains.	Design Analysis

Table 0-2 Evaluating Usability Design Requirements

Sign:	Description	Result
UDR-D	Device	
UDR-D-1	The device handlebars promote a safe lifting posture which keeps the back straight and doesn't require rotating the shoulders and wrists.	Achieved
UDR-D-2	The device handlebars allow for easy extension to lift with four persons in a safe manner.	Achieved
UDR-D-3	The device encourages operation by four persons.	Achieved
UDR-UI	User Interface	
UDR-UI-1	There is a battery indicator present indicating an empty (<33%), half full (<66%) and full battery.>66%)	A readout on the LCD Needs to be developed.
UDR-UI-2	Buttons are dimensioned so as not to protrude outside the handlebars or housing to prevent accidental button presses.	Achieved
UDR-UI-3	The button placement is within the calculated thumb grip point of the participants of the usability study.	Achieved
UDR-UI-4	The display can be read in dark outdoor and light indoor conditions.	Achieved
UDR-UI-5	The tare function zeros the weight displayed on the user interface within 2 seconds.	Achieved
UDR-UI-6	An instruction is present in the user interface indicating the order of the tare and hold functions.	Achieved
UDR-UI-7	An instruction is present on the outside housing of QuickScale. Indicating the steps for weight measurement.	Achieved
UDR-UI-8	A clear indicator, visibly and or audibly depicts the function that the QuickScale is performing.	The display currently reads TARING and HOLD when these functions are enabled. However no audible
UDR-P	Preferences / Nice to have	
UDR-P-1	An optional work instruction is made available for letting the stretcher hang between the operators until a weight measurement is completed	Forensic unit usability tests
UDR-P-2	The device promotes taking up a wide stance and lifting like performing a deadlift.	Achieved
UDR-P-3	The size of the text depicted is large enough so someone who isn't near or far-sighted can see the depicted text from an arm's length away.	Achieved
UDR-P-4	The display on the user interface remains within the user's direct line of sight at all times, even when obstructed by clothing or body parts.	Student usability tests and forensic unit usability tests

5. Discussion

At the outset of this thesis, two goals were established:

1. Finish the QuickScale prototype, design the modules needed for building in the electronics and for adding user-friendly, intuitive controls.
2. Design and conduct user studies with forensic investigators and use the obtained information to further improve the QuickScale construction, electronics and usability.

By using a design analysis and usability engineering approach the QuickScale prototype was further refined by implementing user interfaces in the design, satisfying the first goal of the thesis. As per the usability engineering approach, formative evaluations were carried out in the form of usability tests. During these usability tests, three different control configurations were presented to both students and forensic end users. The results of these tests were used in the development of the latest version of QuickScale, satisfying the second goal of the thesis and bringing QuickScale closer to implementation in forensic practice. To illustrate the progress made in Figure 5.1 the steps carried out in usability engineering are depicted.

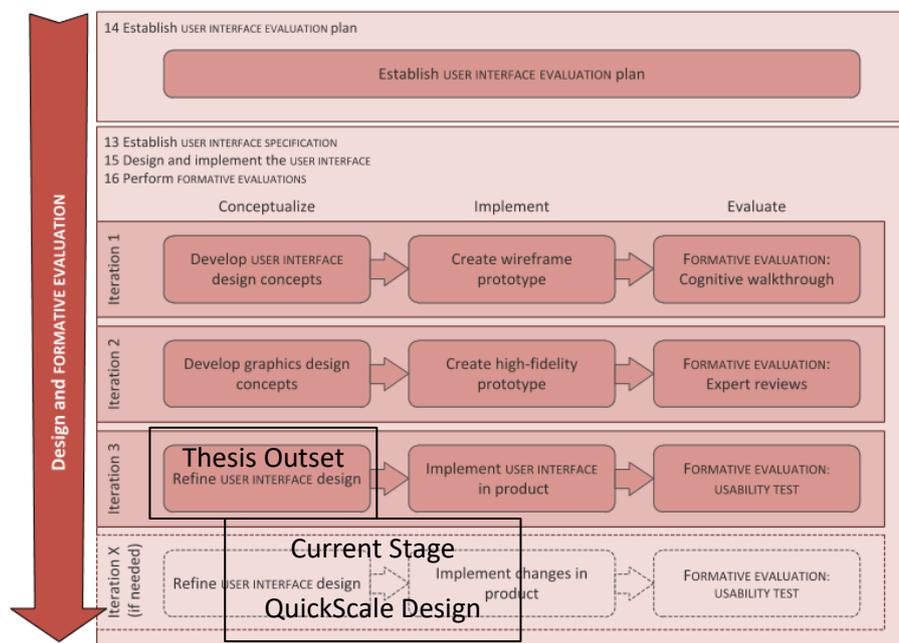


Figure 5.1: User interface development overview, image adapted from NEN-EN-IEC 62366-2

Reflection: Design analysis

During the functional prototype preparation, several difficulties presented themselves in the assembly of the QuickScale. While assembling the prototype, due to a lack of assembly drawings, there was no way for the manufacturers to check if the parts fit together correctly. This resulted in a lot of parts requiring further machining, filing and grinding. Especially troublesome was fitting both the handlebar and the telescopic bar through the housing and the ITEM profiles. Now with assembly drawings provided in Appendix F, this can be prevented for the QuickScale 2.0

Moreover while assembling the electronics of the two units, one Arduino Nano unit sporadically malfunctioned, as a result, the radio communication became a puzzling issue as it malfunctioned mostly and only sporadically worked. These difficulties were overcome resulting in a robust prototype suitable for testing and further analysis.

Reflection: Calibration, validation and usability tests

As presented in the results when evaluating the calibration factors one of the modules (unit 2) had an error of 1.8% in measuring weights up to 70kg (See fig 3.11). As the goal of this thesis is the refining and implementation of the user interface and none of the usability tests relied on the accuracy of the measurements, this was not adjusted. Moreover, the error of the accompanying module (0.28%) proves that the QuickScale modules can reach the desired accuracy albeit the method of calibration needs to be adjusted. For example, by adding more calibration runs. Due to the need for accuracy, this needs to be properly implemented in the final design which introduces compression springs to eliminate the non-linearity of the load cell when measuring low weights.

Considering the validation of the 90kg measurements between the 10-15 and 20-25 degree angle ranges, it was necessary to re-tare the QuickScale due to an accidental button press. However, this re-tare depicted 12.8 kg instead of the 13.8kg tare weight that was used in the previous measurements. The weight of the stretcher had not changed and in the continuation of the validation, 1kg was added to the weight measured as the difference was exactly known. This difference of 1kg is likely due to the non-linear behaviour of the load cell when measuring weights below 20kg, and hysteresis from the previous measurement could also play a likely role as a 0.5kg difference could be measured during the validation of the calibration factors.

Of note was that during these validation measurements, lifting 90kg and at the same time tilting the QuickScale up to 25 degrees is very uncomfortable for the person lifting as the weight pulls straight down, the only feasible way this would work is if the person lifting would lean back almost enough to put their feet under the weight they are lifting, which is not very realistic.

The results of the usability tests showed an overlap in participants' preference for the two-button configuration and the low number of user errors for this control configuration.

There were several shortcomings in the usability tests, The first is that there was no control for the dominant hand of participants. Left-handed participants were using their non-dominant hand during the usability tests, it is not mentioned in the captured videos as well and cannot be corrected for in the results.

Second, the forensic end users had one control configuration to test. This means that the forensic end-users might have liked the single button configuration that was left out better but they never got to try this configuration.

Third, the weight that was used during the experiments was a maximum of 34kg and this is not the average weight of mortal remains. This however should be done as a formative evaluation before the QuickScale is implemented, it should also be used in different lighting conditions and in combination with the actual carriage and stretcher.

Fourth, the usability tests do not account for all aspects related to the control of the QuickScale which might result in more user-friendliness. Like the time it takes to press a button before it registers or when users can expect the display to update. These can be addressed in future usability tests.

Reflection: Final design and evaluation

In the new version of the QuickScale initially, the goal was to produce the new version as well, but due to time constraints, mistakes and processes that took longer than expected the new version was not produced. To compensate for the lack of a produced QuickScale 2.0. Very few new parts were introduced and only some have been altered. The QuickScale 2.0 can be made with many of the parts that are already available. The lower assembly housing the load cell only needs to be taken apart, the M8 holes tapped in the ITEM profiles, the spring guides inserted and the newly designed springs installed. However, the handlebar, upper housing and the lid need to be re-made. This was not strictly a design criterion but more a trade-off to minimise the time it would take to complete the next version. Other trade-offs that were made during the design of the QuickScale 2.0 differed per design challenge. These were as follows:

Load-cell non-linearity

Despite some new parts being made from chemically resistant polymers, it is expected that the weight of the QuickScale will increase due to the larger housing, wider handlebar, U-profiles and springs. However, not all this weight will act on the load cell. At the same time, the parts in contact with the spring might deform ever so slightly. Meaning that a longer and/or stronger spring might be better suited. A possible workaround for finding the “right” spring could be to have a manner of tensioning the spring. This could be done by adjusting the spring guide to unscrew out of the ITEM profile.

User interface

The ‘Mode’ and ‘Clear’ functionalities of the QuickScale 2.0 represented by both buttons on the housing were not part of the usability tests. The ‘Clear’ button clears both the held and tared weight and the ‘Mode’ button stops the pairing and allows users to use the QuickScale module singly. These are part of the operation of the QuickScale and should be integrated into further User Interface development and usability tests.

Electronics Housing

The housing of the electronics was by far one of the biggest challenges of the design problems due to the constrained space. Altering the housing helped make the LCD Screen fit in the slanted edges of the QuickScale 2.0 but an intermediate part was still necessary. It could be an option to not make the outer lid out of metal and unify all the electronics in one lid assembly. The PCB that will connect was designed in KiCad so an accurate representation is not visible in the 3D-Solidworks CAD models, the PCB schematic is detailed in Appendix G.

A trade-off that was considered was if the cabling to the buttons went either through the handlebar or the housing. This was chosen to be through the housing as performing repairs on the wires inside the handle would be harder. In the final version of the QuickScale design the cabling can still be fed through the handlebar as it is harder to reach and therefore more unlikely to be damaged.

Handlebar grip including extension

Both a risk analysis and a finite element analysis of the extended handlebars should be performed because when the extended handlebars are connected 4 people will lift the most weight. In this situation there are twice as many people that can get injured than with regular use and while it is unlikely to break down immediately. It would still be prudent to test the QuickScale 2.0 handlebar and extending parts to ascertain if the ASCI 316 parts fatigue under the highest expected loads.

Instruction & Safety

The instructions on the QuickScale are basic, additional instructions like examples of use, the lowering of the carriage workaround(as described on p37) and troubleshooting should be provided in a user

manual. A point to note is that in the final measure step, users can also opt to just call out the weight to others in the vicinity. The freezing of the display is still necessary if only two people are present and one of them needs to take a picture of the weight depicted on the LCD screen afterwards. Also, the 'Zero' on the instruction sticker needs to be adjusted to 'Tare' to make both the instruction sticker and the text on the LCD screen the same. This is a leftover of the usability tests and the Quick Start guide design as initially it was thought that 'zeroing' was the accepted international term for 'Taring'. On a final note, the QuickScale 2.0 prototype should be produced and tested in its intended use environment.

7. Conclusions & Recommendations

In this thesis, the QuickScale user interface was developed and a refined version of the QuickScale designed. This system integrates with equipment used by forensic investigators and first responders to measure the weight of mortal remains on a crime scene. This was accomplished by a design analysis and usability engineering approach.

Using 3D-printed PLA parts a prototype was developed. The QuickScale prototype can measure weight within a margin of error of 1.3%, even when tilted up to 25 degrees. After analysing the design, a particular use error was identified: the accidental re-taring of the QuickScale. Three different user interfaces were developed which tried to address this error and these were tested by students and end-users in usability tests.

In analysing both participant groups, due to the differences between the two user groups the System the usability scores cannot be compared. The differences in the usability scores might be attributed to the target group, the tested configurations and the time the usability test took to complete.

However, the comparatively higher score in usability (A+) among the forensic unit participants is promising in implementing the QuickScale.

Using the results from the usability tests the user interface which had a button for each function, was selected. Furthermore, the usability tests also helped determine a secondary set of design requirements based on the interactions participants had with the QuickScale and the questionnaires they answered afterwards

The design requirements formulated during the design analysis and the usability tests were satisfied in the design of QuickScale 2.0. This refined version contains:

- An ambidextrous user interface developed with the help of end-users.
- Correcting pre-loaded springs for non-linearity of the load cell when measuring low weights.
- Handlebars with improved grip and which can easily be extended to measure large weights.
- Safety labels with an abbreviated guide on the field use and stickers indicating the controls

Of the 30 design requirements, 27 have been met. The exceptions are an indication of remaining battery life and the possibility that both units can display a difference in weight larger than 0.5 kgs, especially at the start of weight measurements. These need to be addressed in future developments.

Further steps to fabricate the necessary components for the construction of the QuickScale 2.0 need to be taken. During the design special care was taken to only alter what is necessary so most parts of the current QuickScale prototype can be re-used for the QuickScale 2.0. After completion, new formative evaluations in the form of usability tests in the intended use environment should take place in combination with other tools developed for the Thermanus project and any findings to improve this integration should be implemented.

The QuickScale 2.0 is an end user-oriented design step toward more accurate post-mortem interval estimation and contributes to more accurate forensic science.

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Appendix A: User-Interface Background

User interface as designed by W. Tang

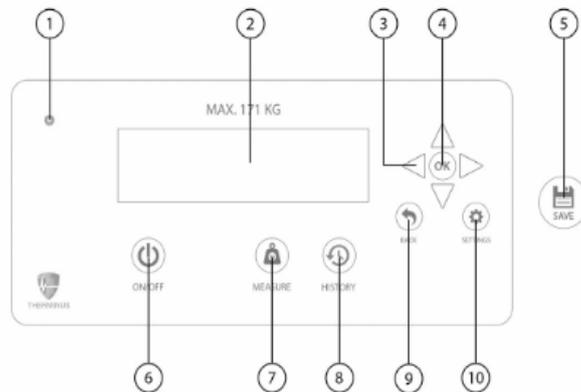


Figure A.0.1: User interface of a QuickScale module as designed by W. Tang

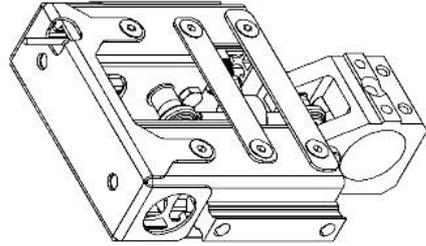
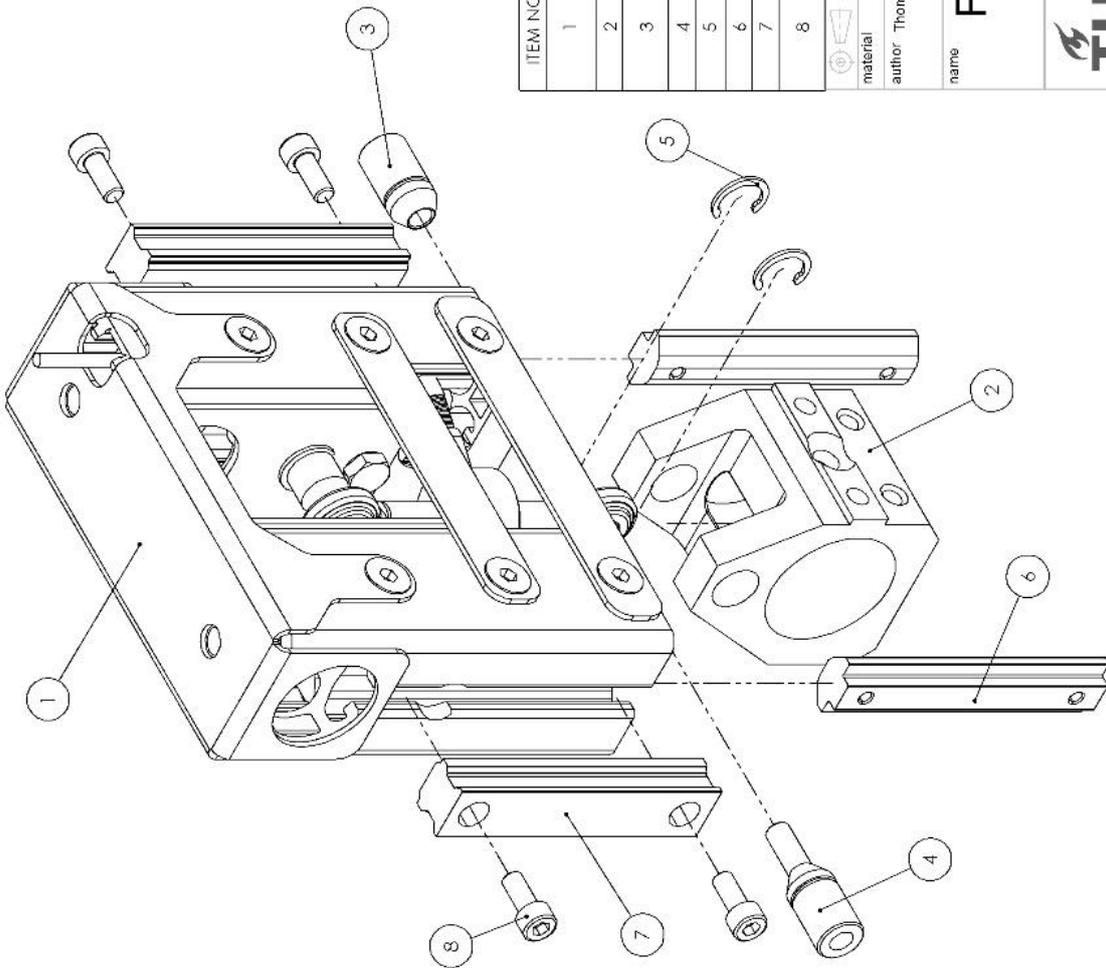
Table A-0-1: Numbered functions of User-Interface Elements

Number	Part	Description
1	LED light	Usage: Green: measuring device is on Red and blinking: measuring device is overloaded, lifted too tilted, battery empty (problem) Battery: Green: battery is fully charged Red: Battery is being charged
2	Display	Displaying values, (error) messages, and battery status
3	Arrows	Moving in the selection menu
4	OK	Selecting a choice
5	Save	Save the weight currently being measured. Long press: determine the tare weight Short press: subtract the tare weight of the weight currently being weighed (determine body weight)
6	On and off button	Turn the measuring device on or off
7	Measure	Indicate that weighing will now take place
8	Back	Step back in the selection menu
9	Settings	Go to the settings
10	History	Go to all stored measurements (last 10 measurements)

Appendix B: Prototype Assembly Drawings:

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	FMA_P021_R002	U-Profile: 40.67 x 77.5 x 40	1
2	FMA_P028_R002	Male Loadcell Carrier Pin: 56 x R12	1
3	FMA_P030_R002	Female Loadcell Carrier Pin: 41.50 x R12	1
4	FMA_P048_R002	Right Extrusion Profile: 40 x 40 x 112	1
5	FMA_P049_R002	Left Extrusion Profile: 40 x 40 x 112	1
6	FMA_P020_R002	Top Fixture: 123 x 43 x 47	1
7	FMA_A002_R002	Load Cell + 2xFittings + Cable	1
8	DIN 7991 - M6 x 12 --- 5.7N		10
9	FMA_P032_R002	Horizontal Fastener: 106 x 15 x T1.5	2
10	DIN EN 24017 - M6 x 12-N		2
11	FMA_P033_R002	Locking Ring D11	2
12	FMA_P037_R002	T-Slot Nut: Purchase Part	12
13	FMA_P051_R002	Horizontal Fastener: 95x 15 x T1.5	1

material	author: Thomas Anker, 4703367	units	mm	scale	1:2	quantity	1	date	08/03/2023	remark	Assembly Drawing Upper Loadcell Assembly
mass	group	Forensics Engineering	gr								
name FMA_AS001_R002											
										format	A3
										drawing no.	1



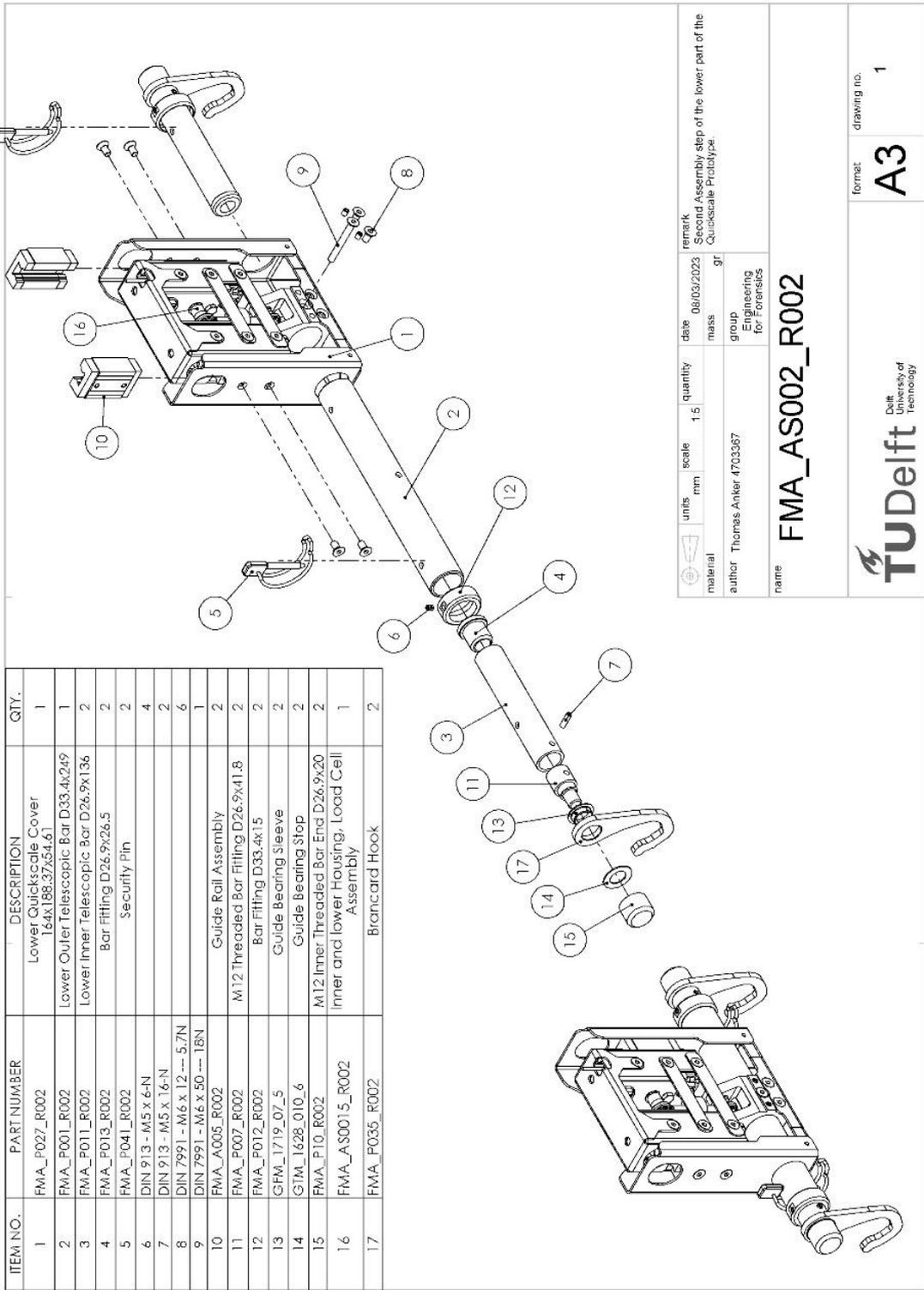
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	FMA_AS001_R002	Top Loadcell Assembly: 123 x 43 x 113.5	1
2	FMA_P026_R002	Loadcell Anchor 48.22x58.92x45	1
3	FMA_P040_R002	Lower Female Loadcell Pin R12x22.5	1
4	FMA_P039_R002	Lower Male Loadcell Pin R12x37	1
5	FMA_P033_R002	Locking Ring D11	2
6	FMA_P016_R002	Linear Guide Rail ITEM Fixture	2
7	FMA_P018_R002	Linear Guide Rail 74x15x12.4	2
8	DIN 912 M5 x 12 --- IZN		4

material	units	mm	scale	1:1	quantity	<<np>>	date	08/03/2023	remark	Second Assembly step
author	Thomas Anter	4703367	mass	gr	group	Engineering for Forensics				

name **FMA_AS0015_R002**

TU Delft
Delft University of Technology

format: **A3**
drawing no.:



units mm scale 1:5 quantity 15 date 08/03/2023 remark Second Assembly step of the lower part of the Quickscale Prototype.
 mass gr
 author Thomas Anker 4703367 group Engineering for Percepsis

name FMA_AS002_R002

format A3 drawing no. 1

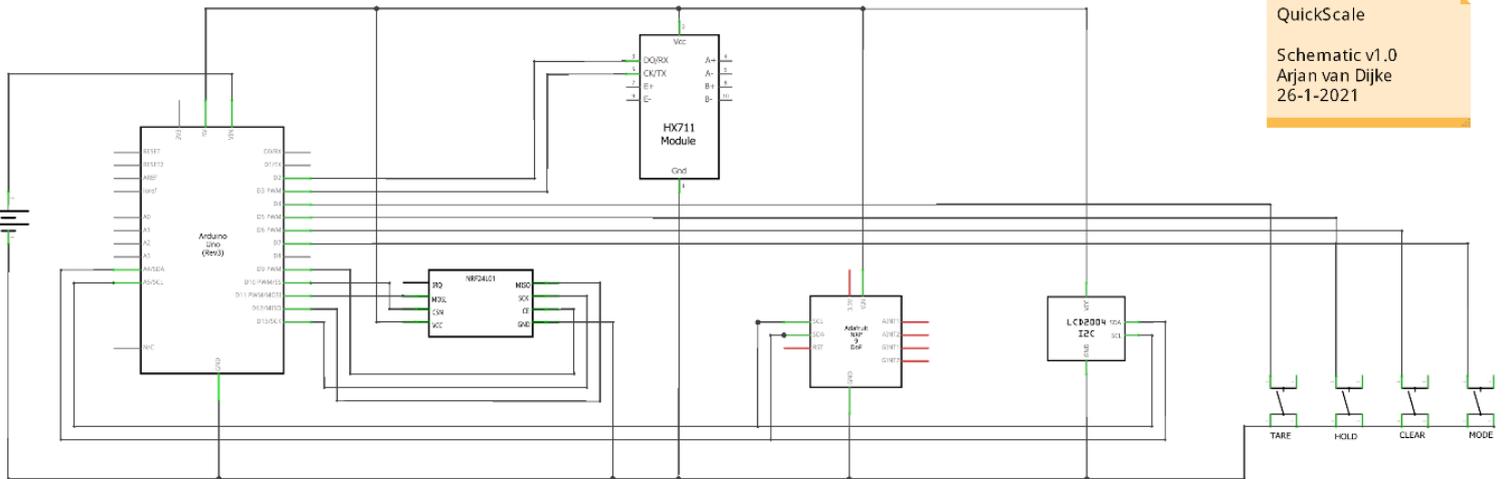


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	FMA_AS002_R002	Lower Housing Complete Assembly	1
2	FMA_P002_R002	Handlebar (400x26.9DO 21.7DI)	1
3	FMA_P023_R002	Upper Outer Housing	1
4	FMA_P045_R002	Bar Fitting D38.4x15	2
5	FMA_P042_R002	Handlebar Seal	2
6	FMA_P024_R002	Upper Lid	1
7	FMA_P022_R002	Lower Lid (156x60)	1

 TU Delft Delft University of Technology		name FMA_AS003_R002
 material author Thomas Anker 4703367	units mm scale 4703367	quantity group Engineering for Forensics
 date 09/03/2023 mass gr	format A4	remark QuickScale Assembly drawing no.

