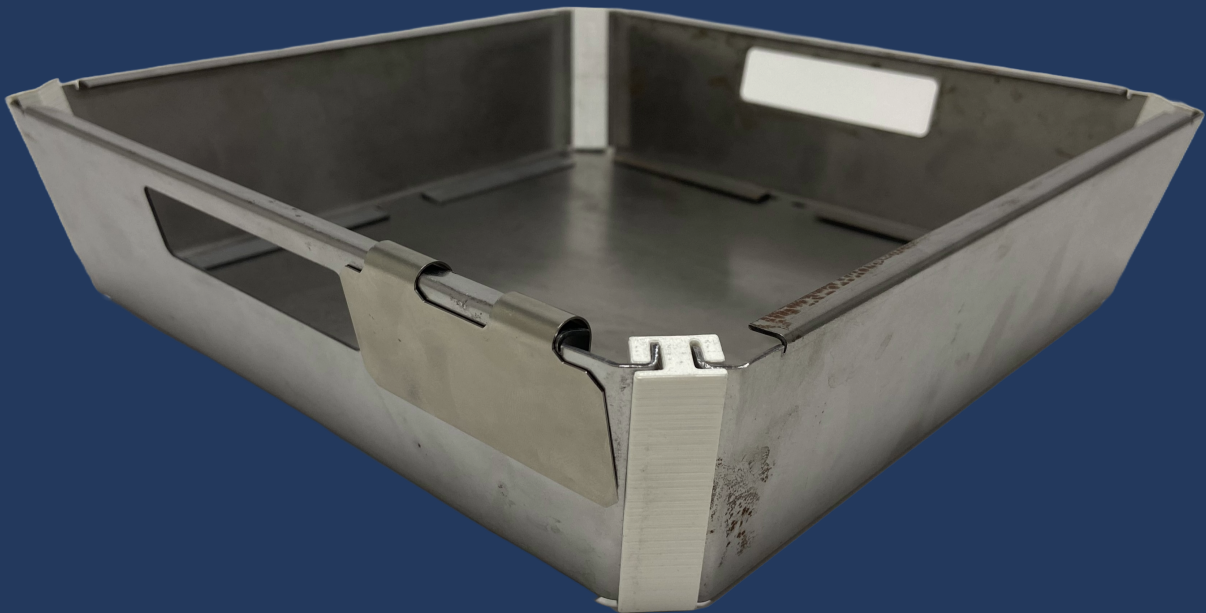


MSc thesis

Redesign of the instrument sets
for efficient storage and transport

Sagar Matai



Redesign of the instrument sets for efficient storage and transport

Thesis report

by

Sagar Matai

to obtain the degree of Master of Science
in BioMedical Engineering
at the Delft University of Technology
to be defended publicly on Friday December 15, 2023 at 10:00 AM.

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Preface

In front of you lies my thesis 'Redesign of the instrument sets for efficient storage and transport'. This thesis focuses on the design of an instrument set for efficient storage and transport. Before writing this thesis, I conducted a literature study into efficient methods for transporting instrument sets. This literature study is titled 'Literature research of methods to efficiently transport instrument sets' and the article I wrote can be found in Appendix A.

This thesis is the final part of my master's degree in BioMedical Engineering (BME) at the Faculty of Mechanical, Maritime, and Material Engineering (3mE) at the Delft University of Technology. After five years of studying, the end is now in sight. After failing my Statics and Mechanics of Materials exams in the first semester of my first year of my bachelor's degree in Mechanical Engineering and almost choosing to quit the study as I had to pass all other subjects for a positive BSA, I am proud that 5 years later I graduated for my Bachelor's degree in Mechanical Engineering and Master's degree in BioMedical Engineering. Sadly, this period in my life is coming to an end but it's time to take the next step.

There are several people I would like to thank specifically for their guidance through this project:

- Bart Van Straten, Niels van Straten and Tim Horeman for the opportunity to complete my MSc thesis at Van Straten Medical B.V..
- My daily supervisor Bart van Straten for the supervision, his feedback and availability despite his busy agenda and for sharing useful contacts.
- My university supervisor Tim Horeman for his expert and clear comments, justified criticism and valuable knowledge during this project. This has undoubtedly improved the quality of my work.
- All interviewees within Van Straten Medical B.V. such as logistics, repair and fixation and CSSD for their time, input and energy.
- All workshop employees at Van Straten Medical B.V. (fixation department) and TU Delft (IWS/IWM) for the development process of the prototypes.
- The sterilization department within Van Straten Medical B.V. for answering all my questions regarding cleaning, disinfection and sterilization and carrying out the tests of my prototypes.
- Harry Leeuw (DSMH at St. Antonius hospital in Utrecht) for his help in carrying out the tests.
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- Finally, my family and loved ones for their support during this graduation project, but certainly throughout my entire study period. Especially my parents for their unconditional love and support and my brothers for their encouragement and support. They always tell me to do what makes me happy and they always support me no matter what decision I make.

S.R. Matai
Delft, November 2023

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Nomenclature

3D	Three-Dimensional
3mE	Mechanical, Maritime, and Materials Engineering
AC-MH	Acceptance Criteria Must Haves
AC-SH	Acceptance Criteria Should Haves
AC-CH	Acceptance Criteria Could Haves
BME	BioMedical Engineering
CAD	Computer-Aided Design
CO ₂	Carbon dioxide
CSSD	Central Sterile Services Department
DIN	Deutsches Institut für Normung
DSMH	Sterile Medical Devices Expert
FDM	Fused Deposition Modeling
ISO	International Organization for Standardization
MSMH	Sterile Medical Devices Employee
PLA	Polylactic acid
PP	Polypropylene
R-MH	Requirement Must Haves
R-SH	Requirements Should Haves
R-CH	Requirements Could Haves
SS	Stainless Steel

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Part I

Scientific Article

Redesign of the instrument sets for efficient storage and transport

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Abstract—Introduction: Surgical instruments are stored, transported, cleaned, disinfected, and sterilized in instrument sets. These instrument sets have a predetermined fixed size, which means they cannot be stored or transported efficiently when empty or used efficiently for different types of instruments. This report presents the design of an instrument set that is adaptable in shape for efficient storage and transport. **Method:** Based on a questionnaire completed by various departments that come into contact with instrument sets, such as the CSSD, logistics and repair and fixation, the context, the requirements and wishes of van Straten Medical. B.V. and CSA Services B.V., 15 requirements and criteria have been established. Five concepts were developed based on a morphological chart, after which a Harris profile showed that stacki is the best concept. **Result:** Stacki was further developed and designed using the 3D CAD software SolidWorks. 3 prototypes were created using water/laser cutting and 3D printing. To evaluate the prototypes and identify critical points, 3 tests were carried out regarding completion, ease of use, and strength. These tests have shown that the prototype is promising, but that the corner needs to be redesigned to make the prototype even better. **Discussion:** Of the requirements, 7 requirements have been met, and 6 requirements were not tested. For further research, these remaining requirements can be tested by applying the points of improvement. **Conclusion:** A prototype with perforations made from the final materials could be made and this new prototype could be tested for cleaning, disinfection, and sterilization. Finally, the idea with two half sides instead of one long side can also be further developed and tested. Overall, the instrument set is promising for further development, with this design as a starting point.

Keywords—(Surgical) instruments, instrument set, efficient storage and transport, adaptable in shape, CSSD

I. INTRODUCTION

A. Context

With a growing need for healthcare, healthcare needs to innovate to reduce its carbon footprint. Healthcare in the Netherlands is responsible for 7% of the total CO₂ emissions in the Netherlands [1]. The goal of the Netherlands is to reduce CO₂ emissions by 55% in 2030 [1]. Every sector must contribute its share to achieve this goal, including healthcare. Reducing transport movements is one of the possibilities to reduce costs and CO₂ emissions within the healthcare sector.

Nowadays, surgical instruments are transported, stored, cleaned, disinfected, and sterilized in instrument sets, shown in figure 1. These instrument sets are used for transport of surgical instrument sets to and from hospitals and/or the central sterile services department (CSSD).



Figure 1. Example of a standardized 1/1 DIN instrument set with a flat bottom, perforated sides, and drop handles [2]

At the CSSD, these instrument sets are used to clean, disinfect, and sterilize the surgical instruments in an autoclave. Finally, these instrument sets are also used for the storage of surgical instruments within both hospitals and the CSSD. These instrument sets are thus vital for surgical instruments. Figure 2 shows a flowchart of the instrument sets, showing the steps in the workflow from cleaning to use during surgery.



Figure 2. Showing the steps in the workflow from cleaning to use during surgery

Nowadays, many different instrument sets for surgical instruments are already available. These all have different shapes, designs, or sizes. The shape and design can be very different, but the sizes are standardized. Within this standardization, there are also various options, such as the ISO or DIN sizes. The most common are those of the Deutsches Institut für Normung: DIN [3]:

- 1/1 DIN: 480x250 millimeters with different heights starting from 30 millimeters
- 1/2 DIN: 240x250 millimeters with different heights with a maximum height of 100 millimeters
- 1/4 DIN: 120x250 millimeters with different heights with a maximum height of 100 millimeters
- 3/4 DIN: 360x250 millimeters with different heights with a maximum height of 100 millimeters

However, these instrument sets have a predetermined fixed size. If these instrument sets are transported or stored empty, empty space is created that is not used during storage and transport. A consequence of this is that air is stored or transported. To solve this problem, an instrument set must be designed for efficient storage and transport. With this new design of the instrument sets, twice as many instrument sets can be stored in the same space as now. In addition, more instrument sets can also be transported. In this way, the costs and CO₂ emissions of these instrument sets can be reduced.

B. Problem definition

The medical market faces the problem that instrument sets in which (surgical) instruments are stored, transported, cleaned, disinfected, and sterilized nowadays have a predetermined fixed size. This means that one fixed space cannot be optimized for the number of (surgical) instruments that differ per (surgical) procedure. This creates excessive volumes in terms of empty space when these instrument sets are stored and transported empty.

C. Objective

To reduce the storage & transport volume, a redesign of instrument sets such as stainless steel mesh and wire baskets, should be reconsidered taking volume reductions into account, so that these instrument sets can be stored and transported in a more efficient way.

D. The company

Van Straten Medical B.V. is a Dutch company founded in 1975 and is currently supplier and manufacturer of surgical instruments and disposables [4]. Van Straten Medical B.V. builds on a sustainable future based on a vision of circular principles. Over the years, Van Straten Medical B.V. focused on making healthcare sustainable by improving the lifespan of the instruments. In addition, Van Straten Medical B.V. is also working to make healthcare more environmentally friendly. Medical waste is recycled and from this waste, simple but smart new products are made. In addition, Van Straten Medical B.V. is also working on repairing broken instruments, so that they get a second life.

In short, the activities of Van Straten Medical B.V. are the production, supply, maintenance, and repair of high-quality instruments and disposables [4]. The goal of Van Straten Medical B.V. is to make healthcare more sustainable based on a vision of circularity!

E. Thesis outline

The methods are explained in the next chapter. First, the requirements are discussed, after which the morphological chart is shown, from which 5 concepts are generated. These 5 concepts are then described with their advantages and disadvantages and are visualized using figures. Subsequently, a concept was chosen based on a Harris profile, after which this winning concept was further developed into a final design, which was eventually manufactured and tested. Then the tests are discussed to validate this prototype and to identify any critical points. The chapter that follows describes the results. First, the prototype is discussed, after which the results of the different tests are discussed. The next chapter discusses the results. First, there is a discussion about whether the requirements have been met, after which the design and manufacturing methods used are discussed. After that, the tests and the associated results are discussed. Finally, recommendations for further research are made. A conclusion is drawn in the last chapter.

II. METHODS

A. Requirements

To gain a better insight into the current design of the instrument sets, a questionnaire was created. This questionnaire relates to the advantages and disadvantages, the requirements and wishes, and the shortcomings of the current instrument sets. This questionnaire, see appendix B (Dutch) and C (English) has been completed by various departments within Van Straten Medical B.V., such as the CSSD, logistics, repair, and fixation. This questionnaire shows that the main problem of these instrument sets is that they cannot be stacked properly. In addition, the handles are a problem. They break down too quickly or instruments get in the way. Finally, this questionnaire shows that there is no good way to attach the nameplates to the instrument set. See appendix D for all results of this questionnaire.

Based on the context, Van Straten Medical B.V. & CSA Services B.V. wishes and previous designs of the instrument set a set of requirements and criteria is specified. The MoSCoW method [5] is used to determine this set of requirements. The MoSCoW method consists of four categories of initiatives: must have, should have, could have, and will not have (this time). The SMART method has formulated the requirements and criteria [6]. Based on the SMART method, Specific, Measurable, Achievable, Realistic, and Time-related requirements and criteria have been formulated. In this section these requirements and the associated criteria categorized in three categories: must have, should have, and could have are listed in table 1 and appendix E. In appendix F, a table can be found in which all these requirements and criteria are explained in more detail.

Table 1. Requirements and criteria for the instrument sets

Requirements	Criteria
Must haves	Must haves
R-MH1: it must be made of Stainless Steel 304 or 316.	AC-MH1: it must be made of Stainless Steel 304.
R-MH2: it must be made with the following dimensions 480x250x60 mm (1/1 DIN).	AC-MH2: it must be possible to apply the design to different DIN sizes (e.g. 1/2 DIN).
R-MH3: it must be able to undergo steam sterilization.	AC-MH3: it must withstand temperatures of at least 134 degrees Celsius for at least 3 minutes.
R-MH4: it must be able to undergo alkaline and/or enzymatic cleaning.	AC-MH4: it must withstand disinfectant.
R-MH5: it must be possible to pack the instrument sets without tearing the wrapping paper.	AC-MH5: it must be a rounded whole without sharp edges and protruding parts.
Should haves	Should haves
R-SH1: it should come out drip-dry out of the disinfection machine.	AC-SH1: it should be permeable to water.
R-SH2: it should not be heavier than 8.5 kg when filled.	AC-SH2: the instrument set should be the same weight as current existing empty instrument sets with a 0.5 kg margin.
R-SH3: it should have a strong construction and be robust, in a way that the instrument set will not be damaged when filled with instruments.	AC-SH3: it should not bend, break or fall apart.
R-SH4: it should be possible to assemble and disassemble the instrument set without explanation.	AC-SH4: the assembly of the parts should take two minutes.
R-SH5: it should be possible that the maximum cost price is 30 euros.	AC-SH5: the costs should be as low as possible, where the material costs are a maximum of 10 euros and the manufacturing costs are a maximum of 20 euros.
Could haves	Could haves
R-CH1: it could be possible to transport the empty instrument sets efficiently.	AC-CH1: it could be possible to transport 4 empty instrument sets instead of 3 empty instrument sets nowadays.
R-CH2: it could be possible to stack the instrument sets (empty and filled).	AC-CH2: it could be possible to stack 4 instrument sets empty and filled.
R-CH3: it could be possible to adjust the instrument set in the x or y direction.	AC-CH3: it could be possible to adjust the instrument set for different size instruments.
R-CH4: it could be possible to attach nameplates to the instrument sets.	AC-CH4: it could be possible to attach the nameplates to the instrument sets using an external part.
R-CH5: it could be possible to lift the instrument set using drop handles.	AC-CH5: it could be possible to lift the instrument set using drop handles and with a lid on it.

B. Concept

To generate concepts, a morphological chart with 6 functions, shown in figure 3 and appendix G, has been made. The 6 functions are: permeable to water, efficient transport (when empty), stackable, size reduction, nameplates, and handles. From this morphological chart, 5 concepts have been worked out, which are further explained and elaborated below. The 5 concepts, see the 5 colored lines in figure 3, are based on efficient transport, easiest stacking, fastest shape adjustment, easiest realization and as many of the same components.

Function	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5
Permeable to water	Hexagonal	Circular	Square	Other shape	
Efficient transport (when empty)	Click and snap mechanism	Special bottom frame design	Leaf spring	Complete disassembly	Foldable by hinge
Stackable	Special bottom frame design	Hopper-locking mechanism	Silicone corner piteong	Stack mechanism	Wetelo
Size reduction			Sliding mechanism	Break lines	Hinge
Nameplates	Extendable nameplate	Ring	Clip	Magnet	Pin
Handles	Outside	Gap	Standard	Handle	Rotatable

Figure 3. Morphological chart with 5 colored lines for the 5 different concepts

1) Concept generation:

FOLDI: The first concept, foldi, shown in figure 4 is an instrument set that consists of several parts that are connected to each other using hinges. It is the red line in the morphological chart, shown in figure 3 and is based on transporting the instrument sets as efficiently as possible.

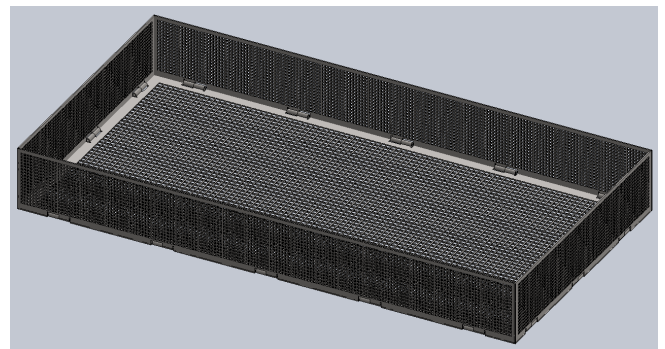


Figure 4. SolidWorks model of foldi in a 1/1 DIN format

Due to this hinge mechanism shown in figure 5, foldi is also foldable, shown in figure 6, which is useful concerning efficient transport when these instrument sets are transported empty. However, foldi cannot be adjusted in size.

Because it consists of several parts, the parts are easily replaceable. More time is now needed to assemble foldi. In addition, foldi is stackable using silicone corner pieces. A disadvantage is that extra parts are required for stacking foldi and that these extra parts can get lost. An advantage is that no additional mechanism in the design is needed on the instrument set to stack foldi.

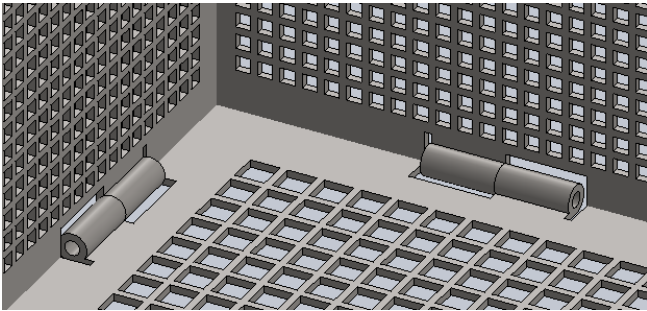


Figure 5. SolidWorks model of the hinge mechanism of foldi

The nameplates can be attached with a ring. This is also commonly used today. An advantage is that this works easily. A disadvantage is that it sticks out. The handles of foldi are the standard handles. The advantage is that most users are familiar with these handles and are used to them. A disadvantage, according to the questionnaire, is that instruments can come in between, so a solution must be found for this. Finally, foldi is permeable to water through square holes.

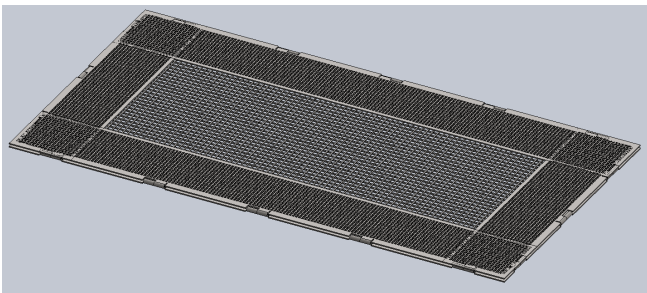


Figure 6. SolidWorks model of foldi when folded

STACKI: The second concept, stacki, shown in figure 7, is an instrument set that has a special design of the bottom. It is the blue line in the morphological chart, shown in figure 3 and is based on stacking the instrument sets as easily as possible. Due to this special bottom frame design, stacki is easy to transport efficiently when these instrument sets are empty. In addition, stacki is also easier to stack, as shown in figure 8. However, stacki cannot be adjusted in size. Because the bottom has a special design, the bottom of such an instrument set fits into the top of another instrument set, shown in figure 8. The advantage is that stacki consists of 1 part. As a result, no time is needed to assemble stacki. This saves costs and time. The nameplates can be attached to stacki using a clip around the raised edge. This mechanism works well and is easy to use. A gap has been made for the handles. Finally, stacki is water-permeable through hexagonal holes.

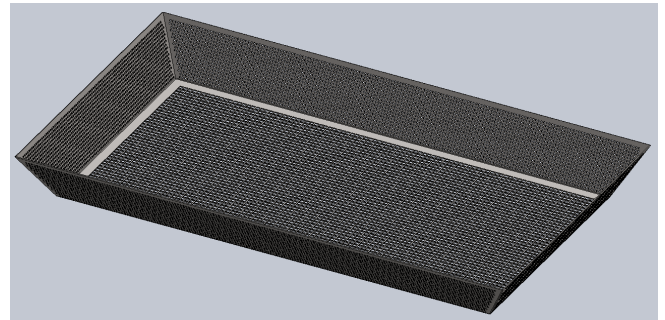


Figure 7. SolidWorks model of stacki in a 1/1 DIN format

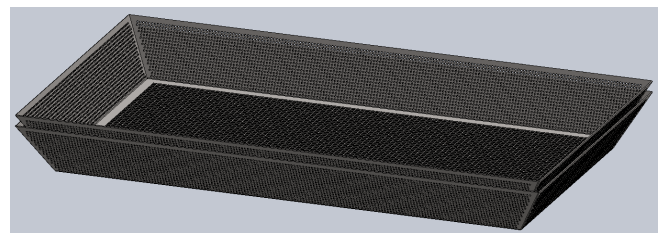


Figure 8. SolidWorks model of stacki when stacked

CLICKI: The third concept, clicki, shown in figure 9, is an instrument set that consists of several parts and is attached to each other using a click mechanism. It is the green line in the morphological chart, shown in figure 3 and is based on adjusting the instrument set shape as quickly as possible.

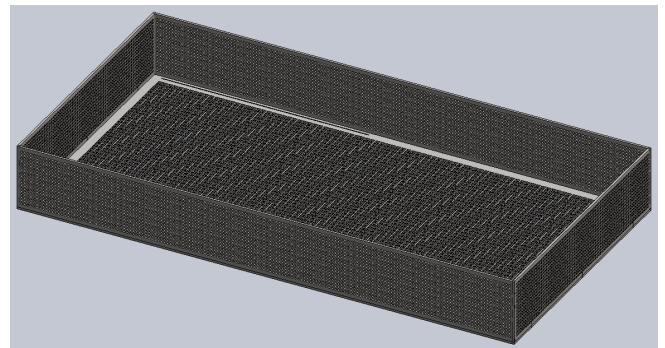


Figure 9. SolidWorks model of clicki in a 1/1 DIN format

This click mechanism ensures that clicki is efficient for transport when transported empty. However, the parts have to be clicked in and out each time. This will take additional time. It also takes extra time to assemble it after empty transport. Because clicki consists of several parts, the parts are easily replaceable. A special stacking mechanism is used, making these instrument sets stackable. The bottom has a special edge that fits into the top of an empty instrument set. Clicki is adjustable in shape using a sliding mechanism, shown in figure 10. This way it can be used efficiently for different types of instruments. Due to the sliding mechanism, clicki can be used as 1/1 DIN, shown in figure 9, but also as 1/2 DIN, shown in figure 11. Extendable nameplates are used. This is easy because no additional part is required.

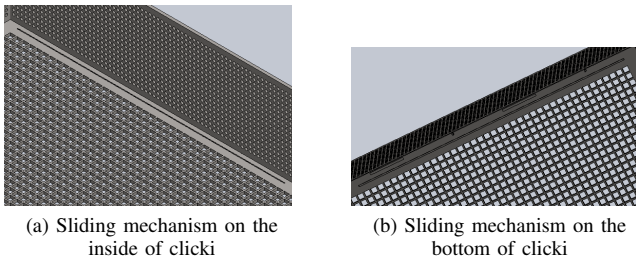


Figure 10. SolidWorks model of the sliding mechanism of clicki

The handles can be found on the outside. A disadvantage is that these handles protrude on the outside. An advantage is that no instruments can get between the handles. Finally, clicki is permeable to water through round holes.

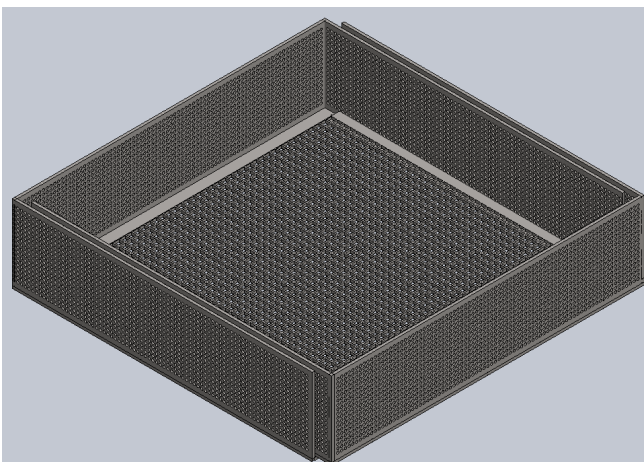


Figure 11. SolidWorks model of clicki in a 1/2 DIN format

LEAFI: The fourth concept, leafi, shown in figure 12 is an instrument set that consists of several parts and is attached to each other using a leaf spring. It is the gray line in the morphological chart, shown in figure 3 and is based on realizing the instrument sets as easily as possible.

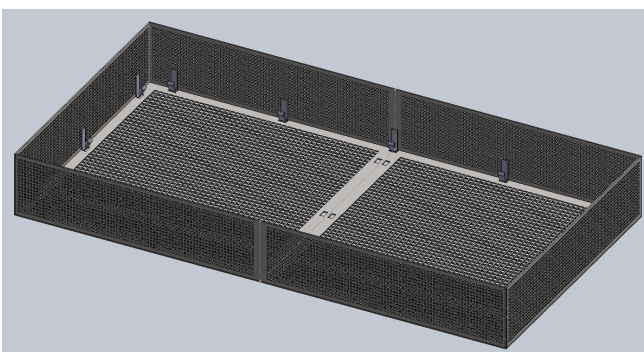


Figure 12. SolidWorks model of leafi in a 1/1 DIN format

The leaf spring ensures that these instrument sets are efficient for transport when transported empty.

However, the parts have to be clicked in and out each time. This will take additional time. It also takes extra time to assemble it after empty transport. Because leafi consists of several parts, the parts are easily replaceable. A stacking mechanism is used, making leafi sets stackable. The stacking mechanism consists of parts that project upwards, making it stackable. Leafi is adjustable in shape using break lines. By folding these break lines 3 times, the sides and bottom can be adjusted in shape. This way it can be used efficiently for different types of instruments. Due to the break lines, leafi can be used as 1/1 DIN, shown in figure 12, but also as 1/2 DIN, shown in figure 13. The name plates can be attached to leafi using a pin. The handles can be found on the outside. These handles are different compared to the handles of the other concepts. A disadvantage is that these handles protrude on the outside. An advantage is that no instruments can get between the handles. Leafi is permeable to water through round holes.

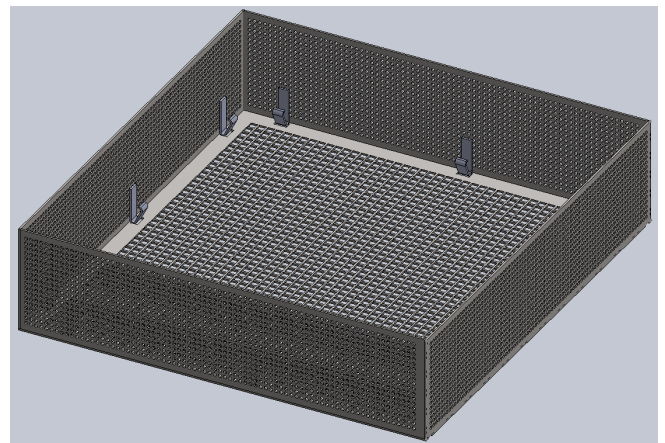


Figure 13. SolidWorks model of leafi in a 1/2 DIN format

HINGI: The fifth concept, hingi, shown in figure 14 is an instrument set that is adaptable in shape using a hinge mechanism. It is the black line in the morphological chart, shown in figure 3 and is based on making the instrument sets from as many of the same components as possible.

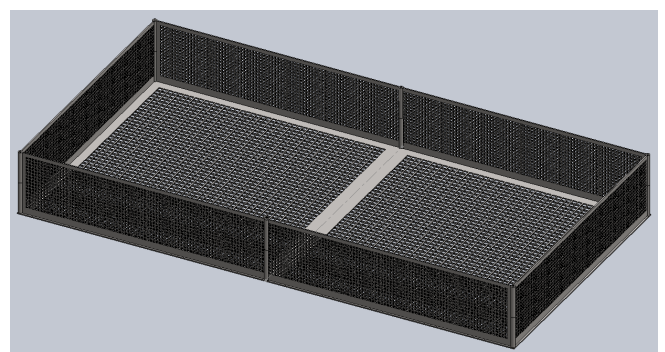


Figure 14. SolidWorks model of hingi in a 1/1 DIN format

This way it can be used efficiently for different types of instruments. This is possible through the following mechanism:

there is a width line in the middle and by folding this width line 3 times, the bottom can be adjusted in shape. An advantage is that hingi can be adjusted to the length and width of instruments in this way. Hingi is made in such a way that it is easy to transport efficiently when empty. Due to the break lines and the hinge mechanism, shown in figure 15, hingi can be used as 1/1 DIN, shown in figure 14, but also as 1/2 DIN, shown in figure 16.