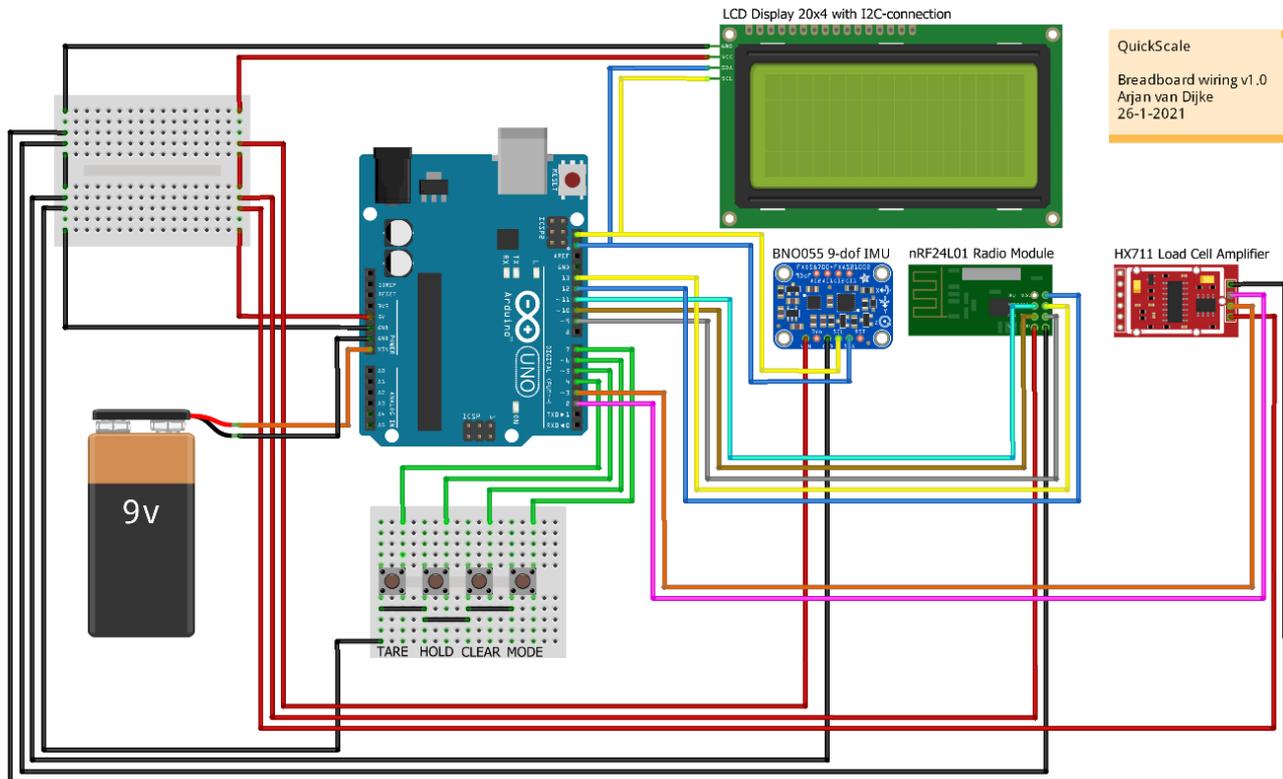
Appendix C: Electronics Circuit and provided Arduino Sketch

Arduino Sketch Provided separately.



QuickScale
Schematic v1.0
Arjan van Dijke
26-1-2021

fritzing



QuickScale
Breadboard wiring v1.0
Arjan van Dijke
26-1-2021

fritzing

Appendix D Design Requirements:

According To the KTO Report:

Following the literature review, a prototype for weighing a body on the crime scene was designed during KTO-B. The prototype and weighing process must each meet the following requirements as outlined below:

Weighing

- No more than three steps may be added to the regular procedure on the crime scene (see figure 1): pick up device, perform weighing, and return device.
- Weighing must not contaminate or damage the body.
- Weighing must be brief (maximum deviation of 5 minutes from regular procedure on the crime scene).

Measurement equipment

- The equipment must be transportable in the forensic team's bus to the crime scene.
- The equipment must be easy to use and maintain.
- The equipment must be safe for the user.
- The equipment must measure the weight of an average adult in the Netherlands (men 84 kg and women 70 kg) [4] with an accuracy of 1 kg.
- The equipment weighs a maximum of 23 kg [5] and must be portable.

Material

- The material must not undergo permanent deformation under load.
- The material's lifespan must not be significantly reduced by cleaning with chemicals.

Seven concepts were developed and elaborated upon in response to the requirements. These concepts were compared using a Harris profile (see Appendix 9.10). The following criteria were considered:

- The availability of materials:
- A SolidWorks model of the handle (aluminium)
- The feasibility of the system (likelihood that it can be realized within the allotted time)
- The portability of the system
- The size of the intervention
- The safety of the system
- The simplicity of use
- Whether the system can be cleaned with chemical agents
- Whether the system is durable
- The cost of the system

The best concept was found to be a frame with a weighing sensor. This concept was then further elaborated upon. Another Harris profile was created for the possible weighing methods: using a number of load cells, a suitcase scale, a spring system, or separate strain gauges (see Appendix 9.11). The criteria considered were:

- The weight range of the system
- The error sensitivity of the system
- The weight of the system

- The cost of the system
- The difficulty of attaching the system
- The size of the system

In this comparison, the cost and weight of the system were less important than usability and error sensitivity. The spring system was found to be the best concept, but due to time constraints, load cells were chosen as they were available immediately upon ordering.

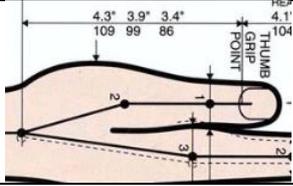
The final concept is a weighing system consisting of handles in which load cells are incorporated and an extendable aluminium frame with cross members onto which the body can be placed in a body bag.

Table with the Design requirements as they were formulated by W.Tang.

Number	Information	Source
	Device	
1	The use of the device adds no more than three steps to the regular procedure at the crime scene: grab device, perform weight measurement, and put device back	Task/target group research by W.Tang
2	The weight measurement takes a maximum of 5 minutes to perform	Task/target group research W.Tang
3	The device can be taken in the forensic team's bus to the crime scene	Task/target group research W.Tang
4	The use of the device does not contaminate the body of the victim	Task/target group research W.Tang
5	The use of the device does not make any changes to the current state of the victim's body	Task/target group research W.Tang
6	The device is safe for the user	Task/target group research W.Tang
7	The user can use the device without problems after a maximum of 60 minutes of instruction	Task/target group research W.Tang
8	The device can be maintained within 10 minutes	Task/target group research W.Tang
9	The device can be disassembled to replace parts	Process diagram W.Tang
10	The device shows how it should be held	Process diagram W.Tang
11	The device shows how it should be attached to the bed of the carrier	Process diagram W.Tang
12	Attaching and disconnecting the handles from the bed does not require tools	Process diagram W.Tang
13	When the device is operated from a control panel, it cannot be operated from the other control panels of the device	Process diagram W.Tang
14	The device must be able to be attached to a stretcher and an accident transport box	Use environment W.Tang
15	The device must be able to be attached to the head ends of the stretcher	Carriers W.Tang
16	The device must be able to be attached to the handles of the lower half of the accident transport box	Carriers W.Tang
17	The attachment hooks of the device must be able to be attached to the carrier at different distances from each other	Funeral carriers W.Tang
19	The device must be able to be used by both two and four persons simultaneously	Task/target group research W.Tang
20	The handles of the device can be used by at least 80% of the possible users	Task/target group research W.Tang
	User Interface	
21	The measuring system contains a safety system to prevent physical hazards when lifting outside the measuring range	Process diagram W.Tang
22	The device displays the state of the battery	Process diagram W.Tang
23	The control panel is within reach during lifting and carrying of the bed	Process diagram W.Tang
24	The display screen is readable during the carrying of the bed	Process diagram W.Tang
25	The measurement value can be stored	Task/target group research W.Tang
26	There must be a possibility to take a photo of the measurement value	Task/target group research W.Tang
	Weight Measurement	
27	The device performs the weight measurement by carrying the body	Function research W.Tang
28	The body is kept in balance while carrying it	Function research W.Tang
29	There is no torsion on the load cells	Function research W.Tang
30	There are no forces in the x- and y-directions on the load cells	Function research W.Tang
31	The weight measurement must be performed after the body has been placed in a body bag or accident transport box and before the body is transported to a mortuary	Task/use environment W.Tang
32	The device must measure the body weight of the deceased with an accuracy of an average adult in the Netherlands with an accuracy of 1.3%	Client/Target audience research W.Tang

33	The device must be able to measure weights from 8 to 171 kg with an accuracy of 1.3%	Research on measuring range W.Tang
	Material / design	
34	The device must fit in a Peli case Forensic bus	Research on material/design W.Tang
35	The device must not be larger than the largest Peli case: 1208 x 611 x 499 mm Forensic bus	Research on material/design W.Tang
36	The lifespan of materials and components must not be shortened by cleaning the surface	Process flow research W.Tang
37	The material of the device must be resistant to chlorine	Target audience research W.Tang
38	The material of the device must be UV-resistant	Client W.Tang
39	The material of the device must be resistant to strong disinfectants	Client W.Tang
40	The material must be corrosion-resistant	Client W.Tang
41	The material of the device must not deform permanently under a load of less than 256.5 kg	Client/Target audience research W.Tang
42	The construction of the measuring system must be able to handle a maximum weight of 256.5 kg	Measuring range research W.Tang
	Preferences / Nice to Haves	
43	The parts must be purchased parts	Process flow research W.Tang
44	No instructions are required for using the device	Client W.Tang
45	The body of the deceased must be kept level while being carried	Function research W.Tang

Appendix E Usability Test prerequisites

Signed informed consent?	Yes <input type="checkbox"/>	No <input type="checkbox"/>
Anthropomorphic Hand Data		
Measuring Hand Width. 	44:	
The distance from the radial to ulnar side of the hand, measured at the distal extremities of the metacarpals in mm.	47:	
	Measuring Thumb Grip point: Wristcrease to most distal thumb metacarpal:	
Nitril Gloves Handed over?	Yes <input type="checkbox"/>	

First Time Use

Hold AND Tare <input type="checkbox"/> Switch Select <input type="checkbox"/> Timed Button <input type="checkbox"/>	Video. <input type="checkbox"/> Adjust Weight. <input type="checkbox"/>	User Errors:	Quick Start Guide Checks:
Hold AND Tare <input type="checkbox"/> Switch Select <input type="checkbox"/> Timed Button <input type="checkbox"/>	Video. <input type="checkbox"/> Adjust Weight. <input type="checkbox"/>	User Errors:	Quick Start Guide Checks:
Comparison Question: Was this easy to use or easier than the previous configuration?	<input type="checkbox"/> Yes. Why?		<input type="checkbox"/> No. Why?
Hold AND Tare <input type="checkbox"/> Switch Select <input type="checkbox"/> Timed Button <input type="checkbox"/>	Video. <input type="checkbox"/> Adjust Weight. <input type="checkbox"/>	User Errors:	Quick Start Guide Checks:
Comparison Question: Was this easy to use or easier than the previous configurations?	<input type="checkbox"/> Yes. Why?		<input type="checkbox"/> No. Why?

Continued Use / Learning Curve	User Errors	Quick-Start Checks
Configuration 1: Hold AND Tare <input type="checkbox"/> Switch Select <input type="checkbox"/> Timed Button <input type="checkbox"/> Enable Video <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> Adjust Weight <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	1)	1)
	2)	2)
	3)	3)
Configuration 2: Hold AND Tare <input type="checkbox"/> Switch Select <input type="checkbox"/> Timed Button <input type="checkbox"/> Enable Video <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> Adjust Weight <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	1)	1)
	2)	2)
	3)	3)
Configuration 3: Hold AND Tare <input type="checkbox"/> Switch Select <input type="checkbox"/> Timed Button <input type="checkbox"/> Enable Video <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> Adjust Weight <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	1)	1)
	2)	2)
	3)	3)
Handed out Questionnaire?	<input type="checkbox"/> Yes	<input type="checkbox"/> No. Why:

Post Test System Usability Score Questionnaire

Thank you for using the QuickScale Prototype. As a final wrap up we would like to answer a couple of questions about its use.

First and only Open Question:

If I had to choose the best configuration for the controls of the QuickScale it would be:

1. The Separate Measure And Tare buttons.
2. Having A switch between the Measure and Tare Functions.
3. The Single Button configuration.

Because:

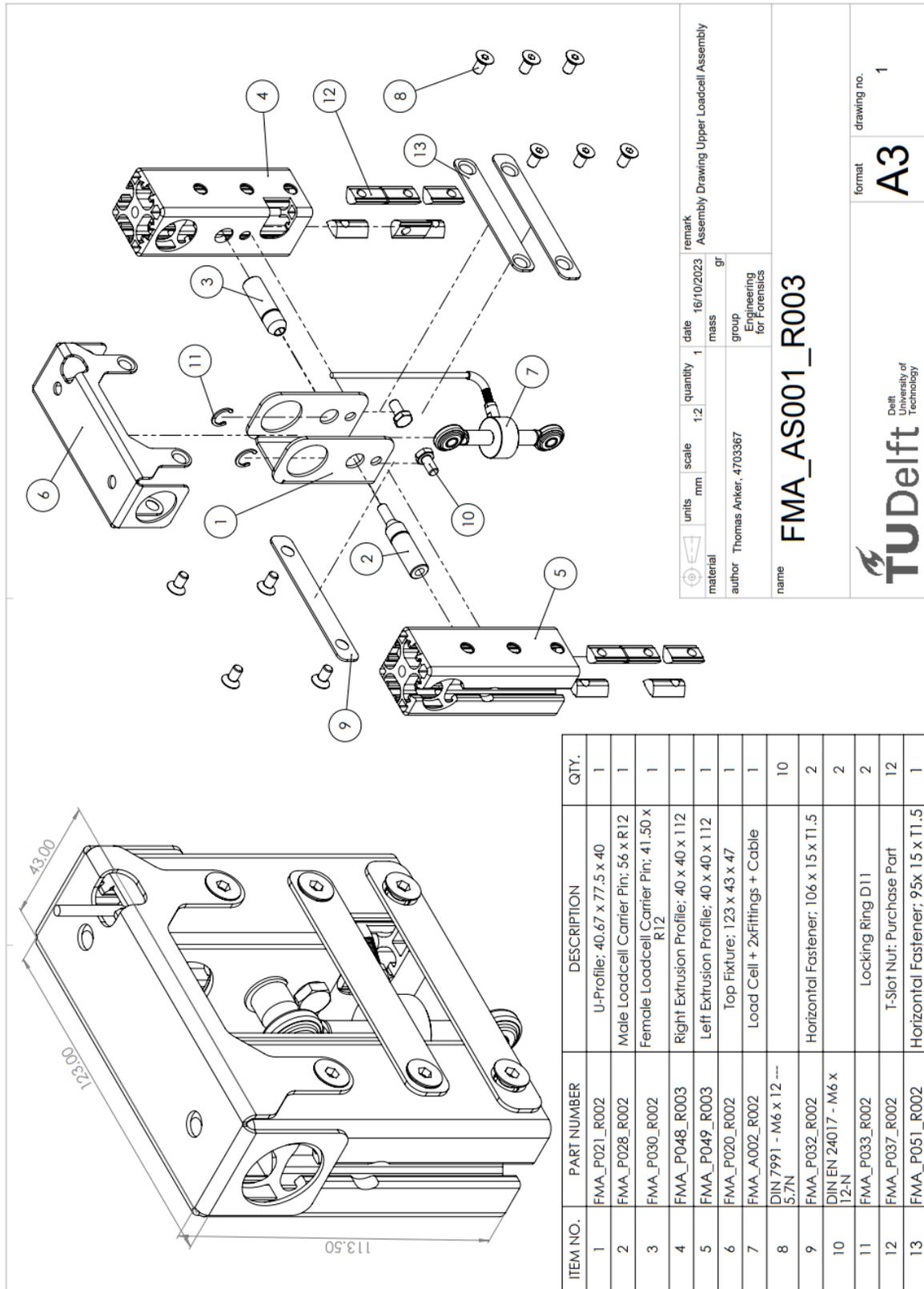
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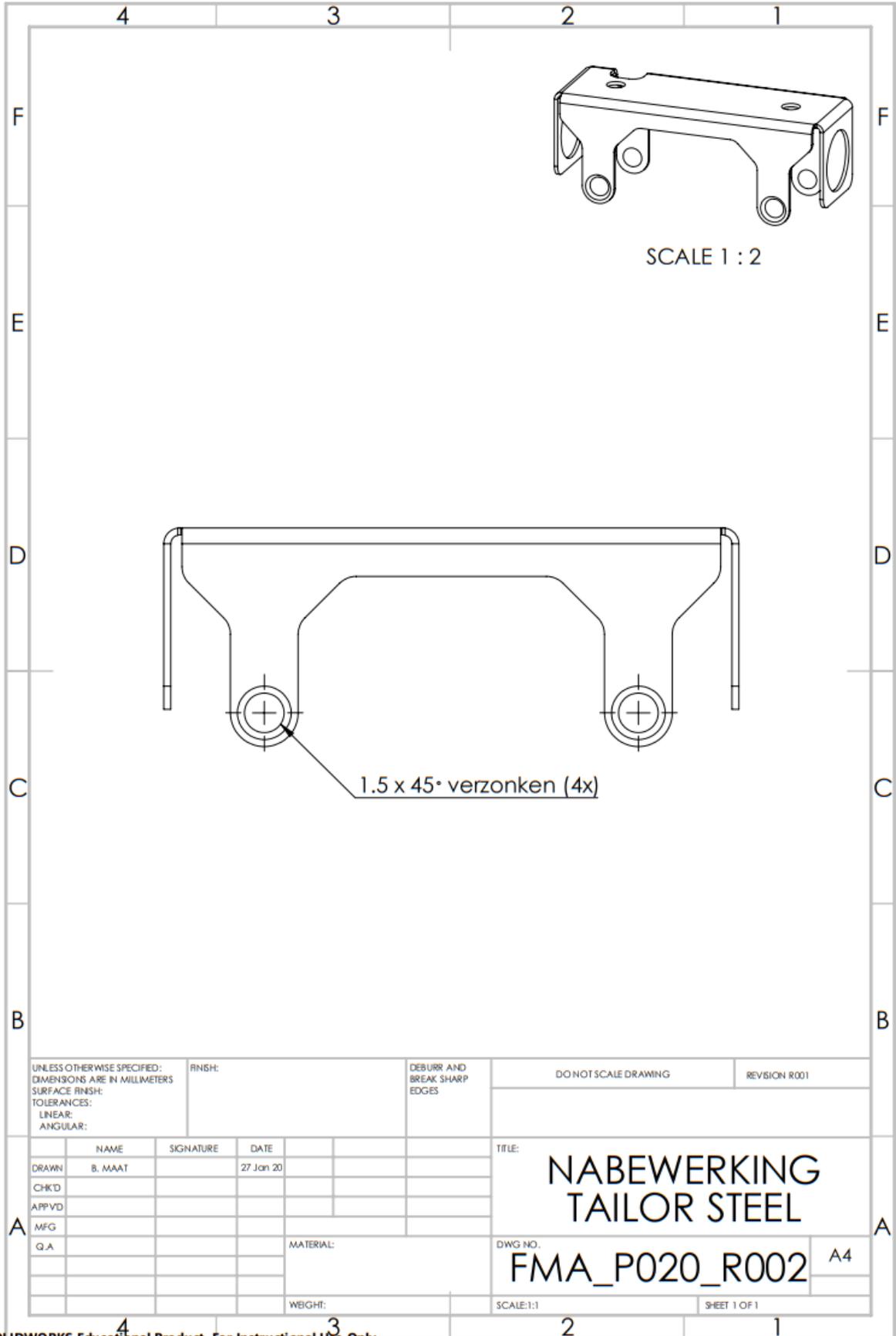
.....;

Please score the following items with one of five ranging from strongly agree to strongly disagree:

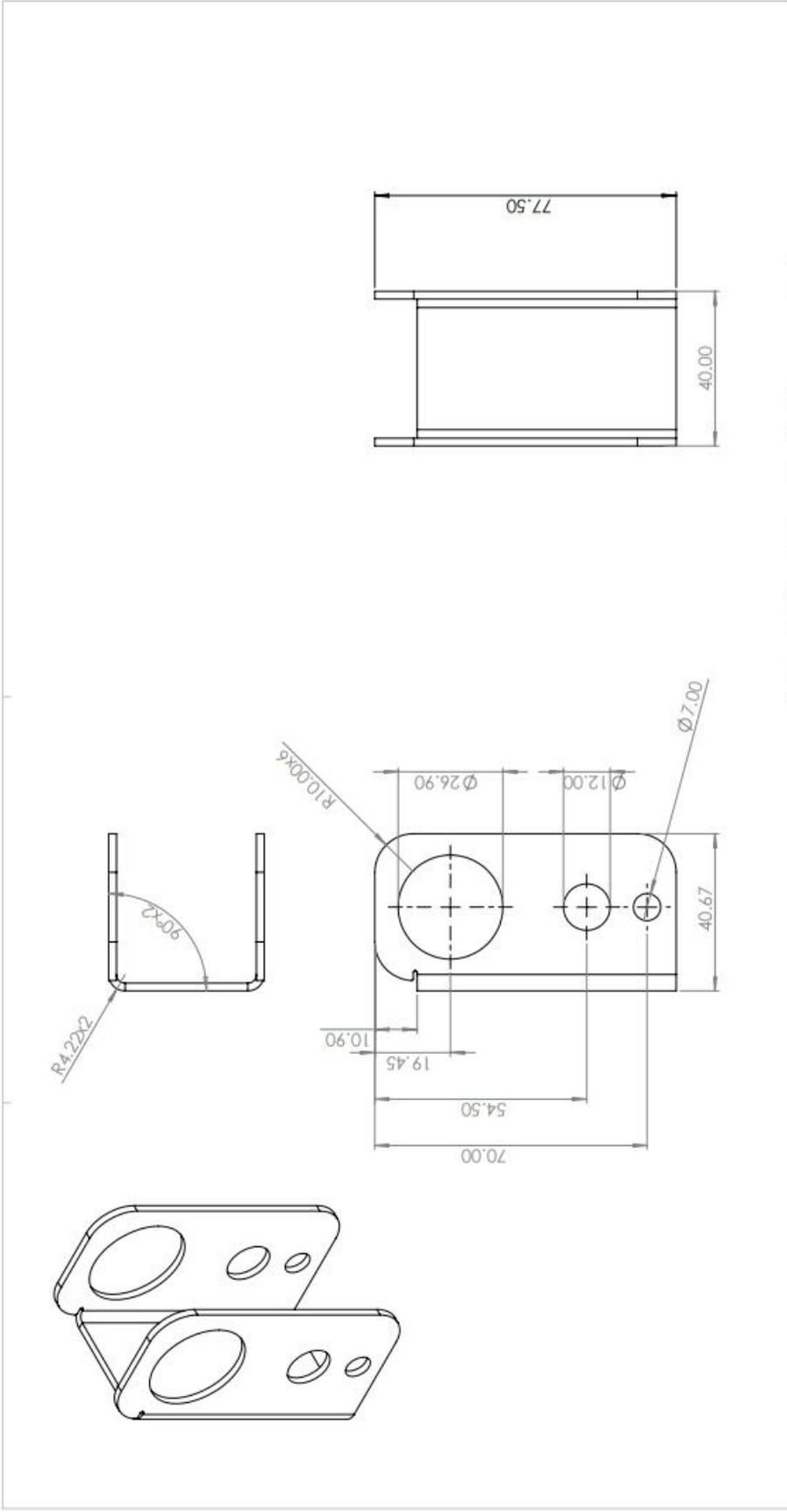
1. I think that the QuickScale accurately obtains the weight of a body and does this quicker than first transporting the mortal remains by car and using a weighing scale at the morgue.	Strongly Agree	Agree	Agree Nor Disagree	Disagree	Strongly Disagree
	<input type="radio"/>				
2. While learning about and figuring out the controls I found the QuickScale unnecessarily complex.	Strongly Agree	Agree	Agree Nor Disagree	Disagree	Strongly Disagree
	<input type="radio"/>				
3. During the experiments I thought the QuickScale was easy to use.	Strongly Agree	Agree	Agree Nor Disagree	Disagree	Strongly Disagree
	<input type="radio"/>				
4. I think that I would need the support of a technical person to be able to use the QuickScale.	Strongly Agree	Agree	Agree Nor Disagree	Disagree	Strongly Disagree
	<input type="radio"/>				
5. I found the various functions in the QuickScale were well integrated.	Strongly Agree	Agree	Agree Nor Disagree	Disagree	Strongly Disagree
	<input type="radio"/>				
6. I thought there was too much inconsistency in using the QuickScale.	Strongly Agree	Agree	Agree Nor Disagree	Disagree	Strongly Disagree
	<input type="radio"/>				
7. I would imagine that most people would learn to use the QuickScale very quickly.	Strongly Agree	Agree	Agree Nor Disagree	Disagree	Strongly Disagree
	<input type="radio"/>				
8. I found the QuickScale very cumbersome to use.	Strongly Agree	Agree	Agree Nor Disagree	Disagree	Strongly Disagree
	<input type="radio"/>				
9. I felt very confident using the QuickScale.	Strongly Agree	Agree	Agree Nor Disagree	Disagree	Strongly Disagree
	<input type="radio"/>				
10. I needed to learn a lot of things before I could get going with the QuickScale.	Strongly Agree	Agree	Agree Nor Disagree	Disagree	Strongly Disagree
	<input type="radio"/>				

Appendix F QuickScale 2.0 Technical Drawings:

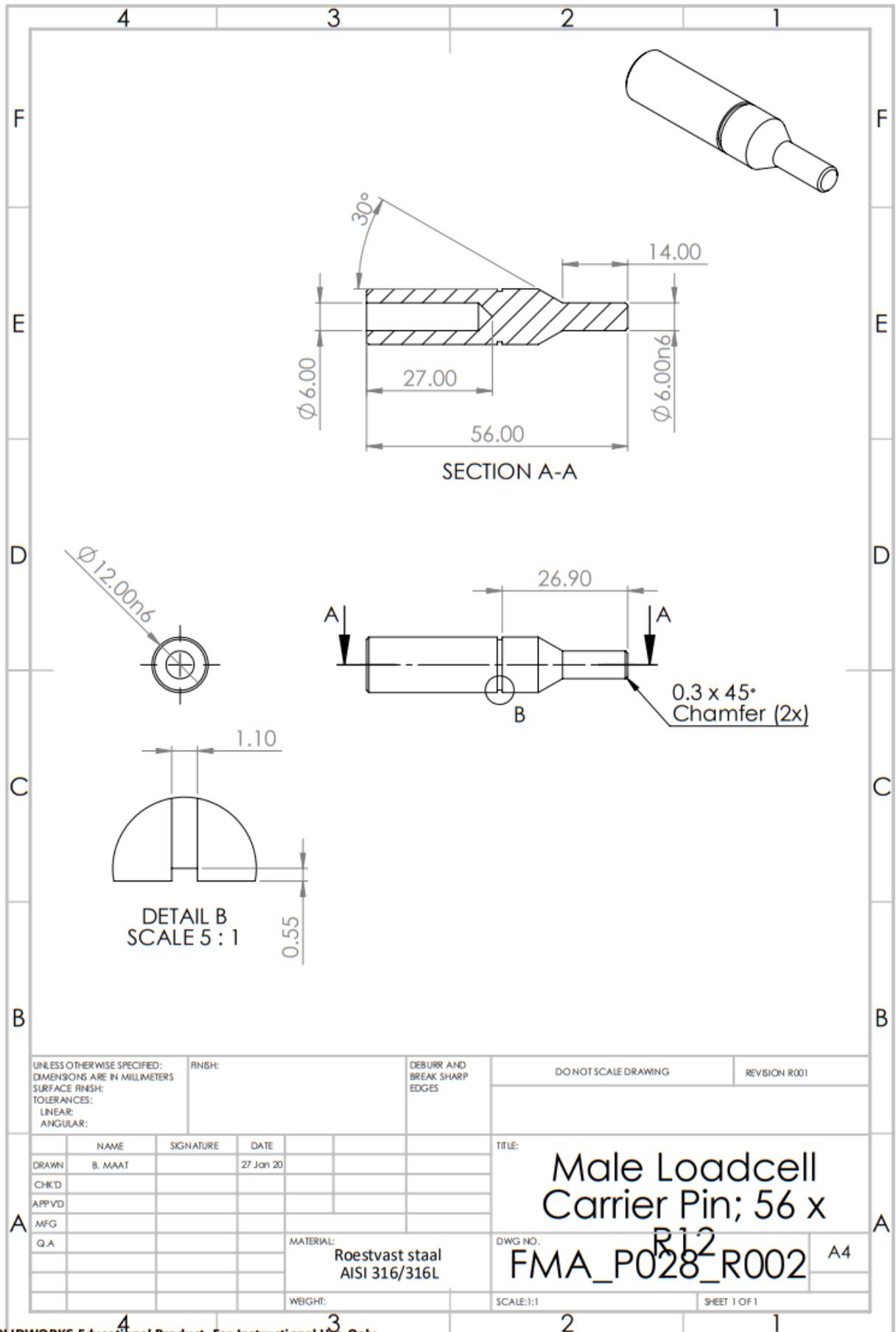




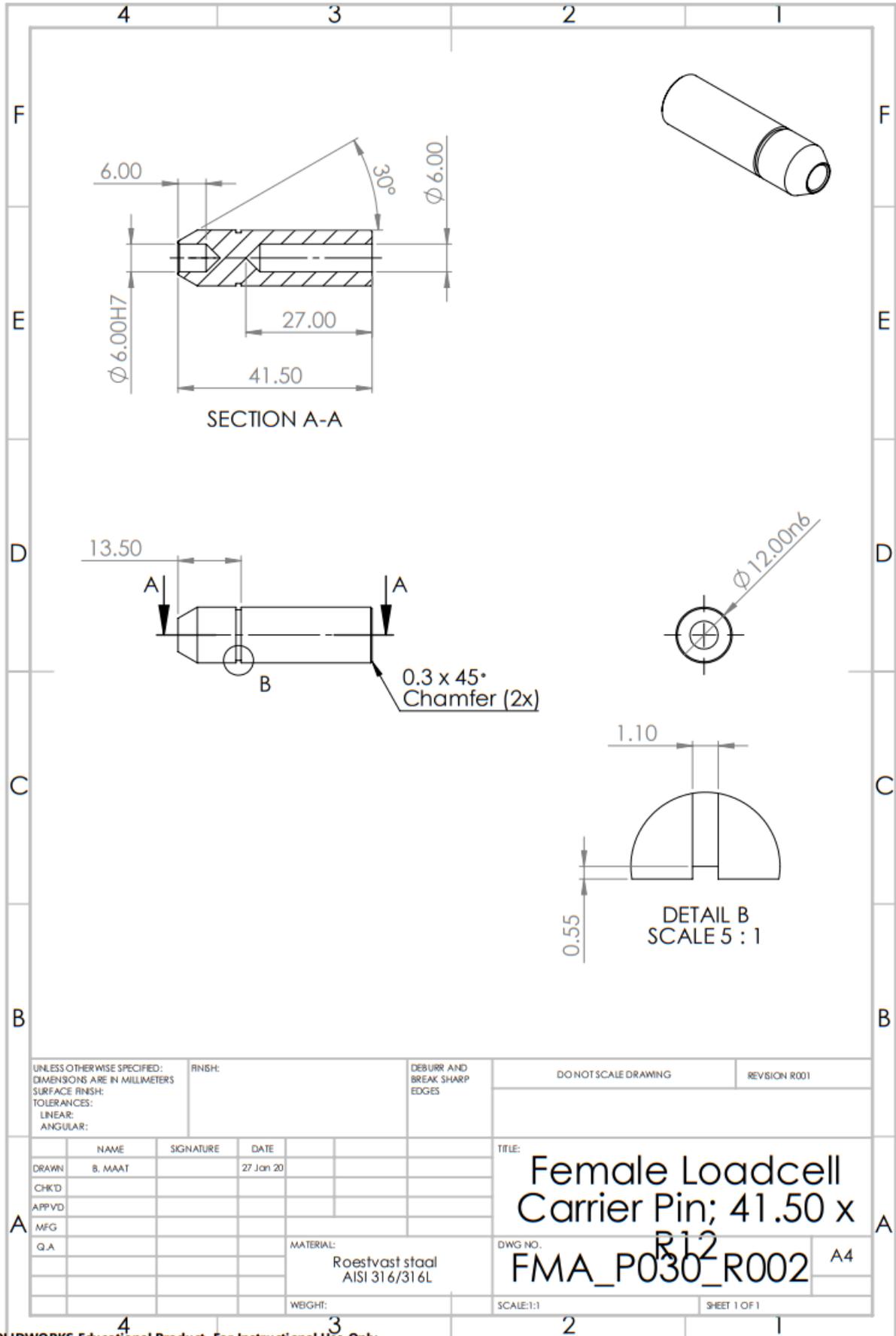
SOLIDWORKS Educational Product. For Instructional Use Only.



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	author	T.A.Anker@student.tudelft.nl									
	name	FMA_P021_R002									
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								format	A3	drawing no.	1/1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:	DEBURR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING	REVISION R001
DRAWN	B. MAAT	SIGNATURE	DATE	27 Jan 20	Male Loadcell Carrier Pin; 56 x R12 FMA_P028_R002 A4	
CHK'D						
APP'VD						
MFG						
Q.A						
MATERIAL: Roestvast staal AISI 316/316L				DWG NO.	SCALE:1:1	
WEIGHT:				SHEET 1 OF 1		



UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN MILLIMETERS
 SURFACE FINISH:
 TOLERANCES:
 LINEAR:
 ANGULAR:

FINISH:

DEBURR AND
 BREAK SHARP
 EDGES

DO NOT SCALE DRAWING

REVISION R001

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DRAWN	B. MAAT		27 Jan 20
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APPVD			
MFG			
Q.A			

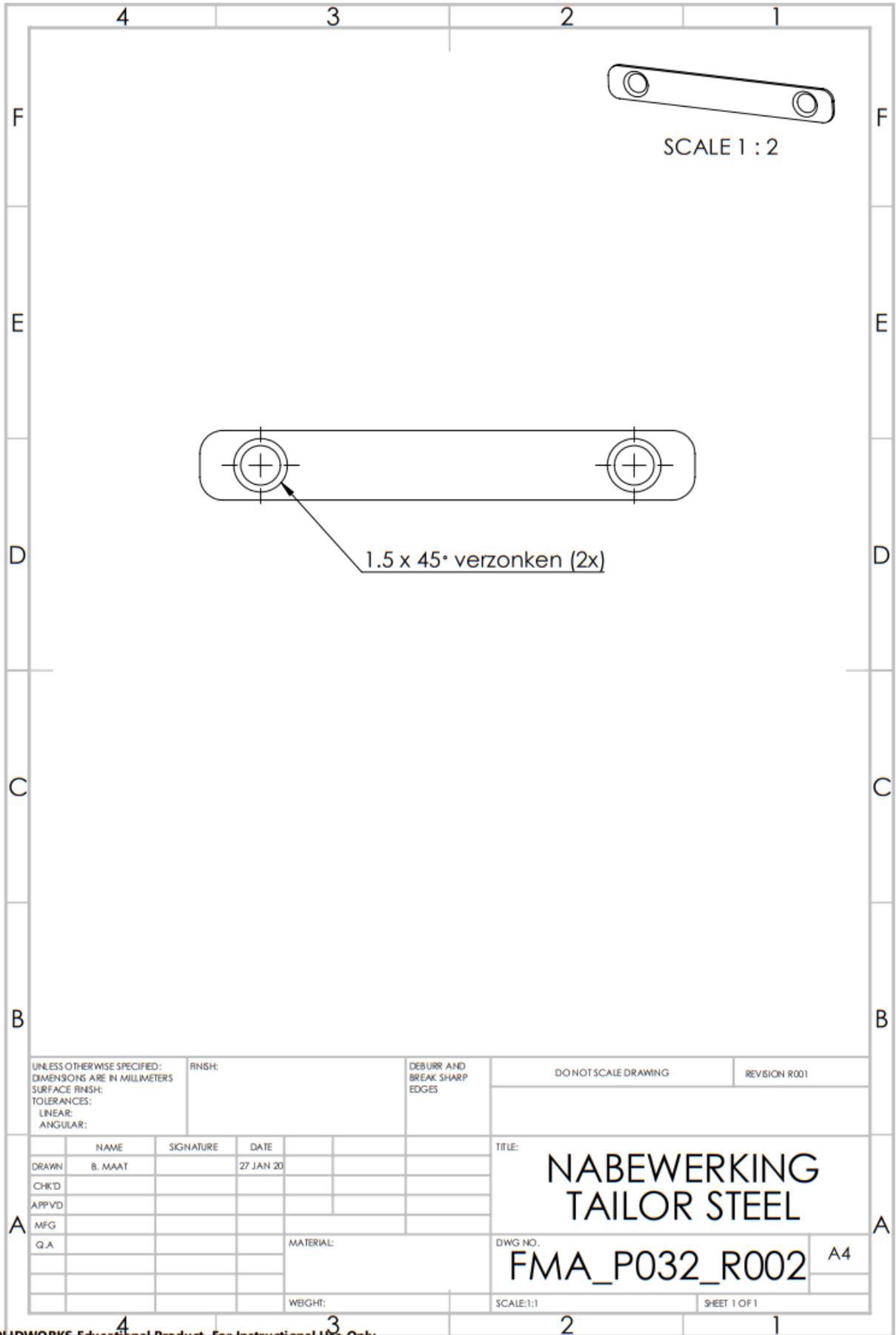
TITLE:
**Female Loadcell
 Carrier Pin; 41.50 x**
 R12
FMA_P030_R002 A4

MATERIAL:
 Roestvast staal
 AISI 316/316L

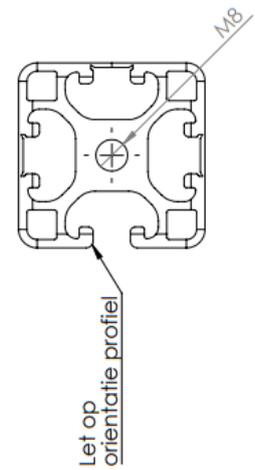
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SCALE:1:1

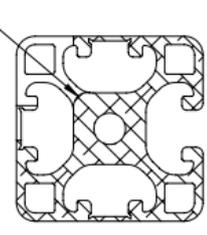
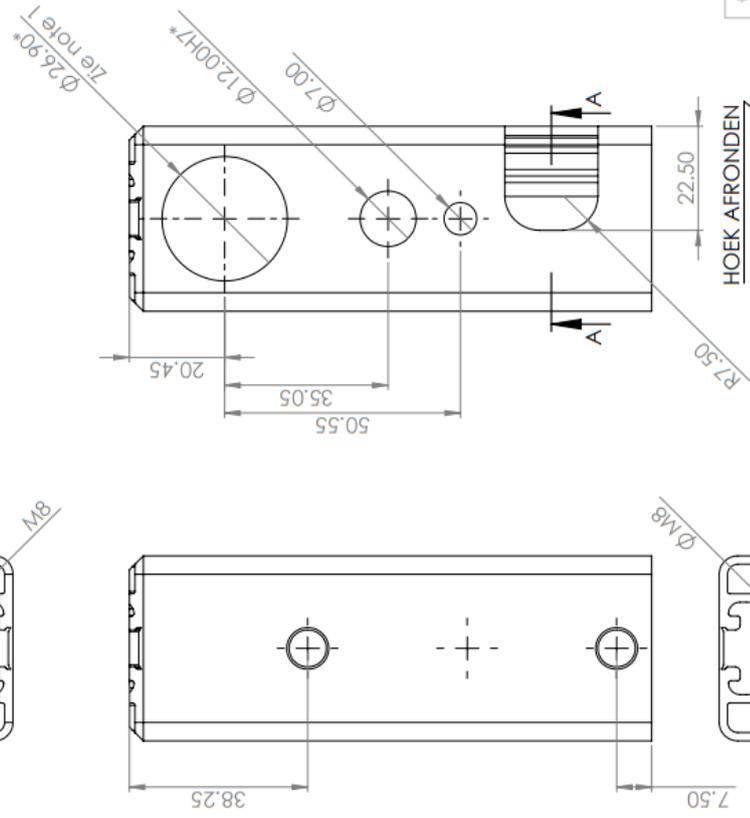
SHEET 1 OF 1



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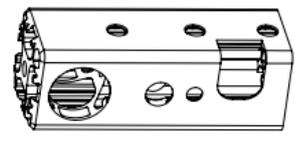


NOTE 1. OVERGANGSPASSING NAAR
BUITENDIAMETER BUIS (NAMETEN WERKELIJKE
DIAMETER BUIS)



SECTION A-A

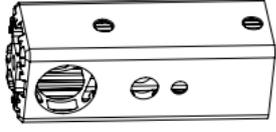
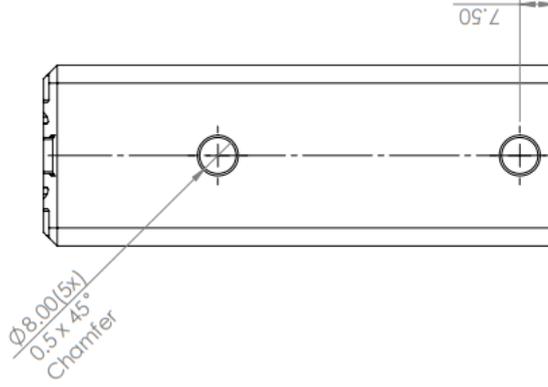
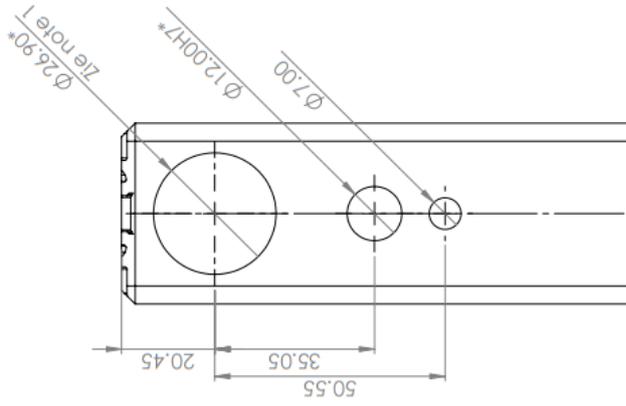
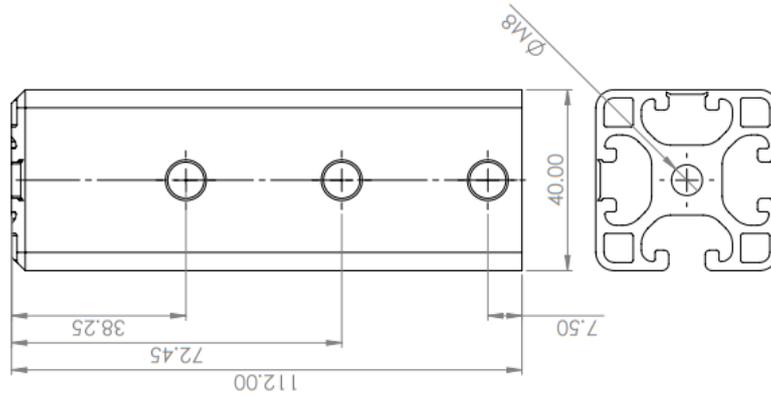
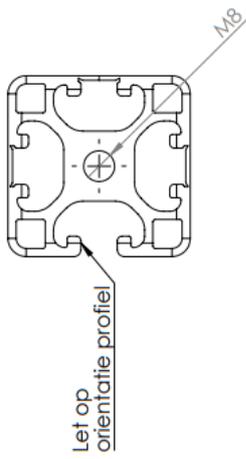
Alle gaten geboord door enkel de eerste laag van het ITEM profiel.
Tenzij anders aangegeven met een *. In geval van een * het gat volledig door het ITEM profiel boren.