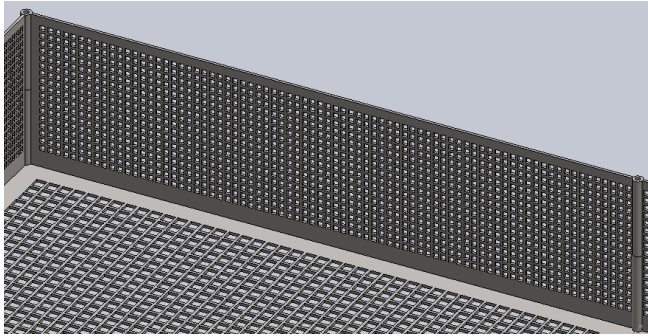


Figure 15. SolidWorks model of the hinge mechanism of hingi

Hingi is stackable using Velcro. Hingi is easy to disassemble and assemble. This way it can be completely disassembled if it is transported empty. Because hingi consists of several parts, the parts are easily replaceable. The nameplates can be attached to hingi using magnets. The handles of hingi are rotatable. These rotatable handles are almost the same as the standard handles that are commonly used today. Finally, hingi is permeable to water through square holes.

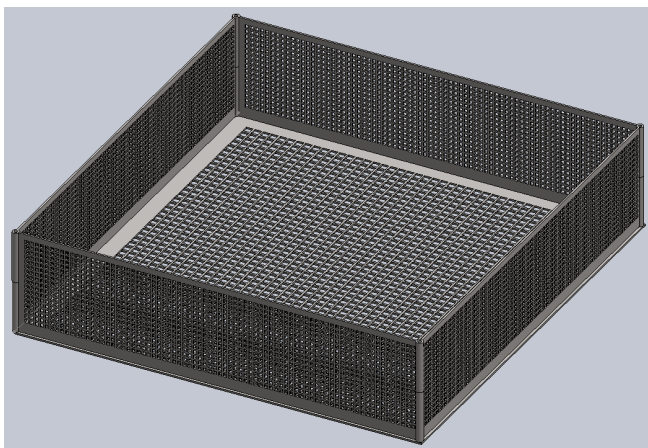
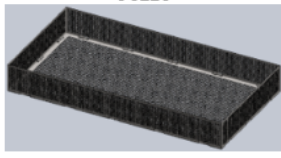
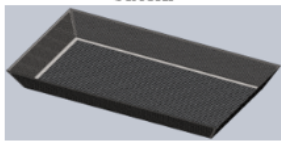
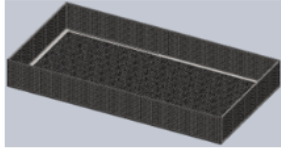
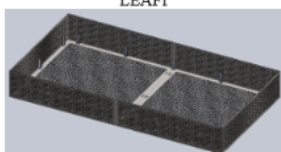
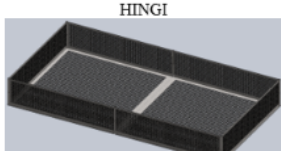


Figure 16. SolidWorks model of hingi in a 1/2 DIN format

2) Concept selection:

To select the final concept, a Harris profile, shown in table III and appendix I, was used to choose the best solution. The Harris profile is a graphic representation of the strengths and weaknesses of the final concepts concerning predefined design requirements and criteria. The requirements/acceptance criteria set out in table 1 are used as criteria against which the concept is measured. The first column contains these key criteria for the assessment. The following columns include the 5 concepts with the scores for each of the individual criteria.

Table II. The advantages and disadvantages of the different concepts

	Advantages	Disadvantages
 <p>FOLDI</p>	<ul style="list-style-type: none"> + Parts are easily replaceable + Foldable through a hinge mechanism + No additional stack mechanism in design + Nameplates easily attached with a ring + Standard handles 	<ul style="list-style-type: none"> - More time is needed to assemble - Not possible to adjust the size - Extra parts required to stack - Nameplates stick out - Instruments can come between the handles
 <p>STACKI</p>	<ul style="list-style-type: none"> + Easy to transport and store when empty + Easy to stack + Consist of one part + No time is needed to assemble. This saves costs and time + Easy nameplates and handles 	<ul style="list-style-type: none"> - Not possible to adjust the size
 <p>CLICKI</p>	<ul style="list-style-type: none"> + Parts are easily replaceable + Special stacking mechanism + Adjustable in shape + No additional part for nameplates + No instruments between handles 	<ul style="list-style-type: none"> - Click mechanism for efficient transport. This takes additional time and an extra action - Handles protrude on the outside
 <p>LEAFI</p>	<ul style="list-style-type: none"> + Parts are easily replaceable + Easy stacking mechanism + Adjustable in shape + No instruments between handles 	<ul style="list-style-type: none"> - Extra mechanism for efficient transport. This takes additional time and an extra action - Nameplates - Handles protrude on the outside
 <p>HINGI</p>	<ul style="list-style-type: none"> + Adjustable in shape + Efficient for different types of instruments + Parts are easily replaceable + Rotatable handles 	<ul style="list-style-type: none"> - Extra mechanism for efficient transport. This takes additional time and an extra action - Stackable through Velcro - Magnet nameplates

The results of the Harris profile combined with the advantages and disadvantages, shown in table II and appendix H of each concept give stacki as the most promising concept.

3) Concept combination:

As can be seen in the Harris profile in table III, stacki is by far the best concept. Stacki is in itself the best concept but also scores better individually on the various components than the other concepts. However, stacki, as shown in the Harris profile in table III, has 1 disadvantage. Stacki is not adaptable in shape. However, this is an important requirement, see R-CH3, for this research. Making the shape adaptable ensures that the instrument set can be used as a 1/1 DIN, but also as a 1/2 DIN.

After a lot of thinking and trying out different ideas, a mechanism was invented for adjusting the shape. The ideas from clicki, leafi, and hingi, such as break lines, hinges, or a sliding mechanism, have also been tried on stacki, but these turned out to be unfeasible on stacki due to the angled corners of stacki. The mechanism for adjusting the shape of stacki will be discussed in section II-C.

1) *Paper test*: the first test performed on the prototype is a paper test. The prototype should not have sharp edges or protruding parts, for the safety of hospital staff and the sterility of the instrument sets. First, hospital staff can cut themselves due to sharp edges or protruding parts. In addition, the polypropylene (PP) paper ensures that the instrument sets remain sterile. If the paper is damaged, this will no longer be the case. To reduce the chance of sharp edges or protruding parts, the various parts are 'tumbled', shown in figure 19. In addition, the various parts have also been auctioned.



Figure 19. The different parts from the final prototype that are tumbled

The purpose of this test is to verify that the prototype is suitable for being wrapped by 2-layer sterile PP paper and to validate that the prototype has no sharp edges or protruding parts. The paper test involves sliding the prototype wrapped with PP paper onto the table, in the same way as in hospitals shown in figure 20.



(a) Paper test of the 1/2 DIN final prototype



(b) Paper test of the 1/1 DIN final prototype

Figure 20. Paper test of the two final prototypes

The prototype passes this test if there are no holes in the PP paper after performing the test. This is checked by holding the PP paper next to the window after the test and checking whether light passes through any holes. If light comes through, it means that there are holes in the PP paper. If no light comes through, that means there are no holes in the PP paper.

This test was carried out with the 1/2 DIN and the 1/1 DIN prototype. For both formats, the test was performed 8 times. 3 times empty with the prototype, and 3 times filled with instruments with the prototype, shown in figure 21.

1 time empty with an existing instrument set as a check, and 1 time filled with instruments with an existing instrument set as a check, shown in figure 22.



(a) 1/2 DIN prototype filled with instruments



(b) 1/1 DIN prototype filled with instruments

Figure 21. The 1/2 and 1/1 DIN prototypes filled with instruments during the paper test



(a) 1/2 DIN existing instrument set filled with instruments



(b) 1/1 DIN existing instrument set filled with instruments

Figure 22. The 1/2 and 1/1 DIN existing instrument sets filled with instruments during the paper test

2) *User test*: the next test performed on the prototype is an user test. An user test was chosen to test the ease of use and to process any feedback for future research. For the user test, several different tests were carried out by different professionals. These professionals include Harry Leeuw, Sterile Medical Devices Expert (DSMH) at St. Antonius Hospital in Utrecht, shown in figure 24 and 25, Niels van Straten, board of directors at Van Straten Medical B.V., and mainly employees of the CSSD (MSMH), shown in figure 23. It was decided to mainly conduct the user test with employees from the CSSD because these employees are the ultimate users.



(a) CSSD staff while assembling the 1/2 DIN prototype



(b) CSSD staff while packing the 1/2 DIN prototype

Figure 23. CSSD staff during the user test

To evaluate these design requirements, the following tests, see appendix N for the user test form, were performed. The professionals first had to assemble and disassemble the 1/2 DIN prototype, first without explanation and then with explanation to see how easy it was to assemble and disassemble.



(a) Harry Leeuw while assembling the 1/2 DIN final prototype



(b) Harry Leeuw testing the handles of the 1/2 DIN prototype

Figure 24. Harry Leeuw during the user test



(a) Harry Leeuw while packing the 1/2 DIN final prototype



(b) Harry Leeuw while packing the 1/1 DIN final prototype

Figure 25. Harry Leeuw packing the prototype

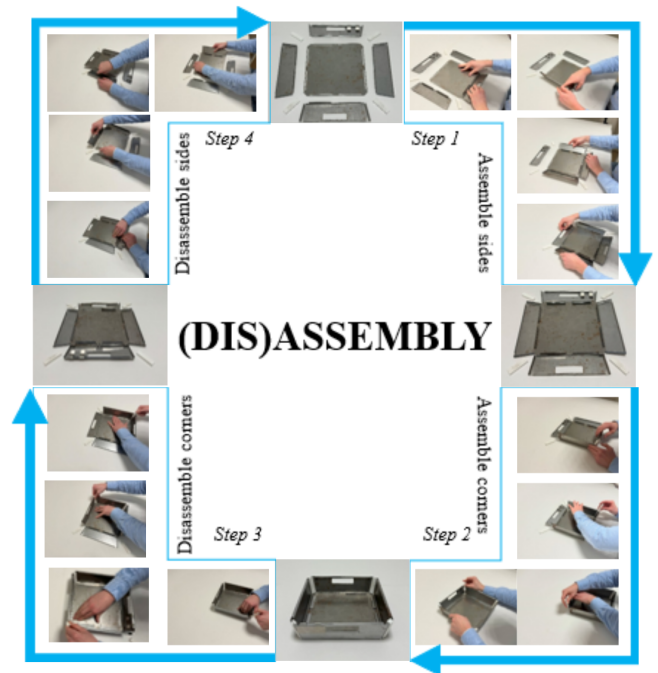


Figure 26. The assembly and disassembly of the 1/2 DIN prototype

Figure 26 and appendix P show the assembly and disassembly plan of the 1/2 DIN prototype, divided into the following 4 steps: assemble sides, assemble corners, disassemble corners, and disassemble sides. The assembly and disassembly of a 1/1 DIN prototype are the same as that of the 1/2 DIN prototype. Then the professionals had to lift the prototype and walk around with it, first empty without instruments and then filled with instruments to test the new design of the handles. Finally, the professionals had to wrap the prototype in the PP paper to see if it caused any problems and took extra time. The professionals had to perform the same tests with the 1/1 DIN prototype.

3) *Drop test:* As a final test, a drop test was chosen to check the strength and robustness of the prototype. This test involves dropping the prototype from 1.20 meters onto a hard surface. This is an ISO standardized test (ISO 7965-1) [7]. The drop test provides insight into the design of the prototype by evaluating how well the prototype can withstand falls. It was decided to perform this test last, in case the prototype is broken or damaged and the other tests cannot be performed. The purpose of this test is to verify with objective evidence that the prototype is suitable for transport. The prototype passes this test on 3 conditions. First of all, the prototype or the various parts must not be bent after performing this test. In addition, the prototype may not be broken. Finally, the prototype must not have fallen apart after the test. This test was carried out with the 1/2 DIN and the 1/1 DIN prototype. The prototype is dropped 10 times from 1.20 meters in different directions (on corners, edges, and surfaces). This test is done without (surgical) instruments. Before the start of the test, the test items were checked for any visual damage.

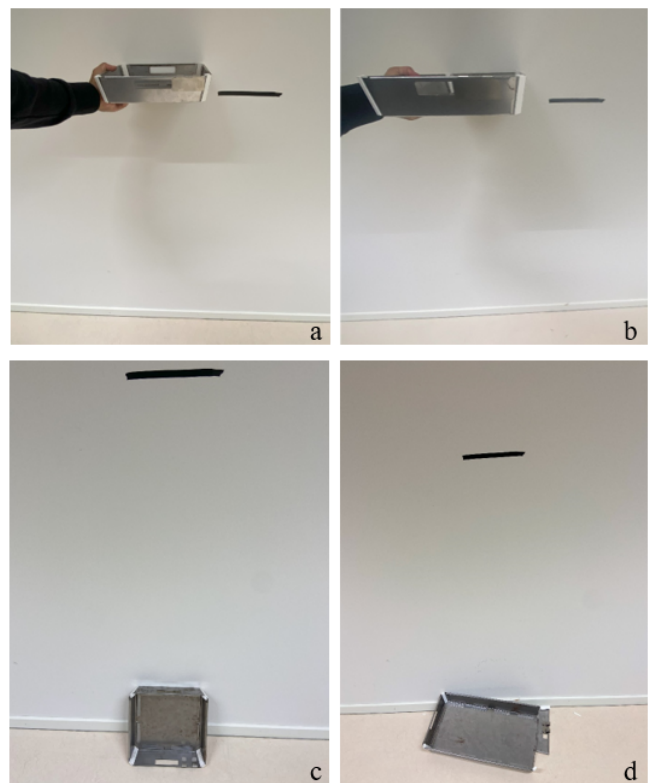


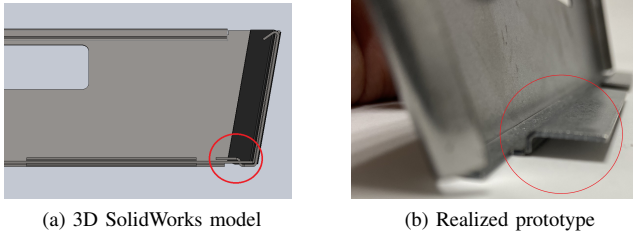
Figure 27. Drop test of the two final prototypes (a) Before the drop test of the 1/1 DIN final prototype, (b) Before the drop test of the 1/2 DIN final prototype before, (c) After the drop test of the 1/2 DIN final prototype, (d) After the drop test of the 1/1 DIN final prototype

III. RESULTS

A. Prototype

A total of 3 prototypes have been made, which are all different from each other. This section describes the 3 prototypes and shows images of the 3D models and the realized prototypes.

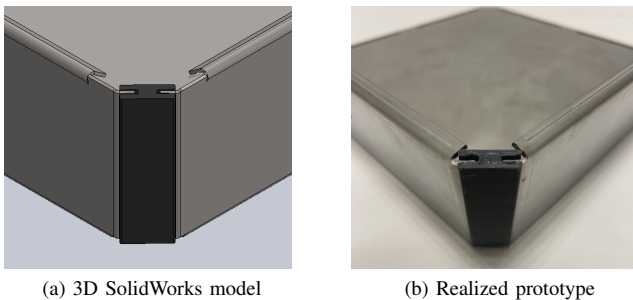
1) *Prototype I:* Prototype I aimed to test the click mechanism, shown in figure 28, between the sides and the bottom, and the corner, shown in figure 29, between the sides, both described in section II-C.



(a) 3D SolidWorks model

(b) Realized prototype

Figure 28. Click mechanism between the sides and the bottom



(a) 3D SolidWorks model

(b) Realized prototype

Figure 29. Corner between the sides from prototype I

Only 1 part is made of both sides, while two of both sides are needed for the instrument set. Only 1 of the required 4 corners was printed. This was done to save material because at first, it was just testing. Figure 30 shows the 3D model of prototype I and figure 31 shows the real model of prototype I.

Prototype I was completely made at Van Straten Medical B.V.. The sides and bottom were made by water cutting. The material of these parts is stainless steel, and the thickness is 1.2 mm. These parts were then bent using the Xpert 40 from Bystronic Inc. [8]. The corner, shown in figure 29, was printed with the Fused Deposition modeling (FDM) printer of Van Straten Medical B.V. This FDM printer has a nozzle diameter of 0.4 mm and uses Polylactic acid (PLA) as material.

2) *Prototype II:* The purpose of prototype II was to test the corner between the sides. The corner of prototype I did not work completely. The sides fell apart, and the corner was very easy to slide off. The design of the corner has been adjusted, shown in figure 32. Of the required 4 corners, only 1 has been printed. This was done to save material because at first, it was just testing. Figure 33 shows the 3D model of prototype I and figure 34 shows the real model of prototype I.

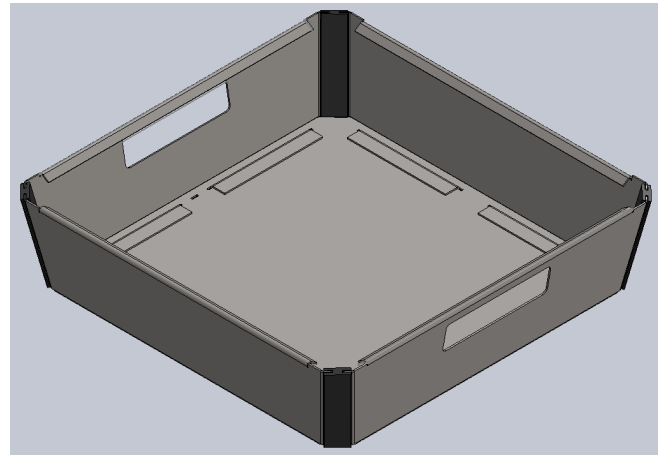


Figure 30. 3D SolidWorks model of the 1/2 DIN prototype I

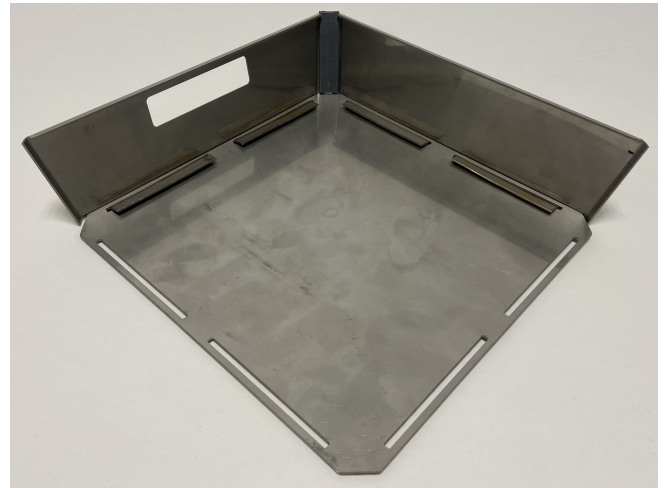
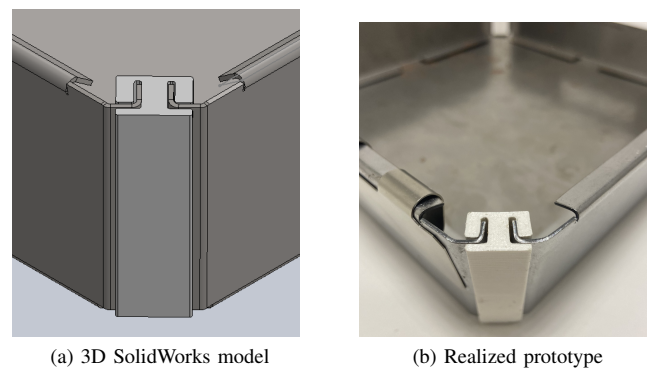


Figure 31. Realized model of the 1/2 DIN prototype I



(a) 3D SolidWorks model

(b) Realized prototype

Figure 32. Corner between the sides from prototype II

Prototype II was partly made at Van Straten Medical B.V. and partly made at TU Delft. The sides and bottom are made by laser cutting at TU Delft. The material of these parts is steel, and the thickness is 1 mm.

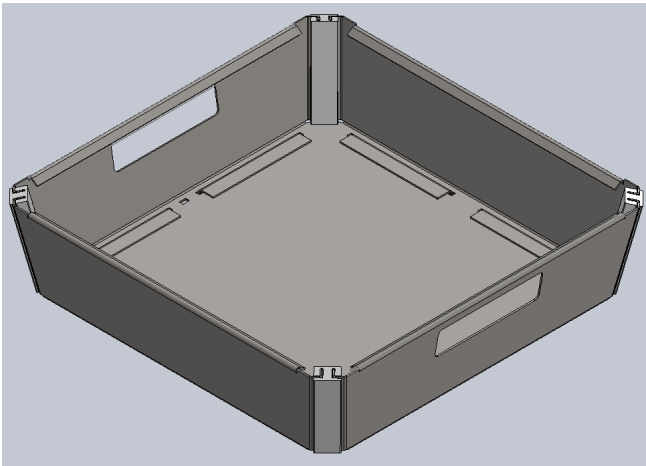


Figure 33. 3D SolidWorks model of the 1/2 DIN prototype II

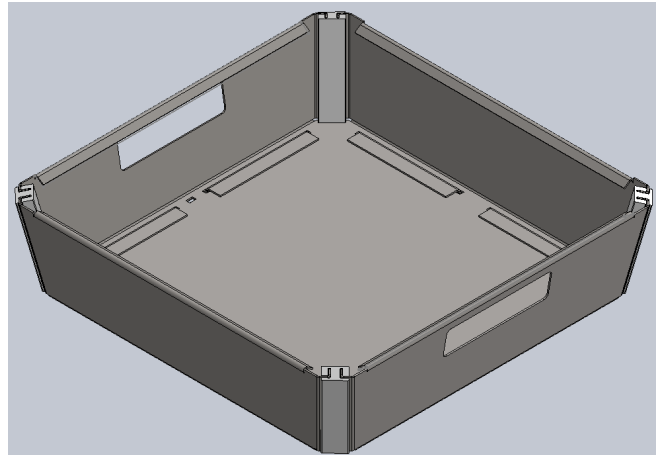


Figure 35. 3D SolidWorks model of the 1/2 DIN final prototype



Figure 34. Realized model of the 1/2 DIN prototype II

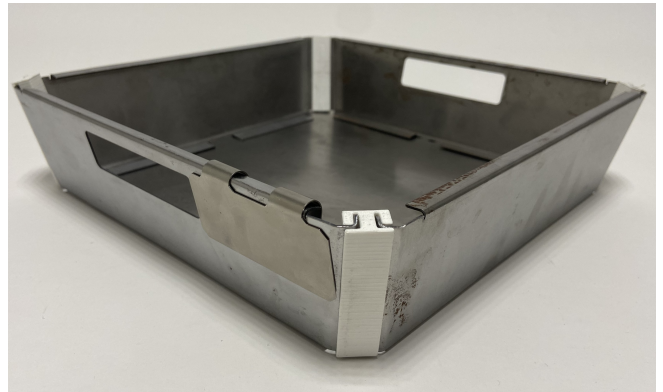


Figure 36. Realized model of the final 1/2 DIN prototype

These parts were then partly bent using the Xpert 40 from Bystronic Inc. [8] at Van Straten Medical B.V. and partly bent by a standard press brake by hand at Van Straten Medical B.V.. The corner, shown in figure 32, was printed with the Fused Deposition modeling (FDM) printer at TU Delft. This FDM printer has a nozzle diameter of 0.4 mm and uses Polylactic acid (PLA) as material.

3) *Final prototype:* Prototype III was made for the purpose of being the final prototype. For this reason, both 1/2 DIN and 1/1 DIN size instrument sets have been made. Since this is the final prototype, it was decided to make all parts, see appendix J: 1 bottom of a 1/2 DIN size, 2 long sides of a 1/2 DIN size, 1 bottom of a 1/1 DIN size, 2 long sides of a 1/1 DIN size, 2 short sides, and 4 corners. The short sides of a 1/2 DIN size also work as the short sides of a 1/1 DIN size. The design of the corner is the same as the design of prototype II as this design worked. Figure 35 shows the 3D model of the 1/2 DIN final prototype and figure 36 shows the real model of the 1/2 DIN final prototype. Figure 37 shows the 3D model of the the 1/1 DIN final prototype and figure 38 shows the real model of the 1/1 DIN final prototype.

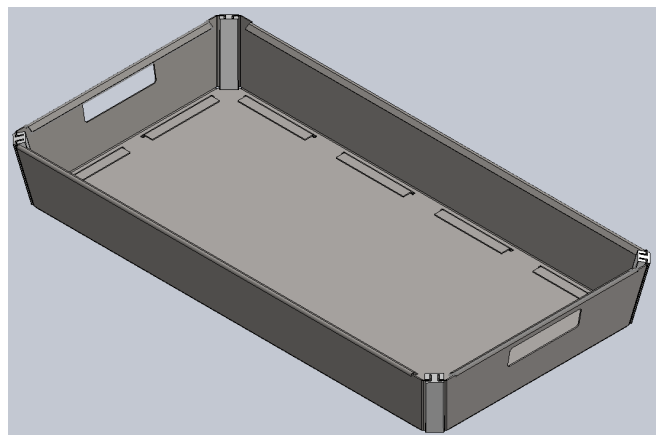


Figure 37. 3D SolidWorks model of the 1/1 DIN final prototype

The final prototype was partly made at Van Straten Medical B.V. and partly made at TU Delft. The sides and bottom are made by laser cutting at TU Delft. The material of these parts is steel, and the thickness is 1 mm.

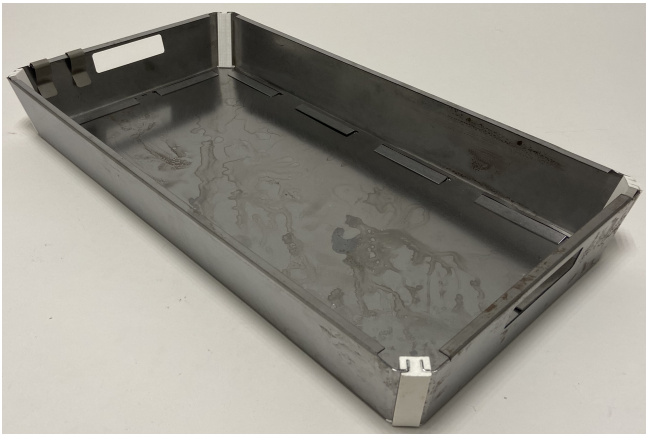


Figure 38. Realized model of the final 1/1 DIN prototype

These parts were then partly bent using the Xpert 40 from Bystronic Inc. [8] at Van Straten Medical B.V. and partly bent by a standard press brake by hand at Van Straten Medical B.V.. The corner, shown in figure 32, was printed with the FDM printer at TU Delft. This FDM printer has a nozzle diameter of 0.4 mm and uses Polylactic acid (PLA) as material. Appendix K contains images of all parts and the assembly of the final prototype and appendix Q contains the technical drawings of all parts and the assembly of the final prototype.

B. Testing

This section describes in detail the results of the tests performed on the prototypes. Section III-B1 describes the results of the paper test. Section III-B2 describes the results of the user test. Finally, section III-B3 describes the results of the drop test.

1) *Paper test:* The test results of the paper test of the 1/2 DIN prototype are shown in table IV and those of the 1/1 DIN prototype are shown in table V. Figure 39 shows the result of test 1 of the paper test of the 1/2 DIN prototype and the result of test 1 of the paper test of the 1/1 DIN prototype. The figures of the other 7 tests of the paper test of the 1/2 DIN prototype are shown in appendix M2 and the figures of the other 7 tests of the paper test of the 1/1 DIN prototype are shown in appendix M3.

Table IV. The test results of the paper test of the 1/2 DIN prototype

Test	Test sample	Full or empty	Result	Figure
1	Prototype	Empty	Pass	Figure M2.1
2	Prototype	Empty	Pass	Figure M2.2
3	Prototype	Empty	Pass	Figure M2.3
4	Prototype	Filled with instruments	Pass	Figure M2.4
5	Prototype	Filled with instruments	Pass	Figure M2.5
6	Prototype	Filled with instruments	Pass	Figure M2.6
7	Existing instrument set	Empty	Pass	Figure M2.7
8	Existing instrument set	Filled with instruments	Pass	Figure M2.8

Tables IV and V and the figures in Appendix M2 and M3 show that the PP paper did not have a hole or was damaged during any of the tests, while the same actions as in hospitals were performed. Therefore, it can be concluded that the prototype passed this test. The results of the paper test are further discussed in section IV-D.