SCALE 1 : 2

DEBURR AND
BREAK SHARP
EDGES

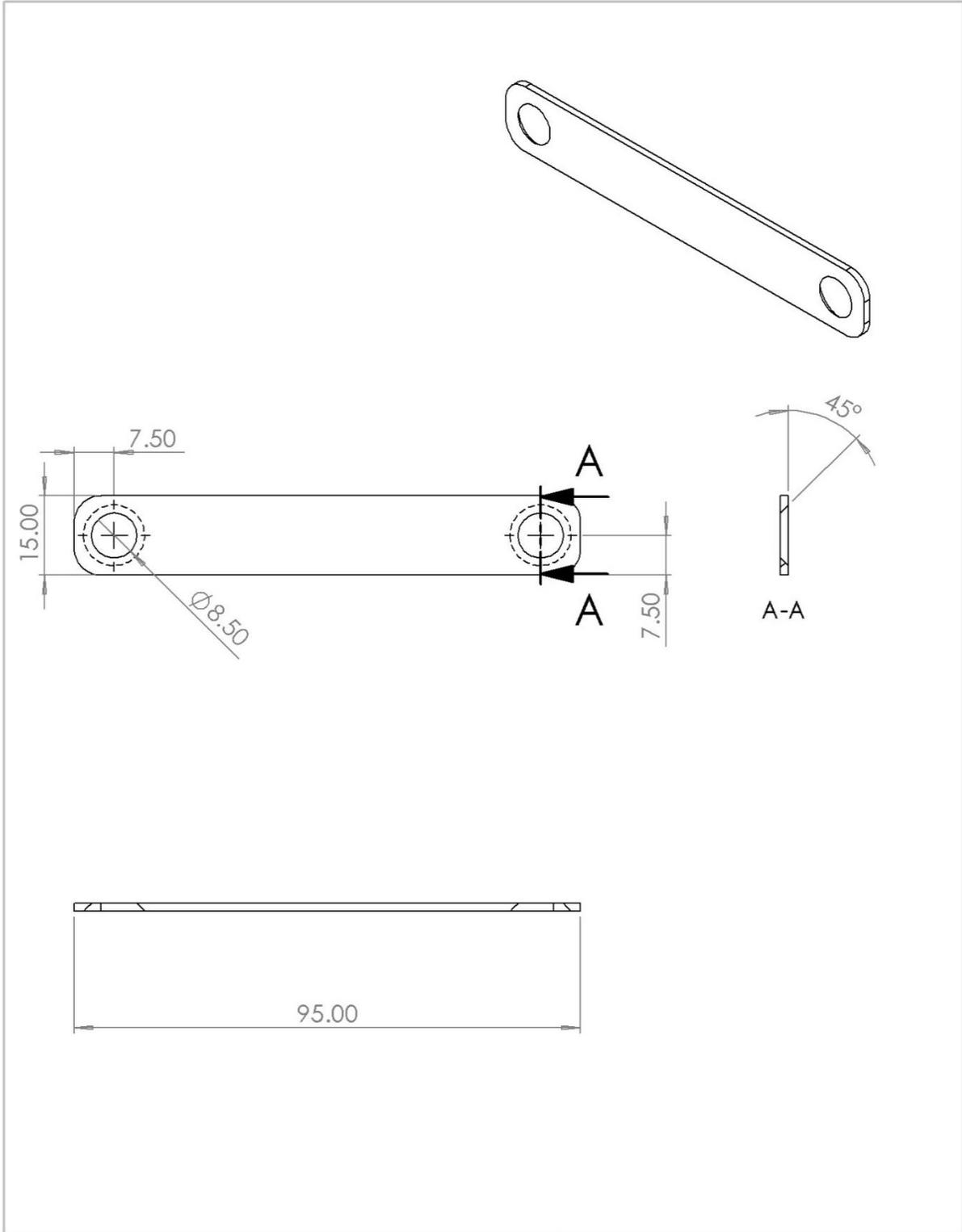
		NABEWERKING ITEM PROFIEL <small>REVISION R002</small>	
material Aluminum ITEM Profile 8 3N 40x40 light author Thomas Anker, 4703367. Adapted from Barjlan Maat, Maat engineering	date 30/08/2023 mass group Engineering 4 Forensics	quantity 1 scale 1:1 units mm	remark drawing no. 1 format A3 SHEET 1 OF 1
Left Item Profile 112x40x40		TITLE: FMA_P048_R003	
		drawing no. 1	



SCALE 1 : 2

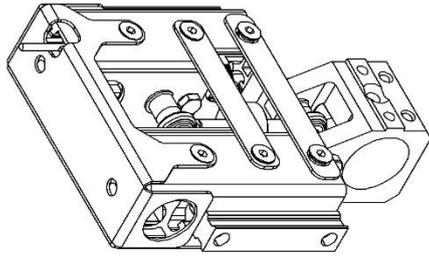
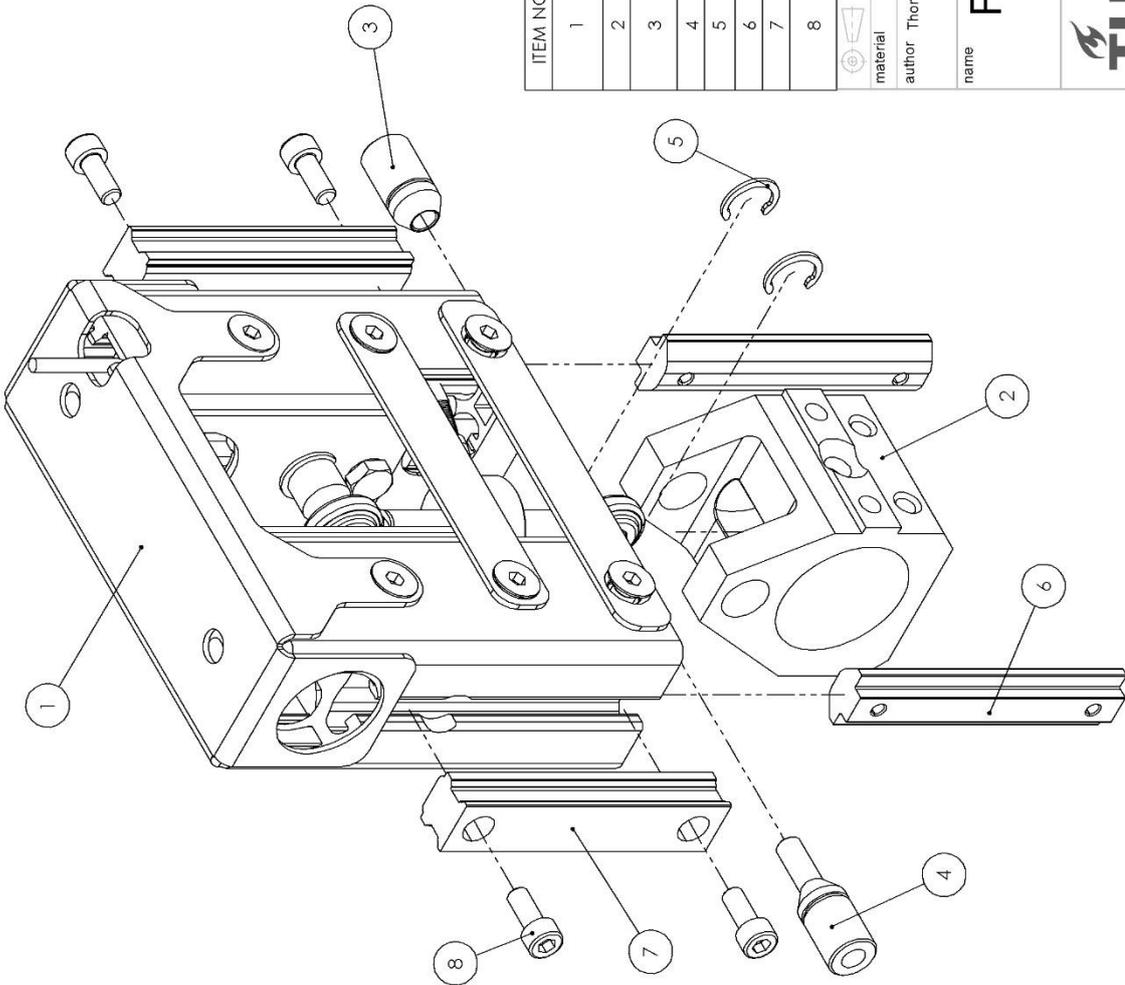
units	mm	scale	1:1	quantity	1	date	30/08/2023	remark	Nabewerking Item Profiel
material	Aluminium profile 8 3N, 40x40	light		mass	gr	group	Engineering 4 Forensics		
author	Thomas Anker, 4703367. Adapted from Barjan Maat, Maat engineering								
name	Right Item Profile 112x40x40 FMA_P049_R003								
								format	A3
								drawing no.	1

Alle gaten geboord door enkel de eerste laag van het ITEM profiel.
Tenzij anders aangegeven met een *. In geval van een * het gat volledig door het ITEM profiel boren.



	units mm	scale 1:1	quantity <<nr>>	date 30/08/2023	remark <<remarks>>
material			mass gr		
author <<names & student numbers>>			group <<group>>		
name FMA_P051_R002				format A4	drawing no. <<drawing no.>>

C:\Users\Totot\Documents\Master Biomedical Engineering\Thesis\TherminusQuickScale-CAD\1.25-Therminus QuickScale V1.25-Assembly Step 1\F



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	FMA_AS001_R002	Top Loadcell Assembly; 123 x 43 x 113.5	1
2	FMA_P026_R002	Loadcell Anchor 48.22x58.92x45	1
3	FMA_P040_R002	Lower Female Loadcell Pin R12x22.5	1
4	FMA_P039_R002	Lower Male Loadcell Pin R12x37	1
5	FMA_P033_R002	Locking Ring D11	2
6	FMA_P016_R002	Linear Guide Rail ITEM Fixture	2
7	FMA_P018_R002	Linear Guide Rail 74x15x12.4	2
8	DIN 912 M5 x 12 --- 12N		4

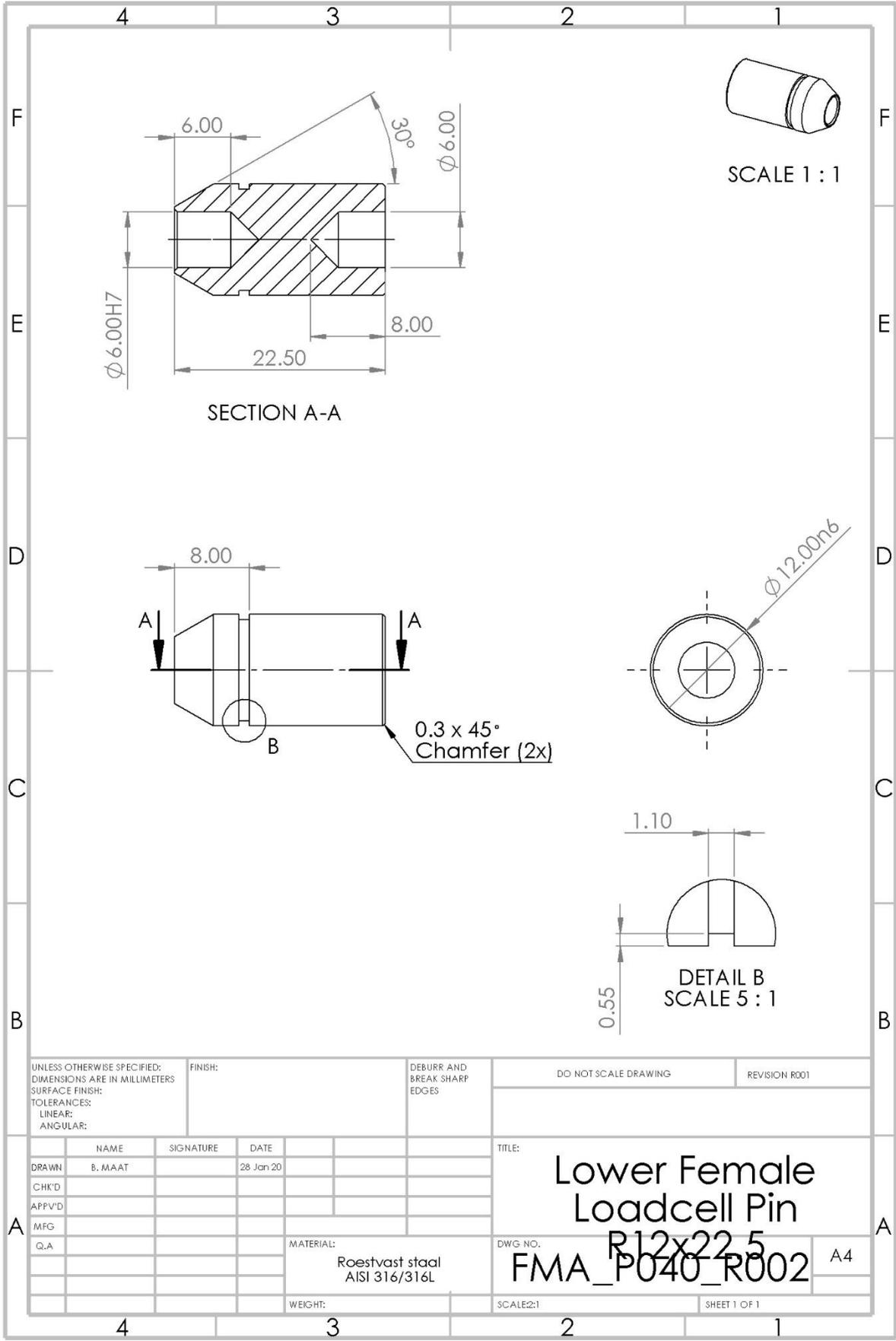
units	mm	scale	1:1	quantity	<<n p>>	date	16/10/2023	remark	Second Assembly step
material						mass	gr	group	Engineering for Forensics
author	Thomas Anker 4703367								

name **FMA_AS0015_R002**

format drawing no.

A3





UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN MILLIMETERS
 SURFACE FINISH:
 TOLERANCES:
 LINEAR:
 ANGULAR:

FINISH:

DEBURR AND
 BREAK SHARP
 EDGES

DO NOT SCALE DRAWING

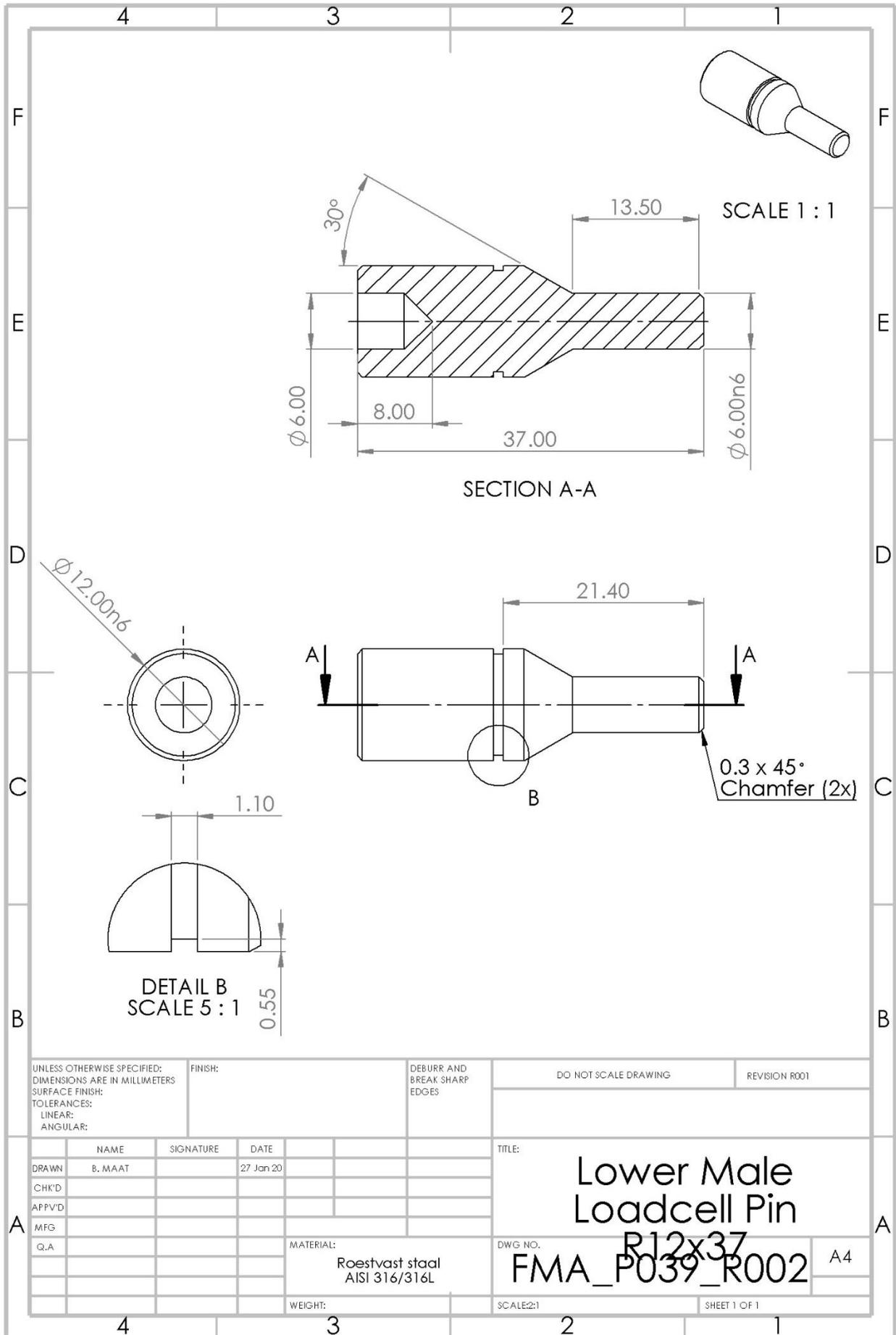
REVISION R001

NAME	SIGNATURE	DATE
DRAWN B. MAAT		28 Jan 20
CHK'D		
APPV'D		
MFG		
Q.A		
MATERIAL: Roestvast staal AISI 316/316L		WEIGHT:

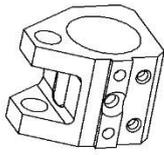
TITLE:
**Lower Female
 Loadcell Pin**
R12x22.5
FMA_P040_R002 A4

DWG NO. FMA_P040_R002 A4

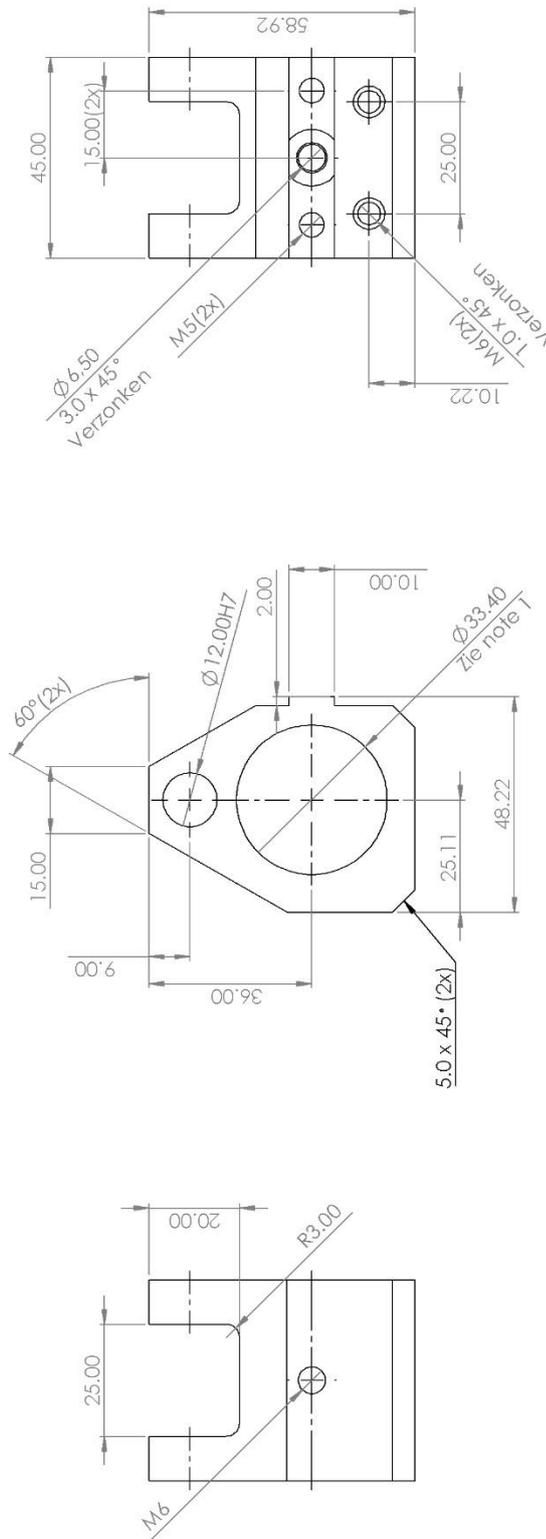
SCALE:2:1 SHEET 1 OF 1



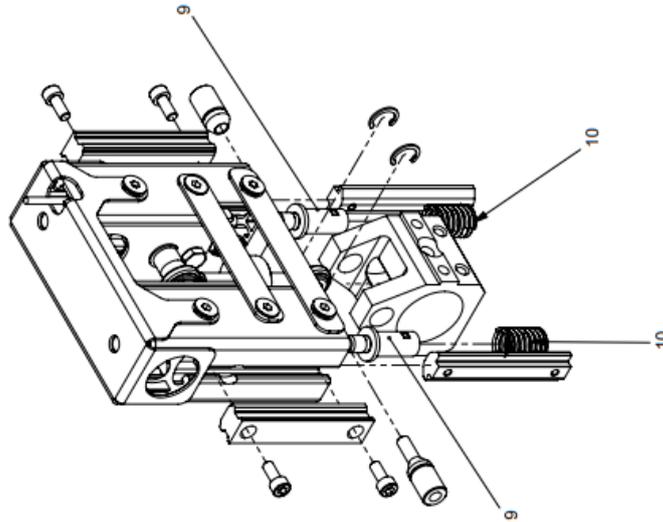
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		FINISH:		DEBURR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING		REVISION R001	
DRAWN B. MAAT		SIGNATURE		DATE 27 Jan 20		TITLE: Lower Male Loadcell Pin R12x37			
CHK'D						DWG. NO. FMA_P039_R002			
APPV'D						SCALE:2:1			
MFG						SHEET 1 OF 1			
Q.A				MATERIAL: Roestvast staal AISI 316/316L		A4			
				WEIGHT:					



SCALE 1 : 2



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS DIMENSIONS IN PARENTHESES ARE FOR INFORMATION ONLY		INCH TO MILLIMETER CONVERSION TABLE (DIMENSIONS IN PARENTHESES ARE FOR INFORMATION ONLY)		DEBURR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING		REVISION 8001	
NAME	SIGNATURE	DATE			TITLE:		Loadcell Anchor 48.22x58.92x45		
DRYAN		27 Jan 20			DWG NO.:		FMA_P026_R002		
CHKD					MATERIAL:		Aluminium legering (bv. AlMg4)		
APPRD					WEIGHT:		A3		
APR					SHEET 1 OF 1		2		
QA					WEIGHT:		3		
					SHEET 1 OF 1		2		

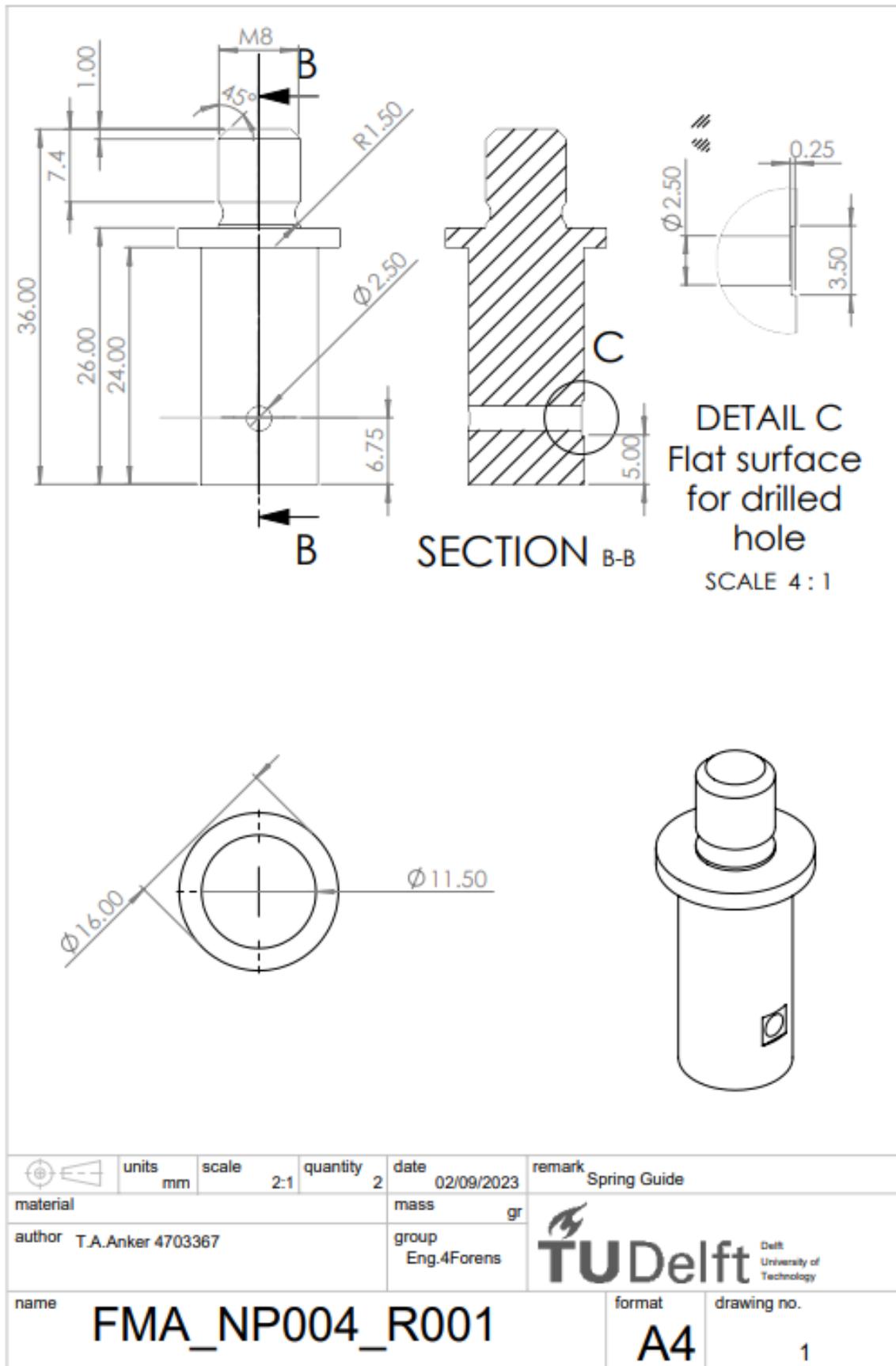


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	FMA_AS001_R003	Top Loadcell Assembly, 123 x 43 x 113.5	1
2	FMA_P026_R002	Loadcell Anchor 48.22x68.92x45	1
3	FMA_P040_R002	Lower Female Loadcell Pin R12x22.5	1
4	FMA_P039_R002	Lower Male Loadcell Pin R12x37	1
5	FMA_P033_R002	Locking Ring D11	2
6	FMA_P016_R002	Linear Guide Rail ITEM Fixture	2
7	FMA_P018_R002	Linear Guide Rail 74x15x12.4	2
8	DIN 912 M5 x 12 --- 12N		4
9	FMA_NP004_R001	Spring Guide	2
10	ast_c0600-063-1500-m_prt	C0600-063-1500m Spring L21.2	2

material
 units mm
 scale 1:5
 quantity 1
 date 30/09/2023
 mass gr
 group Engineering 4Forensics
 author T.A.Anker (4703367)
 remark The Spring guide was designed to fit security pins. Use These during installation