Table V. The test results of the paper test of the 1/1 DIN prototype

Test	Test sample	Full or empty	Result	Figure
1	Prototype	Empty	Pass	Figure M3.1
2	Prototype	Empty	Pass	Figure M3.2
3	Prototype	Empty	Pass	Figure M3.3
4	Prototype	Filled with instruments	Pass	Figure M3.4
5	Prototype	Filled with instruments	Pass	Figure M3.5
6	Prototype	Filled with instruments	Pass	Figure M3.6
7	Existing instrument set	Empty	Pass	Figure M3.7
8	Existing instrument set	Filled with instruments	Pass	Figure M3.8



(a) Test 1 of the paper test of the 1/2 DIN prototype



(b) Test 1 of the paper test of the 1/1 DIN prototype

Figure 39. PP paper after performing the paper test

2) *User test:* The test results of the user test with the 1/2 DIN prototype are shown in table VI and for the 1/1 DIN prototype are shown in table VII. Appendix O contains an extensive table with all the results of the user test.

Table VI. The test results of the user test of the 1/2 DIN prototype

Person	Assembly	Handles	Wrapping
1	Assembling and disassembling is difficult. However, you assemble 1 set in a while and not 50 sets per hour.	Good position of the handles and easy to clean.	Easy to pack in a traditional way.
2	Disassembling the prototype is easy. Assembling is not that intuitive.	The handles are sharp.	<i>Test not performed.</i>
3	Assembling is difficult. Adjust the corners slightly to make it easier.	Handles have sharp edges. Make the handle slots larger for people with large hands.	Packing the prototype takes some getting used to, but other than that no problems.
4	Once you understand assembling and disassembling it, it is easy to do.	No difference in the handles when the prototype is empty or filled with instruments.	The prototype has no vulnerable parts.
5	Adjust the corner so that it goes more smoothly. Material can also be a reason for things being stiff.	Instruments can protrude through the handles.	The prototype is easy to pack.
6	Putting it together and taking it apart is difficult. You must practice and understand it well.	Nice design of the handles. It works fine.	The paper was torn once. The packing, however, was done with some force. It could also be because it is a prototype.
7	Disassembling the prototype is obvious. Assembling it takes some getting used to, but after that, it is easy to do.	A larger handle slot for people with large hands.	The sides at an angle do not cause any additional difficulties.
8	Takes a little longer because you have to assemble and disassemble it. Adaptability in shape is an advantage.	The prototype handles are different from the drop handles, but it works fine.	The angle is chosen right so that it does not give a strange crease.

Looking at the results from table VI, table VII, and the table in appendix O, it can be concluded that the prototypes passed the user test. Some improvements would make the prototypes even better. The user test showed that the corners are not yet working optimally. For future research, these corners should be redesigned to make assembly and disassembly smoother. In addition, the user test showed that the perforations are missing. These will naturally be added to the final design. There were also positive things that emerged during the test. The prototypes did not cause any problems when packing with the PP paper and the professionals were positive about the stackability of the prototype.

Table VII. The test results of the user test of the 1/1 DIN prototype

Person	Assembly	Handles	Wrapping
1	Assembling and disassembling is smoother than the 1/2 DIN prototype.	The handle works the same as the 1/2 DIN prototype.	No difference in packing standard set or the prototype.
2	<i>Test not performed.</i>	<i>Test not performed.</i>	<i>Test not performed.</i>
3	Assembling and disassembling is difficult, just like the 1/2 DIN prototype. Adjust corners.	The 1 DIN prototype has sharp edges. Make the handle slots larger.	No comments.
4	Assembling and disassembling is easy. Good idea to use the sides for both sizes.	-	-
5	Adjust the corner (same as 1/2 DIN) slightly.	See note at 1/2 DIN.	See note at 1/2 DIN.
6	Smart to use the sides with handles twice.	The handles work well.	The paper is not torn now. Depends on how the prototype is finished
7	Flexible, because 3 additional parts for 1 DIN	Make a bigger slot for the handles	No difficulties
8	Just like 1/2 DIN, beautiful and efficient design	The handles are fine.	The angle was chosen exactly right, otherwise, there would be a strange fold.

However, one of the 7 CSSD employees had their PP paper torn while packing the prototype, shown in figure 40.



Figure 40. PP paper torn during the user test

Finally, some comments applied to the prototypes, but not to the design. The test showed that the handles, but also other parts, had sharp edges, which need to be better rounded. However, the test also showed that the professionals thought the handles were an improvement compared to the current handles. The results of the user test are further discussed in section IV-D.

3) *Drop test:* The test results of the drop test with the 1/2 DIN prototype are shown in table VIII and with the 1/1 DIN prototype in table IX.

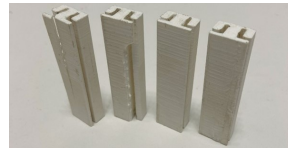
Table VIII. The test results of the drop test of the 1/2 DIN prototype

Test	Impact on	Results	Figure before	Figure after
1	Surface 1	Pass	Figure M5.1	Figure M7.1
2	Edge surface 1-2	Pass	Figure M5.2	Figure M7.2
3	Surface 2	Pass	Figure M5.3	Figure M7.3
4	Edge surface 2-3	Fail	Figure M5.4	Figure M7.4
5	Surface 3	Pass	Figure M5.5	Figure M7.5
6	Edge surface 3-4	Pass	Figure M5.6	Figure M7.6
7	Surface 4	Pass	Figure M5.7	Figure M7.7
8	Edge surface 4-1	Fail	Figure M5.8	Figure M7.8
9	Top	Pass	Figure M5.9	Figure M7.9
10	Bottom	Pass	Figure M5.10	Figure M7.10

Table IX. The test results of the drop test of the 1/1 DIN prototype

Test	Impact on	Results	Figure before	Figure after
1	Surface 1	Pass	Figure M6.1	Figure M8.1-M8.10
2	Edge surface 1-2	Fail	Figure M6.2	Figure M8.1-M8.10
3	Surface 2	Fail	Figure M6.3	Figure M8.1-M8.10
4	Edge surface 2-3	Fail	Figure M6.4	Figure M8.1-M8.10
5	Surface 3	Fail	Figure M6.5	Figure M8.1-M8.10
6	Edge surface 3-4	Unable to perform	Figure M6.6	Figure M8.1-M8.10
7	Surface 4	Unable to perform	Figure M6.7	Figure M8.1-M8.10
8	Edge surface 4-1	Unable to perform	Figure M6.8	Figure M8.1-M8.10
9	Top	Unable to perform	Figure M6.9	Figure M8.1-M8.10
10	Bottom	Unable to perform	Figure M6.10	Figure M8.1-M8.10

From the results of table VIII, table IX, and the images in appendices M5-M8, it can be concluded that the prototype failed the drop test. In the 1/2 DIN prototype, 2 corners were broken and in the 1/1 DIN prototype, all corners of the 1/1 DIN were broken, shown in figure 41. The entire 1/1 DIN prototype fell apart after 5 tests, whereby a corner broke off the second time and the subsequent 3 tests also failed, shown in figure 43. The bottom of the 1/1 DIN final prototype was also deformed during the drop test, shown in figure 42. The results of the drop are further discussed in section IV-D.



(a) The 2 corners broken of the 1/2 DIN prototype



(b) The corners of the 1/1 DIN prototype after the drop test

Figure 41. Results of the corners of the drop test of the two final prototypes

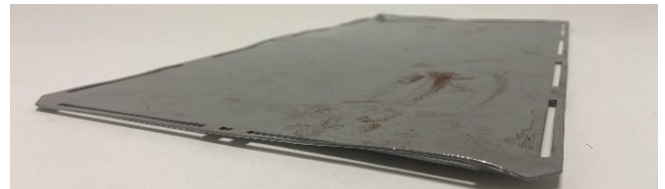


Figure 42. The bottom of the 1/1 DIN prototype deformed during the drop test



Figure 43. The 1/1 DIN prototype after the drop test

IV. DISCUSSION

A new instrument set for efficient storage and transport was developed and evaluated. The different prototypes provided insight into the design and manufacturing methods used. These insights will be discussed in this section, after first discussing whether the requirements have been met. The tests and the associated results are then discussed. Finally, a starting point for future work is made through recommendations for further development of the instrument set.

A. Requirements

Of the 15 requirements mentioned in section II-A, 7 have been met, and 6 requirements were not tested. Requirement **R-MH1** of the 'Must Haves' has not been met because the final prototypes are made of steel. The final product will be made of stainless steel (SS) 304 or 316. Requirement **R-MH2** has been met, because two prototypes have been made in a 1/2 and 1/1 DIN size. The design can therefore be applied to different DIN formats. The prototypes have not been cleaned, disinfected, or sterilized. For this reason, it cannot be stated whether requirements **R-MH3** and **R-MH4** have been met. For further development of the prototypes, it is necessary to check whether the design meets requirements **R-MH3** and **R-MH4** by cleaning, disinfecting, and sterilizing the prototypes. Requirement **R-MH5** has been met, see section II-D1. The paper test confirmed that the prototypes do not have any sharp edges or protruding parts.

Three requirements of the 'Should Haves' have been met. The prototypes do not yet have perforations. In addition, as described above, the prototypes have not been cleaned, disinfected, or sterilized. Therefore, it cannot be confirmed that requirement **R-SH1** has been met. Requirement **R-SH2** has been met because the prototypes weigh as much as the existing instrument sets. The 1/2 DIN prototype weighs 1.00 kg compared to 0.84 kg of an existing instrument set and the 1/1 DIN prototype weighs 1.67 kg compared to 1.19 kg of an existing instrument set, shown in figure 44. Both prototypes are in the 0.5 kg margin. In addition, the perforations are still missing, and it is not made of stainless steel (SS). This will further reduce the weight of the prototypes.

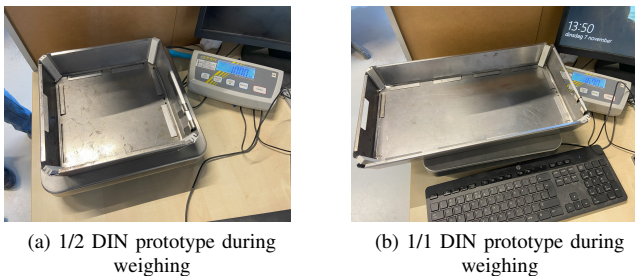


Figure 44. Weight of both prototypes

Requirement **R-SH3** has not been met, because the 1/1 DIN prototype fell apart during the drop test. During this drop test, this prototype was also bent and most of the corners fell apart.

Requirement **R-SH4** has been partially met. The corners make assembling the prototype quite difficult. To make assembly easier and more intuitive, the corner will be modified for future research. However, assembling and disassembling took less than 2 minutes on average. Requirement **R-SH5** is not tested.

Of the 'Could Haves', 2 requirements have been met, while the other 3 requirements have not been evaluated. Requirements **R-CH1** and **R-CH2** have not been tested because only 1 prototype was made of both sizes. For these two requirements, 4 prototypes of each format were needed. Using SolidWorks, shown in the figure, it can be demonstrated that this should be possible. Requirement **R-CH3** has been met because it is possible to adapt the 1/2 DIN prototype to the 1/1 DIN prototype and vice versa. In this way, the instrument set can be adapted for instruments of different sizes. Requirement **R-CH4** has been met because it is possible to attach a nameplate to the prototypes. Requirement **R-CH5** has not been tested because other handles were chosen instead of drop handles.

B. Design

The assembly of the prototypes went quite smoothly. The first prototype already worked better than expected. Mostly minor adjustments were needed, including extra clearance in the bottom for the click mechanism between the side and the bottom and rounding off the various parts. In addition, there was 1 part of prototype I that required extra attention and several adjustments, which had not been considered during the design of the instrument set but was only thought of with the first prototype in hand. This part was the corner. The corner of prototype I, as described in section II-D2, did not work quite well. The sides fell apart, and the corner slid off quite easily. Because the corner had to be adjusted, the side also had to be adjusted to make the new corner work. Other than that, the side worked well. The corner of prototype II worked much better and kept the sides in place. See figures 29 and 32 for the difference between the corners of prototype I and prototype II. Prototype II worked well, and it was then decided to make the final prototype based on prototype II in a 1/2 DIN and a 1/1 DIN configuration.

C. Fabrication

The different prototypes were made with different production methods than the production methods that would be used for the final product. The limited resources available for creating the prototypes are the reason for this. It was decided to make the prototypes without perforations. This was chosen because the right resources were not available to make the perforations. Ultimately, the perforations are made using a punching machine. The sheet metal is then partially punched to remove material in the bottom and sides of the instrument set. Another option was to make the perforations in the design and include them in water/laser cutting. However, this would take much more time, be more expensive, and would also warp the plate and cause deformations.

In addition, there is room for improvement in the quality of the components.

To keep costs as low as possible, the corners are made from Polylactic acid (PLA) using a Fused Deposition Modeling (FDM) printer, as design errors can be identified at an early stage, and this would waste valuable filament. In addition, an FDM printer is fast but sometimes inaccurate, making it suitable for rapid prototyping. The intention is that the corners will be made using the injection molding method from recycled polypropylene (PP). Subsequently, the materials for the sides and the bottom, from which the instrument will be made, were not used. The prototypes are made of steel, while the final product should be made of stainless steel (SS) 304 or stainless steel (SS) 316.

Finally, the various parts were partly bent using the Xpert 40 from Bystronic Inc. [8] at Van Straten Medical B.V. and partly bent by a standard press brake by hand at Van Straten Medical B.V.. Some parts could not be completed because the right resources were not available. The click mechanism of the sides with the bottom could not be folded because the correct knives were not available for folding this small distance. These parts are folded separately and joined together by welding, shown in figure 45.



(a) The parts on the screen before welding

(b) The parts on the screen after welding

Figure 45. The parts joined together by welding

D. Testing

First, the paper test was performed. Both prototypes passed this test. 2-layer PP paper was used. In this way, the worst-case scenario was assumed as this PP paper contains the fewest layers. However, this test was performed by a fellow student and not by an employee of the CSSD. However, the actions and movements that a CSSD employee performs are attempted to be imitated. However, CSSD employees also tested both prototypes, testing various components. 1 of these parts was packaging the prototypes. As discussed in section II-D2, one of the 7 CSSD employees had their PP paper torn while packing the prototype, shown in figure 40. However, this employee himself indicated that he packed it with a lot of force and more force than normal. This test, where the PP paper was torn, can therefore be neglected compared to the other tests, where the PP paper was not torn. Overall, the paper test showed that both prototypes do not have sharp edges or protruding parts, such that the PP paper tears or becomes damaged.

The user test has shown that users are positive about the design of the realized prototypes. The biggest benefit users reported was the stackability of the new design, shown in figure 46. However, only 1 prototype of both formats was created, so the stackability of the design has not been tested. To test the stackability, an additional prototype must be made of both sizes. The users' positive thoughts about stackability can then be confirmed. Most users also indicated that they missed the perforations. As discussed in section II-D2, the perforations will be added in the final design. In addition, the user test showed that disassembling the prototypes went quite smoothly, but that assembling the prototypes was not so intuitive. This was partly because it was not clear to the user how the corners should be inserted. The corners could be inserted in 4 ways, where 2 worked. It sometimes took quite some time for the user to figure out how to insert the corner. To solve this problem, a solution must be devised so that the corner only fits one way. In addition, placing the corner was also a bit stiff. This could be because it is a prototype and not all distances are yet perfect. It was also not ideal that the corner was made of PLA because it rubbed against the steel.

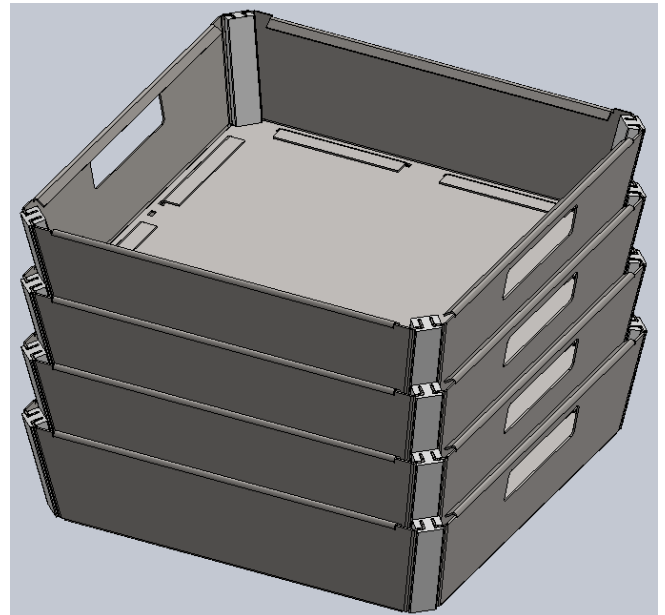


Figure 46. Stackability of the 1/2 DIN prototype shown in SolidWorks

The drop test showed that the prototypes failed this test. The 1/2 DIN prototype passed the test 8 times and failed 2 times, due to the corners, shown in figure 41. The 1/1 DIN prototype passed the test 1 time, only the first time, and failed 4 times. The other 5 times it was not possible to perform the test, because the prototype and the corners had completely fallen apart, shown in figure 43. The only time the 1/1 DIN prototype passed the test was on the short side of the prototype. The next 4 tests, where the prototype failed the test each time, involved 2 corners and the long side twice. One of the possible reasons that the corners broke off quickly could be that the corners are made of PLA. The goal is to make these corners from recycled PP through injection molding. A solution for the PLA corners could be to reduce their brittleness and make the corners more flexible by adding a small rubber piece.

E. Future work/Recommendations

There are several recommendations to improve the prototypes. Firstly, it must be ensured that the corners are made more nicely rounded. It is better if there are as many curves as possible. In addition, it is better to uncarve the various parts. Care must also be taken to ensure that the bottom or other parts do not have sharp edges. This is all about the finish of the prototype.

The corners will ultimately be made from recycled polypropylene (PP) by injection molding. The 3D-printed corners of the prototypes provide a good impression of the design. The next step is to look at the feasibility of these corners using the injection molding method, which is more expensive but more accurate. The corners are largely ready for injection molding, but a few minor adjustments are needed, such as draft angles of 1 degree. A total of 1 mold will be required to develop the corners. In addition, there will be no material costs for Model Engineering as the corner will be made from 100% recycled PP. This 100% recycled PP will be supplied by Van Straten Medical B.V..

In addition, the sides and bottom are ultimately made of 304 or 316 stainless steel (SS). 316 stainless steel (SS) is the most corrosion-resistant material and is generally the most commonly used material. However, it is also possible to use 304 stainless steel (SS), as current instrument sets are also made from this. 304 Stainless steel (SS) is cheaper than 316 stainless steel (SS) and has almost the same properties.

A possible improvement for future research is to replace the long side with 2 short sides, shown in figure 47.

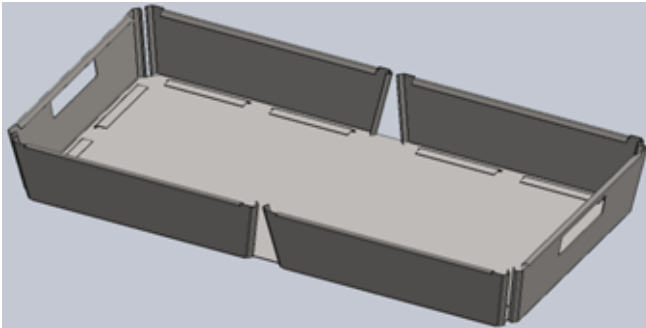


Figure 47. 1/1 DIN prototype for future research

This way you need even fewer parts. Only the bottom of the 1/2 DIN and 1/1 DIN instrument sets differ. The sides, both the short and the long ones, are then the same. There must be a connecting piece in the middle between the two short sides. During the user test, it emerged that opinions were divided. Some professionals think it is not desirable, because it requires an extra action, and the torsional stiffness and strength are then reduced, and some professionals see it as an advantage, because the long sides are then gone, and you need fewer parts. It would be a challenge to make this connecting piece. However, it would not cause any problems in terms of hygiene.

V. CONCLUSION

To store and transport instrument sets, in which (surgical) instruments are stored, transported, cleaned, disinfected, and sterilized, more efficiently, an instrument set with sloping sides, which is adaptable in shape, has been successfully designed, made, and tested. A total of 5 concepts were developed based on a morphological chart, after which the best concept was selected based on a Harris profile. This concept has been further developed and designed using the 3D CAD software SolidWorks. A total of 3 prototypes were then realized using water/laser cutting and 3D printing. The final prototype has sloping sides, making the prototype efficient for storage and transport when empty. In addition, the prototype is adjustable in shape using a click mechanism and corners. This means that the instrument set can be adjusted from a 1/2 DIN to a 1/1 DIN. A gap was chosen for the handles. The prototypes were used to evaluate the design and identify critical points through 3 tests. In these 3 tests, the prototypes are tested for sharp edges/protruding parts, ease of use, and strength/robustness. These tests have shown that the prototype has no sharp edges/protruding parts, improvements on the corner are needed to make the prototype even better and the strength/robustness needs to be improved. The stackability of these instrument sets came out as the biggest advantage of these tests. Further research could be done by creating a prototype with perforations and testing this new prototype for cleaning, disinfecting, and sterilization. The remaining requirements can then be met by applying the points of improvement from the tests. Finally, the idea of two half sides instead of one long side can also be tested. Overall, the instrument is promising for further development, with this design as a starting point.

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1. Results of the user test

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Appendix A

Literature review

Literature research of methods to efficiently transport instrument sets

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Abstract—Surgical instruments are transported in instrument sets if they need to be transported for cleaning, disinfection and sterilization. These instrument sets have the problem that they have 1 standard size and therefore cannot be transported efficiently. This literature research has investigated existing methods for efficient transport. Among other things, foldable containers were examined. The search was carried out with the help of the Scopus and Google Scholar databases. Ultimately, 48 relevant articles were used in this literature research. A PRISMA flow diagram was used to demonstrate how the screening process proceeded. The articles mainly concerned foldable containers, foldable mechanisms and compliant mechanisms. The results are therefore mainly about how these foldable containers, foldable mechanisms and compliant mechanisms work and their advantages and disadvantages are mentioned. The biggest advantage of foldable containers is that they are more efficient for transport because less space is needed when these containers are transported empty. However, the downside is that the cost will be higher. A data extraction table has been created with 12 different types of foldable containers with their functioning, folding direction and advantages and disadvantages. These 12 foldable containers can be divided into two groups: foldable containers that can be folded horizontally and foldable containers that can be folded vertically. Further research can be done into the sterility of these foldable containers.

Keywords—*Foldable containers, foldable mechanisms and compliant mechanisms*

I. INTRODUCTION

A. Context

Nowadays, reusable (surgical) instruments are cleaned, disinfected and sterilized, after which they can be used again. In some hospitals, these (surgical) instruments are cleaned, disinfected and sterilized in the hospital itself. However, this is not possible in some hospitals. The surgical instruments of these hospitals are sent to an external party for cleaning, disinfection and sterilization. An example of such an external party is CSA Services B.V.. When these (surgical) instruments are transported from the hospital to CSA services B.V., they are placed in instrument sets, see figure 1 [1]. However, these surgical instrument sets, stainless steel mesh and wire baskets, in which instruments are stored, transported, cleaned, disinfected and sterilized, generally have one size. This means that one fixed space cannot be optimized for the number of instruments that differs per surgical procedure. This creates a large empty space. This extra space increases the transport volume and additional surface area for cleaning and disinfection.



Figure 1. Instrument set with flat bottom, perforated sides and drop handles

My graduation project concerns a design project in which a stainless-steel surgical instrument set is designed for efficient transport. Van Straten Medical B.V. wants a new design for these instrument sets, where these instrument sets must be more efficient for transport and storage. Before embarking on this design project, it is important to investigate existing methods for efficient transport. One of the ways to achieve this is by using a folding mechanism, just like the foldable containers. This literature study aims to provide an overview of existing foldable containers by means of a systematic review. This literature study describes, among other things, the operation of various foldable containers with their advantages and disadvantages.

B. Research questions

This literature research investigates methods to efficiently transport instrument sets or similar boxes, leading to the following research question.

- **Which design methods and/or technologies are developed that can be used as a benchmark to store, clean, sterilize, and transport sterile devices taking adjustable weight and volume into account?**

To answer the research question two sub-questions have been formulated. The first sub-question will focus on different kinds of mechanisms for efficient transport. This research will not only be done in the medical field but also other markets will be investigated. The second sub-question will focus on foldable mechanisms. The two research questions can be found below.

- *What mechanisms are generally available for efficient transport?*
- *What different types of methods are there available for folding and unfolding boxes?*

C. Outline of the literature research

In the next chapter, the method of this systematic review is described. The results are presented in the third chapter. The different topics are discussed with their advantages and disadvantages. To sketch a clear overview of the different topics that have been researched, a categorization has been made. To create this categorization, all papers found have been studied for correlations. Based on the found correlations, 3 main categories have been formulated. Every category represents a range of papers that more or less deal with the same subject. The categories are as follows:

- Category 1: foldable containers
- Category 2: foldable mechanisms
- Category 3: compliant mechanisms

In the fourth chapter, the results are discussed. The method and the databases are discussed, after which the results are discussed and a link is made with the master's thesis topic. Finally, the limitations of this study are indicated and recommendations for further research are made. A conclusion is drawn in the last chapter.

II. METHODS

The method used for this literature research is described in this chapter. It describes the method and sources used. In addition, the strategy used to find the articles is also described. The articles are selected based on criteria. These inclusion and exclusion criteria are also described here. Finally, a flowchart, see figure 2, shows how the articles have been processed.

A. Search strategy

To efficiently find the most relevant information, this literature search will be structured based on the search plan proposed by the TU Delft Library [2]. For a structured presentation of this search plan and the results, the item set for systematic review reporting, as proposed by PRISMA, will be used [3].

This literature search will be based on articles found in the Scopus and Google Scholar databases. For the total search query of three sections used for this literature research, see table 1. Initially, the PubMed and Web of Science databases were also used. However, these two databases gave too many results with the same search query. PubMed gave 59.128 results respectively and Web of Science gave 11.143 results respectively. After screening the first 10 pages of both these two databases for the title, it was decided not to use these databases. After that, it was decided to only perform the search query on Scopus. Google Scholar was mainly used for snowballing. Snowballing means taking an important publication and looking for more information or related topics. Scopus gave 6.323 results. After removing the words "method", "technology" & "system" from section 1, see table 1, the search query gave 1.684 results. To check that no important articles were excluded by removing these three words from section 1, the search query was run with only these three words in Section 1. This yielded 4.639 results. The first 10 pages were screened for the title and then it was concluded that these three words could be removed from section 1 without excluding important articles. Only articles in English are included in this literature research. This left 1.613 articles. These 1.613 articles were screened for the title, abstract, and the remaining full articles were assessed for relevance. The screening phase was carried out based on criteria that are explained in more detail in section II-B. A total of 34 articles were included in this literature research via the search query. In addition, 14 articles were added to this literature research via Google Scholar using snowballing. In total, 48 articles were used in this literature research. The search included articles describing foldable containers, foldable mechanisms and compliant mechanisms.

Table 1. Total search query

Section 1	Section 2	Section 3
"tool" OR "technique" OR "type" OR "design" OR "mechanism" OR "basket" OR "container" OR "box" OR "tray" OR "crate" OR "case"	"transport*" OR "OR wrapping" OR "sterile" OR "storage"	**fold* OR "adaptable" OR "hinge" OR "compliant" OR "deformable" OR "modular" OR "collapsible" OR "adjustable"

The asterisk (*) is placed to replace 0 or more characters to ensure that the plural is also considered and for example fold* can result in "foldable", "folding", "foldability" etc. The "" makes sure that words are found together. The concepts are combined with respectively the operator AND and the alternative search function with OR. The proximity operator (W/5) in Scopus is used to filter out irrelevant articles. This operator searches within five characters for the next topic.

B. Inclusion and exclusion criteria

In the screening phase of figure 2, inclusion and exclusion criteria are used to obtain the included studies. The information from the databases was stored in the citation manager End-note20. The title and abstracts are first screened for their title (phase 1). Titles dealing with transport, container, and foldable and compliant mechanisms are included. The other titles are excluded from this literature research. A few examples of titles that are excluded are titles about energy storage, railway transportation and carbon fibers. In table 2 all the inclusion- & exclusion criteria related to the title are summarized.

Table 2. Inclusion- & exclusion criteria screened on title

Inclusion criteria	Exclusion criteria
Transport	Anode, electrodes or actuator
Container	Batteries or energy storage
Modular structures	Chemical, biological, or molecular
Folding and box wrapping	Electromagnetic field
Compliant mechanism	Proteins or amino acid
	Pressure/stress/ sensor
	Polymeric and ceramic materials
	Railway transportation
	Membrane
	Carbon fibers

After that, the title in combination with the abstract is screened on relevance (phase 2). Abstracts in which foldable container transport, foldable mechanisms and compliant mechanisms were discussed are included in this literature research. Abstracts that dealt with protein folding and transport, polymers and composite materials and public transport, among others, were excluded from this literature research. In table 2 all the inclusion- & exclusion criteria related to the abstract are summarized.

Table 3. Inclusion- & exclusion criteria screened on abstract

Inclusion criteria	Exclusion criteria
Foldable container transport	Nutrient transport or transport through gel
Folding and box wrapping	Games to improve transportation
Foldability in transport industry	Polymers and composite materials
Compliant mechanisms	Energy consumption
Foldable mechanisms	Protein or membrane transport
	Public or port infrastructure transport
	Achieving global logistics sustainability
	Empty container repositioning problem
	Flexible energy storage devices
	Protein folding

After these steps, the full articles are screened (phase 3). Articles in which advantages & disadvantages and examples of foldable containers are discussed are included in this literature research. Articles in which an economic analysis of foldable containers was discussed have been excluded from this literature research. Articles with no full-text available were also excluded. In table 4 all the inclusion- & exclusion criteria related to the full articles are summarized.

Table 4. Inclusion- & exclusion criteria screened on full article

Inclusion criteria	Exclusion criteria
Examples of foldable containers	Construction of a container terminal
Advantages of foldable containers	Returnable container
Disadvantages of foldable containers	Vehicle routing planning
Foldable mechanisms	Container scheduling system
Compliant mechanisms	Folding mechanism for space transportation
	Modular components construction logistics
	Economic analysis
	Container transport problems
	Empty container repositioning problem
	Maritime transport

C. Data items

To show how the process of screening articles went, a PRISMA flow diagram was made, see figure 2.

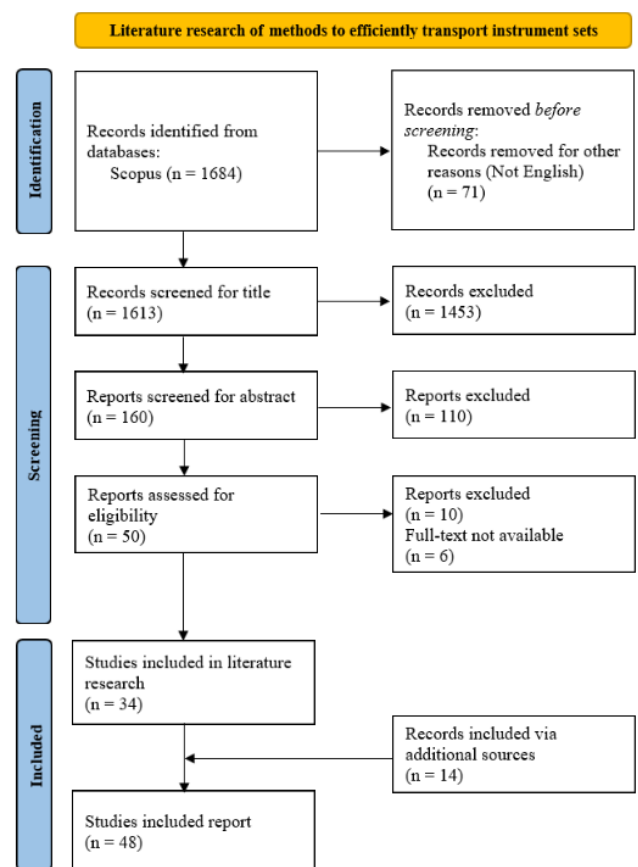


Figure 2. PRISMA flow diagram for literature research

For the synthesis, the data from the literature must be extracted. This is done by creating a data extraction table, see appendix A. The data extraction table is created in Microsoft Excel. The data extraction table discusses the various examples of foldable containers. Their folding directions and advantages & disadvantages are discussed.

III. RESULTS

In this chapter the results of the different categories are discussed. First the results of category 1: foldable containers are discussed, after which the results of category 2: foldable mechanisms are discussed. Finally, the results of category 3: compliant mechanisms are presented.

A. Category 1: foldable containers

Containers are nowadays widely used for the transport of goods. There are approximately 20 million containers in circulation worldwide, and this is rapidly increasing by 3 million containers per year [4]. The rise of containers is due to the need to transport goods over long distances, including between different continents [4]. Foldable containers, see figure 3 [5], are an emerging technology with many different advantages over standard containers [6]. Examples of companies that develop foldable containers are Holland Container Innovations, Cargoshell, American Staxxon, and the Korea Railroad Research Institute [7]–[9].

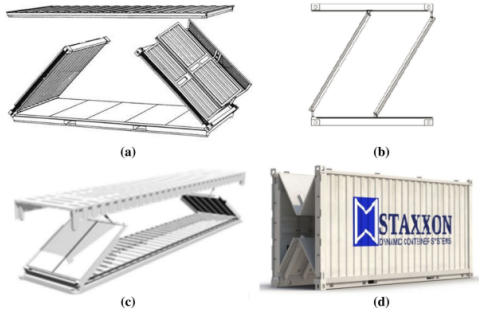


Figure 3. Example of foldable containers. a) Fallpac; b) ZBox; c) 4FOLD; d) Staxxon

Standard containers, see figure 4 [10] are nowadays the most commonly used containers. These containers have a standard size approved by the International Organization for Standardization (ISO): a Twenty-foot Equivalent Unit (TEU) which is a 20-ft container that is 5,894 m long, 2,376 m high, and 2,348 m wide, and a Forty-foot Equivalent Unit (FEU), which is a 40-ft container that is 12,031 m long, 2,376 m high, and 2,348 m wide [11]. In addition to standard containers, there are also many other types of different containers, such as reefer, flat rack, open-top, pen, tank, bulk, and ventilated containers.



Figure 4. 20-ft and 40-ft standard container

One of the problems with moving empty containers is that they require the same space for transport and storage as full containers. Foldable containers could be a solution to this problem [12]. Different types of foldable containers (containers with sides, ends, and base designed in a way that it folds up into a flat configuration) have been marketed, but there has not yet been a major breakthrough of foldable containers. One of the causes could be the costs (of the folding and unfolding process, manufacturing, maintenance, and repair) of such a foldable container. The advantage of a foldable container should be that less space is required for transport and storage when the container is empty, as it can be folded. For example, foldable containers would require 75% less space if they were transported empty [13]. In this way costs in terms of transport, handling, and storage can be saved [5]–[9], [11]–[19], [19]–[27]. Another additional advantage of foldable containers is that these foldable containers can be reused more often, reducing resource wastage [12]. Foldable containers can be important when it comes to sustainability. For example, when empty, 4 to 6 containers can be folded and stacked, so that they then have the same size as a standard container [5], [8], [15], [18] [17]. In addition, the use of foldable containers makes transport capacity more efficient. For example, fewer trucks are needed and the number of kilometers traveled by a truck is also less. Finally, fewer truck drivers are also needed, which helps with the shortage of truck drivers [13]. In addition, foldable containers could have a positive impact on the environment. For example, fewer trips of empty containers and fewer trucks are needed, so foldable containers could help reduce the carbon footprint [18], [22]. However, there are also several disadvantages to foldable containers. For example, the purchase costs, production costs, and repair costs of such foldable containers are high. In addition, there are additional costs for folding and unfolding the foldable containers, additional facilities and equipment are required and the risk of physical damage with the foldable containers is greater [5], [7], [9], [13], [18], [19], [19], [20], [20], [24], [26], [27].

Examples of foldable containers are shown below. These examples with their advantages and disadvantages are further discussed in section IV-C.

- 4FOLD
- Six-In-One (SIO)
- Fallpac container
- Cargoshell
- 5-tier foldable container
- 3-in-1 foldable container
- Foldable container in [14]
- Foldable container for sapota fruit
- Shipping bulk container
- Zbox
- Staxxon
- Collapsecon

B. Category 2: foldable mechanisms

Foldable mechanisms are used today in many different applications. One of the biggest advantages of foldable mechanisms is that it has compact storage [28]. 1 of the examples where it is used is in household tasks, such as folding clothes. Another application in the medical industry in which foldable mechanisms are often used today is in the packaging of boxes or baskets for surgical instruments [29], see figure 5. In [29], a method of folding fabrics or wrapping a box of fabric is proposed [29]. To make it as realistic as possible, domain randomization was applied and it was decided to convert the texture of the fabric and the box into simulation data [29]. The results of this study showed that this can be applied to fabrics and boxes of different colors, sizes, textures, and geometric shapes [29].

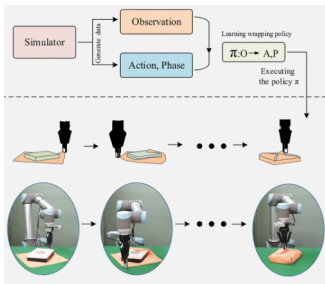


Figure 5. Robot arm wrapping a box

Another example of foldable mechanisms used in the medical industry is origami-inspired foldable structures, see figure 6.

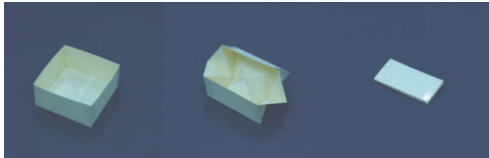


Figure 6. Prototype origami box

Rigid foldability and flat foldability are the properties to be considered for origami folding structures [30]. However, folding such an origami folding structure is a challenge. Therefore, different folding schemes, see figure 7, have been made available, but they all have their advantages and disadvantages [30].

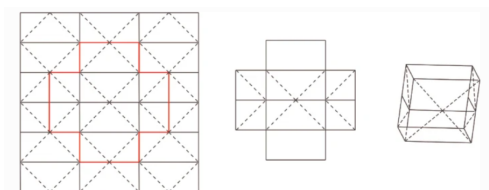


Figure 7. Crease pattern origami folding structure

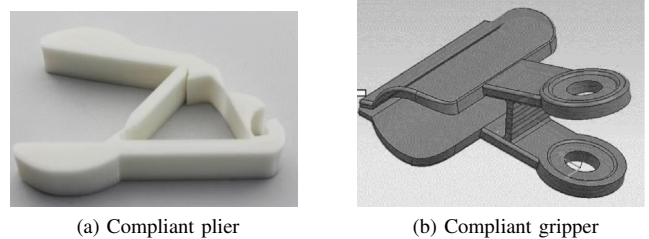
C. Category 3: compliant mechanisms

Compliant mechanisms are mechanisms with an alternative design that offer many advantages. See figure 8 for compliant mechanisms used in daily life.



Figure 8. Daily compliant mechanisms

Compliant mechanisms are considered compliant if the flexibility of the components is used to achieve something useful [31], [32]. It can thus be defined as ‘a monolithic flexible structure in which force and motion are transmitted using elastic deformation’ [33]. A very good example of a compliant mechanism in the human body is the heart. For example, it can endure a very long time and many cycles without failure. Factors that influence compliant mechanisms (and their flexibility) are load, geometry, and material properties [33]. Some advantages of compliant mechanisms are fewer parts, less wear, and tear, less weight, and savings in production costs [33], [34]. However, there are also challenges when designing a compliant mechanism, such as the flexibility of the compliant mechanism. It is not easy to create compliant mechanisms. Many iterations, different designs, and the right choice of materials are required to obtain the desired result of the compliant mechanism [34]. (The development of) Materials thus also play an important role in the advancement of compliant mechanisms over the past years. A material with high strength and low Young’s modulus is recommended for the design of a flexible and strong compliant mechanism. One of the examples is the 3D printing technology and the various materials involved. Compliant mechanisms have been used in recent years for various applications, such as the transport micromechanics, biomedical, and robotics industries. Examples of compliant mechanisms are shown in figures 9.



(a) Compliant plier

(b) Compliant gripper

Figure 9. Examples of compliant mechanisms

IV. DISCUSSION

This literature research gives an overview of the current literature about foldable containers, foldable mechanisms, and compliant mechanisms. In this chapter, first a general discussion on the method and databases will be presented. After that, the results of the study are discussed and a link is made with the master's thesis topic. Finally, the limitations of this research are pointed out and recommendations for future research are made.

A. Literature gap

Before starting this literature study, it was unknown how much literature would be found per category. Most literature appeared to be available on foldable containers. Most of the articles included in this literature research are in the field of foldable containers. However, part of the articles on foldable containers has been excluded because these articles dealt with empty container repositioning, which discusses the problem of empty containers at ports and the economic effects of this. The articles that are included in this literature study mainly focused on what foldable containers are, the advantages and disadvantages, and examples of such foldable containers. For the accuracy of the results, it would be good if more research was done into the design of foldable containers. Finally, the literature on foldable and compliant mechanisms was limited. It was mainly about what foldable and compliant mechanisms are and a few examples were mentioned.

B. Method and databases

As discussed in section II-A, the following databases were initially used: PubMed, Web of Science, Scopus and Google Scholar. Ultimately, only Scopus and Google Scholar were used. PubMed and Web of Science gave too many search results and after screening the first ten pages for titles, it was decided not to use these databases. After that, the entire search was carried out in Scopus. Google Scholar was mainly used for snowballing. For future research, it is recommended to use Google Scholar as an exploratory research first. You can then choose to use the first 10 pages, because the most interesting work can be found there. After this, the databases PubMed, Web of Science or Scopus can be used for the main search, because the search can be well structured within these databases. Subsequently, it is also important to adhere to broad inclusion criteria in the beginning to ensure that no relevant articles are missed.

C. Results

In this section, the results of category 1: foldable containers are discussed. Several examples are given, each with its advantages and disadvantages. The results of category 2: foldable mechanisms and category 3: compliant mechanisms are not discussed because too little literature was found for these categories.

An example of a new foldable container hoping for a breakthrough is the 5-tier foldable container see figure 10.



Figure 10. 5-tier foldable container

The advantage of this 5-tier foldable container compared to the existing foldable containers is that it is possible to stack 5 containers at the same time instead of the usual 4 containers, i.e., the folding ratio has changed from 4:1 to 5:1 [5]. Other requirements that such a foldable container should meet are low costs for folding and unfolding the containers, low manufacturing costs, compatibility with existing equipment for intermodal transport and structural robustness [5]. The folding and unfolding process of the 5-tier foldable container by means of a hinge mechanism, see figure 11 needs 2 persons and 2 forklifts. This process will take about 10 minutes [5].

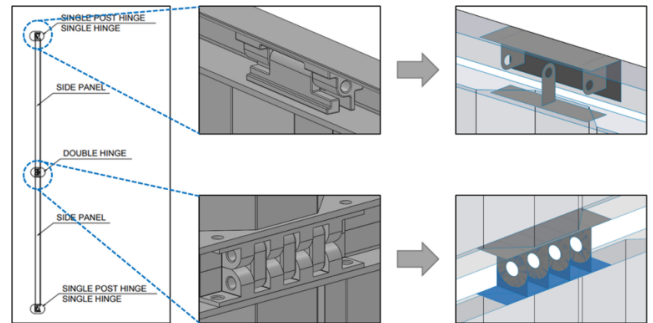


Figure 11. Hinge mechanism 5-tier foldable container

Another type of foldable container is the foldable container described in [14]. These foldable containers can be folded and unfolded without special equipment. In this way, these foldable containers can be easily folded and unfolded at any location [35].

An example of a foldable container that is easy to use is the 3-in-1 foldable container, see figure 12. This container is made in such a way that it is possible to fold and unfold the container using 1 button [12]. This way both costs and time can be saved, making these containers more economical and practical [12].

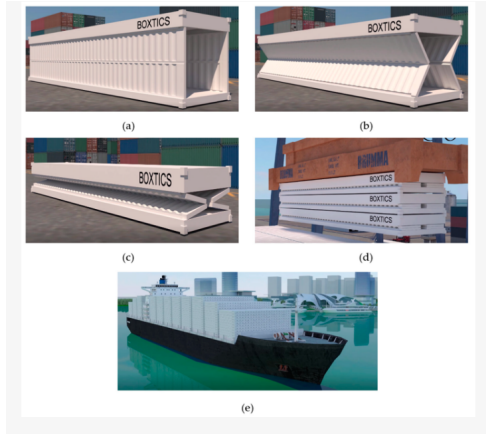


Figure 12. 3-in-1 foldable container

A completely different example of a foldable container is the foldable container designed for the transport of sapota fruit, see figure 13 (a type of fruit commonly used in India). This container is fully foldable and reusable [36]. (Sapota) Fruit is nowadays transported in different ways: wooden boxes, jute bags, baskets, cardboard boxes, plastic crates, trays, plastic bags, etc. [36]. These are all quite expensive, offer little safety, and usually have to be thrown away after 1 use [36]. This container has been specially developed to limit transport losses of the fruit. Divider sheets are provided to support the fruit, see figures 13 and 14. The container is folded using Velcro and is made of corrugated polypropylene (PP) sheet [36]. Furthermore, the container has been developed for a weight of 10 kg. The dimensions of the container are 390 x 325 x 245 mm with a weight of 1,400 kg. In addition, a full corner reinforcement has been applied on four corners for protection during transport. The folded dimensions of the container were 725 x 585 x 30 mm.

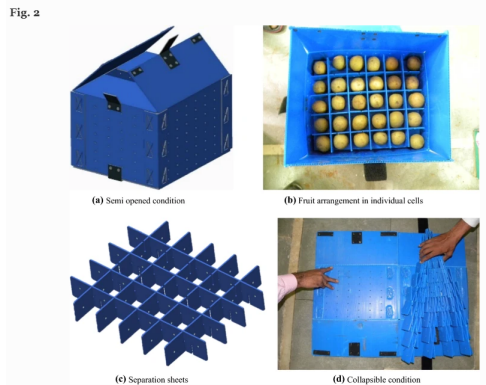


Figure 13. Developed transportation container

Fig. 1

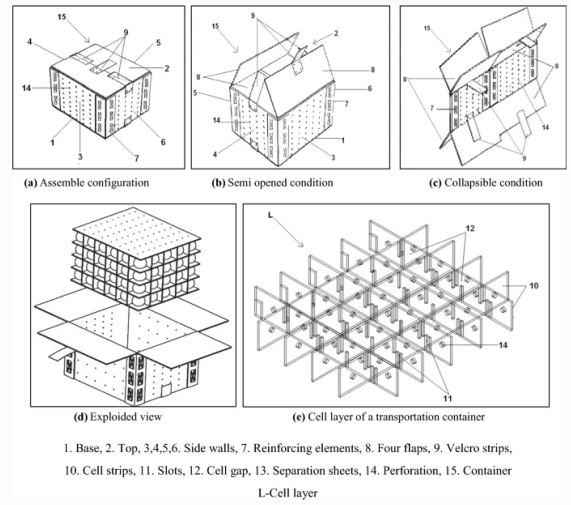


Figure 14. Different perspective views of transportation container

Another example of a foldable container is the shipping bulk container, see figure 15 [4].

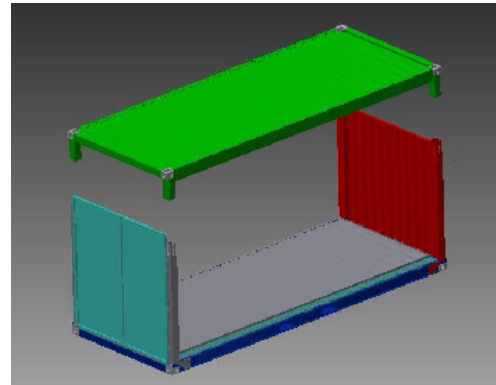


Figure 15. Shipping bulk container

This shipping bulk container consists of several parts that are attached using standardized molded corner cubes and a hinge mechanism, see figure

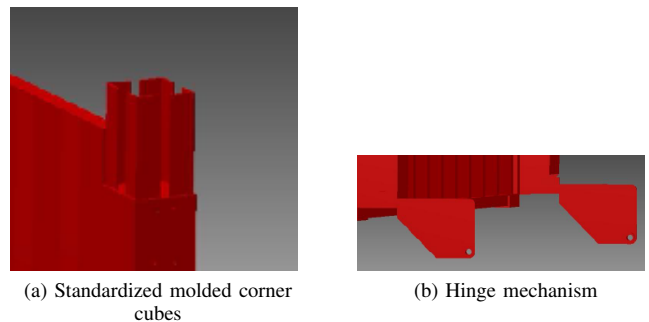


Figure 16. Standardized molded corner cubes & hinge mechanism

The folding mechanism works as follows: first, the roof is lifted with a crane, after which the side walls that are attached to the bottom are folded in using hinges. 1 wall is lower and it is mounted on a thin-walled profile because one wall can then be folded over the other wall. Finally, the front and back wall are folded. When using this folding container, four folded containers can be placed instead of 1 empty standard container, see figure 17.

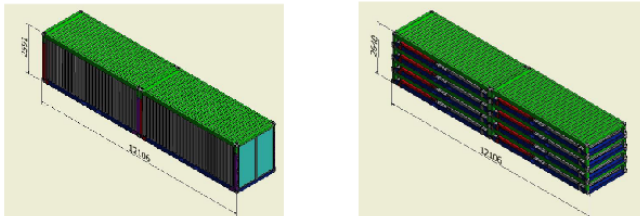


Figure 17. Unfolded & folded shipping bulk container

4FOLD is a foldable container produced by Holland Container Innovations [7]. Due to its space-saving, this foldable container can save up to 37% on CO2 emissions and costs [37]. This foldable container is folded using standard lifting equipment (reach stacker driver) with the help of 3 people in less than 4 minutes, see figure 18 [7].

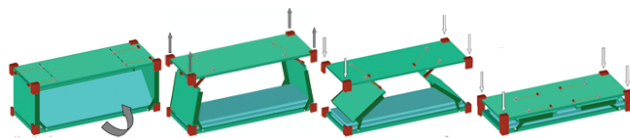


Figure 18. Folding process of the 4FOLD container

In total there are 60 different folding locations available all over the world [37], [38]. In this way, the 4FOLD is a very cost-effective foldable container. This 40ft foldable container can be folded to a quarter of its volume if it needs to be transported empty [37]. 4 folded containers can be transported as 1 standard container, see figure ?? [39]. This means that 1 truck is needed to transport 4 empty containers. As a result, fewer trips are required by sea and by land, which also reduces costs. A disadvantage of the 4FOLD is that it is slightly higher than a standard 40ft container and has a little less volume [38].



Figure 19. 4FOLD

The first commercialized foldable containers are the Six-In-One (SIO) container and the Fallpac container, see figure 20 and 21 [5], [22], [25], [26], [40].

The SIO container is a fully demountable 20 ft container that can be folded and stacked 6 high (when folded). It was designed 20 years ago by the Swiss company SIO Container Company (SCC). The first generation could bear a weight of 20 tons and the second generation could bear a weight of 24 tons. The most striking thing about this foldable container is the lack of hinges. A disadvantage of the SIO container is the higher tare weight compared to a standard container. The SIO container has a higher net weight of 500-600 kg [20]. Another disadvantage of the SIO container is that the costs for folding and unfolding the container and the purchase costs are too high [41]. A final problem of the SIO container is the damage and theft susceptibility [41]. The SIO container has 7 different elements that are connected using locks. As a result, production and manufacturing costs are very low. Not choosing hinges was related to the adverse effects of hinges such as corrosion, etc. [22], [25], [26], [40]. To fold the SIO container 3 persons and a forklift are needed and this will take more than 15 minutes [5].

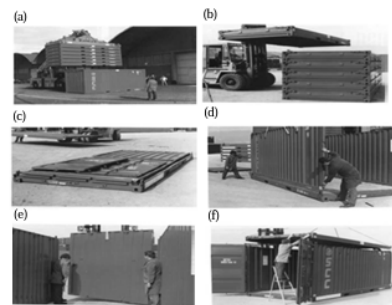


Figure 20. SIO container

The Fallpac container is a 20 ft container that uses demountable and foldable parts. The roof is demountable, and the rest of the parts are foldable, 4 folded containers can be stacked in a fifth erected container. Like the SIO container, the Fallpac can bear a weight of twenty-four tons. The tare weight of the Fallpac container is about 400 kg, which is about 1700 kg heavier than the tare weight of a standard 20 ft container [41]. A disadvantage of the Fallpac container is that two people and a forklift truck are required to fold and unfold the Fallpac container within 10 minutes [25], [26], [40], [42].

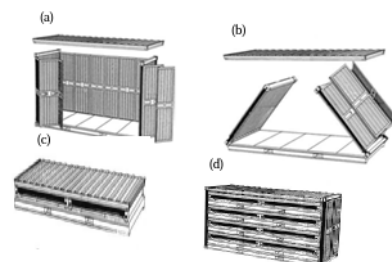


Figure 21. Fallpac container

Another foldable container is the Cargoshell, see figure 22, which is made of aluminum and composite materials. Composite offers many advantages to this foldable container. Composite, for example, is lighter than steel. This makes the cargo shell container 400 kg lighter than a standard steel container. In addition, composite is durable, easy to clean, and does not corrode [43], [44]. The cargo shell can be folded and unfolded by 1 person without any additional equipment. This process of folding and unfolding takes 30 seconds. It can also be done by 2 persons with additional equipment. However, this takes 30 minutes [44], [45]. The volume of the cargo shell when folded is a quarter of a standard container [44], [46]. A major disadvantage of the cargo shell is that it is about 3 times as expensive as a standard steel container [44], [47].



Figure 22. Cargoshell

The Zbox from Navlandis Logistics Technologies is another foldable container. This foldable container ensures that moving foldable containers is between 30% and 70% cheaper [48]. The Zbox also reduces CO2 emissions by 20%, the need for land for storage by 80% and the management costs for empty containers by 50%. When folded, the Zbox can transport 5 containers instead of 1 standard container, see figure 23 The folding process is easy and needs the standard machines for folding, see figure 24 The Zbox has no acquisition costs. The costs depend on the savings it generates.

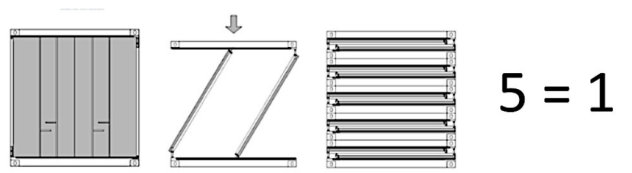


Figure 23. Zbox



Figure 24. Zbox folding mechanism

The Staxxon foldable container from the US and the Collapsecon foldable container from Australia are unique foldable containers. They fold into an accordion shape instead of horizontally [5]. Vertical stacking has the advantage of increasing stacking capacity and can be placed anywhere on a ship [49].

The Staxxon foldable containers can be folded like an Accordion as 2, 3, 4, or even 5 empty containers as 1 standard container [50], see figure 25 and 26.

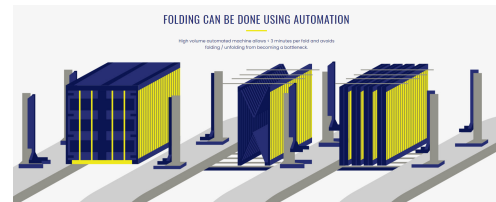


Figure 25. staxxon folding mechanism

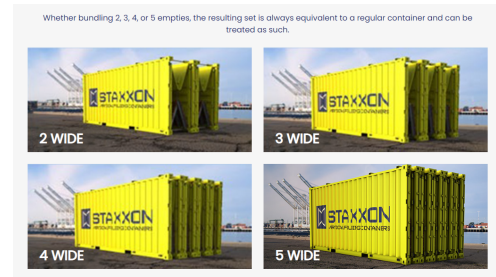


Figure 26. staxxon 2, 3, 4 of 5 containers

The panels and doors are folded inwards, the top is folded down and the bottom up and finally, one side is pushed to the other side. Using an automated machine, the folding process takes less than 3 minutes in total. In addition, it can also be done with 2 people with a forklift. This then takes about 10 minutes. An advantage of the Staxxon foldable containers is that fewer trucks are needed to transport the containers, see figure 27 [50].

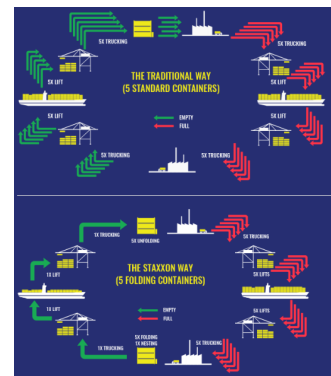


Figure 27. traditional way vs staxxon way

Collapsecon is a foldable container that can be folded up to 4 containers into 1 standard container, see figure 28 and 29.



Figure 28. Collapsecon



Figure 29. Collapsecon2

Just like the Staxxon container, it is folded like an accordion. Using an automated system, the folding process takes less than 2 minutes, see figure 30. There are also no loose parts. To ensure that the system is simple, efficient, affordable, and safe, collapsecon is designed to be folded/unfolded using the COS. Each container is touched only once in the process. In this way, the overall handling requirement is reduced. In addition, each unit assembles using the end frames, meaning there are no external parts.



Figure 30. Folding process of the Collapsecon foldable container

D. Relevance for master's thesis

My graduation project concerns a design project in which a stainless-steel surgical instrument set is designed for efficient transport. Such surgical mesh and wire baskets, in which instruments are cleaned, disinfected, sterilized, stored and transported have typically one size. This means that one fixed space cannot be optimized for the number of instruments that differ per surgical procedure. This creates an extensive empty space. This excessive space increases transport volume and extra surface for cleaning and disinfection. It is important to ensure that these instrument sets are more efficient for transport and storage. One of the ways to achieve this is by using a foldable mechanism, just like the foldable containers. One of the major disadvantages of such a foldable mechanism is usually that the costs will be higher. In this case, costs mean the costs for the folding and unfolding process, manufacturing, maintenance, and repair. The big advantage, however, is that less space is required for transport and storage. However, this in turn can save costs in terms of transport, handling, and storage.

E. Limitations and future research

This literature study aimed to provide an overview of foldable containers, foldable mechanisms, and compliant mechanisms. Comparable research does not exist in the literature. However, the fields of foldable containers are not completely comparable to instrument sets. Nevertheless, it has been interesting to research foldable containers and mechanisms and see if this can be applied to instrument sets for efficient transport. For further research, it would be interesting to do more research into the design and the choices behind these foldable containers. In addition, other markets could be considered where foldable mechanisms play an important role. Finally, further research could be done into the sterility of such foldable mechanisms.