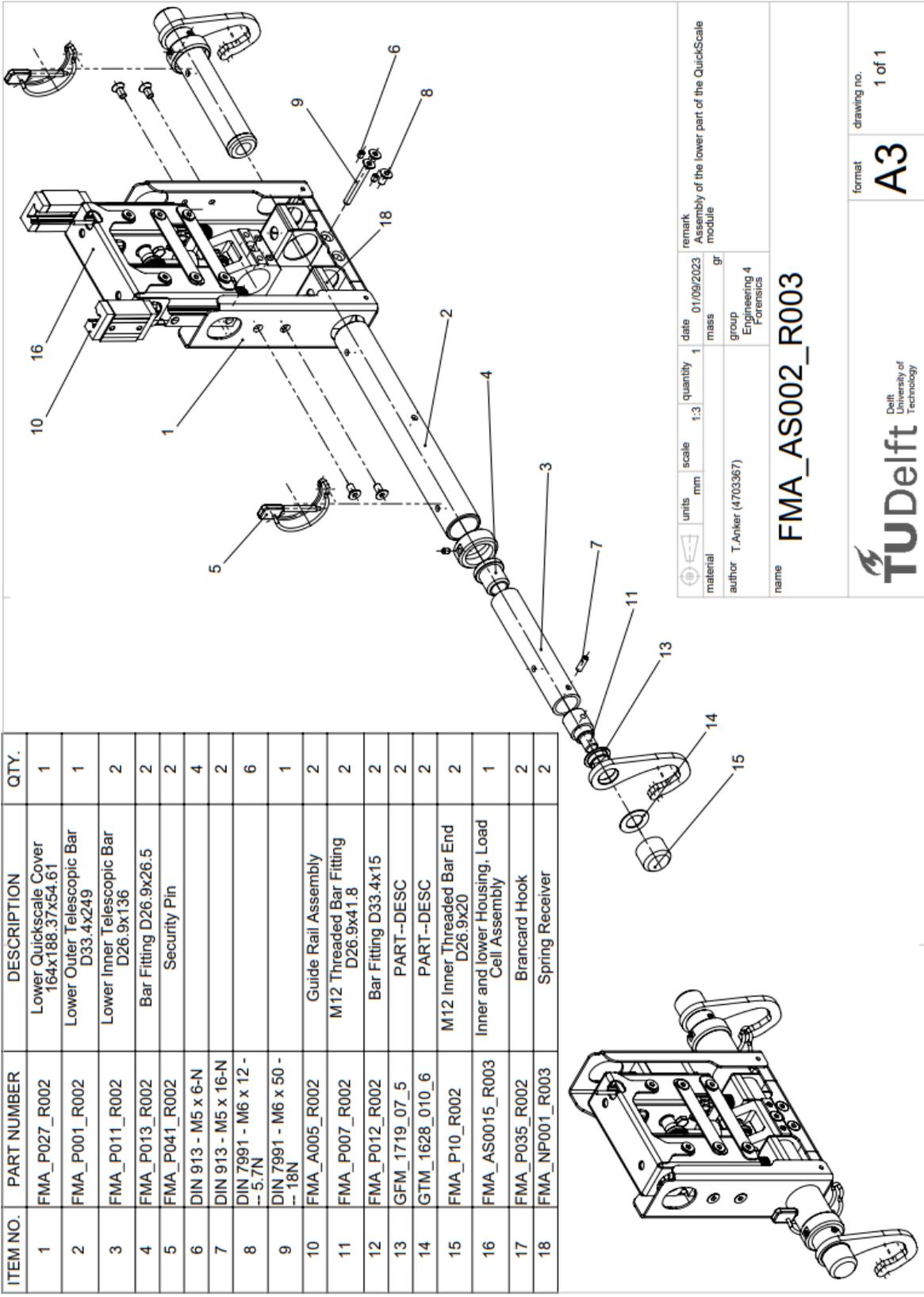
name **FMA_AS0015_R003**

TU Delft
 Delft University of Technology
 format **A3**
 drawing no. **1 of 1**



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ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	FMA_P027_R002	Lower QuickScale Cover 164x188.37x54.61	1
2	FMA_P001_R002	Lower Outer Telescopic Bar D33.4x249	1
3	FMA_P011_R002	Lower Inner Telescopic Bar D26.9x136	2
4	FMA_P013_R002	Bar Fitting D26.9x26.5	2
5	FMA_P041_R002	Security Pin	2
6	DIN 913 - M5 x 6-N		4
7	DIN 913 - M5 x 16-N		2
8	DIN 7991 - M6 x 12 - --5.7N		6
9	DIN 7991 - M6 x 50 - --18N		1
10	FMA_A005_R002	Guide Rail Assembly	2
11	FMA_P007_R002	M12 Threaded Bar Fitting D26.9x41.8	2
12	FMA_P012_R002	Bar Fitting D33.4x15	2
13	GFM_1719_07_5	PART--DESC	2
14	GTM_1628_010_6	PART--DESC	2
15	FMA_P10_R002	M12 Inner Threaded Bar End D26.9x20	2
16	FMA_AS0015_R003	Inner and lower Housing, Load Cell Assembly	1
17	FMA_P035_R002	Brancard Hook	2
18	FMA_NP001_R003	Spring Receiver	2



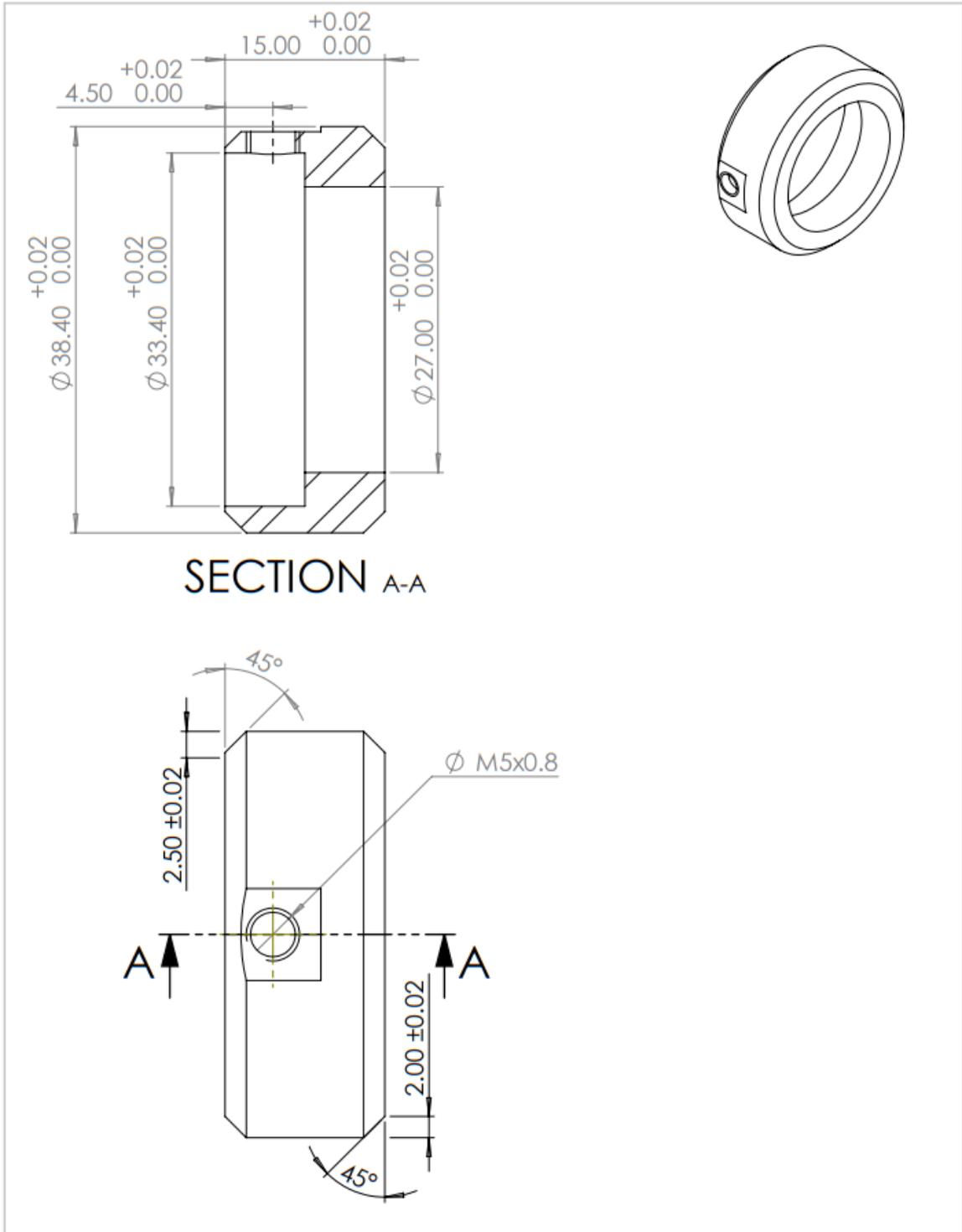
material	author	T.Anker (4703367)	units	mm	scale	1:3	quantity	1	date	01/09/2023	remark	Assembly of the lower part of the QuickScale module
	group	Engineering 4 Forensics	mass									
	gr											

name **FMA_AS002_R003**

format **A3**

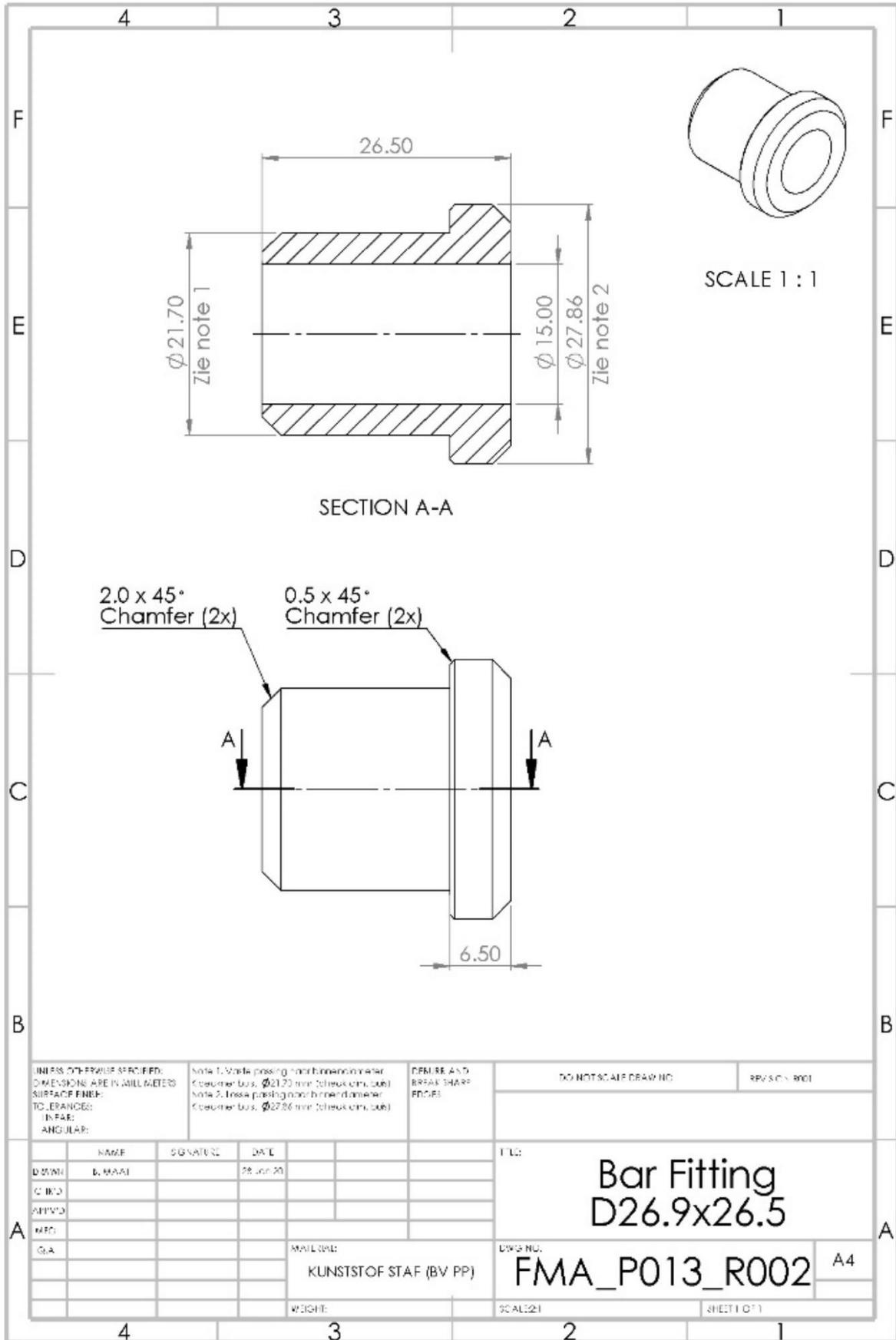
drawing no. **1 of 1**

TU Delft
Delft University of Technology



	units mm	scale 2:1	quantity X4	date 10/05/2021	remark Stainless steel SS 316 / 316L
material	author Thomas Anker		mass gr	group MISIT	 Delft University of Technology
name FMA_P012_R0025	format A4	drawing no. <<drawing.no.>>			

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UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN MILLIMETERS
 SURFACE FINISH:
 TOLERANCES:
 (IN FRACTIONS)
 ANGULAR:

NOTE 1: Inside passing round bottom diameter
 (counter-bus, $\varnothing 21.70$ mm (2decimals))
 NOTE 2: Inside passing round bottom diameter
 (counter-bus, $\varnothing 27.86$ mm (2decimals))

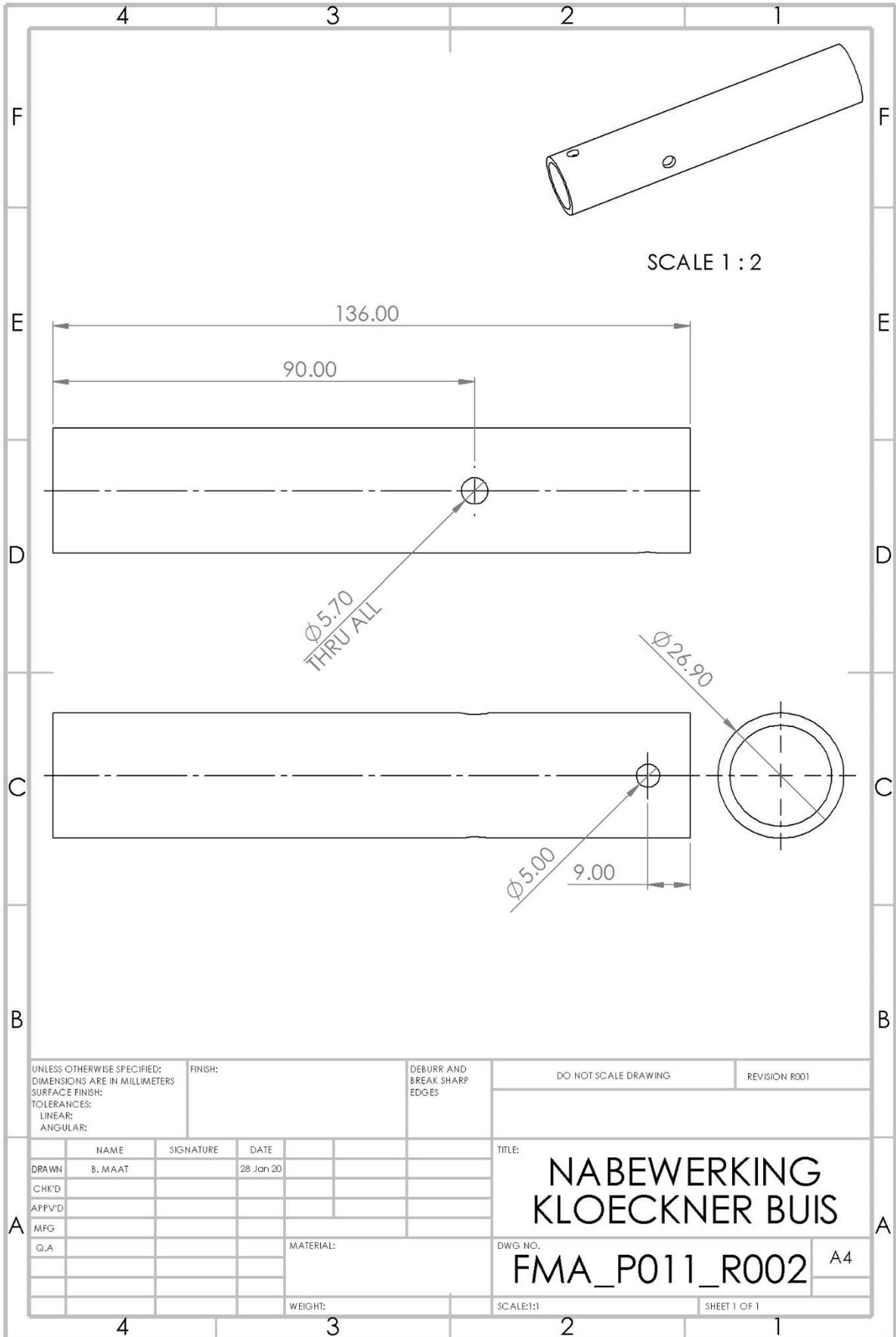
REMOVE AND
 BREAK SHARP
 EDGES

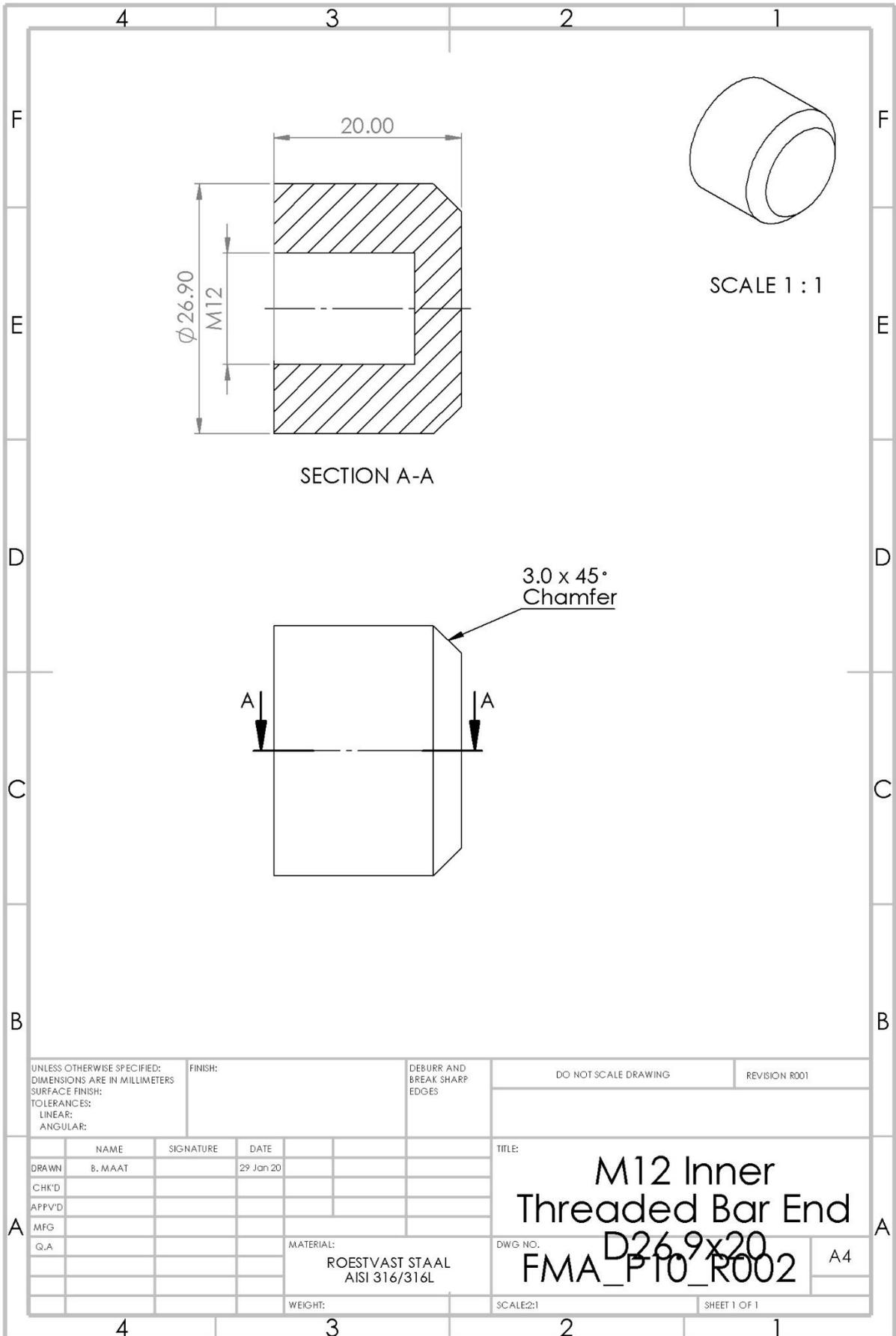
DO NOT SCALE DRAWING

REVISION: 001

NAME	SIGNATURE	DATE
DRAWN B. MAAL		28 Jun 20
CHECKED		
APPROVED		
MFG		
QA		
MATERIAL: KUNSTSTOF STAF (BV PP)		
WEIGHT:		

TITLE: Bar Fitting D26.9x26.5	
DWG NO. FMA_P013_R002	A4
SCALE: 2:1	SHEET 1 OF 1





UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN MILLIMETERS
 SURFACE FINISH:
 TOLERANCES:
 LINEAR:
 ANGULAR:

FINISH:

DEBURR AND
 BREAK SHARP
 EDGES

DO NOT SCALE DRAWING

REVISION R001

	NAME	SIGNATURE	DATE
DRAWN	B. MAAT		29 Jan 20
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

M12 Inner
 Threaded Bar End
 D26.9x20
 FMA_PT0_R002

A4

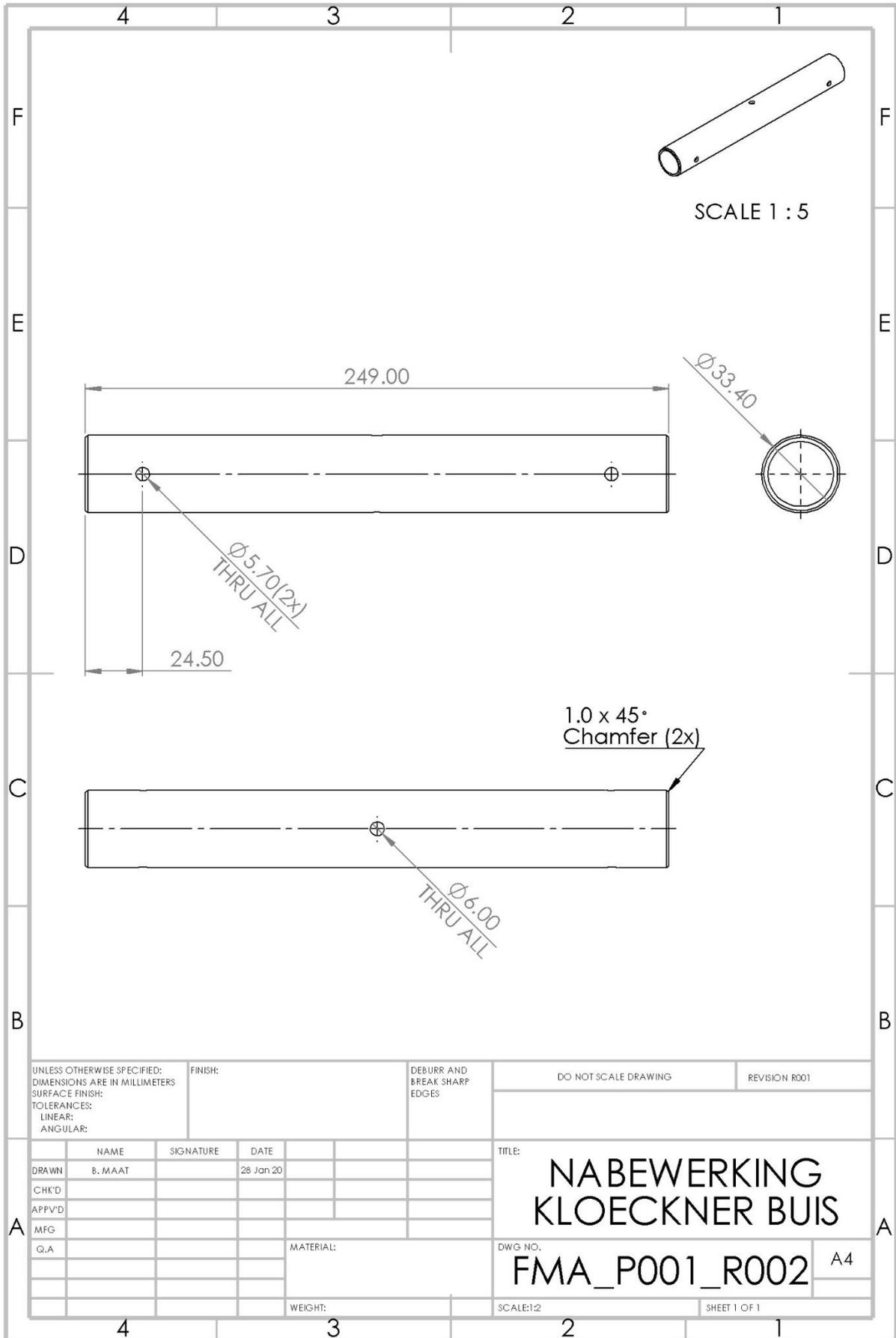
MATERIAL:
 ROESTVAST STAAL
 AISI 316/316L

DWG NO.