V. CONCLUSION

This literature study aimed to map different mechanisms related to efficient transport of stainless steel surgical instrument sets. The different categories discussed here are foldable containers, foldable mechanisms, and compliant mechanisms. During this research, several examples of foldable containers emerged. First, foldable containers are explained, after which the advantages and disadvantages of foldable containers, in general, are mentioned. The biggest advantage of foldable containers is that they allow for more efficient transport because less space is needed for transport and storage when the container is empty. After all, it can be folded. On the other hand, the costs of foldable containers are higher. The costs included are costs for the folding and unfolding process, manufacturing, maintenance, and repair. Finally, 12 different foldable containers were discussed, each with its advantages and disadvantages. These 12 different foldable containers can be divided into two large groups: foldable containers that can be folded horizontally and foldable containers that can be folded vertically. 10 of the 12 foldable containers discussed in this literature study fall into the group that can be folded horizontally. An example is the Cargoshell, which can be folded and unfolded by 1 person without any additional equipment and takes less than 30 seconds. The other 2 foldable

containers fall into the group that can be folded vertically. An example is the Staxxon, which can be folded like an accordion as 2, 3, 4, or even 5 empty containers as 1 standard container. For further research, it would be important to look at the sterility of such foldable mechanisms. All in all, these foldable containers have proven that they can have a positive effect on efficient transport, and there is certainly potential to apply this to surgical instrument sets.

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APPENDIX A
DATA EXTRACTION TABLE

DATA EXTRACTION TABLE

Foldable container	Sources	Folding mechanism	Folding direction	Advantages	Disadvantages				
5-tier foldable container	[5]	The various parts of the 5-tier foldable container are connected to each other by means of hinges so that they can be easily rotated	Horizontal	- Low costs for folding and unfolding the containers	- 2 persons and 2 forklifts needed for folding process				
				- Low manufacturing costs	- Within 10 minutes				
				- Structural robustness					
				- 5:1 folding ratio					
3-in-1 foldable container	[12]]	The 3-in-1 foldable container is folded and unfolded by means of 1 button	Horizontal	- Costs and time saved	<i>No disadvantages found in literature</i>				
				Foldable container in [14]	[14], [35]	The foldable container in [14] is folded and unfolded without special equipment	Horizontal	- Easily folded and unfolded at any location	<i>No disadvantages found in literature</i>
								Foldable container for sapota fruit	[36]
				- Divider sheets to support the fruit	- It can be used for a weight of 10 kg				
				- Fully foldable and reusable					
				- Full container reinforcement on 4 corners for protection during transport					
Shipping bulk container	[4]	The shipping bulk container is folded as follows: first the roof is lifted with a crane, after which the side walls that are attached to the bottom are folded in by means of hinges. 1 wall is lower and it is mounted on a thin-walled profile because one wall can then be folded over the other wall. Finally, the front and back wall are folded.	Horizontal	- Several parts	- Screws needed for fixation				
				- 4:1 folding ratio					
				- Tunnels on the frame to transport the containers with forklift trucks					
4FOLD	[7], [37], [38], [39]	The 4FOLD is folded using standard lifting equipment with the help of 2 people in less than 4 minutes	Horizontal	- 60 different folding locations available all over the world	- 3 persons and standard lifting equipment (reach stacker driver) needed for folding process				
				- 4:1 folding ratio	- Slightly higher and little less volume than a standard 40 ft container				
				- Can be folded to a quarter of its volume if transported empty					
				- Less than 4 minutes					
				- Can save up to 37% on CO2 emissions					
				- Cost effective					
Six-In-One (SIO)	[40], [22], [25], [5], [26], [20], [41]	The Six-In-One (SIO) consists of 7 different elements that are connected to each other using locks	-	- Production and manufacturing costs low	- High costs for folding and unfolding and purchase costs				
				- 6:1 folding ratio	- Higher tare weight (500-600 kg more) than a standard container				
				- Can bear a weight of 24 tons	- Damage and theft susceptibility				
				- No hinges	- 3 persons and a forklift needed				
				- Fully dismantlable	- More than 15 minutes				
Fallpac container	[40], [22], [25], [26], [41]	The Fallpac container uses demountable and foldable parts. The roof is demountable and the rest of the parts are foldable, 4 folded containers can be stacked in a fifth erected container	Horizontal	- Can bear a weight of 24 tons	- 2 persons and a forklift needed				
				- Dismountable roof	- Within 10 minutes				
					- Higher tare weight than a standard container				
Cargoshell	[43], [46], [45], [47], [44]	The cargoshell can be folded and unfolded by 1 person without any additional equipment. This process of folding and unfolding takes 30 seconds. It can also be done by 2 persons with additional equipment. However, this takes 30 minutes.	Horizontal	- Made of aluminum and composite materials	- Can also be folded and unfolded by 1 person with additional equipment but takes then 30 minutes				
				- 400 kg lighter than a standard steel container	- 3 times as expensive as a standard steel container				
				- Can be folded and unfolded by 1 person without any additional equipment and takes less than 30 seconds					
				- 4:1 folding ratio					

DATA EXTRACTION TABLE

Fold-able container	Sources	Folding mechanism	Folding direction	Advantages	Disadvantages
ZBox	[48]	The folding process of the Zbox is easy and needs the standard machines for folding.	Horizontal	- Between 30% and 70% ' heaper	- Needs standard machines for folding
				- 5:1 folding ratio	
				- No acquisition costs. The costs depend on the savings it 'enerates	
Staxxon	[5], [50], [49]	The Staxxon can be folded like an Accordion as 2, 3, 4 or even 5 empty containers as 1 standard container. The panels and doors are folded inwards, the top is folded down and the bottom up and finally, one side is pushed to the other side. Using an automated machine, the folding process takes less than 3 minutes in total. In addition, it can also be done with 2 people with a forklift. This then takes about 10 minutes.	Vertical	- Folding process takes less than 3 minutes in total	- It can also be done with 2 people with a forklift. It then takes about 10 minutes
				- 5:1 folding ratio	- Automated machine needed
Col-lapsecon	[5], [50], [49]	The Collapsecon is folded like an accordion. Using an automated system, the folding process takes less than 2 minutes. There are also no loose parts. To ensure that the system is simple, efficient, affordable, and safe, collapsecon is designed to be folded/unfolded using the COS.	Vertical	- It takes less than 2 minutes	- Automated machine needed
				- 4:1 folding ratio	
				- There are no loose parts	
				- Each container is touched only once in the process, reducing the overall handling requirement	

Appendix B

Questionnaire instrument sets (NL)

Vragenlijst instrumentnetten

Naam	
Afdeling	
Functie	

Mijn afstudeeropdracht betreft een ontwerpproject waarin een herontwerp van de instrumentennetten (480x250mm (1/1 DIN)) met vlakke bodem (droog model), geperforeerde zijkanten en valhandgrepen, zie figuur 1, wordt gerealiseerd.

1 van de nadelen van het huidige ontwerp van deze instrumentnetten is dat deze instrumentnetten niet efficiënt getransporteerd kunnen worden als ze leeg worden opgeslagen of vervoerd. Het doel van dit herontwerp is efficiëntere opslag en transport.



*Figuur 1: instrument net
(480x250 mm (1/1DIN))*

1. Wat is volgens u het probleem van deze instrument netten met betrekking tot transport, reiniging en/of logistiek?

2. Wat zijn handelingen die u nu uitvoert als u in aanraking komt met deze instrumentnetten?

3. Wat zijn voor- nadelen van het huidige ontwerp van de instrument netten?

4. Wat zijn belangrijke eisen en wensen voor deze instrument netten?

5. Wat mist u in het huidige ontwerp van de instrument netten?

6. Wat zou u als gebruiker in het nieuwe ontwerp willen zien?

7. Overige opmerkingen?

Hartelijk dank voor het invullen van deze vragenlijst.

Uw medewerking levert een belangrijke bijdrage tot het nieuwe ontwerp!

Appendix C

Questionnaire instrument sets (EN)

Questionnaire instrument sets

Name	
Department	
Function	

My graduation assignment concerns a design project in which a redesign of the instrument sets (480x250mm (1/1 DIN)) with flat bottom (dry model), perforated sides and drop handles, see figure 1, is realized.

One of the disadvantages of the current design of these instrument sets is that these instrument sets cannot be transported efficiently if they are stored or transported empty. The aim of this redesign is more efficient storage and transport.



Figure 1: instrument set
(480x250 mm (1/1DIN))

-
1. In your opinion, what is the problem of these instrument sets in terms of transport, cleaning and/or logistics?
-
2. What are the actions you take now when you come into contact with these instrument sets?
-
3. What are the advantages and disadvantages of the current design of the instrument sets?

4. What are important requirements and wishes for these instrument sets?

5. What are you missing in the current design of instrument sets?

6. As a user, what would you like to see in the new design?

7. Other comments?

Thank you for completing this questionnaire.

Your cooperation makes an important contribution to the new design!

Appendix D

Results questionnaire

This questionnaire shows that the main problem of these instrument nets is that they cannot be stacked properly. In addition, the handles are a problem. They break down too quickly or instruments get in the way. Finally, this questionnaire shows that there is no good way to attach the nameplates to the instrument net.

Persoon	Afdeling	Functie	Probleem	Handelingen	Voor en nadelen	Eisen en wensen	Tekortkoming	Toevoeging	Opmerkingen
1	CSA	Operationeel manager	-	Ontvangst, reinigen/desinfecteren, inleggen/opdekken, verpakken &	Droogdroog uit de desinfectie machine Zand en meshbodem kunnen loslaten	Niet roesten	-	Betere meshbodem	-
2	CSA	Teamhoofd	Voor CSA geen probleem. Alleen moeilijk te stapelen	Uitsorteren, opdekken, inpakken, transporteren van instrument sets	Bij het stapelen in de stelling glijden ze van elkaar af	Niet scherp en niet te zwaar	-	Beter stapelbaar	-
3	CSA	MSMH	Geen. Fijne netten in gebruik, wassen, steriliseren en transport	Wassen, opdekken, inpakken, steriliseren en opruimen.	Geen. Gebruiken alleen gevulde sets en mogen ze niet stapelen	Stevig, goed veilig, goed wasbaar, goede maat	Hoeljes om makkelijk te stapelen bij leg transport	Onnodige investering vanuit dit standpunt	-
4	CSA	Medewerker ster. Med	Geen. Er mogen geen instrumentensets gestapeld worden	Transport, reiniging, nacontrole, inleggen, verpakken en steriliseren	Geen uitstekende delen, makkelijk in te pakken, past goed in transportbak/kar	Goed reinigbaar, makkelijk in gebruik, gaan lang mee ondanks intensief gebruik worden	Een inlay, maar die kan erin gemaakt worden	-	-
5	Logistiek	Hoofd logistiek	Niet goed stapelbaar, veel ruimte in beslag	Opslag en versturen	-	-	-	Beter stapelbaar	-
6	Logistiek	Medewerker	Niet goed stapelbaar, veel loze ruimte in om verpakingsdoos. Soms lastig om	-	-	-	-	-	-
7	Repar	Teamleider	Voorreiniging vaak te vol met instrumenten en voor vervoer	Tillen en leeg halen. De rand die los is vastzetten (lassen).	De hendel is niet handig. Er kunnen instrumenten tussen komen.	Stapelbaar	-	-	-
8	Fixatie	medewerker	Geen verpakking en informatie over de optieken	Fixatie controles	Niet sterk, kan makkelijk buigen. Zijkanten vaak ingedeukt	Veilige reiniging en transport	Een steke constructie	Een betere constructie	Netten zijn met transport vaak bol en ingedeukt.
9	Repar	Instrument maker	Instrumenten moeten vaker en beter gefixeerd worden in het net om	Instrumenten eruit halen, repareren, en terug plaatsen.	Stevig, maar soms bereikt het handvat af	-	-	Betere manier om alle instrumenten vast te zetten tegen beschadigingen.	-
10	Repar	Senior repar medewerker	Moeilijk stapelbaar	Revisie van de inhoud	Moeilijk te stapelen.	-	Makkelijk kunnen bevestigen van naamplaatjes	Als ze leeg zijn, dat ze in elkaar vallen voor transport.	-
11	Repar	Reparateur	Gewicht	Instrumenten erin & eruit halen en repareren.	Robuust	Moet robuust en waterdoodtafbaar zijn	Misschien lichter van gewicht	Er zijn natuurlijke vormen zoals honinggraat die zeer robuust zijn en	-
12	Repar/ planning	Senior repar planner	Geen deksel, instrumenten liggen los (snel beschadigen), instrumenten lastig	Reparatie/ revisie van de instrumenten	Fijne valhandgrepen. Soms scherpe randjes (instrumenten niet gefixeerd)	Instrumentarium open gefixeerd erin. Standaard met dekzen	Fixatie en deksel	Fixatie en deksel	-
13	CNC	Teamleider	Neemt teveel ruimte in beslag	Spoelstystemen inbouwen	Stiek, gaat lang mee, recyclebaar. Niet flexibel en neemt leeg veel ruimte in.	Niet Beschermen van instrumenten. Goede doorspoelbaarheid tbv reiniging	-	-	-
14	Fixatie	Snijden	Niet makkelijk stapelbaar	Stips reinigen	Makkelijk spoelbaar en gemakkelijk te bouwen. Slecht stapelbaar, mazen niet	Geen scherpe randen ivm beetpakken en assembleren of reinigen	-	Meer iduur variatie	-
15	Fixatie	medewerker	Geen probleem	-	Niet stevig genoeg	Goede net	-	Bodem wat sterker maken	-
16	Fixatie	medewerker	Niet goed stapelbaar	Assembleren	Veel verschillen in de netten, scherp	Geen scherpe randen	Ontwerp is prima. Alleen verbeteren	Betere/ andere handels	-
17	Fixatie	medewerker	Slecht stapelbaar	Instrument assemblage	Dunne mazen, verschillende maten, kromme bodem	Dikkere mazen, geen scherpe randen, niet krom	hulste maas maken	Stevigere bodem	-
18	Chirurgie HMC/ CEO	Chirurg/ CEO	Transport is volume/gewicht ongunstig. Als de netten eenmaal gevuld zijn met instrumenten eruit halen die later na de	Uitpakken en op sterile tafel zetten cq de instrumenten eruit halen die later na de verkoop.	Volume/ gewicht ongunstig	Laag gewicht, stevigheid, volledig makkelijk te reinigen, volume	-	Opgevooven voor vervoer maar eenmaal uitgevooven dan geen nadelen	-
19	Sales	Teamlead sales	Niet stapelbaar zonder verpakking. bodem is bij schade/loslaten draadstaal	Vanuit verkoop nagenoeg niets. Enkel verkoop.	Gestandaardiseerd in NL en komt droog uit sterilisatie proces. Randen en/of	Geen bramen, rvs, niet roesten	-	Beter stapelbaar, eventueel beter te repareren.	-
20	CSA	Teamhoofd	Door de vlakke bodem glijden ze van elkaar af (dus niet stapelbaar)	Netjes stapelen waarbij ze iets wat uit lood opgestapeld worden	Door de vlakke bodem glijden ze van elkaar af (dus niet stapelbaar)	Geen randen die ertoe leiden dat er drukpunten en/of ander soortig schade	Stabiele stapelbaarheid	Stabiele stapelbaarheid	-
21	IB	Functioneel beheer	Stapelen zeer instabiel wanneer leeg	Scheef stapelen	Instabiel, handvaten klemmen	Stapelbaar zijn	Stapelbaar, vast handgrepen	Stapelbaar, vast handgrepen	-
22	CSA	Senior zorgmanager	Bij navraag onder de medewerkers ervaren wij geen problemen bij de	De standaard procedure, volgens het protocol. Geen speciale handelingen zijn	Bij navraag onder de medewerkers zijn geen nadelen bij de instrumenten is dat er geen scherpe randen of kanten	Het belangrijkste bij elk instrumenten net is dat er geen scherpe randen of kanten	Bij navraag aan de medewerkers missen zij niet iets in het bijzonder	Bij navraag van de medewerkers hebben zij geen specifieke wensen, dan de voor het transport zien wij geen nadelen	Het benoemde nadeel in je inleiding: zij geen specifieke wensen, dan de voor het transport zien wij geen nadelen

* Original files available on request.

Appendix E

List of requirements

Requirements	Criteria
Must haves	Must haves
R-MH1: it must be made of Stainless Steel 304 or 316.	AC-MH1: it must be made of Stainless Steel 304.
R-MH2: it must be made with the following dimensions 480x250x60 mm (1/1 DIN).	AC-MH2: it must be possible to apply the design to different DIN sizes (e.g. 1/2 DIN).
R-MH3: it must be able to undergo steam sterilization.	AC-MH3: it must withstand temperatures of at least 134 degrees Celsius for at least 3 minutes.
R-MH4: it must be able to undergo alkaline and/or enzymatic cleaning.	AC-MH4: it must withstand disinfectant.
R-MH5: it must be possible to pack the instrument sets without tearing the wrapping paper.	AC-MH5: it must be a rounded whole without sharp edges and protruding parts.
Should haves	Should haves
R-SH1: it should come out drip-dry out of the disinfection machine.	AC-SH1: it should be permeable to water.
R-SH2: it should not be heavier than 8.5 kg when filled.	AC-SH2: the instrument set should be the same weight as current existing empty instrument sets with a 0.5 kg margin.
R-SH3: it should have a strong construction and be robust, in a way that the instrument set will not be damaged when filled with instruments.	AC-SH3: it should not bend, break or fall apart.
R-SH4: it should be possible to assemble and disassemble the instrument set without explanation.	AC-SH4: the assembly of the parts should take two minutes.
R-SH5: it should be possible that the maximum cost price is 30 euros.	AC-SH5: the costs should be as low as possible, where the material costs are a maximum of 10 euros and the manufacturing costs are a maximum of 20 euros.
Could haves	Could haves
R-CH1: it could be possible to transport the empty instrument sets efficiently.	AC-CH1: it could be possible to transport 4 empty instrument sets instead of 3 empty instrument set nowadays.
R-CH2: it could be possible to stack the instrument sets (empty and filled).	AC-CH2: it could be possible to stack 4 instrument sets empty and filled.
R-CH3: it could be possible to adjust the instrument set in the x or y direction.	AC-CH3: it could be possible to adjust the instrument set for different size instruments.
R-CH4: it could be possible to attach nameplates to the instrument sets.	AC-CH4: it could be possible to attach the nameplates to the instrument sets using an external part.
R-CH5: it could be possible to lift the instrument set using drop handles.	AC-CH5: it could be possible to lift the instrument set using drop handles and with a lid on it.



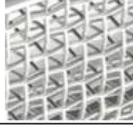
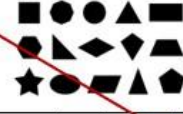
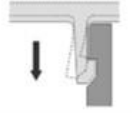






















Appendix F

Reasoning requirements and criteria for the instrument sets

Reasoning requirements and criteria	
Must haves	
R-MH1 & AC-MH1	The instrument set must 100% be made of Stainless Steel (SS) 304 or 316. It is desired to make it from Stainless steel 304. SS 304 is cheaper than SS 316 and they have almost the same properties. It is important that rust formation is prevented.
R-MH2 & AC-MH2	The design must be applicable to different DIN sizes. The most commonly used instrument sets are: 480x250x(40 or 60 or 100) mm 360x250x60mm 240x250x(40 or 60 or 100) mm
R-MH3 & AC-MH3	The instrument set must be able to undergo steam sterilization. The instrument sets must be able to tolerate at least 134 degrees Celsius for a minimum of 3 minutes and a maximum of 5 minutes.
R-MH4 & AC-MH4	The instrument set must be able to undergo alkaline (pH level of 7 or higher) and/or enzymatic cleaning. It must therefore withstand disinfectant, and it must be easy to clean with an open perforation of 4 mm. Ultrasonic cleaning possible.
R-MH5 & AC-MH5	The instrument set must be a nicely rounded whole without sharp edges and protruding parts. This reduces the risk of perforations when packing and unpacking. The top wire also prevents dirt from accumulating on the top of the basket. The instrument set must be able to be packed without tearing the wrapping paper. One of the options is that it can be electrolytically polished. The instrument set must be cuddly. It must have a flat bottom with perforated sides and drop handles, such that there are no voids or cavities for dirt to collect.
Should haves	
R-SH1 & AC-SH1	The instrument set should come out drip-dry out of the disinfection machine. It should therefore be permeable to water and withstand disinfection temperatures.
R-SH2 & AC-SH2	The instrument set when filled should not weigh more than 8.5 kg. Hospitals, however, maintain 8 kg. In addition, the instrument set should be the same weight as current existing empty instrument sets with a 0.5 kg margin.
R-SH3 & AC-SH3	It should have a strong construction and be robust, in a way that the instrument set will not be damaged when filled with instruments. The instrument set should not bend, break or fall apart. In addition, the edges and the bottom should not come loose. It should have a life cycle of at least 5 years
R-SH4 & AC-SH4	The assembly and disassembly of the instrument sets should be possible without explanation and takes two minutes. Parts should not come loose/ vibrate once assembled. In addition, parts should not protrude.
R-SH5 & AC-SH5	The maximum cost price should be 30 euros, where the material costs are a maximum of 10 euros and the manufacturing costs are a maximum of 20 euros.
Could haves	
R-CH1 & AC-CH1	The instrument set could be transported efficiently. Assembled, it could fit into transport containers. Unassembled, it could be able to be transported flat. Parts must not damage/scratch each other during transport. It could be possible to transport 4 empty instrument sets instead of 3 empty instrument set nowadays.
R-CH2 & AC-CH2	The instrument set could be stacked (empty and full). It could be possible to stack 4 instrument sets empty and full.
R-CH3 & AC-CH3	It could be possible to adjust the instrument sets for different size instruments in the x or y direction. For example, it could be possible to change the instrument set from 1 DIN to an instrument set of 1/2 DIN.
R-CH4 & AC-CH4	The nameplates could be attached to the instrument sets using an external part and will not be attached to the handles.
R-CH5 & AC-CH5	The instrument set could be lifted using drop handles with a lid on it. it could not be possible for the handles to break. No instruments could get between the handles.

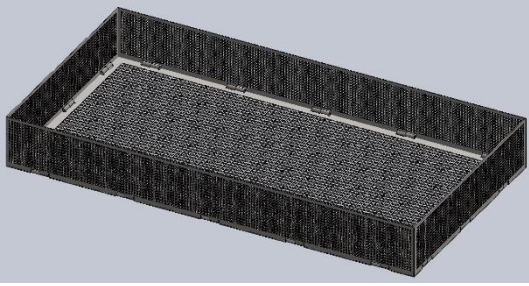
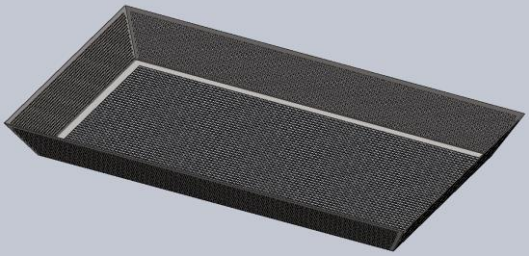
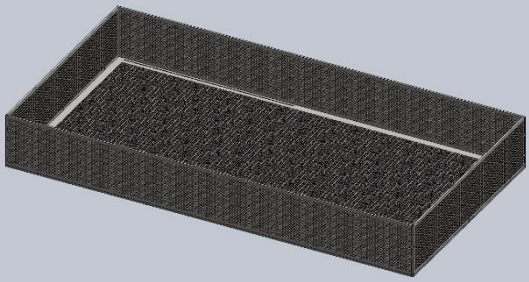
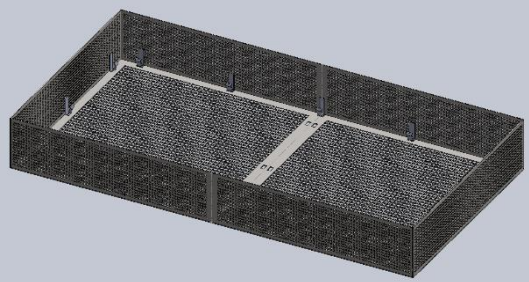
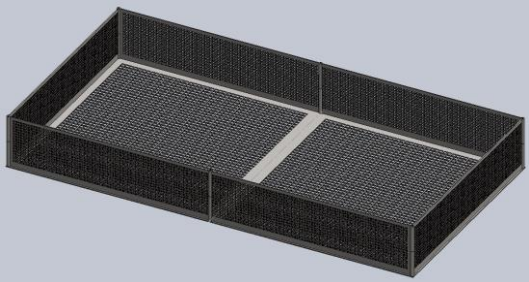
Appendix G

Morphological chart

Function	Solution 1 Hexagonal	Solution 2 Circular	Solution 3 Square	Solution 4 Other shape	Solution 5
Permeable to water					-
Efficient transport (when empty)	Click and snap mechanism 	Special bottom frame design 	Leaf spring 	Complete disassembly 	Foldable by hinge 
Stackable	Special bottom frame design 	Hupfer-locking mechanism 	Silicone corner pieces 	Stack mechanism 	Velcro 
Size reduction	-	-	Sliding mechanism 	Break lines 	Hinge 
Nameplates	Extendable nameplate 	Ring 	Clip 	Magnet 	Pin 
Handles	Outside 	Gap 	Standard 	Handle 	Rotatable 

Appendix H

Advantages and disadvantages of the different concepts

	Advantages	Disadvantages
<p>FOLDI</p> 	<ul style="list-style-type: none"> + Parts are easily replaceable + Foldable through a hinge mechanism + No additional stack mechanism in design + Nameplates easily attached with a ring + Standard handles 	<ul style="list-style-type: none"> - More time is needed to assemble - Not possible to adjust the size - Extra parts required to stack - Nameplates stick out - Instruments can come between the handles
<p>STACKI</p> 	<ul style="list-style-type: none"> + Easy to transport and store when empty + Easy to stack + Consist of one part + No time is needed to assemble. This saves costs and time + Easy nameplates and handles 	<ul style="list-style-type: none"> - Not possible to adjust the size
<p>CLICKI</p> 	<ul style="list-style-type: none"> + Parts are easily replaceable + Special stacking mechanism + Adjustable in shape + No additional part for nameplates + No instruments between handles 	<ul style="list-style-type: none"> - Click mechanism for efficient transport. This takes additional time and an extra action - Handles protrude on the outside
<p>LEAFI</p> 	<ul style="list-style-type: none"> + Parts are easily replaceable + Easy stacking mechanism + Adjustable in shape + No instruments between handles 	<ul style="list-style-type: none"> - Extra mechanism for efficient transport. This takes additional time and an extra action - Nameplates - Handles protrude on the outside
<p>HINGI</p> 	<ul style="list-style-type: none"> + Adjustable in shape + Efficient for different types of instruments + Parts are easily replaceable + Rotatable handles 	<ul style="list-style-type: none"> - Extra mechanism for efficient transport. This takes additional time and an extra action - Stackable through Velcro - Magnet nameplates

Appendix J

Part list

Table J1: An overview of all the parts used to build the 1 DIN prototype.

Name	Quantity	Material	Figure
Bottom	1	Steel	Figure K1
Corner	4	Polylactic acid (PLA)	Figure K2
Long side	2	Steel	Figure K3
Short side	2	Steel	Figure K4

Table J2: An overview of all the parts used to build the 1/2 DIN prototype.