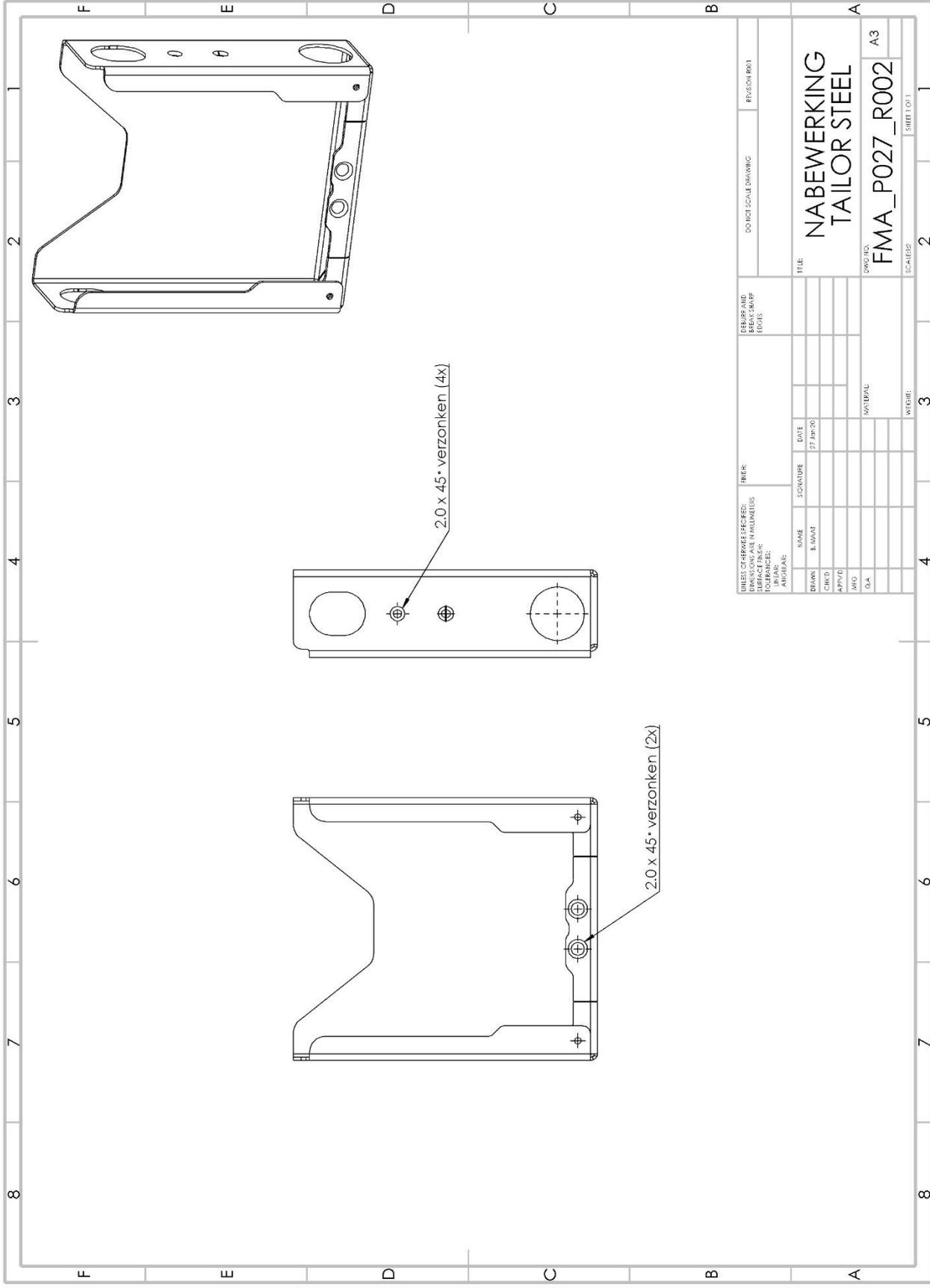
WEIGHT:

SCALE:2:1

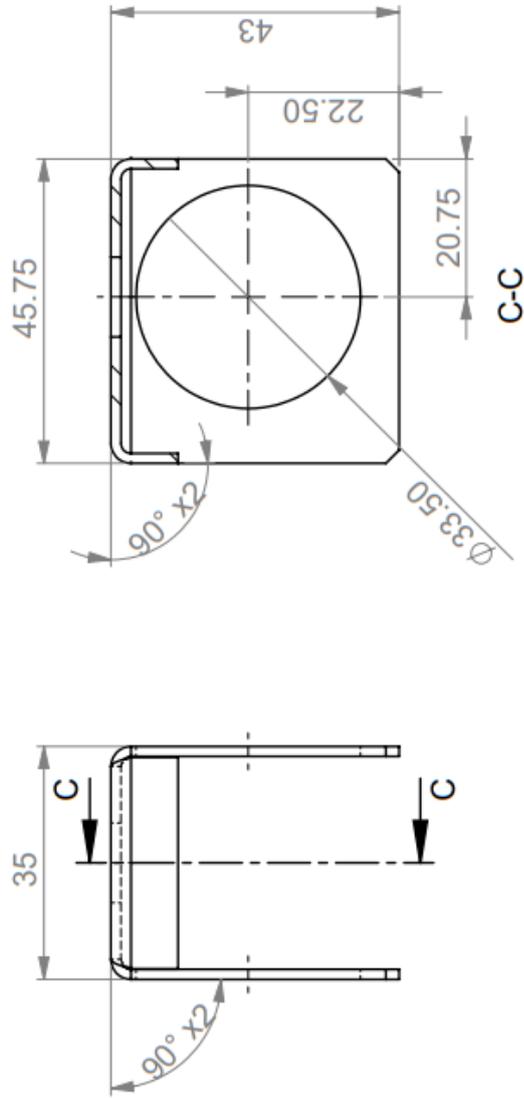
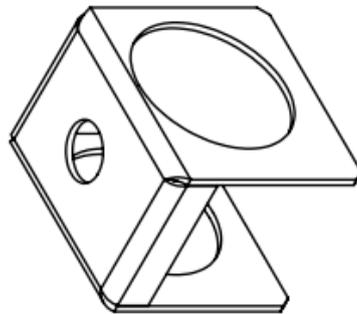
SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS		FINISH:		DEBURR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING		REVISION R001	
SURFACE FINISH:									
TOLERANCES:									
LINEAR:									
ANGULAR:									
NAME		SIGNATURE		DATE		TITLE:			
DRAWN B. MAAT				28 Jan 20		NABEWERKING KLOECKNER BUIS			
CHK'D									
APPV'D									
MFG									
Q.A				MATERIAL:		DWG NO.		A4	
						FMA_P001_R002			
				WEIGHT:		SCALE:1:2		SHEET 1 OF 1	



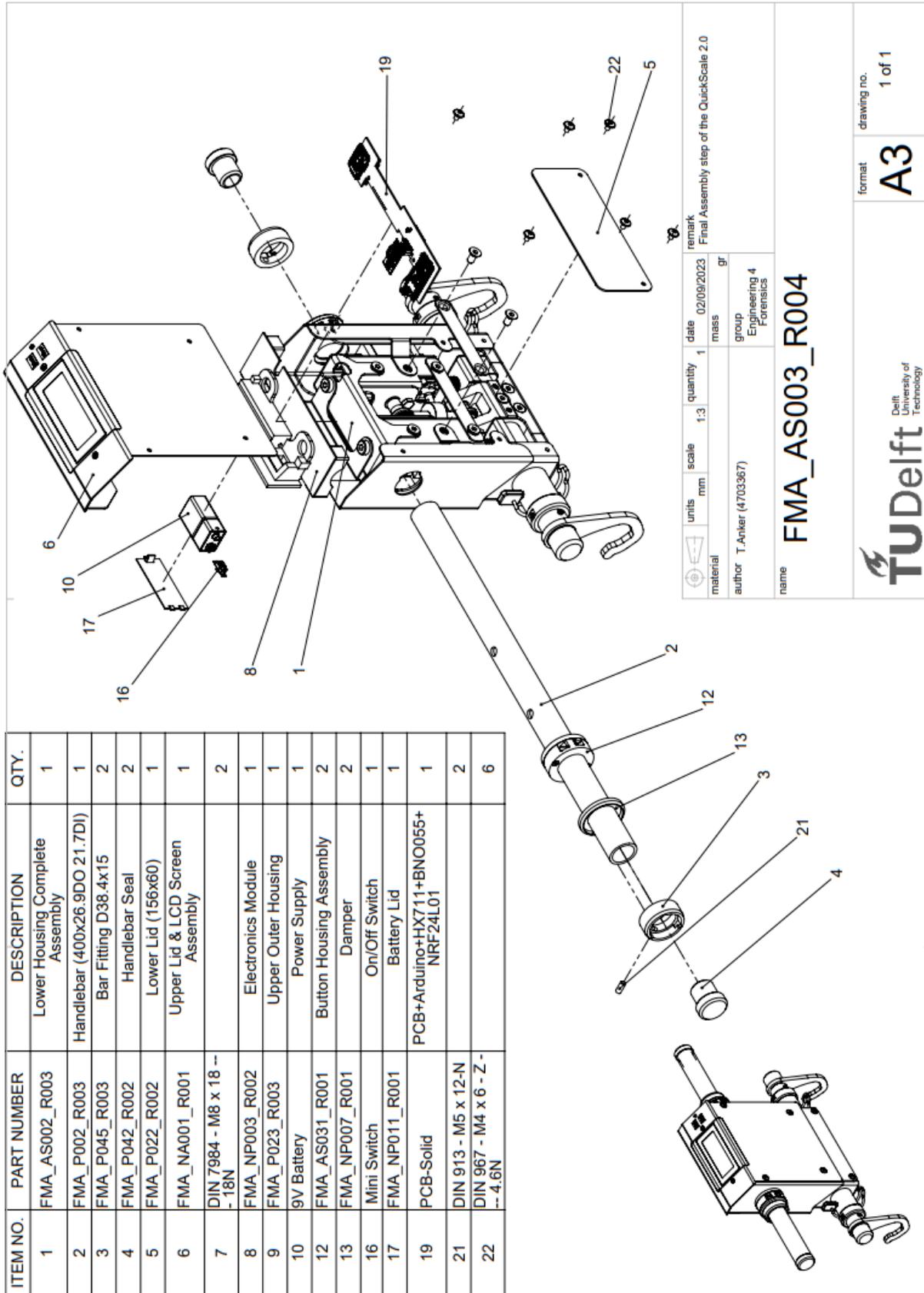
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS DIMENSIONS IN PARENTHESES ARE IN INCHES		DRAWN: DATE		DO NOT SCALE DRAWING		REVISION NO.1	
TOLERANCES: FRACTIONS: DECIMALS: ANGLES:		SIGNATURE		CHECKED: DATE		TITLE:	
NAME		DATE		SCALE		SHEET NO.	
S. WAAT		27 Jun'20		1:1		FMA_P027_R002 A3	
MATERIAL		SCALE		SHEET NO.		1 OF 1	



		name FMA_NP001_R003		remark Spring Receiver	
author T.Anker (4703367)		material AISI 316A/316L Stainless steel		date 01/09/2023	
units mm		scale 1:1		quantity 2	
group Eng. 4 Forensics		mass gr		format A4	
				drawing no. 1 of 1	

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ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	FMA_AS002_R003	Lower Housing Complete Assembly	1
2	FMA_P002_R003	Handlebar (400x26.9DO 21.7DI)	1
3	FMA_P045_R003	Bar Fitting D38.4x15	2
4	FMA_P042_R002	Handlebar Seal	2
5	FMA_P022_R002	Lower Lid (156x60)	1
6	FMA_NA001_R001	Upper Lid & LCD Screen Assembly	1
7	DIN_7984 - M8 x 18 -- - 18N		2
8	FMA_NP003_R002	Electronics Module	1
9	FMA_P023_R003	Upper Outer Housing	1
10	9V Battery	Power Supply	1
12	FMA_AS031_R001	Button Housing Assembly	2
13	FMA_NP007_R001	Damper	2
16	Mini Switch	On/Off Switch	1
17	FMA_NP011_R001	Battery Lid	1
19	PCB-Solid	PCB+Arduino+HX711+BNO055+ NRF24L01	1
21	DIN 913 - M5 x 12-N		2
22	DIN 967 - M4 x 6 - Z - -- 4.6N		6

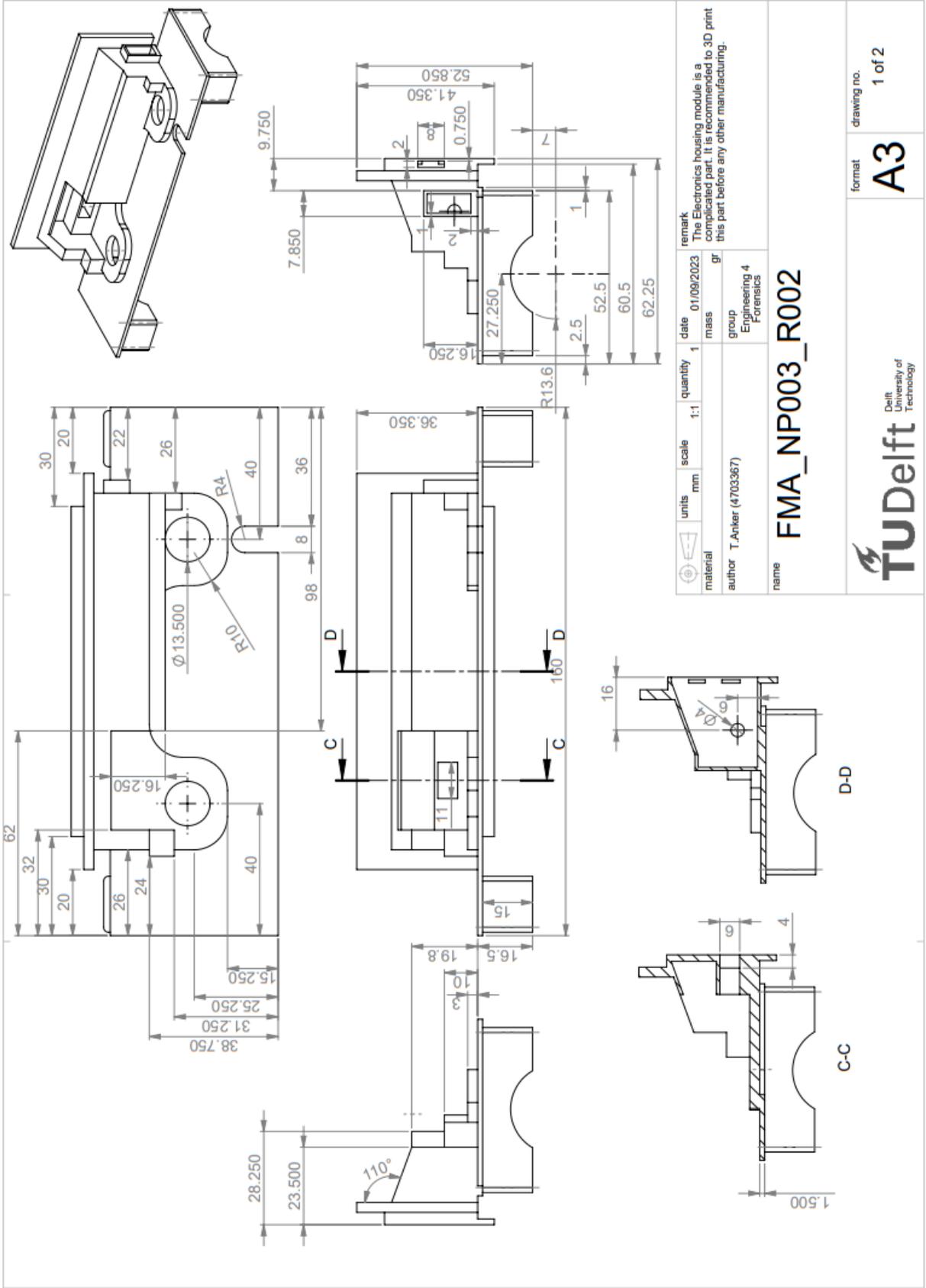


units	mm	scale	1:3	quantity	1	date	02/09/2023	remark	Final Assembly step of the QuickScale 2.0
material						mass			
author	T.Anker (4703367)								
group	Engineering 4 Forensics								

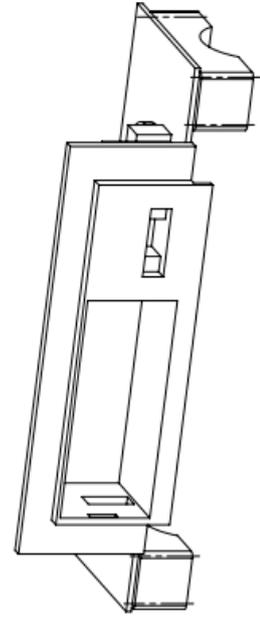
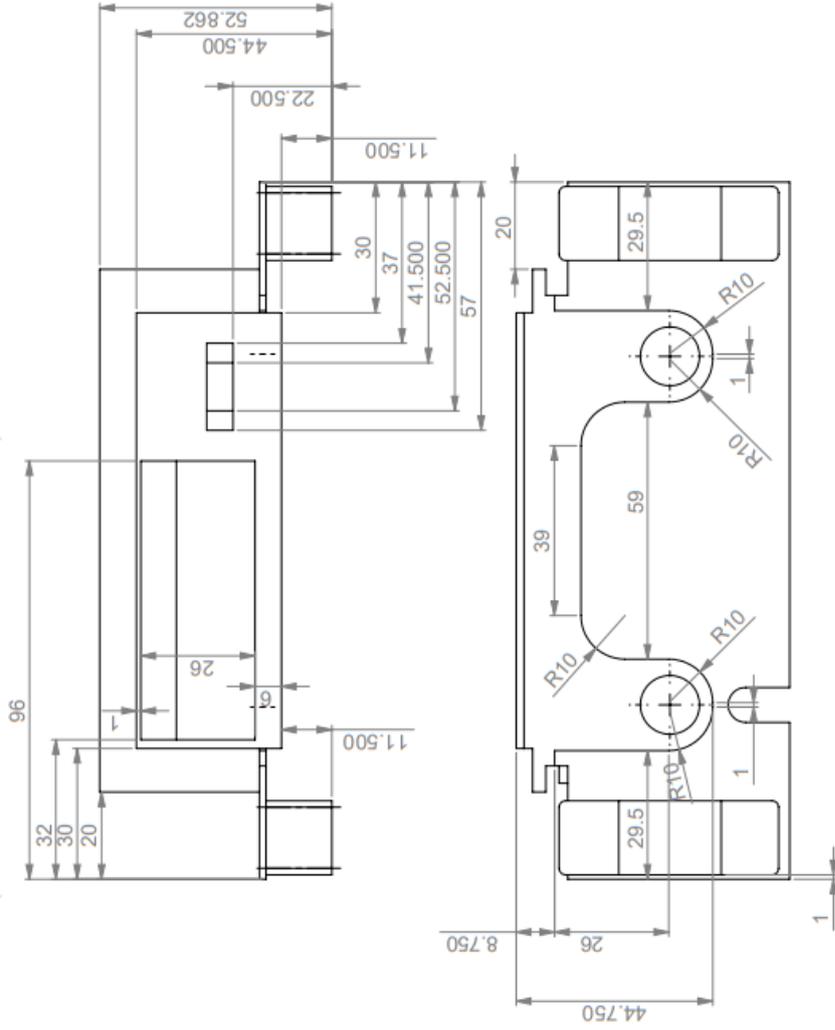
name **FMA_AS003_R004**



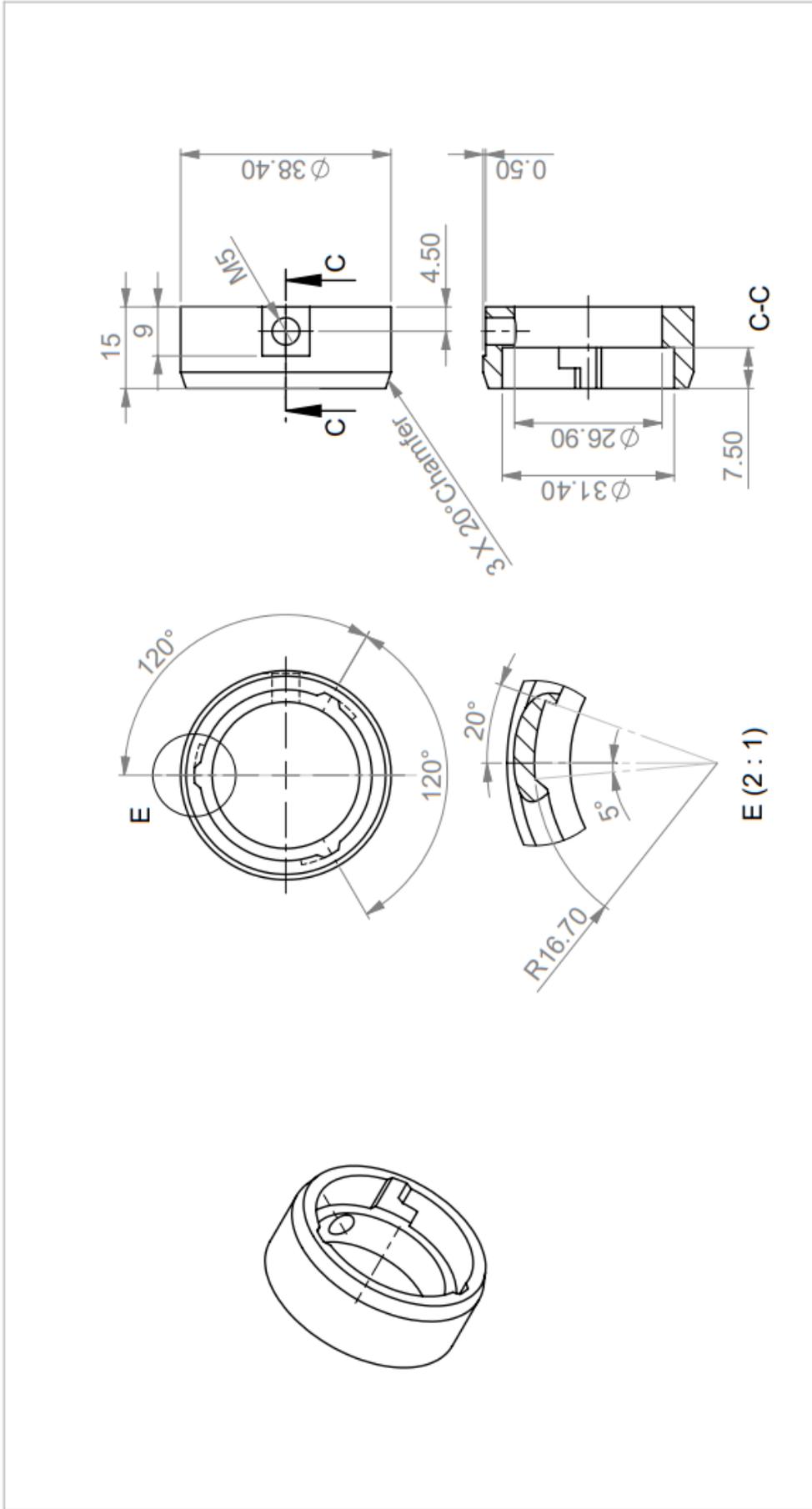
format **A3**
drawing no. **1 of 1**



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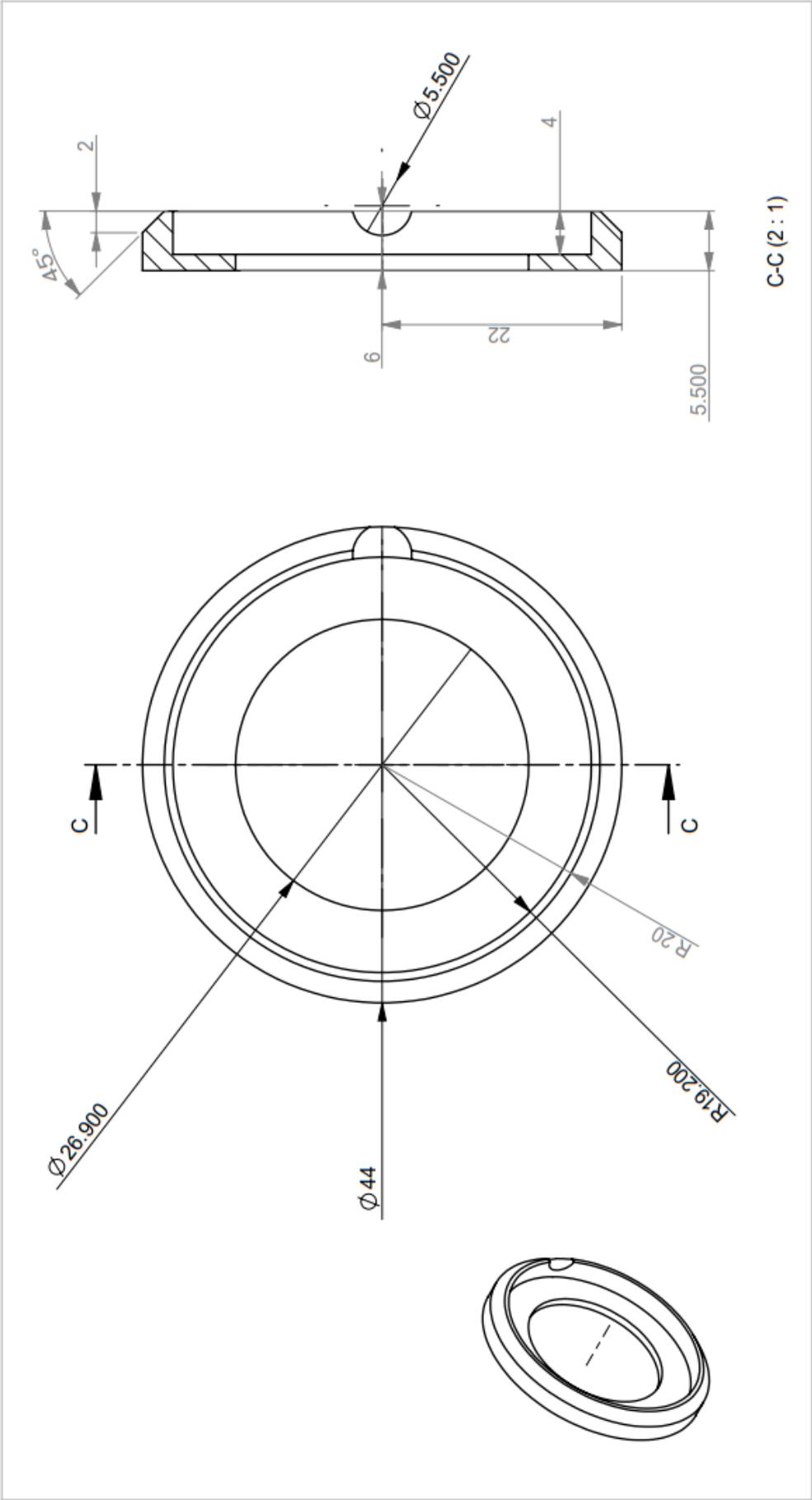


units	mm	scale	1:1	quantity	<qt></qt>	date	01/09/2023	remark	Back and Bottom view. The Electronics housing module is a completed part. It is recommended to 3D print this part before any other manufacturing.
material						mass	gr		
author	T.Anker (4703367)					group	Engineering 4 Forensics		
name	FMA_NP003_R002								
format	A3							drawing no.	2 of 2
									



 TU Delft Delft University of Technology	name FMA_P045_R003		material AISI 316A/316L Stainless Steel		units mm		scale 1:1		quantity 2		date 01/09/2023		remark Bayonet Lock	
	author T.A.Anker (4703367)		group Eng. 4 Forensics		format A4		mass gr		drawing no. 1 of 1					

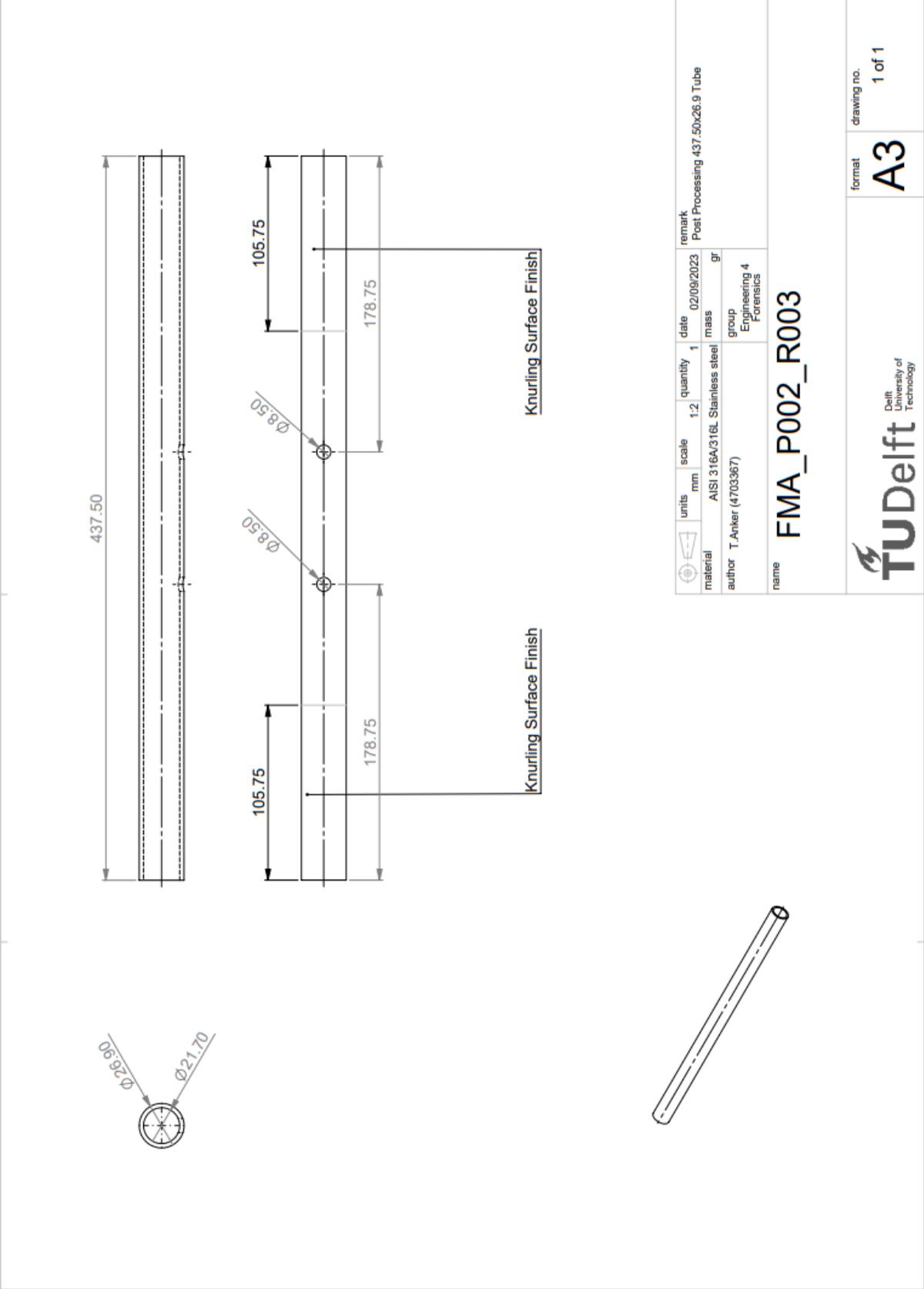
SOLIDWORKS Educational Product. For Instructional Use Only.



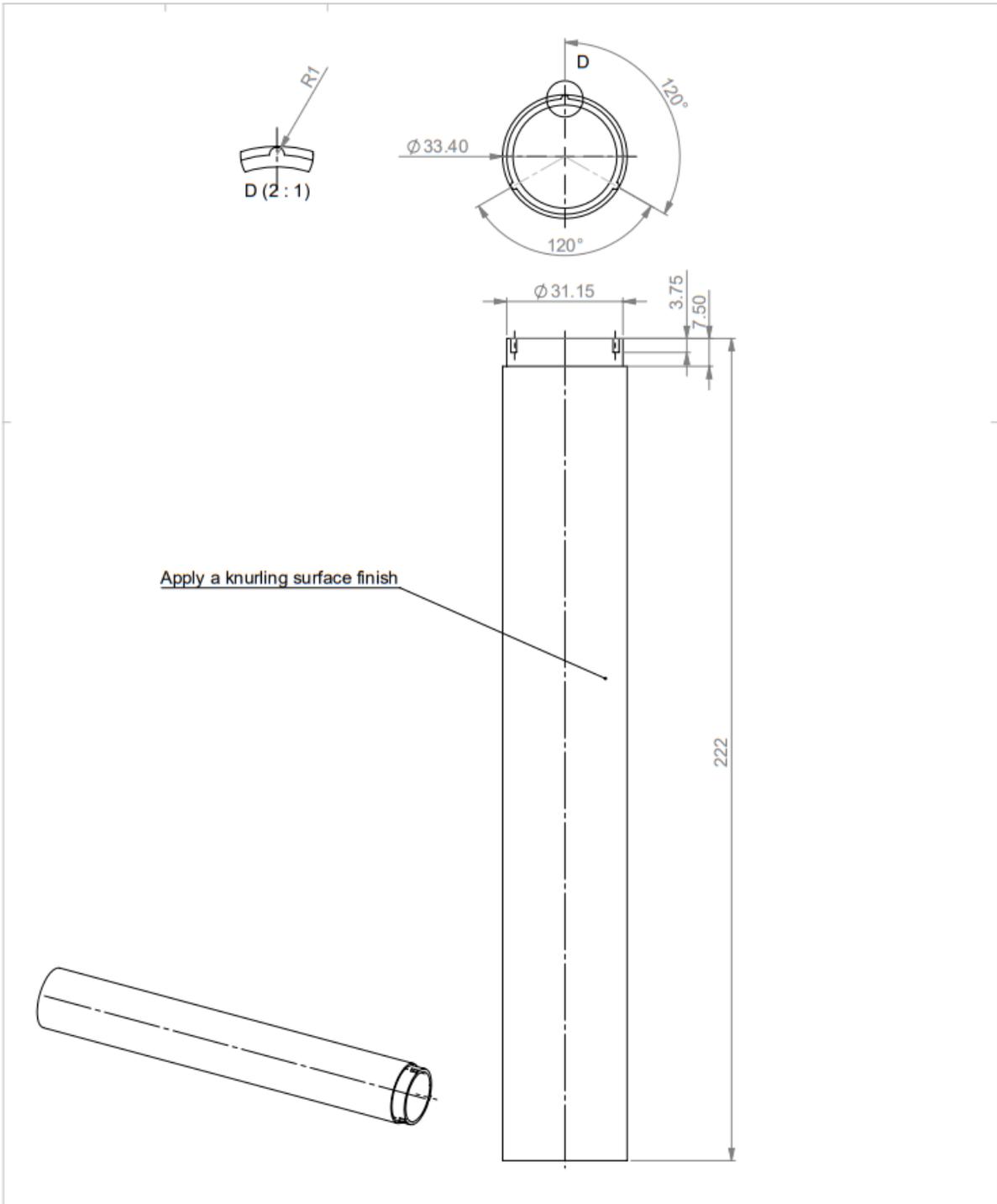
material author T.A.Anker (4703367)		units mm scale 2:1 quantity 2	date 02/09/2023 mass gr	remark Damper
name FMA_NP007_R001		group Eng. 4 Forensics format A4	drawing no. 1 of 1	



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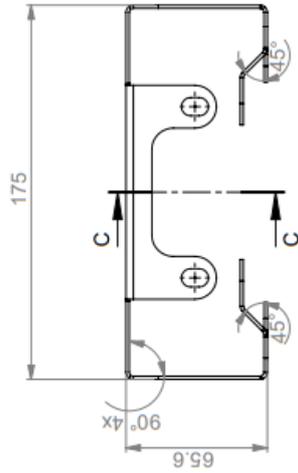
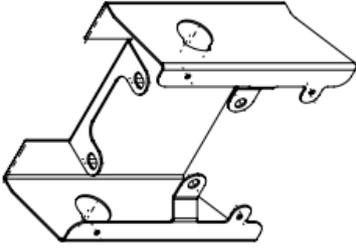


SOLIDWORKS Educational Product. For Instructional Use Only.

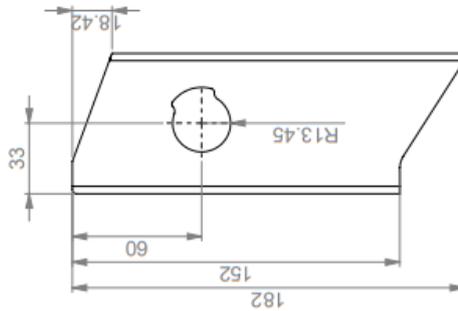
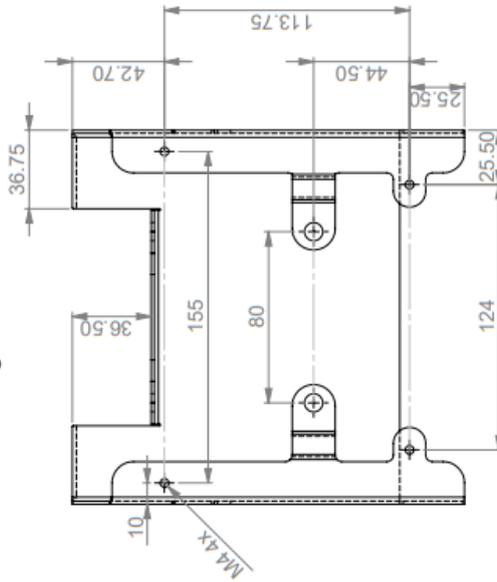
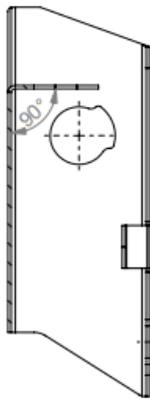


	units	mm	scale	1:2	quantity	2	date	02/09/2023	remark
material							mass	gr	Post Processing Tube 222x33.40 Apply knurling Finish on the outer surface
author	T.Anker (4703367)			group	Engineering 4 Forensics				
name	FMA_P014_R002								
	TU Delft			Delft University of Technology		format	A3		
						drawing no.	1 of 1		

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C-C



units	mm	scale	1:2	quantity	1	date	01/09/2023	remark	Upper Outer Housing
material	AIISI 316A/316L Stainless steel		mass	gr					
author	T.Anker (4703367)		group	Engineering 4 Forensics					

name **FMA_P023_R003**



format **A3**

drawing no. **1 of 1**

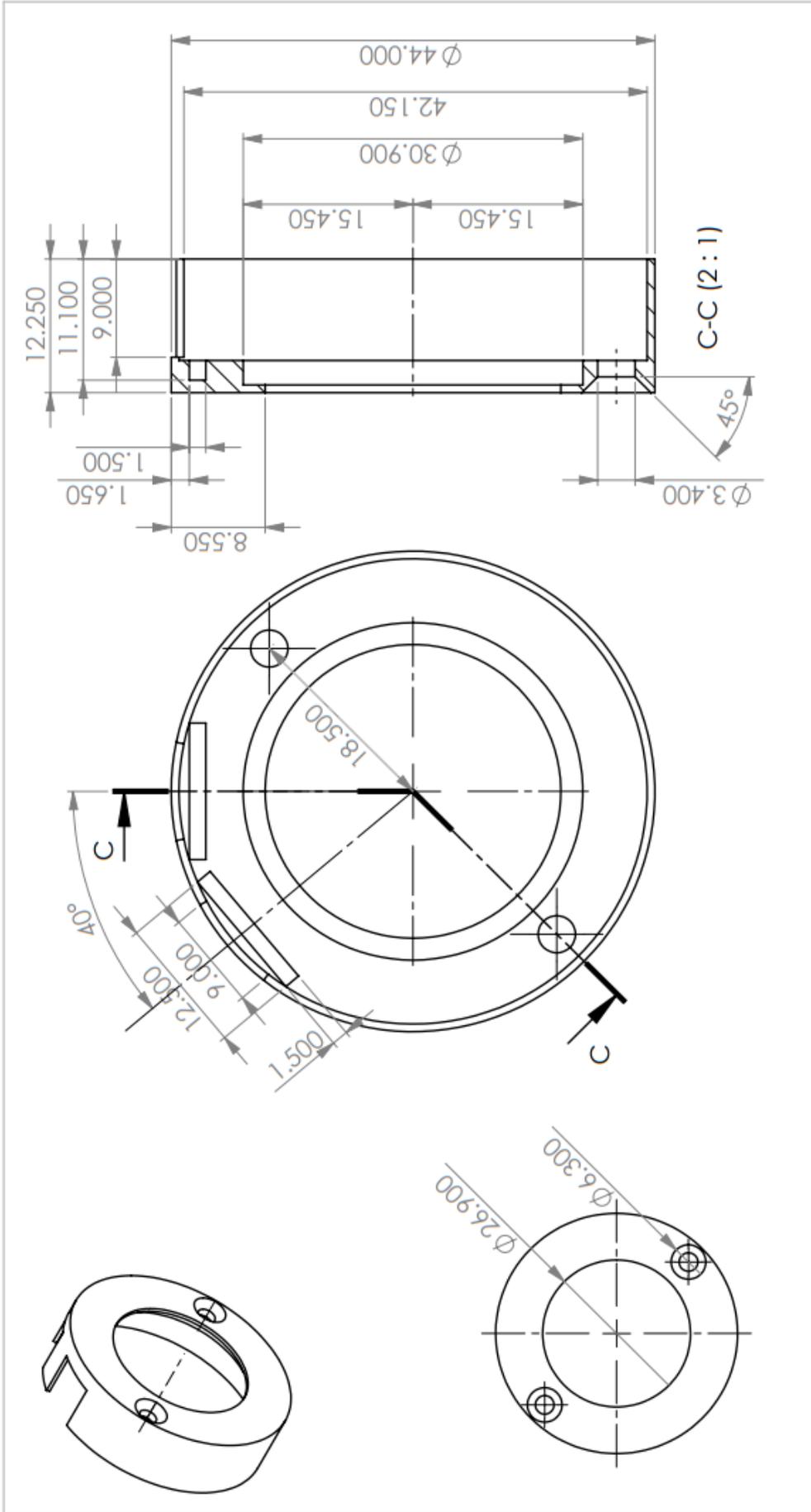
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	FMA_NP005_R001	Handlebar Button Housing	1
2	PushBtnAdjust	Mini Push Button	2
3	Flexible Square Button	3D-Printed Flexible Square Button	2
4	FMA_NP006_R001	Button Housing Lid	1
5	DIN 7991 - M3 x 8 --- 4.8N		2

material		units	mm	scale	1:1	quantity	2	date	01/09/2023	remark	Button Housing Assembly
author		T.Anker (4703367)	group	Eng. 4 Forensics	format	A4	mass	gr	drawing no.	1 of 1	