Name	Quantity	Material	Figure
Bottom	1	Steel	Figure K6
Corner	4	Polylactic acid (PLA)	Figure K7
Long side	2	Steel	Figure K8
Short side	2	Steel	Figure K9

Appendix K

Prototype parts and assembly

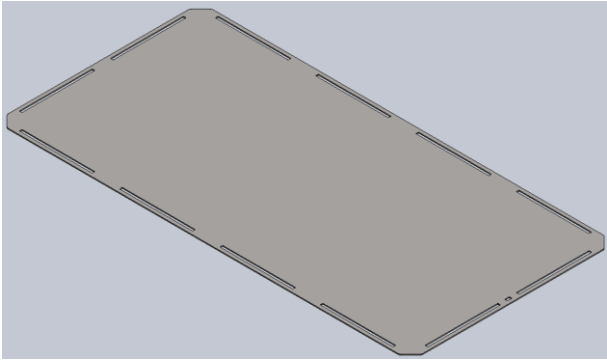


Figure K1: 3D model of the bottom of the 1/1 DIN prototype



Figure K2: 3D model of the corner

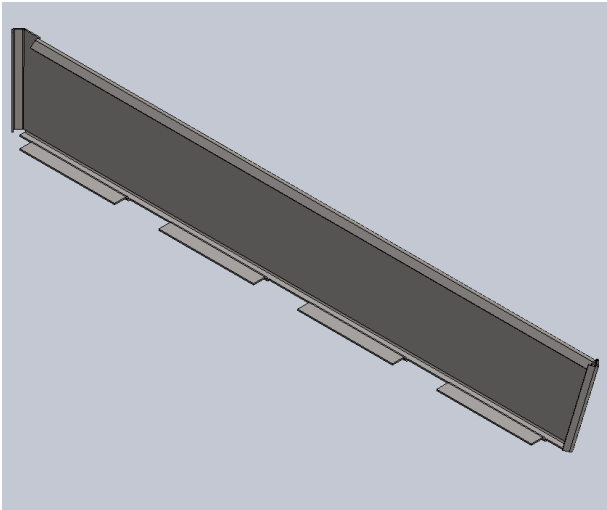


Figure K3: 3D model of the long side of the 1/1 DIN prototype

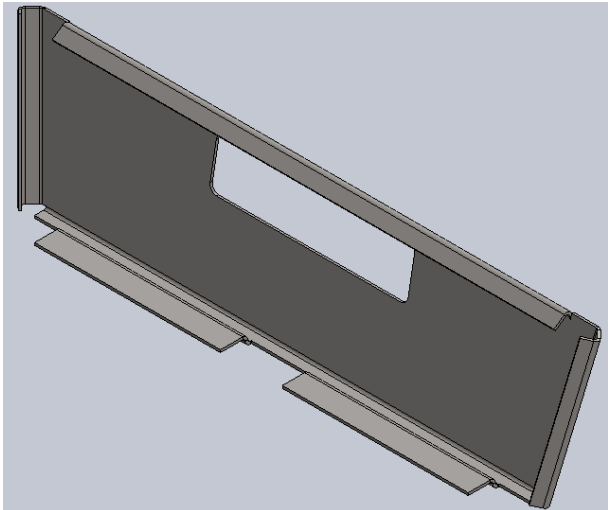


Figure K4: 3D model of the short side of the 1/1 DIN prototype

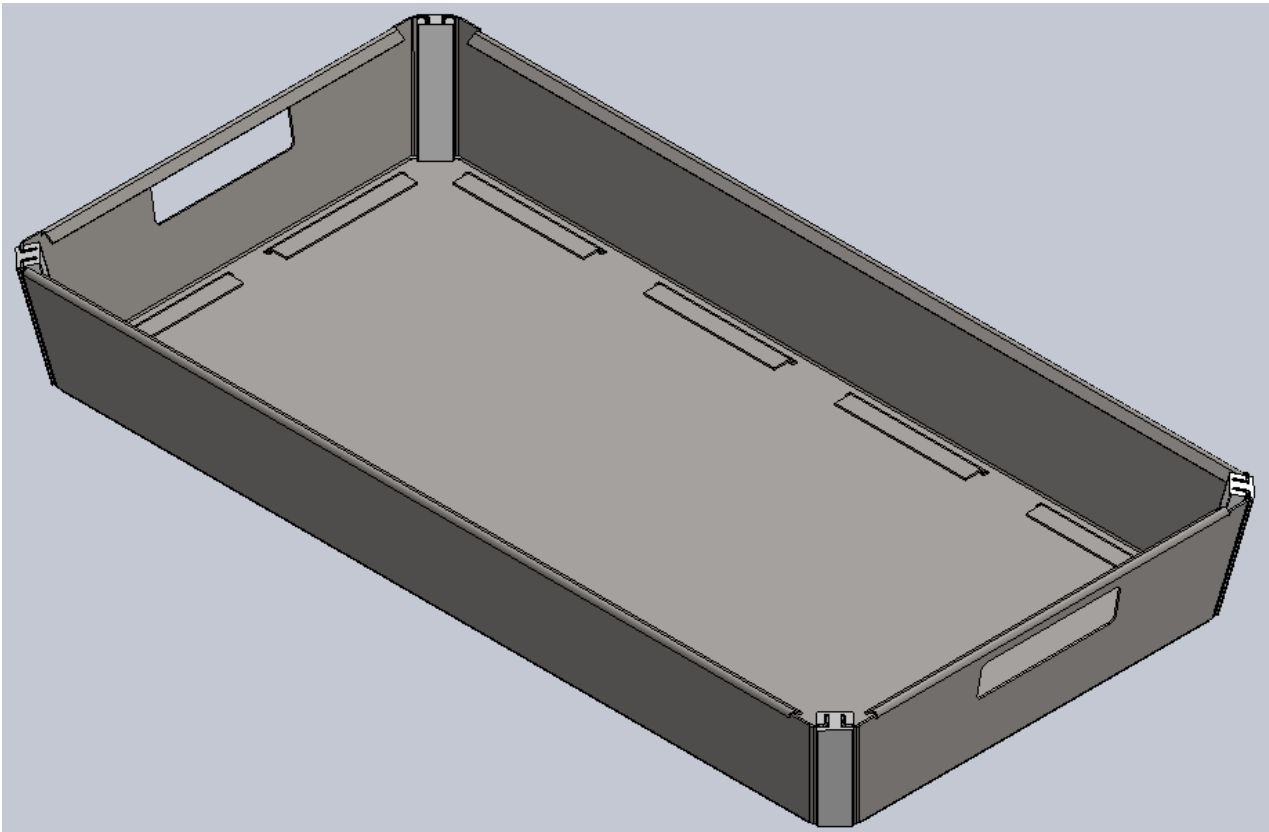


Figure K5: 3D model of the 1/1 DIN prototype

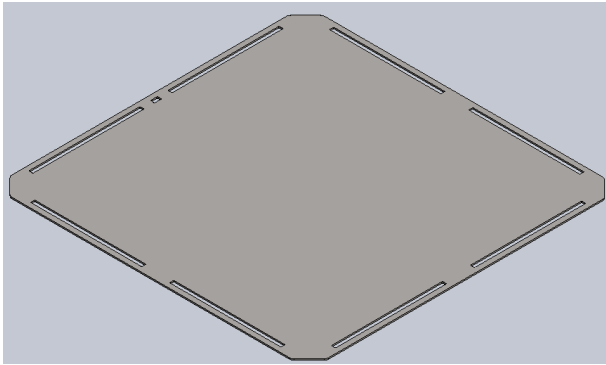


Figure K6: 3D model of the bottom of the 1/2 DIN prototype



Figure K7: 3D model of the corner

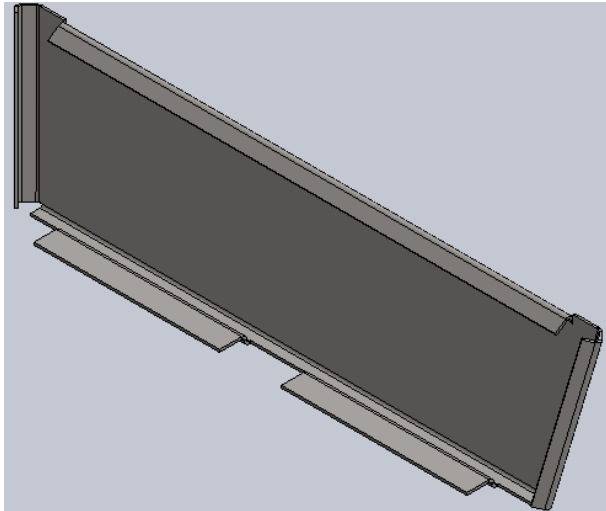


Figure K8: 3D model of the long side of the 1/2 DIN prototype

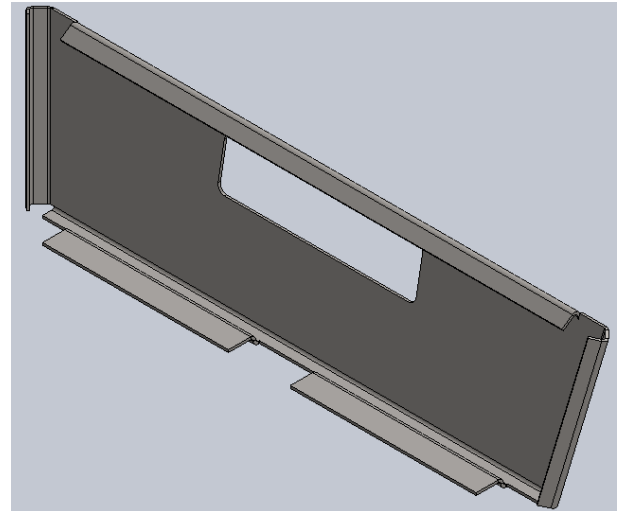


Figure K9: 3D model of the short side of the 1/2 DIN prototype

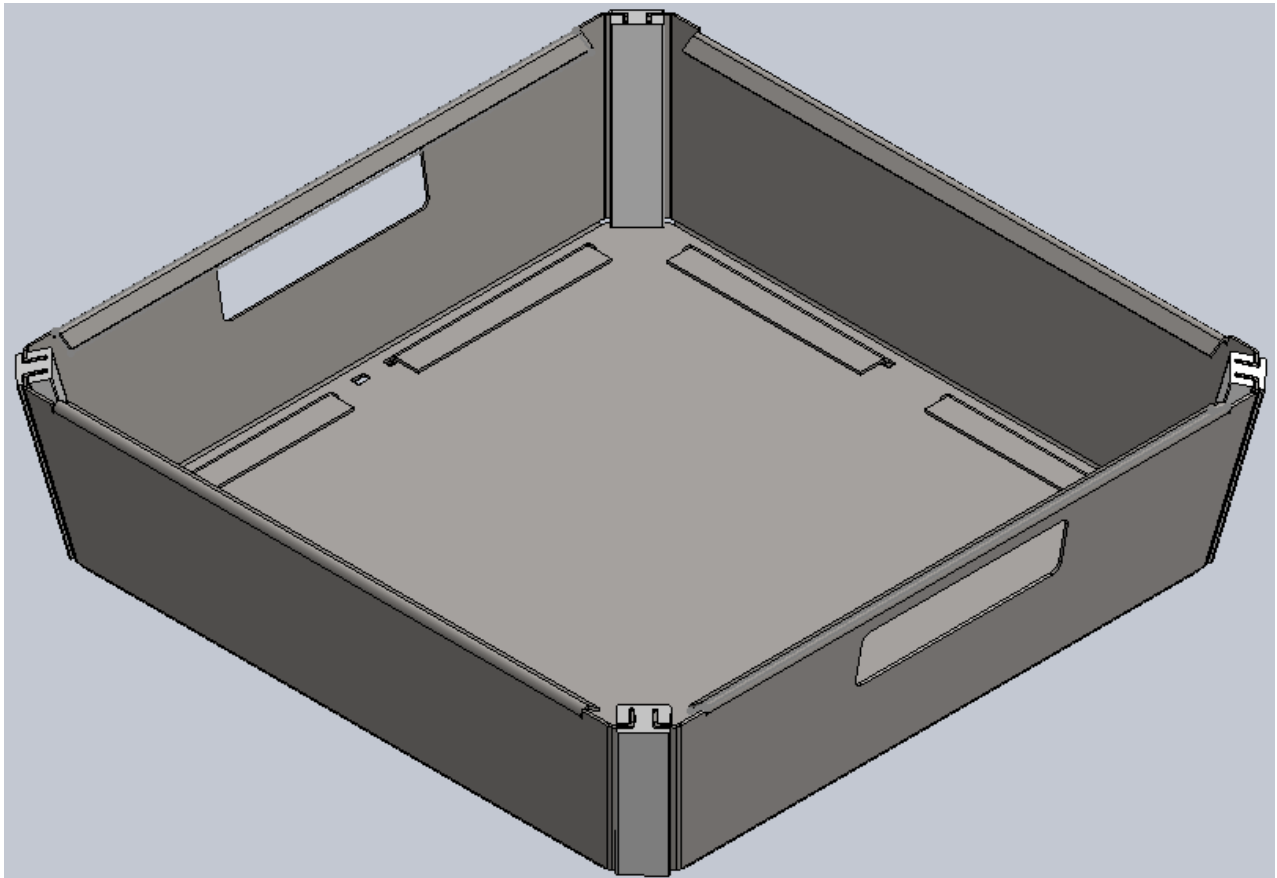


Figure K10: 3D model of the 1/2 DIN prototype

Appendix L

Test protocol

Paper test (MH5)

Introductie

Om te valideren dat het prototype geen scherpe hoeken of uitstekende delen heeft wordt er een polypropyleen papier test gedaan. Deze test houdt in dat het prototype met polypropyleen papier gewikkeld op de tafel wordt geschoven, op dezelfde manier als in ziekenhuizen. Op deze manier kan er getest worden of het papier kapot gaat door eventuele scherpe zijanten of uitstekende delen.

Het doel van deze test is om te verifiëren dat het net geschikt is om ingepakt te worden door steriel PP papier. Er is gebruik gemaakt van 2 laags PP papier en de pakket methode voor het inpakken. De acceptance criteria voor het beoordelen van de test worden als volgt gedefinieerd: ten eerste mag de integriteit van het papier niet worden beschadigd door het instrumentennet. Oftewel er mogen geen gaten in het PP papier zitten. Dit wordt gecontroleerd door het PP papier na de test langs het raam te houden en om te kijken of er licht door komt door eventuele gaatjes.

Voordat dat deze test uitgevoerd wordt, moeten de verschillende onderdelen ‘getrommeld zijn’, om de kans op scherpe hoeken en uitstekende delen te verkleinen. Daarnaast kan er gekozen worden indien nodig om het instrumentennet extra te veilen of glad te maken.

Apparatuur

Er wordt gebruik gemaakt van twee test items: het 1/2 DIN prototype en 1 DIN prototype. Zie tabel 1 en 2 voor de details van deze test items en zie tabel 3 voor de onderdelen die vereist zijn.

Tabel 1: details 1/2 DIN prototype

Beschrijving	Instrument net 1/2 DIN
Dimensies (L x B x H)	240 x 250 x 60 mm
Gewicht	1.00 kg
Figuur	Figuur 28

Tabel 2: details 1 DIN prototype

Beschrijving	Instrument net 1 DIN
Dimensies (L x B x H)	480 x 250 x 60 mm
Gewicht	1.67 kg
Figuur	Figuur 30

Tabel 3: onderdelen vereist

Polypropyleen (PP) papier en tape
Camera/telefoon

Test procedure

Tabel 4: stappenplan van de papier test

<u>Vorbereiding</u>	1. Vind een geschikte testruimte met een tafel
	2. Zet het prototype (1/2 DIN) in elkaar
	3. Pak het prototype in met polypropyleen papier.
<u>Papier test</u>	4. Laat het prototype leeg 8 keer voor 30 seconde over de tafel schuiven. 40 cm naar boven en 40 cm naar links. Terug naar de beginstand. 40 cm naar beneden en 40 cm naar rechts. 90 en 180 graden draaien. Optillen en terug. 3 keer leeg met het prototype, 3 keer gevuld met instrumenten met het prototype, 1 keer leeg met een bestaand instrumentennet ter controle en 1 keer gevuld met instrumenten met een bestaand instrumentennet ter controle.
	5. Controleer of het polypropyleen papier beschadigd is.
<u>Herhaal</u>	6. Zet het prototype (1 DIN) in elkaar.
	7. Herhaal de test met het 1 DIN prototype

User test (SH4, CH3, CH4, CH5)

Introductie

Om het prototype te valideren wordt het getest door de gebruiker. Met deze test kan het gebruikersgemak worden getest en eventueel feedback verwerkt worden voor toekomstig onderzoek.

Deze test houdt in dat het prototype door de gebruiker in elkaar wordt gezet en uit elkaar wordt gehaald. Eerst wordt er geen uitleg gegeven en daarna kan de gebruiker het opnieuw proberen met een uitleg. Dit kan geobserveerd worden en de tijd kan gemeten worden. De gebruiker kan het prototype daarna optillen en ermee rondlopen, eerst leeg zonder instrumenten en daarna gevuld met instrumenten om de handvaten te testen. Tenslotte moet de gebruiker het prototype inpakken in het PP papier om te kijken of dit eventuele problemen oplevert en extra tijd kost. Daarna moet de gebruiker exact dezelfde testen uitvoeren met het 1 DIN prototype.

Zie appendix N, voor het test plan gemaakt voor de gebruiker.

Apparatuur

Er wordt gebruik gemaakt van twee test items: het 1/2 DIN prototype en 1 DIN prototype. Zie tabel 1 en 2 voor de details van deze test items en zie tabel 3 voor de onderdelen die vereist zijn.

Tabel 1: details 1/2 DIN prototype

Beschrijving	Instrument net 1/2 DIN
Dimensies (L x B x H)	240 x 250 x 60 mm
Gewicht	1.00 kg
Figuur	Figuur 28

Tabel 2: details 1 DIN prototype

Beschrijving	Instrument net 1 DIN
Dimensies (L x B x H)	480 x 250 x 60 mm
Gewicht	1.67 kg
Figuur	Figuur 30

Tabel 3: onderdelen vereist

Polypropyleen (PP) papier
Tape
(Chirurgische) instrumenten
Telefoon: camera en timer

Test procedure

Tabel 4: stappenplan van de user test

<u>Voorbereiding</u>	1. Vind een geschikte testruimte met een tafel 2. Laat de gebruiker de introductie vragen beantwoorden
<u>User test</u>	3. Laat het prototype (1/2 DIN) door de gebruiker in elkaar zetten en uit elkaar halen en meet de tijd hiervan. De eerste twee keer zonder uitleg en daarna twee keer met uitleg. 4. Laat de gebruiker de handvaten testen door het op te tillen en vast te pakken. Eerst twee keer leeg en daarna twee keer gevuld met instrumenten. 5. Laat de gebruiker het prototype (1/2 DIN) twee keer in pakken met polypropyleen (PP) papier.
<u>Herhaal</u>	6. Herhaal de test met het 1 DIN prototype (stap 3-5)
<u>Afsluiting</u>	7. Laat de gebruiker de afsluitende vragen beantwoorden

Drop test (SH3)

Introductie

Om de sterkte en robuustheid van het prototype te controleren, wordt er een mechanische val test (ISO 7965-1) [1] gedaan. Deze test houdt in dat het prototype van 1.20 meter naar beneden valt op een harde ondergrond. Dit is een ISO gestandaardiseerde test [1]. Op deze manier kan er gekeken worden wat er kapot gaat aan het prototype. Deze test wordt zonder (chirurgische) instrumenten gedaan.

Het doel van deze test is om te verifiëren met objectieve bewijs dat het prototype geschikt is voor transport. De acceptance criteria voor het beoordelen van de test worden als volgt gedefinieerd: ten eerste mag het prototype niet omgebogen zijn na het einde van de test. Daarnaast mag het prototype niet gebroken zijn. Tenslotte mag het prototype niet uit elkaar gevallen zijn.

Deze test wordt als laatste uitgevoerd voor het geval het prototype kapot gaat en de overige tests niet uitgevoerd kunnen worden. Voor het begin van deze test, wordt ervoor gezorgd dat er genoeg afbeeldingen zijn gemaakt voor het verslag.

Apparatuur

Er wordt gebruik gemaakt van twee test items: het 1/2 DIN prototype en 1 DIN prototype. Zie tabel 1 en 2 voor de details van deze test items en zie tabel 3 voor de onderdelen die vereist zijn.

Voor de aanvang van de test zijn de test items gecontroleerd op eventuele visuele beschadigingen.

Tabel 1: details 1/2 DIN prototype

Beschrijving	Instrument net 1/2 DIN
Dimensies (L x B x H)	240 x 250 x 60 mm
Gewicht	1.00 kg
Figuur	Figuur 28

Tabel 2: details 1 DIN prototype

Beschrijving	Instrument net 1 DIN
Dimensies (L x B x H)	480 x 250 x 60 mm
Gewicht	1.67 kg
Figuur	Figuur 30

Tabel 3: onderdelen vereist

Rolmaat
Camera\telefoon

Test procedure

Tabel 4: stappenplan van de val test

<u>Voorbereiding</u>	1.Vind een geschikte testruimte met een vlakke en harde vloer
	2.Zet het prototype (1/2 DIN) in elkaar
	3.Bepaal de juiste hoogte (1.2 m) voor de val test
	4.Controleer voor aanvang van de test of het prototype visuele beschadigingen heeft
<u>Val test</u>	5.Laat het prototype 10 keer leeg van verschillende kanten van de juiste hoogte (1.2 m) vallen.
	6.Controleer of het prototype beschadigd is en maak foto's
<u>Herhaal</u>	7.Zet het prototype (1 DIN) in elkaar.
	8.Herhaal de test met het 1 DIN prototype

[1] ISO/TC 198 Sterilization of health care products. (1984). Packaging — Sacks — Drop test — Part 1: Paper sacks (ISO 7965-1:1984). [Online]. Available: <https://www.iso.org/standard/14942.html>

Appendix M

Figures of the tests

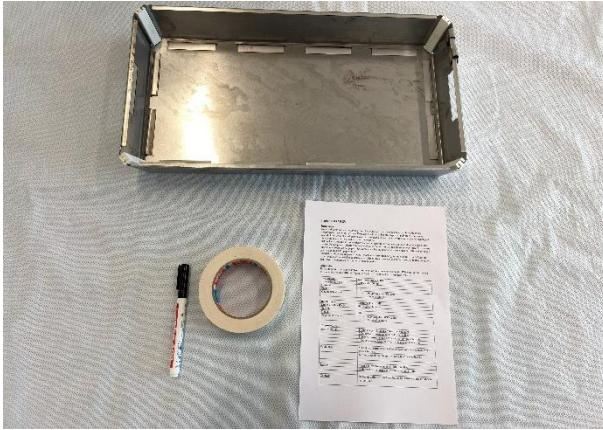


Figure M1.1: set up of the paper test(1/1 DIN)

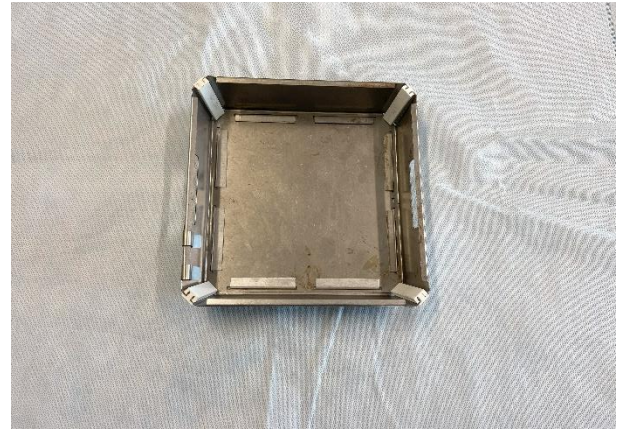


Figure M1.2: set up of the paper test(1/2 DIN)



Figure M1.3: 1/1 DIN prototype packed



Figure M1.4: 1/2 DIN prototype packed



Figure M1.5: performing paper test (1/1 DIN)



Figure M1.6: performing paper test (1/2 DIN)



Figure M1.7: prototype (1/1DIN) with instr.



Figure M1.8: prototype (1/2DIN) with instr.



Figure M1.9: control set (1/1DIN) with instr.



Figure M1.10: control set (1/2DIN) with instr.



Figure M2.1: paper test 1 (1/2 DIN)



Figure M2.2: paper test 2 (1/2 DIN)



Figure M2.3: paper test 3 (1/2 DIN)



Figure M2.4: paper test 4 (1/2 DIN)



Figure M2.5: paper test 5 (1/2 DIN)



Figure M2.6: paper test 6 (1/2 DIN)



Figure M2.7: paper test 7 (1/2 DIN)



Figure M2.8: paper test 8 (1/2 DIN)



Figure M3.1: paper test 1 (1/1 DIN)



Figure M3.2: paper test 2 (1/1 DIN)



Figure M3.3: paper test 3 (1/1 DIN)



Figure M3.4: paper test 4 (1/1 DIN)



Figure M3.5: paper test 5 (1/1 DIN)



Figure M3.6: paper test 6 (1/1 DIN)



Figure M3.7: paper test 7 (1/1 DIN)

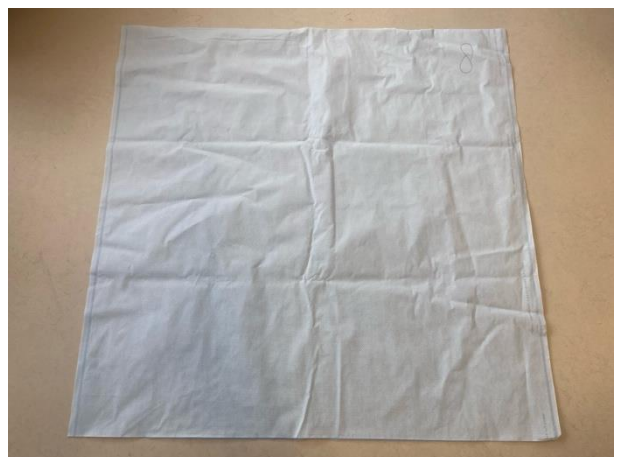


Figure M3.8: paper test 8 (1/1 DIN)



Figure M4.1: set up of the user test



Figure M4.2: Harry reviewing the prototype



Figure M4.3: Harry assembling 1/2DIN prototype



Figure M4.4: Harry assembling the prototype



Figure M4.5: Harry walking with 1/2DIN prototype

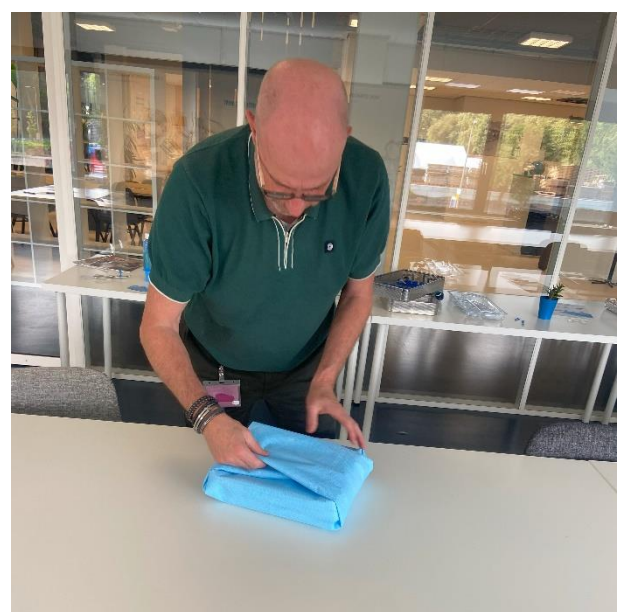


Figure M4.6: Harry packing 1/2DIN prototype



Figure M4.7: Harry assembling 1/1DIN prototype

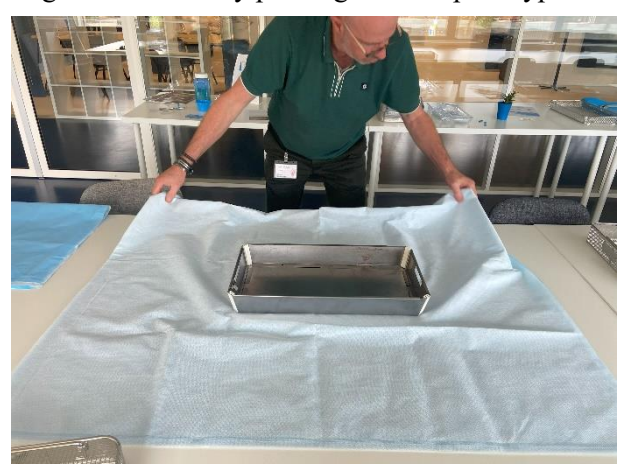


Figure M4.8: Harry packing 1/1DIN prototype

Appendix M5. Before the drop test (1/2 DIN)



Figure M5.1: Surface 1 (1/2 DIN)



Figure M5.2: Edge surface 1-2 (1/2 DIN)



Figure M5.3: Surface 2 (1/2 DIN)



Figure M5.4: Edge surface 2-3 (1/2 DIN)



Figure M5.5: Surface 3 (1/2 DIN)



Figure M5.6: Edge surface 3-4 (1/2 DIN)



Figure M5.7: Surface 4 (1/2 DIN)



Figure M5.8: Edge surface 4-1 (1/2 DIN)



Figure M5.9: Bottom (1/2 DIN)



Figure M5.10: Top (1/2 DIN)



Figure M6.1: Surface 1 (1/1 DIN)



Figure M6.2: Edge surface 1-2 (1/1 DIN)



Figure M6.3: Surface 2 (1/1 /DIN)



Figure M6.4: Edge surface 2-3 (1/1 DIN)



Figure M6.5: Surface 3 (1/1 DIN)



Figure M6.6: Edge surface 3-4 (1/1 DIN)



Figure M6.7: Surface 4 (1/1 DIN)



Figure M6.8: Edge surface 4-1 (1/1 DIN)



Figure M6.9: Bottom (1/1 DIN)



Figure M6.10: Top (1/1 DIN)

Appendix M7. After the drop test (1/2 DIN)



Figure M7.1: Surface 1 (1/2 DIN)



Figure M7.2: Edge surface 1-2 (1/2 DIN)



Figure M7.3: Surface 2 (1/2 DIN)



Figure M7.4: Edge surface 2-3 (1/2 DIN)



Figure M7.5: Surface 3 (1/2 DIN)



Figure M7.6: Edge surface 3-4 (1/2 DIN)



Figure M7.7: Surface 4 (1/2 DIN)



Figure M7.8: Edge surface 4-1 (1/2 DIN)



Figure M7.9: Bottom (1/2 DIN)

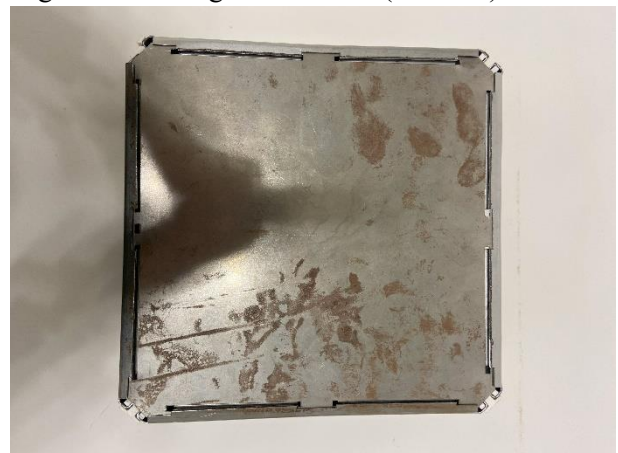


Figure M7.10: Top (1/2 DIN)



Figure M8.1: the prototype broken (1/1 DIN)



Figure M8.2: the prototype broken (1/1 DIN)

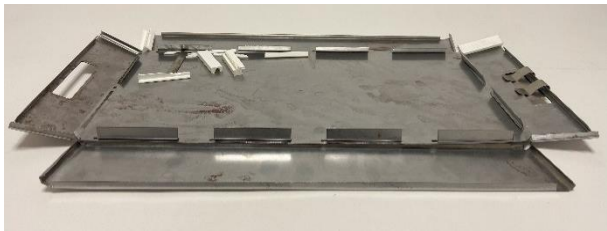


Figure M8.3: after the drop test (1/1 DIN)



Figure M8.4: the corners broken (1/1 DIN)

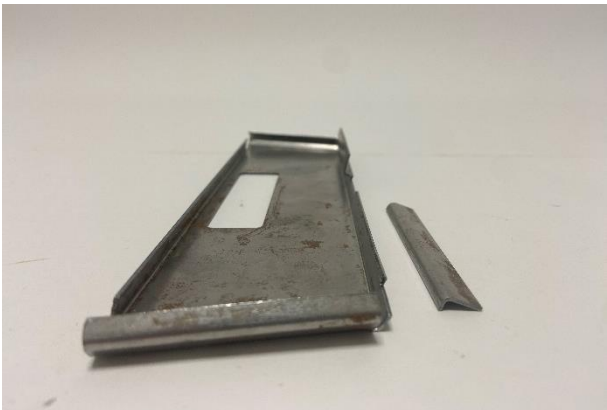


Figure M8.5: short side broken (1/1 DIN)

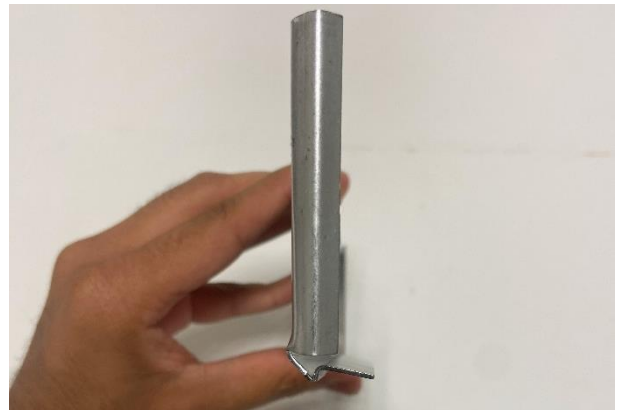


Figure M8.6: short side dented (1/1 DIN)



Figure M8.7: short side dented (1/1 DIN)

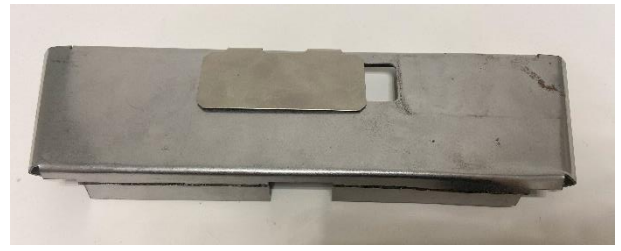


Figure M8.8: short side dented (1/1 DIN)



Figure M8.9: bottom dented (1/1 DIN)

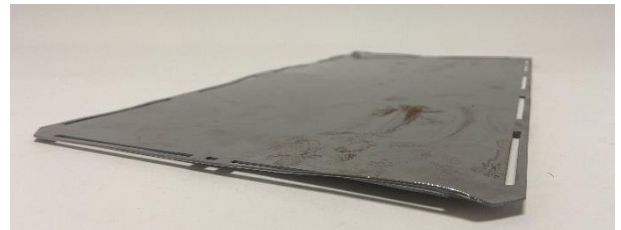


Figure M8.10: bottom dented (1/1 DIN)

Appendix N

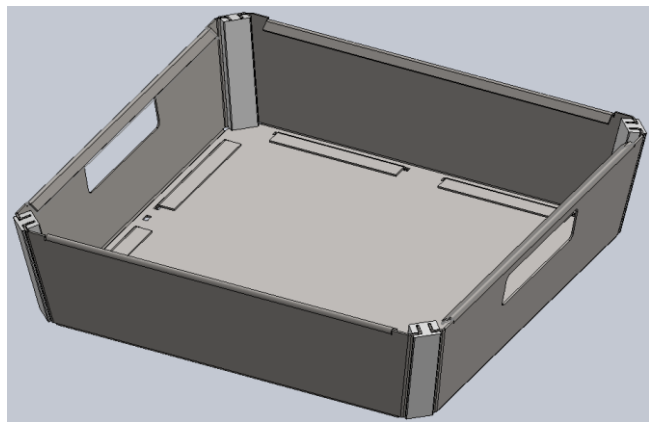
User test

User test instrumentnetten

Naam	
Afdeling	
Functie	

Om het prototype, zie figuur 1, te valideren wordt het getest door de gebruiker. Met deze test kan de gebruikersgemak worden getest en eventueel feedback verwerkt worden voor toekomstig onderzoek.

Het doel van deze test is om te verifiëren dat het net voldoet aan de volgende ontwerp eisen. Eerst worden er een paar algemene vragen gevraagd over het prototype. Daarna wordt onder andere het in elkaar zetten en uit elkaar halen van het prototype getest en de tijd hiervan wordt gemeten. Daarnaast worden ook de handvaten getest. Tenslotte zijn er nog een aantal vragen met betrekking tot toekomstig onderzoek.



Figuur 1: prototype (1/2 DIN)

Introductie vragen

1. Wat is uw eerste indruk van het prototype?

2. Welke voor- en nadelen ziet u voor het uitvoeren van de test al aan het prototype?

3. Wat mist u in dit prototype?

Uitvoeren van de test (1/2 DIN)

Test 1: Zet het instrumenten net (1/2 DIN) in elkaar en haal het uit elkaar. Eerst zonder uitleg en daarna met uitleg.

Zonder uitleg

Test	Welke stap	Tijd gemeten	Beoordeling/ opmerkingen
1	Uit elkaar halen		
2	In elkaar zetten		
3	Uit elkaar halen		
4	In elkaar zetten		

Met uitleg

Test	Welke stap	Tijd gemeten	Beoordeling/ opmerkingen
1	Uit elkaar halen		
2	In elkaar zetten		
3	Uit elkaar halen		
4	In elkaar zetten		

Test 2: Til het instrumenten net op en loop een rondje.

Test	Leeg of vol	Beoordeling/ opmerkingen
1	Leeg	
2	Leeg	
3	Vol	
4	Vol	

Test 3: Pak het instrumenten net (1/2 DIN) in.

Test	Tijd gemeten	Beoordeling/ opmerkingen
1		
2		

Uitvoeren van de test (1/1 DIN)

Test 1: Zet het instrumenten net (1/1 DIN) in elkaar en haal het uit elkaar. Eerst zonder uitleg en daarna met uitleg.

Zonder uitleg

Test	Welke stap	Tijd gemeten	Beoordeling/ opmerkingen
1	Uit elkaar halen		
2	In elkaar zetten		
3	Uit elkaar halen		
4	In elkaar zetten		

Met uitleg

Test	Welke stap	Tijd gemeten	Beoordeling/ opmerkingen
1	Uit elkaar halen		
2	In elkaar zetten		
3	Uit elkaar halen		
4	In elkaar zetten		

Test 2: Til het instrumenten net op en loop een rondje.

Test	Leeg of vol	Beoordeling/ opmerkingen
1	Leeg	
2	Leeg	
3	Vol	
4	Vol	

Test 3: Pak het instrumenten net (1/1 DIN) in.

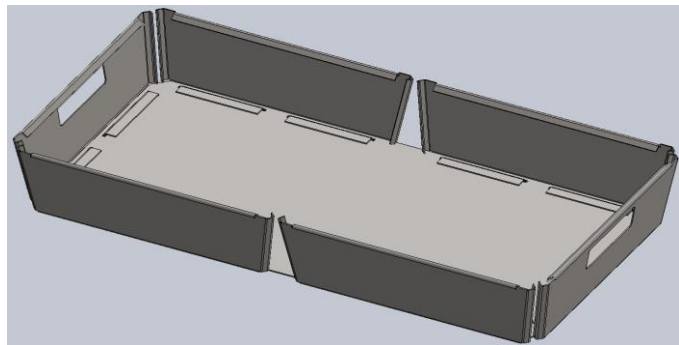
Test	Tijd gemeten	Beoordeling/ opmerkingen
1		
2		

Afsluitende vragen

4. Welke voor- en nadelen ziet u na het uitvoeren van de test aan het prototype?

5. Wat zou u in het volgende prototype willen zien/ mist u in dit prototype?

6. Wat vindt u van het volgende ontwerp, weergegeven in figuur 2?



Figuur 2: prototype voor toekomstig onderzoek

7. Overige opmerkingen?

Hartelijk dank voor het invullen van deze vragenlijst.

Uw medewerking levert een belangrijke bijdrage tot het nieuwe ontwerp!

Appendix O

Results of the user test

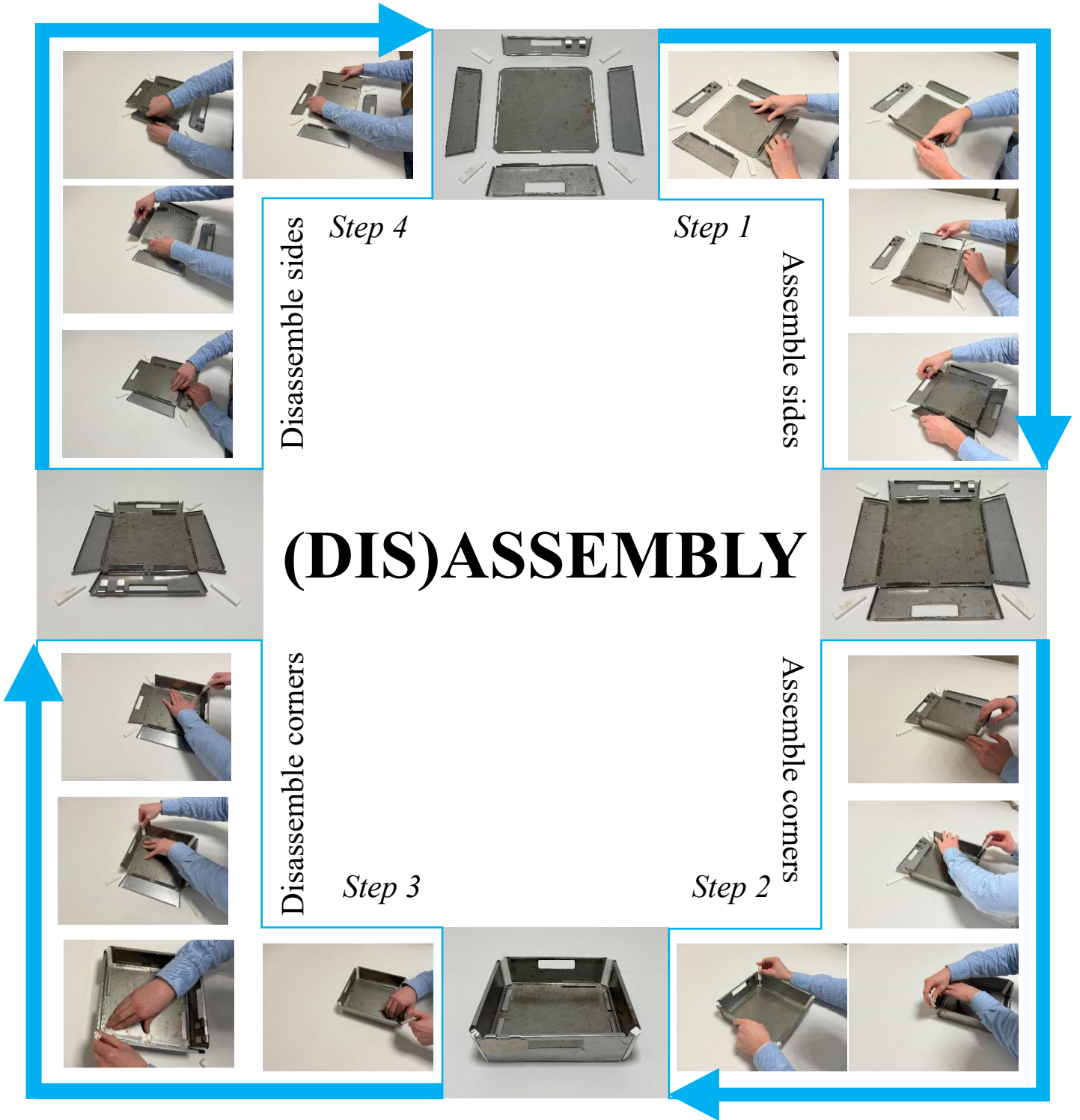
The user test shows that there are improvements that would make the prototype even better. The user test showed that the corners are not yet working optimally. For future research, these corners should be redesigned to make assembly and disassembly smoother. In addition, the user test showed that the perforations are missing. These will naturally be added to the final design. On the other hand, there were also positive things that emerged during the test. The prototype did not cause any problems when packing with the sterile PP paper and people were positive about the stackability of the prototype. Finally, there was also a category of feedback that applied to the prototype, but not to the design. The test showed that the handles (but also other parts) had sharp edges, which need to be better rounded. However, the test also showed that people thought the handles were an improvement compared to the current handles.

Persoon	1	2	3	4	5	6	7	8
Afdeling	CSA (Antonius ziekenhuis)	Van Straten Medical	CSA (Van Straten Medical)	CSA (Van Straten Medical)	CSA (Van Straten Medical)	CSA (Van Straten Medical)	CSA (Van Straten Medical)	CSA (Van Straten Medical)
Functie	Deskundige steriele hulpmiddelen (DSMH)	Board of directors	Medewerker steriele hulpmiddelen (MSMH)	Medewerker steriele hulpmiddelen (MSMH)	Medewerker steriele hulpmiddelen (MSMH)	Medewerker steriele hulpmiddelen (MSMH)	Medewerker steriele hulpmiddelen (MSMH)	Medewerker steriele hulpmiddelen (MSMH)
Introductie								
Eerste indruk	Helder idee, zwaar.	Slim	Vergelijkbaar met de standaard hulpmiddelen.	Mooi idee om ruimte te besparen	Zijkanten schuin, waardoor stapelbaar.	Ontwerp is innovatief	Wenken aan het nieuwe design met schuine zijkanten	Fraai en efficiënt design
Voor en nadelen	Gewicht Stapelbaarheid Perforatie	Vuil kan onder of tussen de randen komen Valhendels	Makkelijker uit elkaar te halen Aanpasbaar in vorm Perforaties	Extra tijd nodig om in elkaar te zetten en uit elkaar te halen Perforaties	Geen extra schroeven nodig	Efficiënter te stapelen	Geen vuil tussen handgrepen, maar wel vuil tussen randen Perforaties	Onderdelen vervangbaar Perforaties
Tekortkoming								
User test (1/2 DIN)								
In elkaar zetten	Stroef, maar je doet 1 net in de zoveel tijd en niet 50 in 1 uur	Uit elkaar halen makkelijk. In elkaar zetten niet intuïtief	Het verloopt stroef. Hoekjes aanpassen	Als je het eenmaal doorhebt, is het prima te doen.	Hoekje beetje aanpassen. Kan ook aan materiaal liggen.	Het gaat stroef en je moet het doorhebben.	Uit elkaar duidelijk. In elkaar even wennen maar te doen	Iets langer bezig, maar flexibel met aanpassen grootte net.
Uit elkaar halen	Goede plaats van de handvaten en goed reinigbaar.	Handvaten scherp	Scherpe randen. Gleuven groter maken	Geen verandering in de handvaten leeg en vol.	Instrumenten kunnen door de handvaten uitsteken.	Mooi ontwerp van de handvaten en werkt prima	Grotere gleuf	Anders dan valhendels maar werkt prima.
Inpakken	Goed in te pakken op traditionele wijze.	Test niet uitgevoerd.	Het is even wennen, maar voor de rest geen problemen	Geen kwetsbare onderdelen	Goed in te pakken.	1 keer gescheurd, maar heel hard gesehoven en prototype	Schuine zijkanten zorgen niet voor extra moeilijkheden	Hoek precies gekozen, anders rare vorm
User test (1 DIN)								
In elkaar zetten	Gaat soepeler dan 1/2 DIN.	Test niet uitgevoerd.	Het verloopt stroef net als 1/2 DIN. Hoekjes aanpassen	Prima te doen. Goed idee om zijkanten bij beide te gebruiken	Hoekje (zelfde als 1/2 DIN) beetje aanpassen	Slim om zijkanten met handvaten 2 keer te gebruiken	Flexibel, want 3 extra onderdelen voor 1 DIN	Net als 1/2 DIN fraai en efficiënt design
Uit elkaar halen	Handvat exact hetzelfde als 1/2 DIN.	Test niet uitgevoerd.	Scherpe randen. Gleuven groter maken	-	Zie opmerking bij 1/2 DIN	Het werkt goed	Grotere gleuf	Prima
Inpakken	Geen verschil in inpakken van recht net of schuin net	Test niet uitgevoerd.	Geen opmerkingen	-	Zelfde als 1/2 DIN	Nu niet gescheurd. Licht aan hoe prototype is afgewerkt	Geen moeilijkheden	Hoek precies gekozen, anders rare vorm
Afsluiting								
Voor en nadelen	Hoekjes is aandachtsgebied Stapelbaarheid	Prinkebaar (OK) personeel. Handvaten open.	Het is iets stroever in de hand en het is even wennen	Goed te stapelen	Design van hoekjes is goed, werkt stroef	Onderdelen zijn nog scherp en het is zwaar	Handvaten werken goed, maar wel grotere gleuf voor de handvaten	Het mechanisme werkt goed en heeft zeker potentie
Toevoeging/tekortkoming	Smaller bovenrand. Groter handvat	Makkelijker in elkaar te zetten. Geurofenseerde onderdelen	Minder scherpe randen en grotere gleuf voor handvaten	Hoekjes aanpassen zodat het sneller gaat.	Hoekje aanpassen zodat het maar op 1 manier past	Minder scherpe onderdelen	Grotere gleuf voor de handvaten	-
Toekomstig ontwerp	Eerst zien dan pas beoordelen.	Niet wenselijk	Meer in en uit elkaar halen dus nadeel	Voor hygiëne maakt hoekje in het midden niet uit.	Hoekje wordt uitdaging om te maken.	Stijfheid wordt wel minder, dus stuk stevigheid kwijt.	Lange zijkanten kwijt voordeel.	Nog minder onderdelen, alleen andere bodem nodig.
Opmerkingen	-	Potentie, intuïteit verder ontwikkelen. Duurzaam	-	Idee is goed	-	Geen opmerkingen	-	Heel goed met betrekking tot minimale transport

* Original files available on request

Appendix P

Flowchart (dis)assembly 1/2 DIN prototype



Appendix Q

Technical drawings

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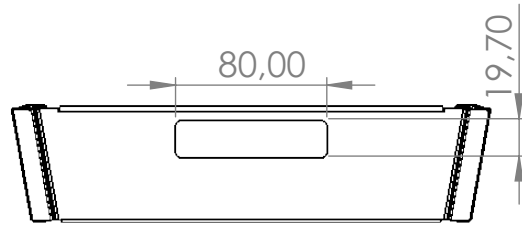
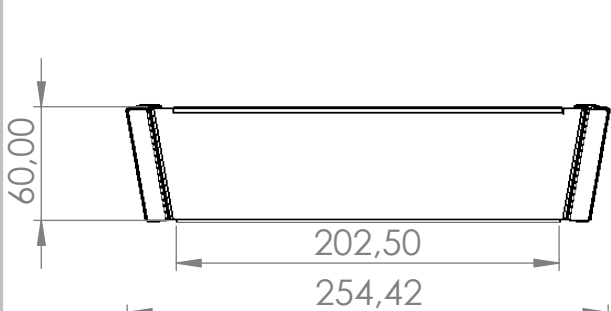
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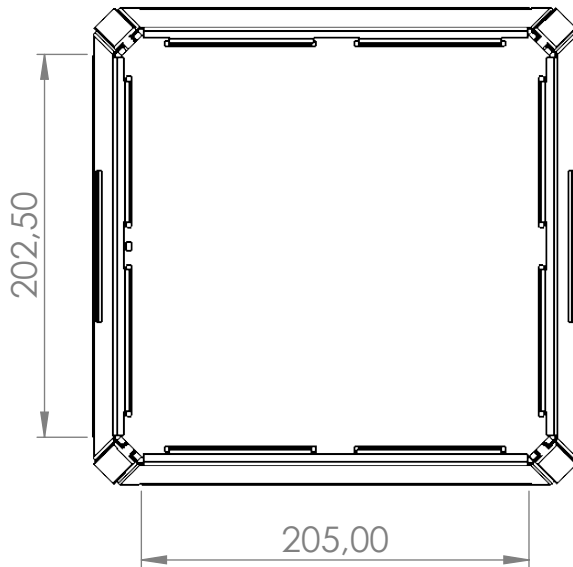
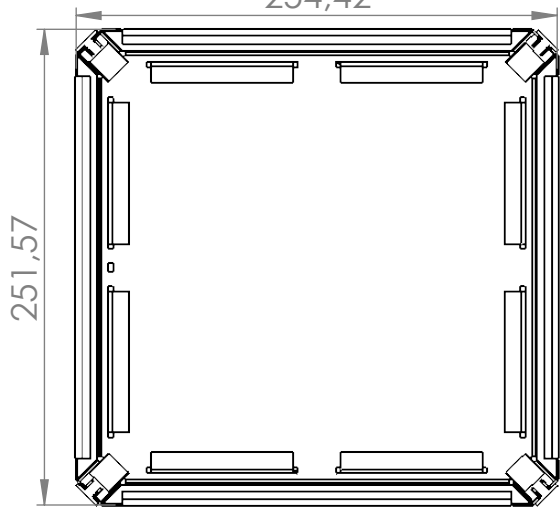
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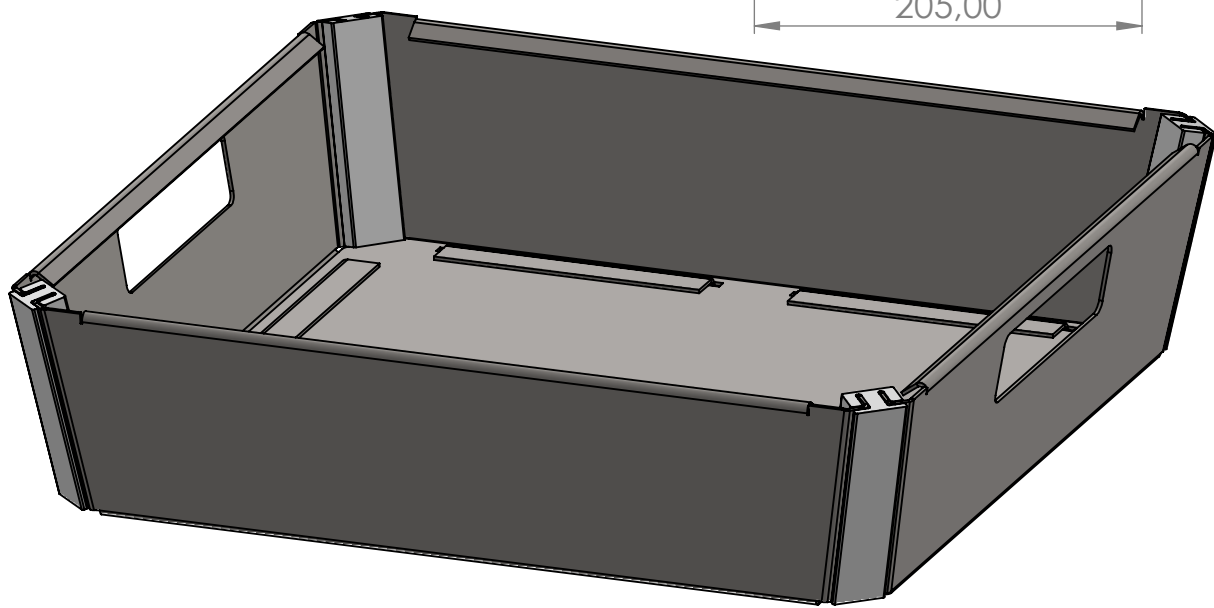