name
FMA_AS031_R001

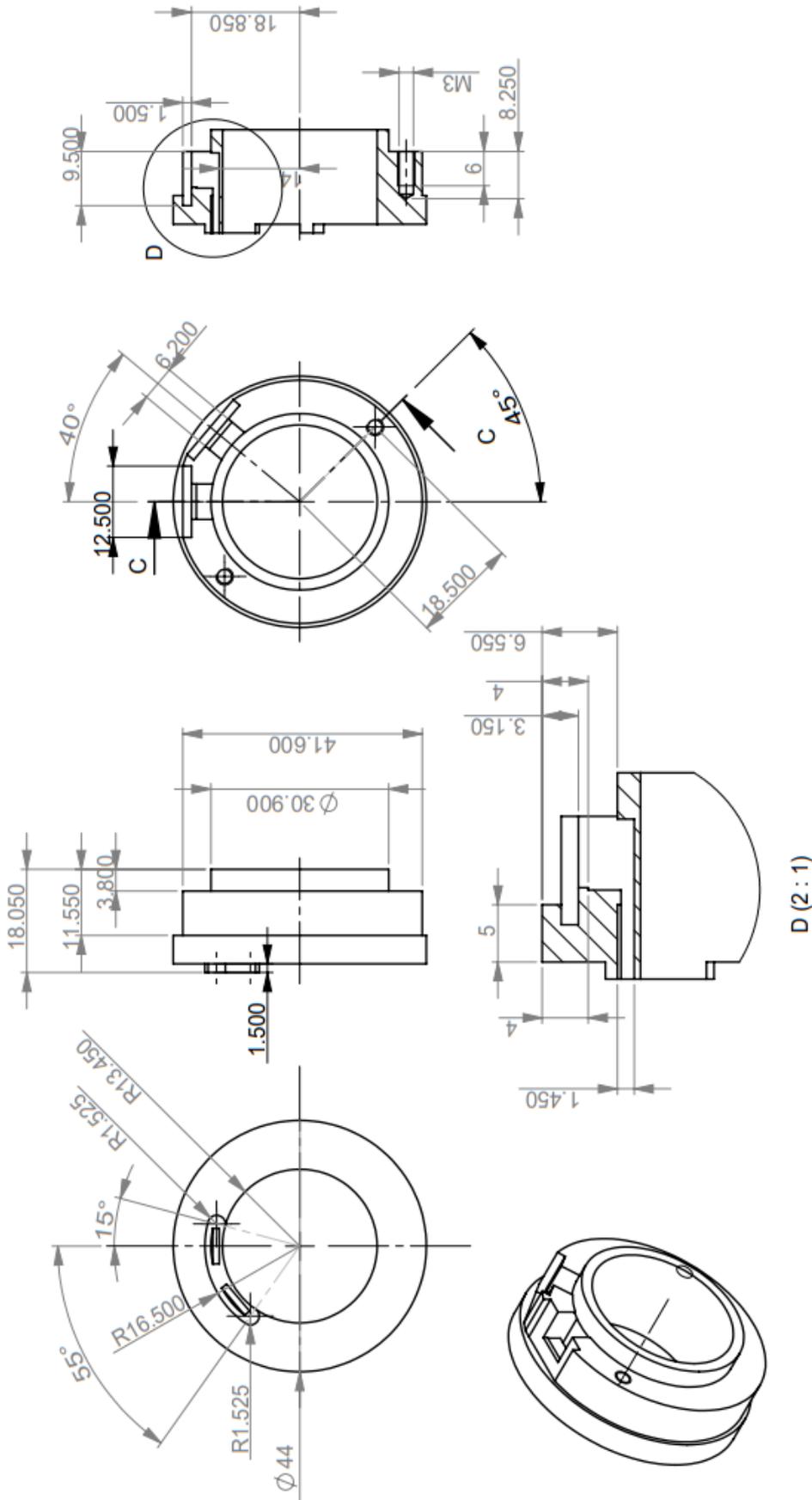
TU Delft
Delft University of Technology

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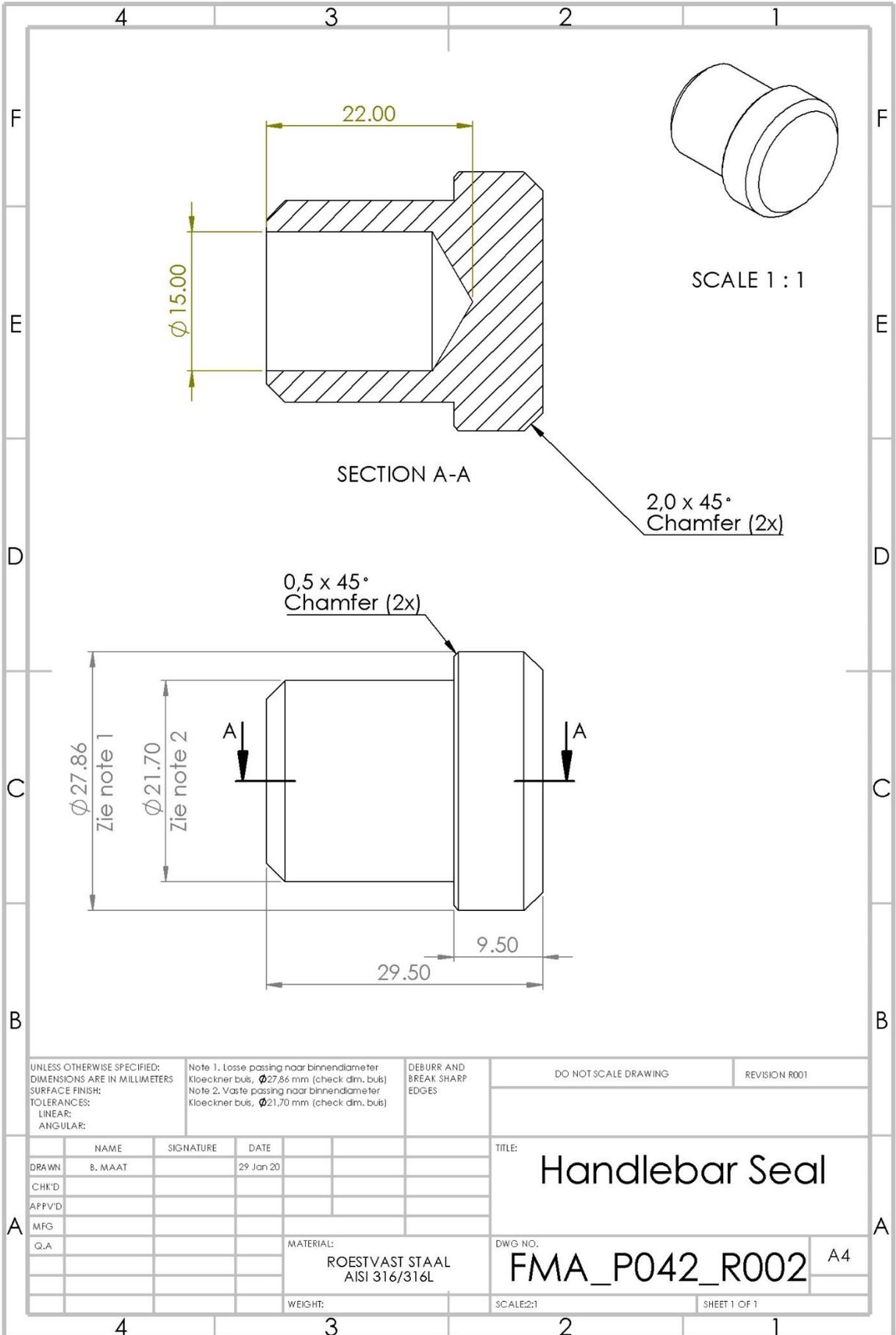
name		EMA_NP006_R001		remark		Button Housing Lid	
TU Delft		Delft University of Technology		date		31/08/2023	
author		T.A.Anker (4703367)		quantity		2	
material				scale		2:1	
units		mm		mass		gr	
group		Eng. 4 Forensics		format		A4	
drawing no.		1 of 1					

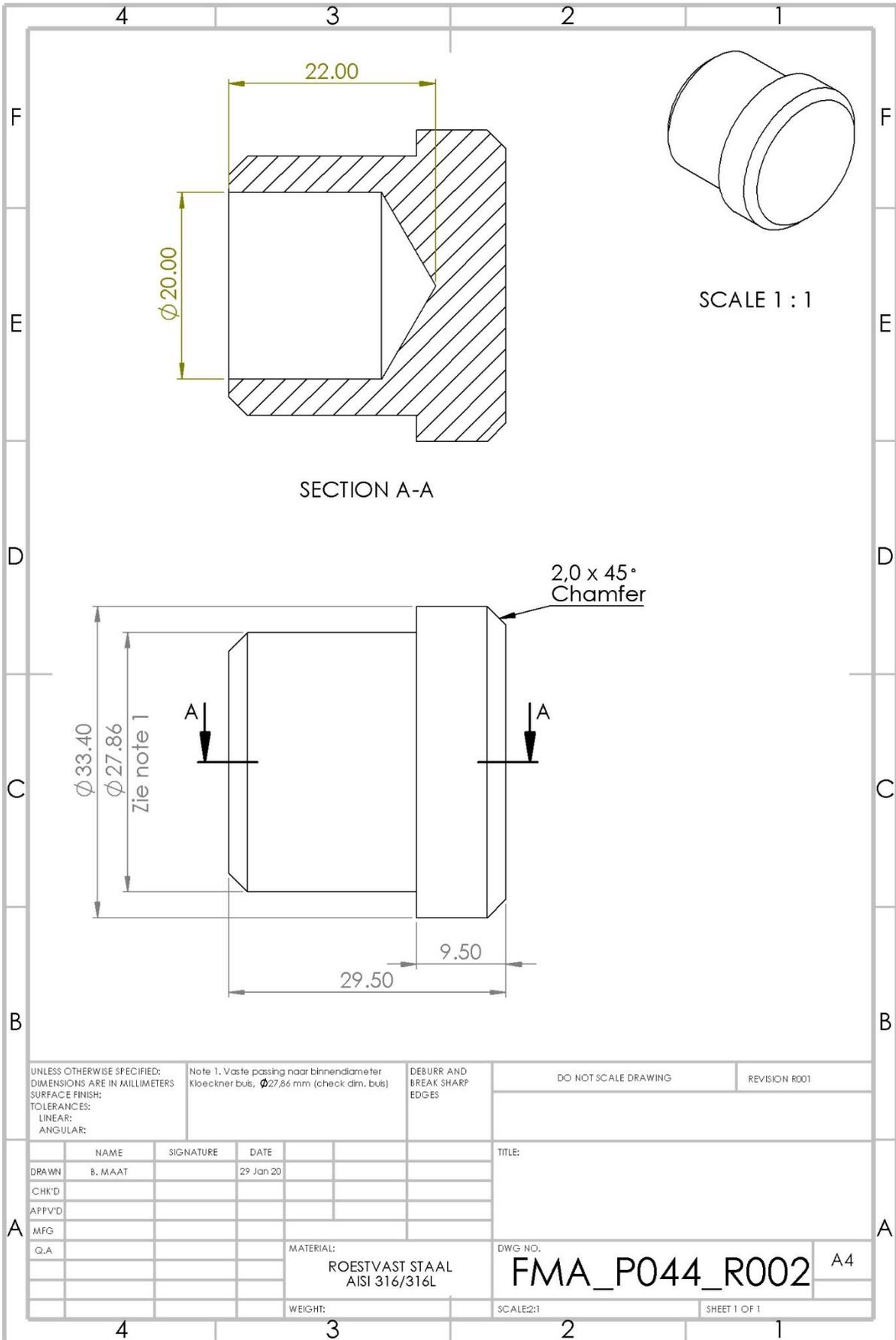
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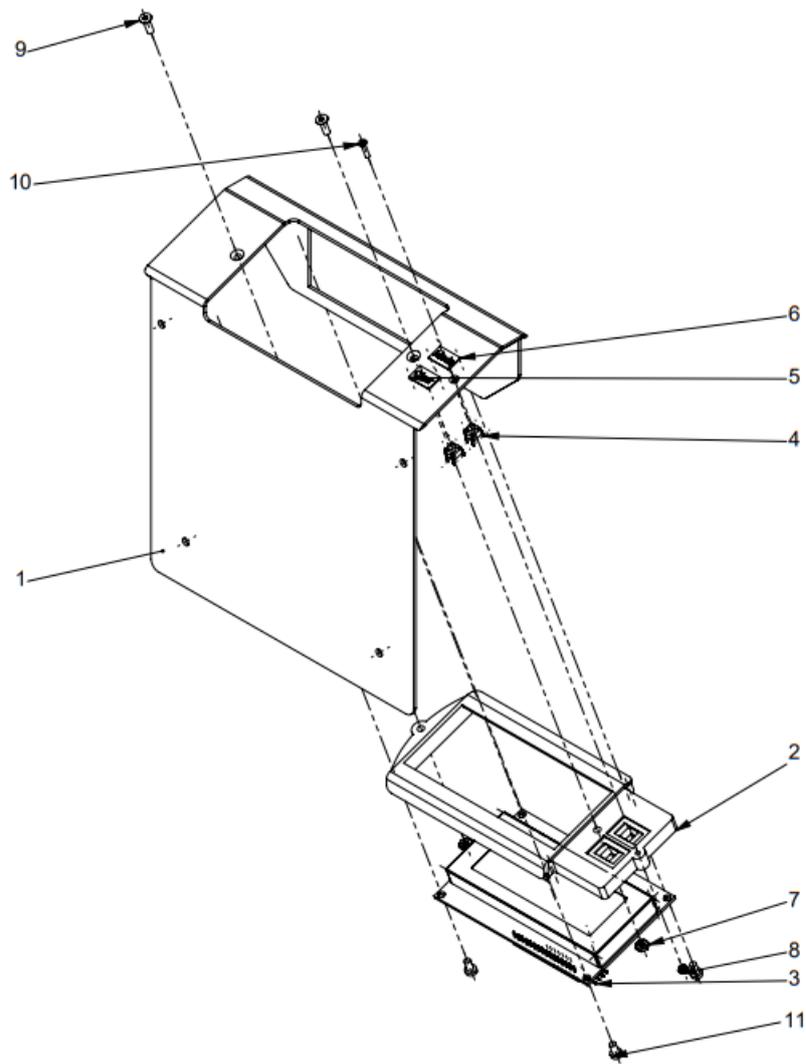
 Delft University of Technology		name FMA_NP005_R001		material author T.A.Anker (4703367)		units mm scale 1:1 quantity 2 date 02/09/2023		remark Handlebar Button Housing	
		group Eng. 4 Forensics		mass gr		format A4		drawing no. 1 of 1	

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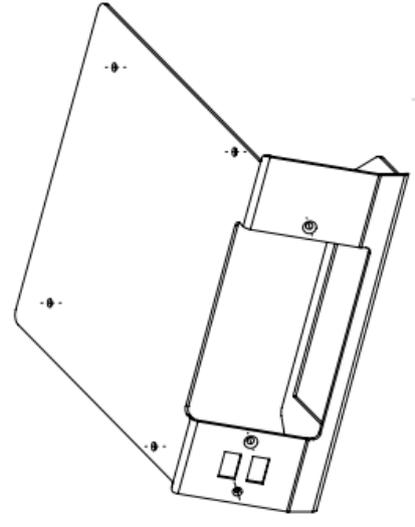
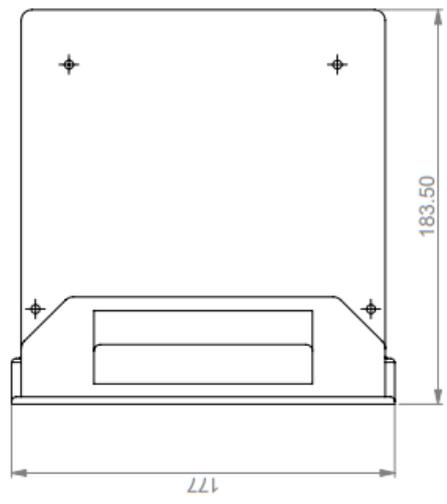
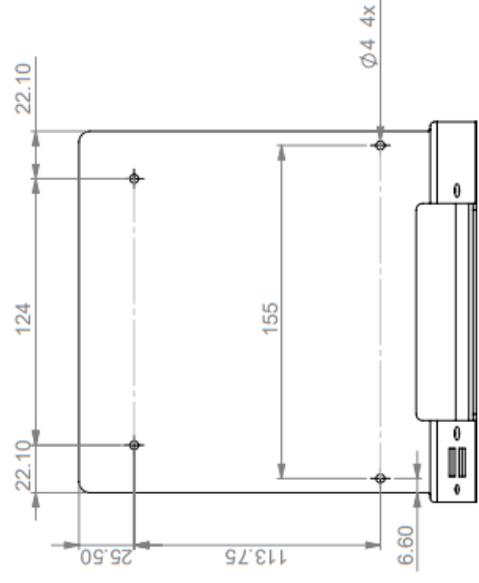
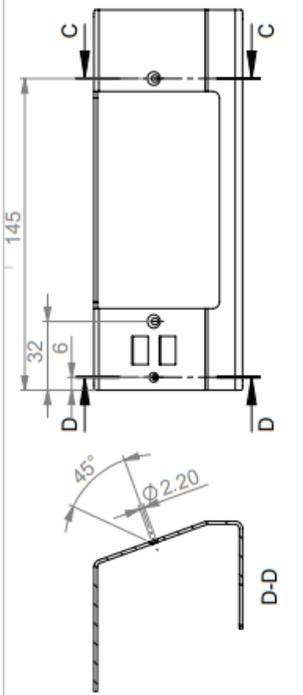
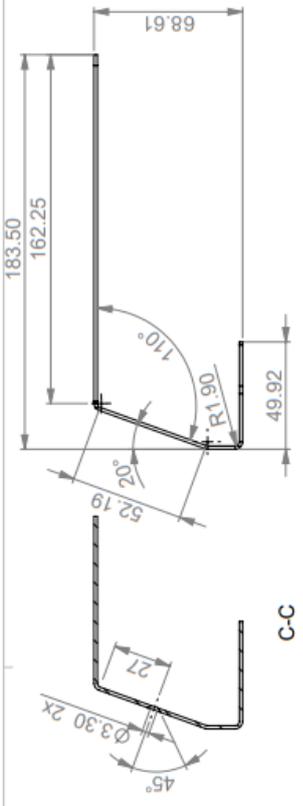
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:		Note 1. Vaste passing naar binnendiameter Kloekner bus, $\Phi 27.86$ mm (check dim. bus)		DEBURR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING		REVISION R001	
DRAWN		SIGNATURE		DATE		TITLE:			
B. MAAT				29 Jan 20					
CHK'D									
APPV'D									
MFG									
Q.A						MATERIAL:		DWG NO.	
						ROESTVAST STAAL AISI 316/316L		FMA_P044_R002	
						WEIGHT:		SCALE:2:1	
								SHEET 1 OF 1	



ITEM.	PART NUMBER	DESCRIPTION	QTY.
1	FMA_P024_R004	Upper Lid	1
2	FMA_NP002_R003	Intermediate LCD Connector	1
3	Lcd i2c.STEP	LCD Screen 20x4 w. I2C	1
4	PushBtn	Mini Pushbutton	2
5	3D button Clear	3D-Printed Flexible Clear Button	1
6	3D button Mode	Flexible 3D-Printed Mode Button	1
7	Hexagon Thin Nut ISO 4035 - M3 - N		2
8	Hexagon Thin Nut ISO 4035 - M2 - N		1
9	DIN 7991 - M3 x 10 --- 6.8N		2
10	DIN EN ISO 7046-1 - M2 x 10 - Z - 10N		1
11	DIN EN ISO 1207 - M3 x 6 - 6N		4

units	mm	scale	1:2	quantity	1	date	31/08/2023	remark	Upper Lid and LCD Screen Assembly
material		mass		group					
author	T.A.Anker (4703367)			group	Engineering 4 Forensics				
name FMA_NA041_R001									
							format	drawing no.	
							A3	1 of 1	

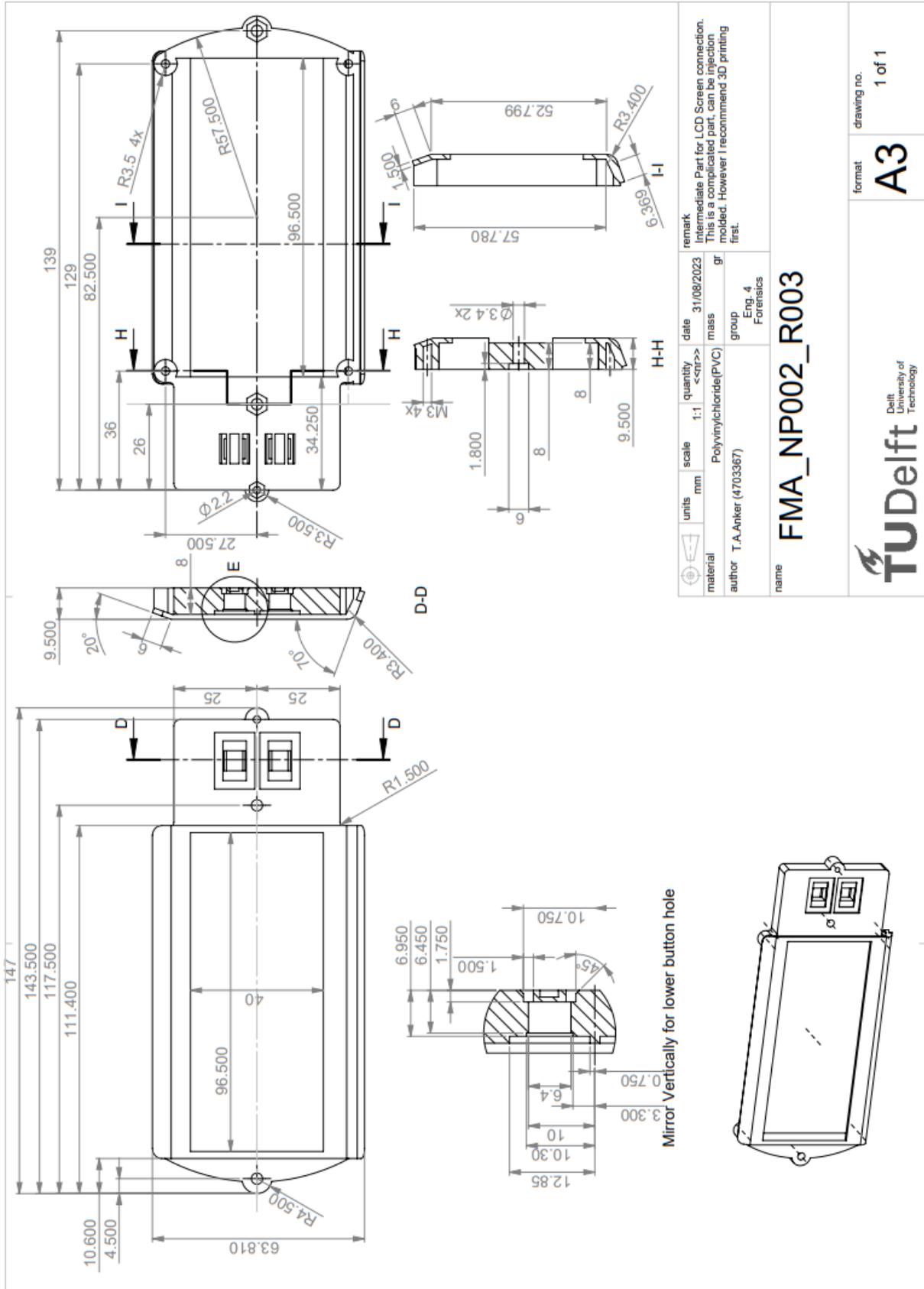
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units	mm	scale	1:2	quantity	1	date	31/08/2023	remark	Thickness 1.5 AISI 316 Stainless Steel Sheet
material	author		mass		group		gr		
T.A.Anker (4703367)		Eng. 4 Forensics		name					
FMA_P024_R004									

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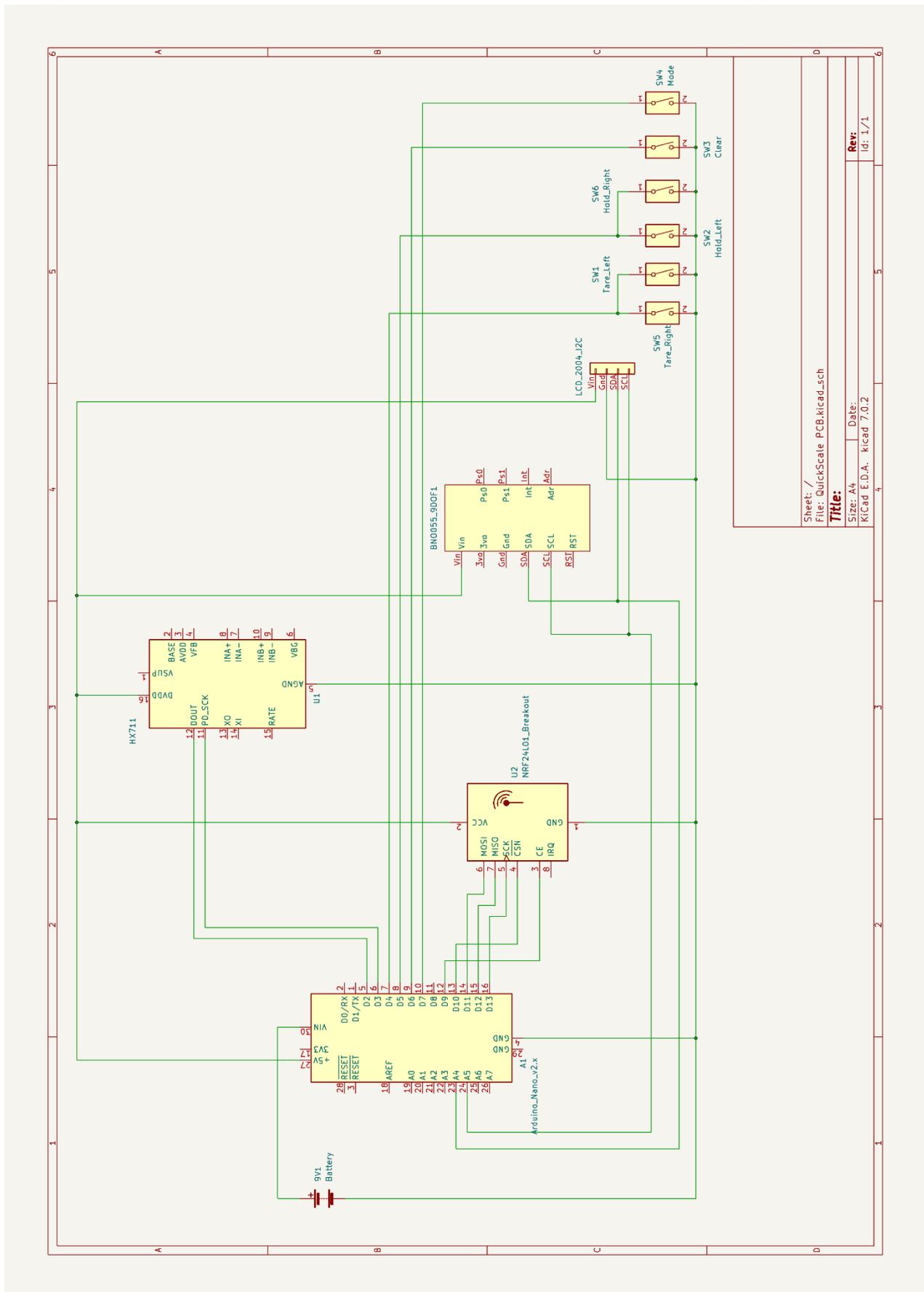
format **A3**
drawing no. **1 of 1**



Mirror Vertically for lower button hole

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Appendix G QuickScale 2.0 Electrical scheme and PCB Design:



Sheet: /
 File: QuickScale_PCB.kicad_sch
Title:
 Size: A4 Date:
 KiCad E.D.A. kicad 7.0.2
 Rev: id: 1/1