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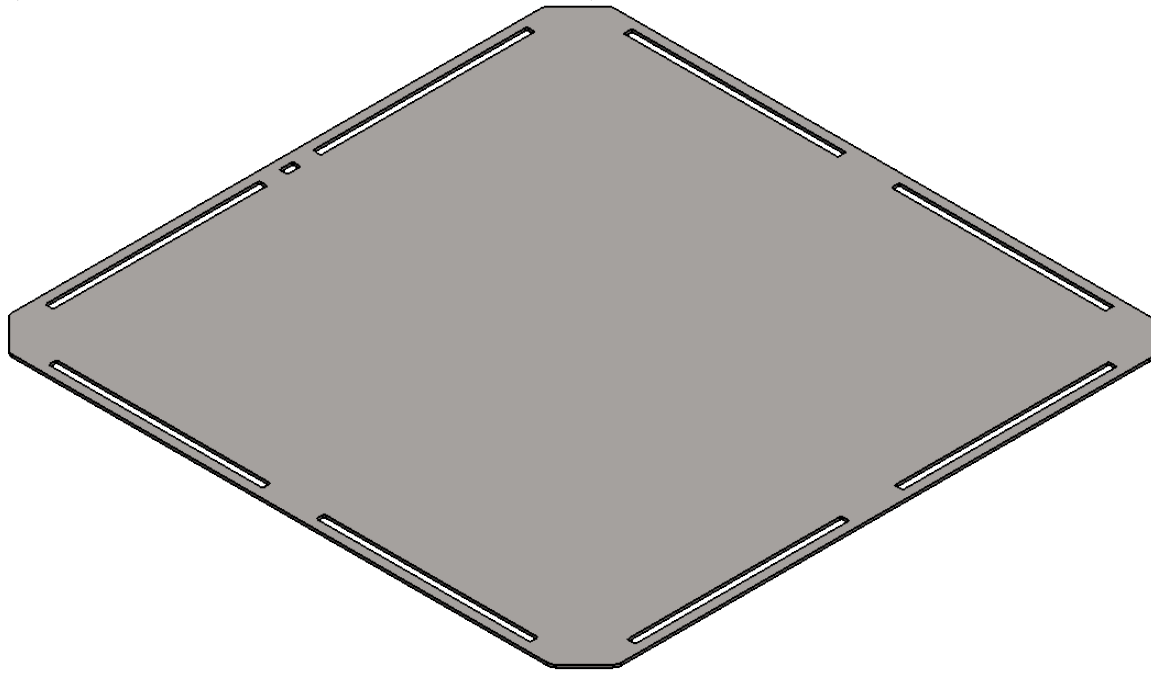
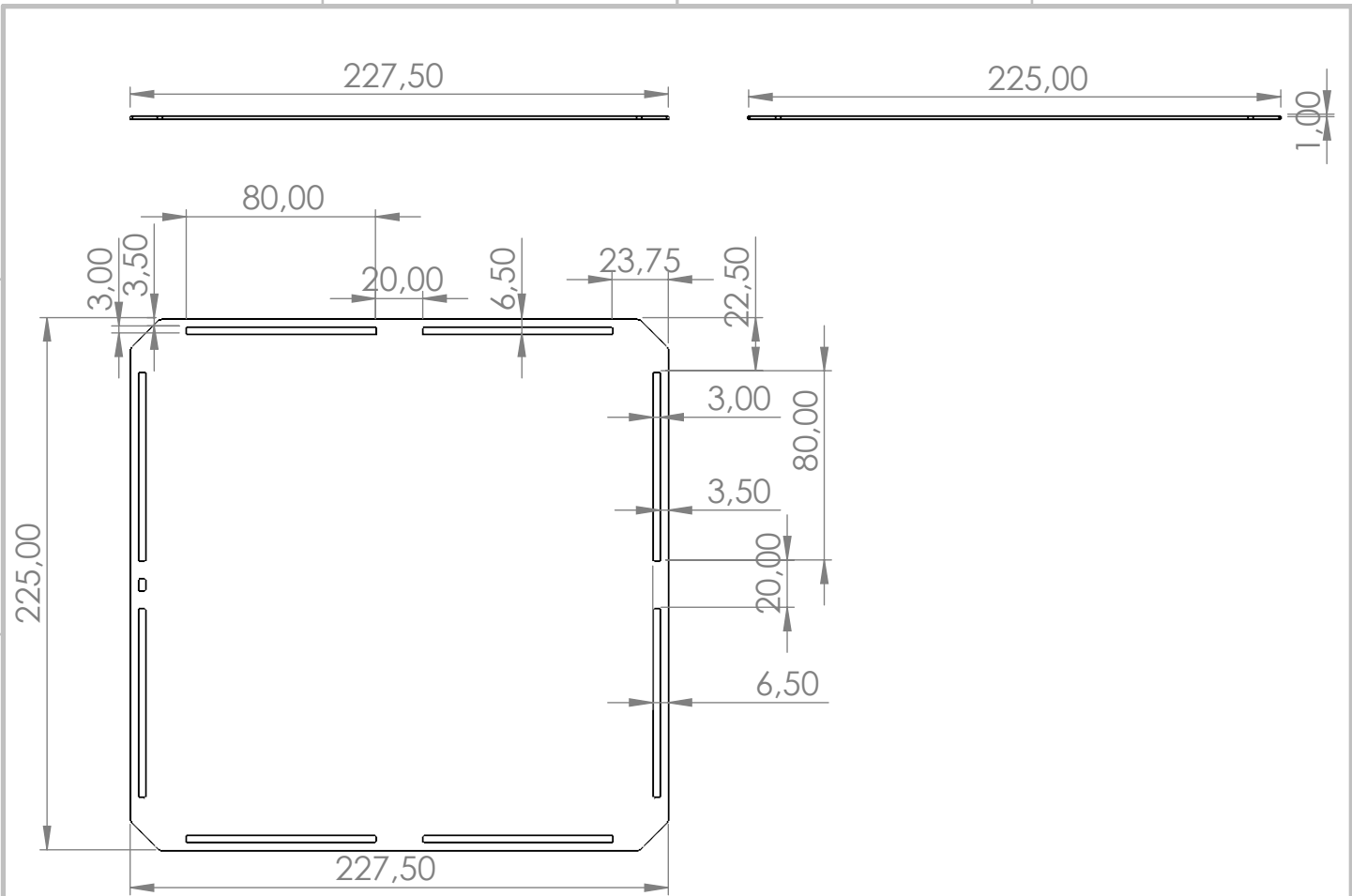
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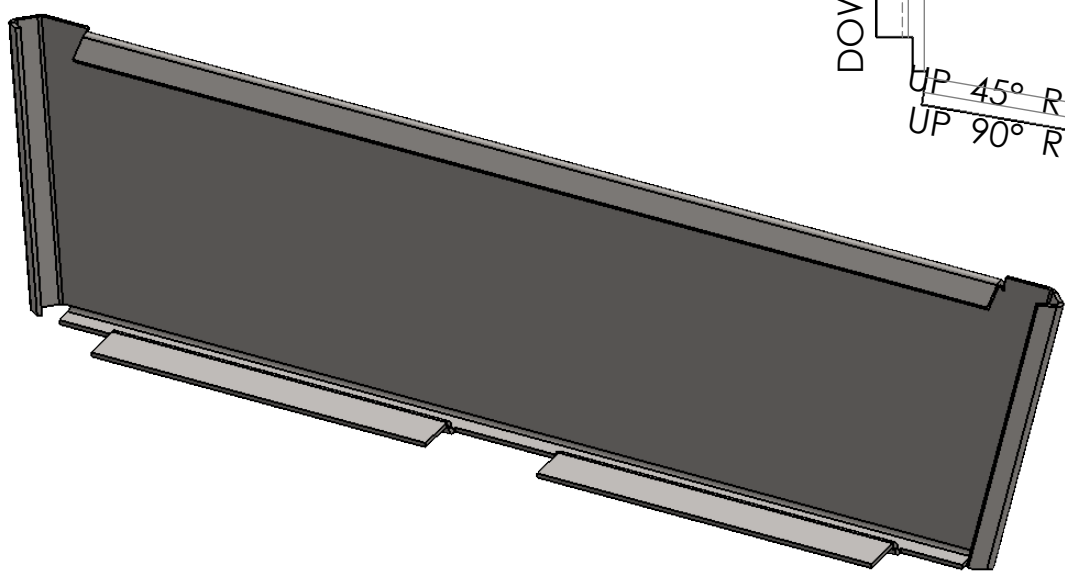
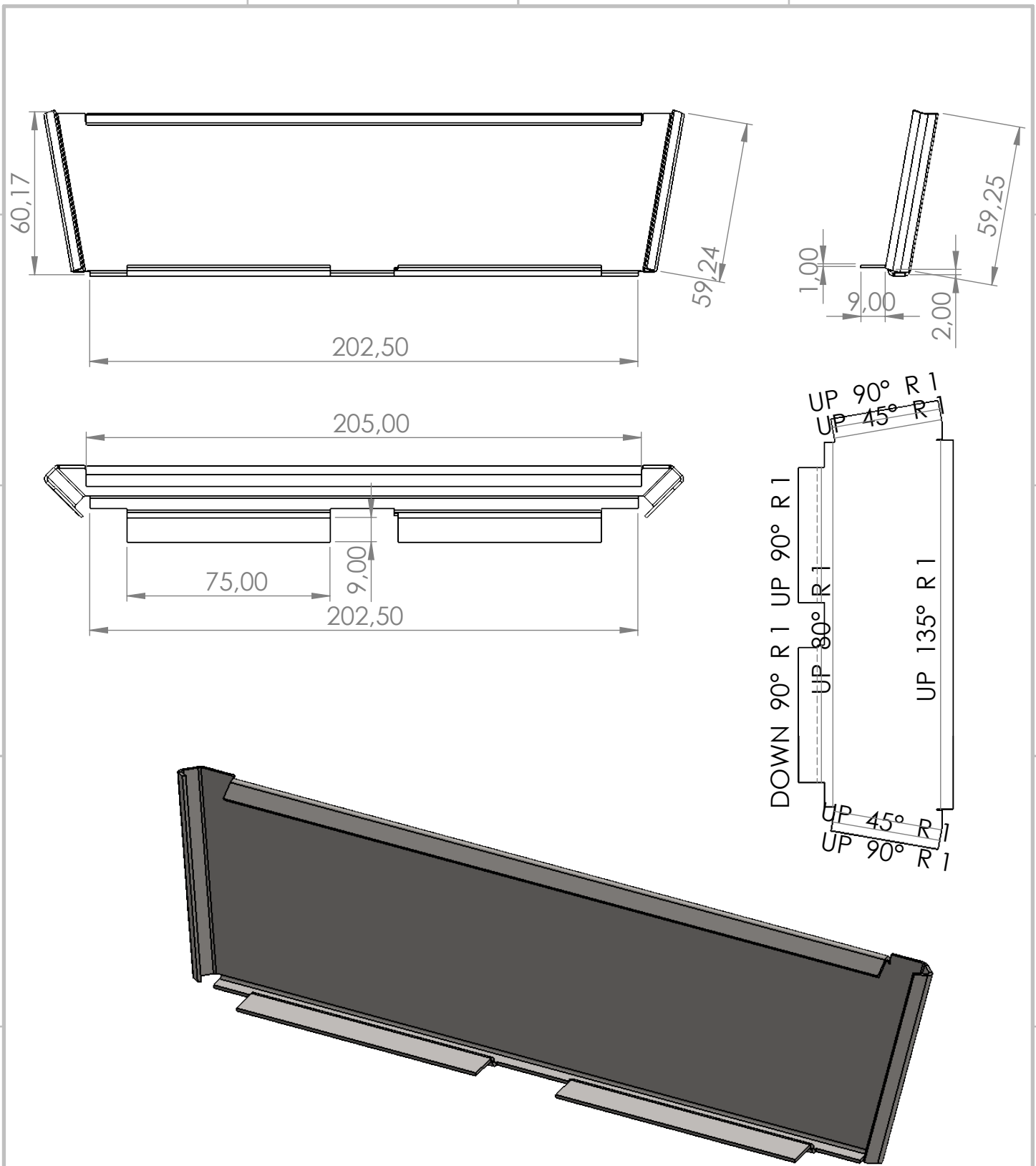
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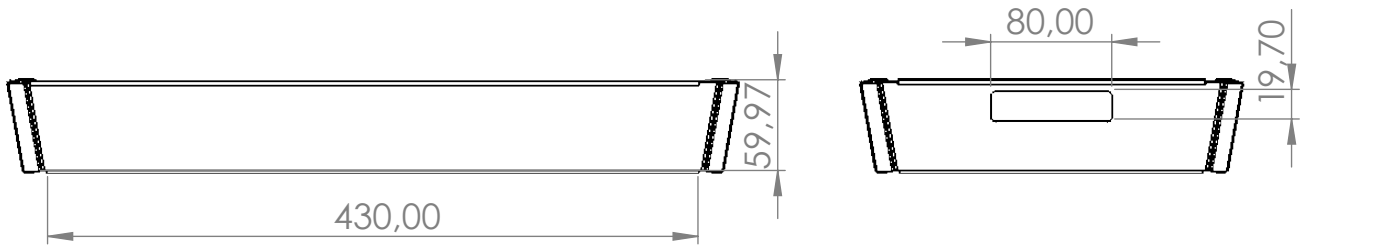
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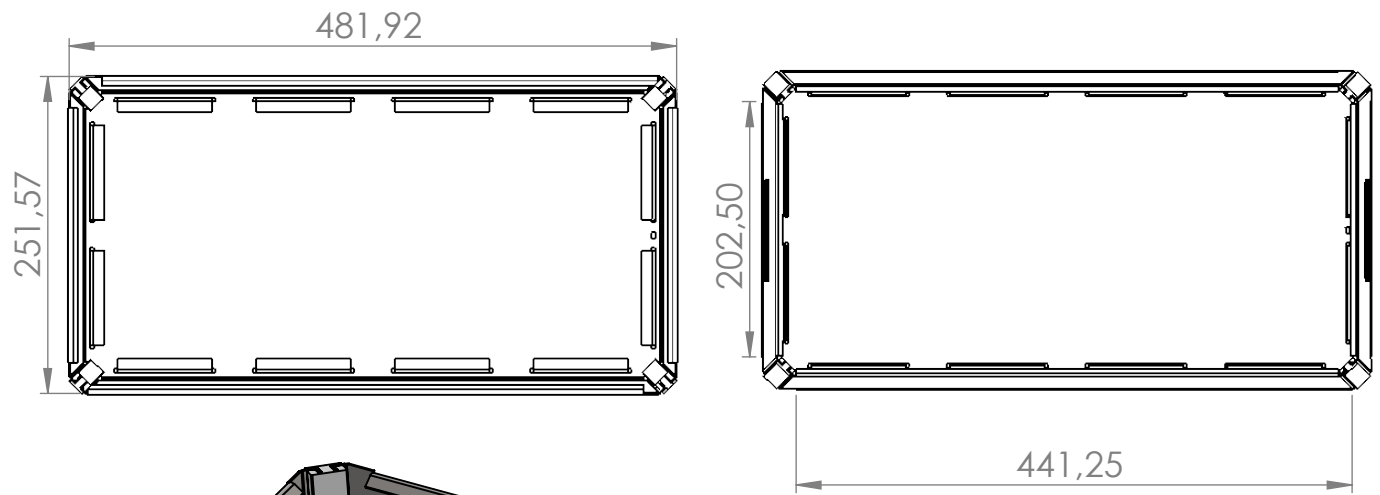
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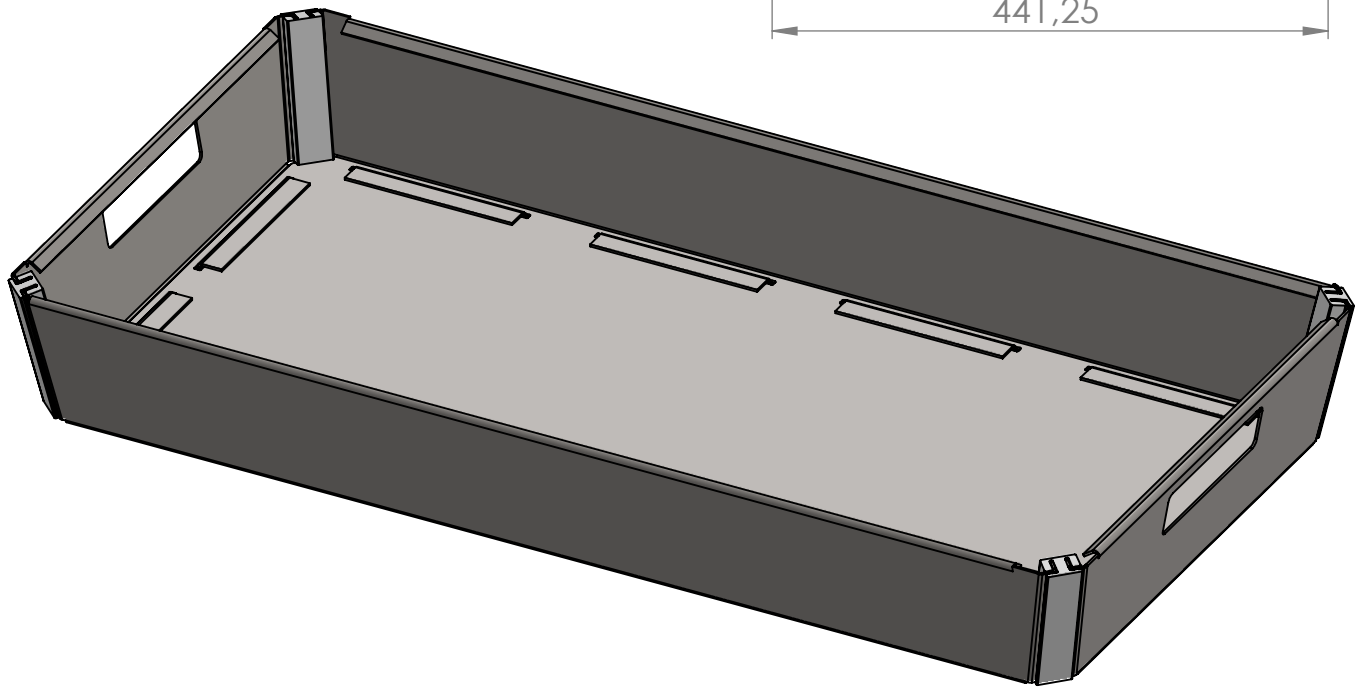
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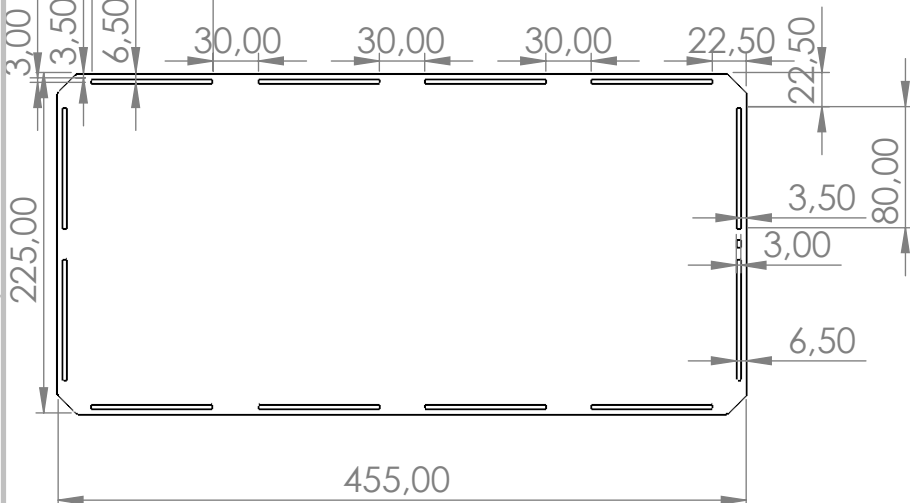
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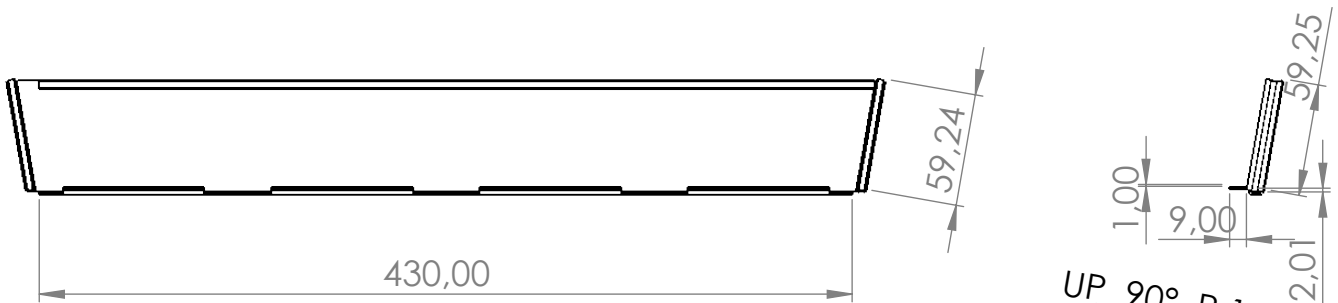
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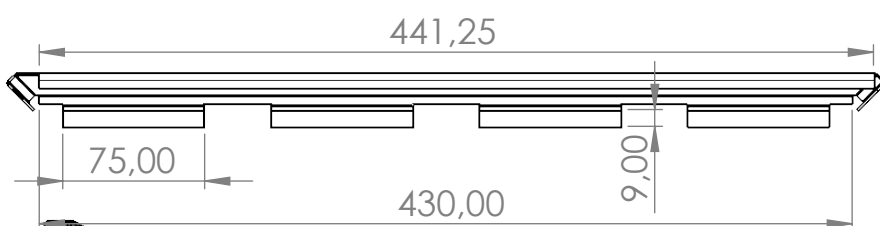
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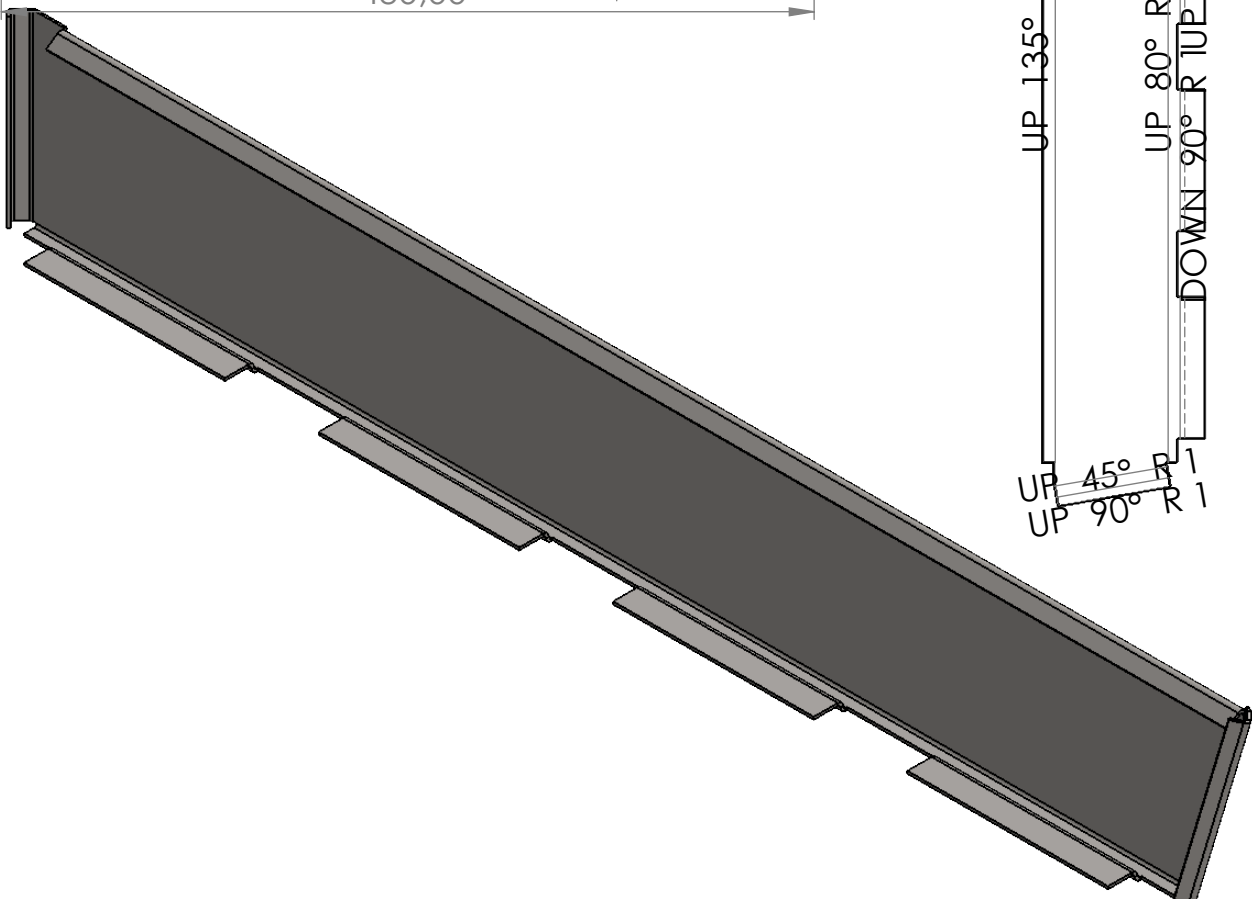
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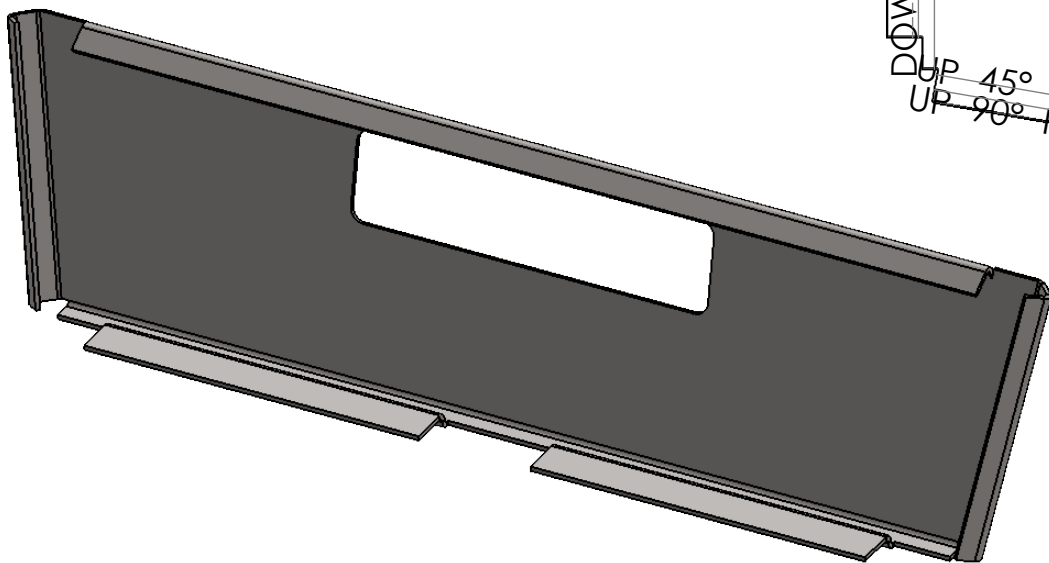
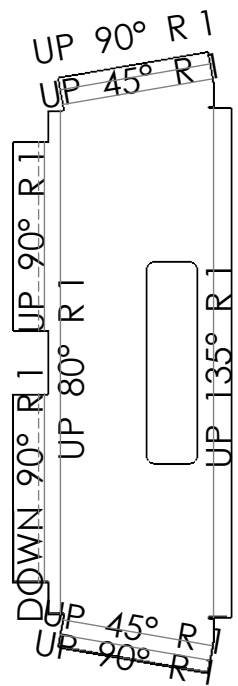
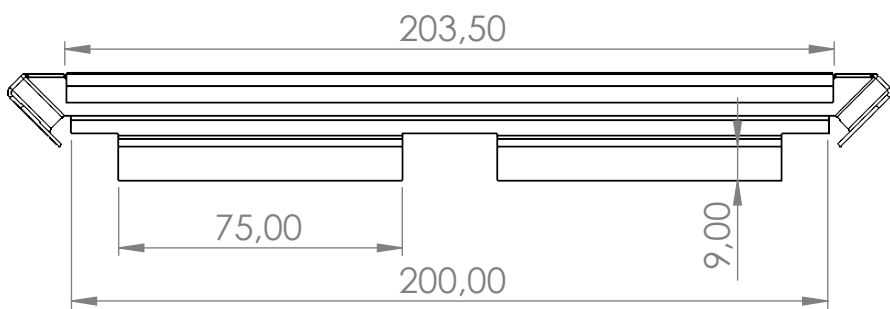
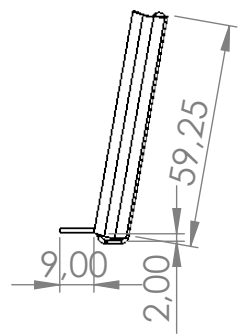
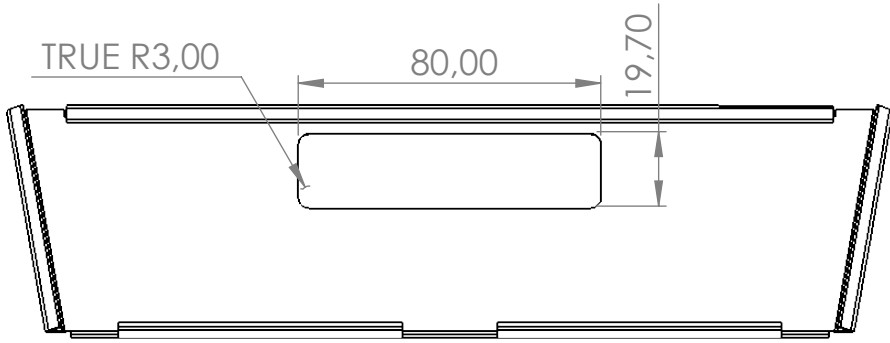
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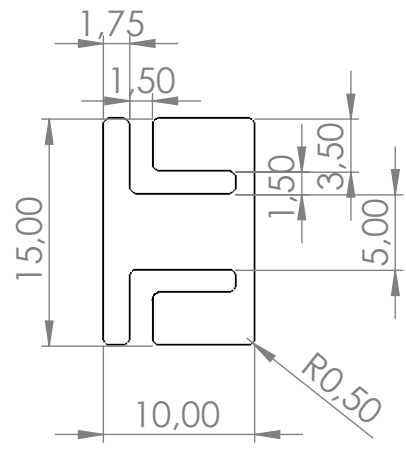
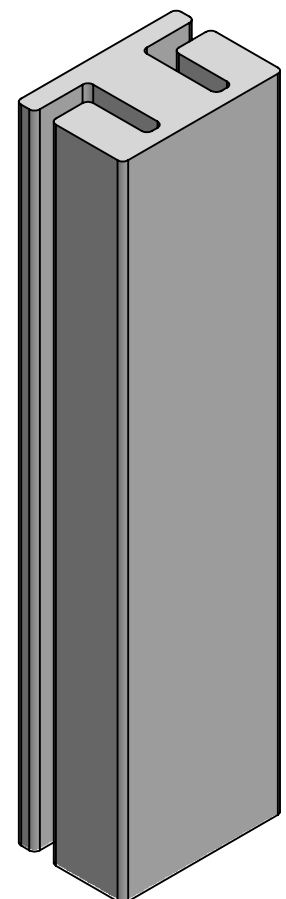
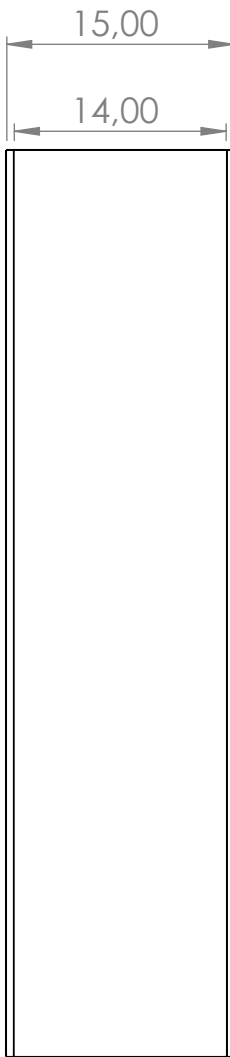
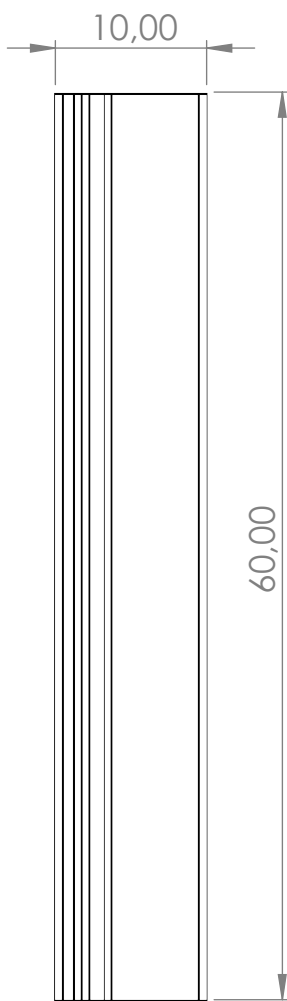
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